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A Life Cycle Cost Analysis of Industry 4.0 Implementation

Jason Liu[1], Wei Shi[2]
[1](*Department of Operations and Management, University of Wisconsin-Stout, USA)*
[2](*Department of Engineering and Technology, University of Wisconsin-Stout, USA)*

ABSTRACT : *Many different worldwide initiatives are promoting the transformation from machine dominant manufacturing to digital manufacturing. The implementation of Internet of Industry 4.0 in the manufacturing industry is continuing to grow, as shown by the extensive research, development, and standardization regarding Industry 4.0. However, Small and Medium Manufacturing Enterprises (SMEs) encounter many barriers and difficulties (economical, technical, cultural, etc.) in the implementation of Industry 4.0. A deficiency of Industry 4.0-related knowledge and experience is still a serious barrier to decision-making in Industry 4.0 implementation. This study develops a methodology to evaluate the impact of Industry 4.0 implementation on life cycle costs to support decision-making of Industry 4.0 implementation in SMEs. This study makes two main contributions that can help SMEs to incorporate Industry 4.0 technologies. The first contribution is a methodology that can support the decision-making of SMEs in Industry 4.0 implementation by proposing a formalized method that includes steps to identify the factors involved in LCC. The proposed method first identifies the cost items related to the Industry 4.0 implementation throughout the product's life cycle. Then, the impact of the Industry 4.0 implementation on life cycle costs is simulated based on the case study of automotive manufacturer. Another contribution is that this research enables the calculation of the impacts of Industry 4.0 implementation for SMEs based on the LCC approach. The input variables, such as the number of failures reduction and repair costs saving, can be calculated according to application cases and Industry 4.0 implementation scenarios. This study will enable the analysis of Industry 4.0 implementation under various conditions and helps examine the pros and cons of Industry 4.0 implementation.*

KEYWORDS - *Industry 4.0, life cycle cost, decision making support*

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I. INTRODUCTION

In the era of digital transformation, technologies related to Industry 4.0, Industry 4.0 technologies such as IoT, additive manufacturing, and AI, are increasingly implemented in previously non-digital products and business services. These new technologies impact the efficiency and effectiveness of products and services, and business models of industrial companies. Consequently, the implementation of Industry 4.0 technologies in the manufacturing companies is in a state of constant growth, as shown by extensive research and standardization regarding Industry 4.0 technologies. Manufacturers can capture new business opportunities by implementing Industry 4.0 technologies with its business model [1]. Industrial companies, especially small and medium-sized enterprises (SMEs), today are facing two important issues: the implementation of 4.0 technologies, that allow to automate and improve plant productivity, and deficiency of Industry 4.0-related knowledge and experience [2]. In response to such specific barriers of SMEs, the purpose of this research is to develop an evaluation method to calculate return on investment (ROI) of Industry 4.0 implementation in SMEs, which explores how Industry 4.0 implementation's financial effects throughout the life cycle of the products and business service [3]. The proposed methodology quantitatively evaluates the impact of Industry 4.0 implementation on the LCC of products or services by integrating the components of the LCC and their causal relationships. This method contributes to SMEs' decision-making about Industry 4.0 implementation.

II. LITERATURE REVIEW

2.1 Cost Breakdown of Lif Cycle Cost (LCC)

Life cycle cost (LCC) mostly focuses on the life-span processes of obtaining, applying and disposing the assets [7], which requires to take consider all the costs during the whole life into account, including the acquisition cost, ownership cost, usage cost, and subsequent disposal cost [8]. All of the costs occur during the life span, including assessment costs, design costs, manufacturing costs, operation costs, disposal costs, etc. [9], could be grouped into four main categories, including R&D cost, production and consumption costs, operation and maintenance cost, and disposal cost [10].

Previous studies have been conducted to explore cost elements and cost breakdown structure of manufacturing industry. One representative research sets up the life cycle cost framework of computer information system, which decomposes the LCC into initial cost, operation cost, and disposal cost [11]. Another research explores LCC framework for industrial robots and categorizes total LCC cost into acquisition cost, operation cost, and disposal and investigates the quality cost factors [12]. In addition, intangible cost has been discussed in a few LCC frameworks, and related cost factors were examined [4, 5, 13]. Considering the similarities in these cost breakdown structures, most of them define acquisition costs, operation costs, maintenance costs, and disposal costs, as well as the intangible costs, to set up a relatively comprehensive framework. However, compared to actual LCC cost, the intangible cost has not been well defined [14]. In summary, there is still a lack of a comprehensive and integrated framework for LCC by considering actual and intangible costs, which makes analysis difficult.

2.2 Cost Factors Related to Industry 4.0 Implementation

Industry 4.0 refers to the production mode based on smart digital technology, highly integrated sensors, automation devices and equipment, machine learning to create a more holistic and better-connected ecosystem for manufacturing. Maintenance interrupts the operation of Industry 4.0 and cost considerations for regular inspections, repair work, and reconfiguration are significantly different from traditional operation [14, 15]. Table 1 and Table 2 summarize the life cycle cost structure of before and after Industry 4.0 implementation.

Table 1. LCC STRUCTURE BEFORE Industry 4.0 implementation

Cost Category	Cost Factors	Source
Operation cost	Depreciation cost	[16-19]
	Energy consumption	[16, 18-19]
	Operator remuneration	[17-18]
	Monitoring labor costs	[16,18]
	Training cost	[19]
	Accessories charges	[15, 19]
Maintenance cost	Replacing parts price	[19, 24-26]
	Consumables charge	[24-26]
	Annual inspection charges	[18, 24-26]
Investment Cost	Equipment cost and transaction cost	[16-19]
	Load interest and tax	[16, 18-19]
	Set-up fee	[17-18]
Intangible cost	Production idle loss	[20-23]
	Production efficiency and productivity loss	[20-23]
	Production defect loss	[20-23]

From the literature, this study summarizes Industry 4.0 life cycle cost factors and further clarify the critical factor that should be paid more attention to the framework of Industry 4.0 implementation, allowing for the decision-making of Industry 4.0.

III. METHODOLOGY

Given the complexity in analyzing life cycle cost of Industry 4.0, the theoretical framework is firstly set up and the cost factors are identified. Then total life cycle cost model for Industry 4.0 Implementation is constructed based on the cost breakdown structure. This study defines the formulas to calculate total life cycle cost and each cost composition. Finally, a case study is conducted to show the application of proposed method.

IV. CASE STUDY

4.1 Description of Case Study

The proposed methodology was applied to the case of Industry 4.0 implementation in Subaru of Indiana Automotive, Inc. (SIA), located in Lafayette, Indiana, is the only Subaru vehicle manufacturing facility outside of Japan. However, SIA has been facing the problems in operations and management, such as increase in operation cost, hard to find workers, 24-hour maintenance, and long downtime. Thus, Industry 4.0 has been applied to improve SIA's operations.

4.2 Results

1) The Scope of analysis

In this case analysis, the research area was the implementation of Industry 4.0 in Subaru of Indiana Automotive, Inc. (SIA), USA. The target process model was Subaru models' assembly lines. The life cycle phase of the analysis was defined as the "maintenance and operation" phase with 2 years due to the availability of data.

2) Identify cost items of Industry 4.0 implementation

This step involves identifying cost items and collecting data based on the interviews about the implementation of Industry 4.0, including investment cost, operational costs, maintenance costs and benefits. The results were summarized in table 1. Based on the results, total cost includes operation cost (OC), maintenance cost (MC), investment cost (IC) and intangible cost (INC). Depreciation cost (DC), Power cost (PC), Plant labor cost (PLC), Monitoring labor cost (MLC), Training cost (TRC) and Accessories charges (AC) were identified as the items of operation cost affected by Industry 4.0 implementation. Maintenance cost includes Regular maintenance cost (RMC), Repair cost (RC) and Annual inspection charges (AIC). Investment cost (IC) identified as Industry 4.0 equipment cost (EC) and Data storage cost (DSC). In addition, Production idle loss (PIL), Production efficiency loss (PEL) and Production defect loss (PDL) were identified as Intangible cost (IC) that would be affected by Industry 4.0 implementation as shown in table 1.

Table 2 Calculation formula for case analysis

Cost Item	**Calculation Formula (2 years)**
Total Cost (TC)	TC=OC+MC+IC+INC
Operation cost (OC)	Operation cost (OC) OC=DC+PC+PLC+MLC+TRC+AC
	Depreciation cost: DC DC = (Monthly depreciation) × 24 months
	Power Cost: PC PC = (Monthly power bill) × 24 months
	Plant labor cost: PLC PLC = (Plant labor cost) × (Number of failures)
	Monitoring labor costs: MLC MLC = (Cost per hour) × (Work time per month) × 24 months
	Training cost: TRC
	Accessories charges: (AC)
Maintenance cost (MC)	Maintenance cost (MC) MC=RMC+RC+AIC
	Regular maintenance cost: RMC RMC= (Monthly Regular maintenance fee)×24 months
	Repair cost: RC RC = Parts cost + On-site labor cost (in-house) + On-site labor cost (outsourced) + Other outsourced costs (salvage work)
	Annual inspection charges: AIC
Investment Cost (IC)	Investment cost: IC IC=EC+DSC
	Industry 4.0 equipment cost: EC EC = 2*Purchase cost/Equipment service life
	Data storage cost (DSC)

Cost Item	Calculation Formula (2 years)
	DSC= Monthly cloud usage fee) × 24 months
Intangible cost (INC)	Intangible cost: INC INC=PIL+PEL+PDL
	Production idle loss: PIL
	Production efficiency and productivity loss: PEL
	Production defect loss: PDL

3) Comparison of cost-effectiveness of Industry 4.0 implementation

In case analysis, the impact of Industry 4.0 implementation on total cost over the life cycle were calculated based on evaluation formula above, as shown in table 2 and figure 1, from which several important findings can be observed. As shown in table 2, total cost will be decreased 28.86% after Industry 4.0 implementation. Operation cost (OC) and Maintenance cost (MC) will be decreased 20% and 30% respectively after Industry 4.0 implementation.

Table 3 Comparison of life cycle cost before and after Industry 4.0 implementation

Cost Item	Comparison of cost before and after (Unit: Thousand $)		
	Cost elements	***Before***	***After***
Operation cost (OC)	**Operation cost (OC)**	**10,900**	**7,550**
	Depreciation cost (DC)	4,200	4,200
	Power Cost (PC)	2,000	2,000
	Plant labor cost (PLC)	1,800	600
	Monitoring labor costs (MLC)	1,500	300
	Training cost: TRC	800	200
	Accessories charges: (AC)	600	250
Maintenance cost (MC)	**Maintenance cost (MC)**	**3,980**	**1,975**
	Regular maintenance cost:	1,500	1,300
	Repair cost: RC	2,400	615
	Annual inspection charges: AIC	80	60
Investment Cost (IC)	**Investment cost: IC**	0	3,000
	Industry 4.0 equipment cost: EC	0	2500
	Data storage cost (DSC)	0	500
Intangible cost (INC)	**Intangible cost: INC**	2,725	0
	Production idle loss: PIL	1,400	0
	Production efficiency and productivity loss: PEL	875	0
	Production defect loss: PDL	450	0
Total cost (TC)	TC=OC+MC+IC+INC	17,605	12,525
Change	Cost reduction rate =(TC before-TC after)/TC before	28.86%	

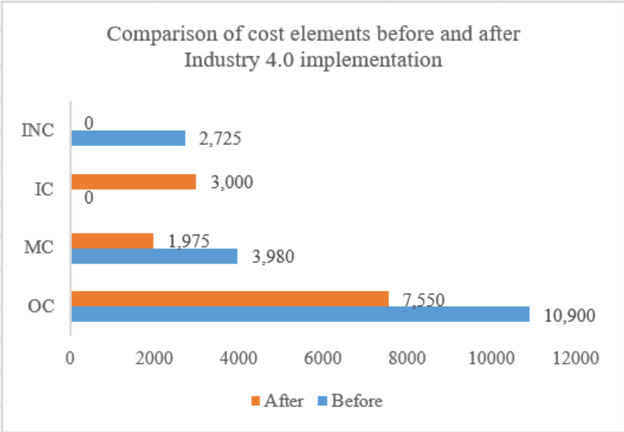

Figure 1 Comparison of Cost Elements before and after Industry 4.0 Implementation

V. DISCUSSION

5.1 Lack of workers and rising labor cost promote Industry 4.0 implementation

Based on the results of case analysis, this research finds that lack of workforce and rising labor cost promote Industry 4.0 implementation, especially robot substitution, which is consistent with previous study [27]. In this case, labor costs account for 37.6% of operation costs before Industry 4.0 implementation. After Industry 4.0 implementation, labor costs account for 14.6% of operation costs. Due to the workforce related costs sharply increased, manufacturing companies are becoming more interested in promoting Industry 4.0 implementation in order to save production cost. Currently, the average costs of industry robots worldwide declined over the past ten years, from around $46,000 in 2010 to $27,000 in 2017. Based on recent forecast, related costs are expected to decrease to $10,856 by 2025 [27]. According to 2022 Wisconsin manufacturing report, workforce is one of the most important issues impacting manufacturers' future success because the industry has been experiencing a growing shortage of qualified workers [28]. Manufacturers are investing more in systems, technology, and automation as a potential solution to their workforce difficulties.

5.2 Implementation Industry 4.0 reduces operation and maintenance costs

Based on the results of case study, we can also conclude that implementation of Industry 4.0 will reduce operation and maintenance costs, from 10,900 and 3,980 thousand dollars to 7,550 and 1,975 respectively. Previous studies prove that new technologies in Industry 4.0 can be used to reduce operations and maintenance costs based on analytical algorithms, such as big data technologies [29, 30]. Regarding how Industry 4.0 will affect the operations and maintenance costs for manufacturing companies, Industry 4.0 based on the sensors, smart devices and other data can be utilized to recommend the actual preventive actions and predict future failures by integrating advanced data analytics with big data considering the environment, equipment and device status, maintenance history and so forth [30]. The results indicate that preventive maintenance based on Industry 4.0 can save 25%–30% maintenance costs, reduce 70%–75% troubleshooting, reduce 35%–45% equipment downtime and increase 20%–25% production [31]. Thus, predictive maintenance based on Industry 4.0 is the latest trend for achieving SMEs' performance goals in order to obtain competitive advantages in the market.

5.3 Implementation Industry 4.0 reduces production loss

Based on the results of case study, we find that implementation of Industry 4.0 will be beneficial for manufacturing companies to reduce loss in terms of production idle loss, production efficiency and productivity loss, and production defect loss. In term of production idle loss and production efficiency and productivity, Industry 4.0 implementation by integrating the data model from engineering through commissioning across manufacturing system (such as CAM, CAD, CAQ, PLM) will enable the seamless dataflow from the R&D phase through final assembly and com missioning phase as well as the whole product life cycle [32]. Previous studies also support that Industry 4.0 by integrating digital information flow allows the improvement of design change from machining to commissioning based on digital twinning, shorter equipment lead time, and significant reduction in labor costs during the stages of assembly and commissioning [33]. Thus, Industry 4.0 implementation results in transparency on manufacturing processes to move towards digital transformation, which will significantly reduce production loss.

VI. CONCLUSION

This study examines the life cycle cost of Industry 4.0 implementation based on a comparative analysis before and after Industry 4.0 implementation. The proposed model identify the cost items related to Industry 4.0 implementation, including investment cost, operation cost, maintenance cost and intangible cost. Applying the proposed model, this research conducts a case study by investigating an automotive manufacturer in USA. As expected, the findings show that lack of workforce and rising labor cost promote Industry 4.0 implementation, especially robot substitution. The results also show that implementation of Industry 4.0 will reduce operation and maintenance costs through predictive maintenance. In addition, this study also indicates that implementation of Industry 4.0 will be beneficial for manufacturing companies to reduce loss in terms of production idle loss, production efficiency and productivity loss, and production defect loss. Overall, the proposed model and case analysis can provide a reference for SMEs to implement Industry 4.0.

On the other hand, this study may have some limitations or remaining issues to be further addressed. Firstly, previous studies indicate that the service life of manufacturing assets will determine their productivity and cost efficiency over their life cycle [27]. Further attention should be given to prove current model and place more emphasis on Industry 4.0's optimum service life. Moreover, it is argued that Industry 4.0 should be more cost-effective in manufacturing scenarios with large scale and high intensity production [34]. Considering Industry 4.0's new technical characteristics, we would like to improve the applicability of proposed model and will keep improving it.

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