Review on Methodology for Life Cycle Costing of Membrane System for Wastewater Filtration

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Abstract. In a competitive environment, manufacturers have to come out with innovative solution to market their product, including implementation of life cycle engineering concept. Life cycle costing (LCC) is one of the aspects that need to be considered when adapting this concept. In addition, costing is another important aspect that needs to be considered carefully. In order to perform LCC analysis, cost estimation is an essential step. Cost estimation model should not only consider pre-production and production cost, design, manufacturing, and assembly, but also post-production, customer use and end of life. Development of cost estimation model or methodology is needed to simplify the LCC analysis so that it can produce more accurate results in shorter time. This paper reviewed on LCC, cost estimation techniques and several developed cost estimation models in order to determine research gap and research direction on developing a methodology to assess LCC of membrane system for wastewater filtration.

Introduction

Membrane technology has been widely used in many industries including in industrial, medical and municipal wastewater treatment system. In addition, membrane technology has been applied in various applications related to water industry [1]. Demand for membrane technology keeps increasing and membrane industry has become an important economic factor that can be used in many applications such as to treat wastewater, produce drinking water, as well as dialysis treatment [2]. Meanwhile, application of membrane technology in wastewater treatment has become common nowadays because it has plenty of advantages compare to the traditional wastewater treatment, such as higher standards, reduce environmental impact of effluents, reduce land requirements and potential for mobile treatment units [3].

Due to increasing awareness towards environmental product and environmental regulation, manufacturers start to adopt and practise the life cycle engineering concept in their working environment, especially during the design stage. Alting [4] suggested several aspects that need to be considered in order to implement life cycle engineering during the design stage, including ease to manufacture, environmental protection, working conditions, resource optimization, life cycle costing and product properties.

In product competitive environment, manufacturers should focus on manufacturing cost, quality and delivery time to survive. Hence, this leads to increasing use of life cycle costing (LCC) in industrial sector. LCC of the product should be measured during the design stage because it influences up to 85% of the product's total cost even though the design stage usually makes up less than 10% of the total cost [5].

LCC is the most detailed method to consider and quantifies all cost factors incurred in the product or process [4]. Many authors agreed that LCC is one of the effective tools in life cycle engineering to measure economic aspects in sustainability perspective. It is an effective tool because it covers the entire product life cycle and it is able to identify the opportunities for cost improvement

[6]. However, some designers refused to conduct LCC analysis because it involves complicated steps as all costs that relate to all activities for producing the product need to consider [7]. Thus, developing a methodology to calculate the LCC will save time because it simplifies the calculation steps and able to generate more accurate results to obtain the optimum decision.

Life Cycle Costing (LCC)

LCC can be defined as the total cost for all activities involved in product manufacturing from the development process to manufacturing stage, and usage stage until disposal stage. The aim of LCC analysis is to determine the lowest possible cost of the product during its life. LCC concept initially comes from the US Department of Defence (DoD) [8] to predict the total cost of expensive weapon that needs to be bought. Apart from that, LCC is used in construction industry, and ISO 15686-5 is a specific standard for LCC in building and construction sector. A survey done by Korpi and Ala-Risku [9] showed that other than construction and military industry, LCC is widely used in energy, transportation and manufacturing industries. Slow adoption of LCC in other industries is due to lack of standard or formal guidelines and lack of reliable past data [10]. Usually, the initial investment cost is the most often or the only criteria in purchasing decision [11]. Generally, LCC analysis consists of these simple steps as shown in Figure 1.
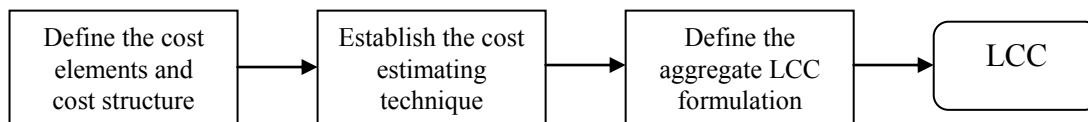

Fig. 1. LCC procedure

Cost element is the entire cost flows which occur during the complete life of product, while cost structure is the activity of categorizing all costs into suitable column to simplify the calculation. Some cost elements that need to be determined to perform LCC analysis [11] are:

1) Initial capital cost including purchase cost, acquisition or finance cost and installation, commissioning or training cost.
2) Life of the asset.
3) Operating and maintenance cost including direct material, direct expenses, indirect labour, indirect materials, establishment cost, direct labour materials, fuel power, equipment and purchased services.
4) Disposal cost including cost of disassembly, demolition, scrapping or selling the asset, adjusted any tax allowance or change upon resale.
5) Information and feedback because LCC is highly dependent on the assumptions and estimates made while collecting data.
6) Uncertainty and sensitivity analysis which usually happen because of the inadequacy of the input data.

Cost Estimation Technique

The cost estimation process usually depends on the level of analysis, either during the early stage of development, during the design stage progress or at the detailed design stage. Cost estimation is important to avoid underestimation which may causes financial loss or overestimation which cause the company to lose orders [7]. Generally, cost estimation technique can be divided into qualitative and quantitative techniques [12,13]. Qualitative technique is an approach that compares a new product with the products that have been manufactured in terms of their similarities. Meanwhile, quantitative approach depends on detailed analysis of a product design, product features and also the manufacturing process.

Niazi et al. [12] has listed intuitive model and analogical model as a qualitative cost estimation technique. Intuitive model is a technique that uses past experience to estimate the cost of the product, and it usually needs a database to help end user to improve the decision making process, and also to plan the cost estimation for new product. Some techniques that can be categorized into this model are case-based methodology that matches the information of previous product with the new product, and secondly is the decision support system (DSS) which uses artificial intelligent (AI) as a decision-aid tool. Analogical model or cost estimation by using analogy is a technique that use similarity of product's attributes with the existing product that has known cost data. Regression analysis and back propagation neural network (BPNN) model are some techniques in the category of analogical model.

In quantitative cost estimation technique, Niazi et al. [12] listed two models; parametric and analytical. Parametric model is a model that uses mathematical and statistical methodologies to estimate cost. Cost is expressed as a function of its constituent variables. Practically, this method is a simple and easy method to calculate the total cost of the product if the cost elements and drivers are easy to determine. On the other hand, analytical model is a technique that is usually used in the final stage of design process because it requires a lot of information regarding all resources consumed during the production cycle. Examples of analytical models are operation-based approach, breakdown approach, tolerance-based cost model and activity-based costing (ABC) system.

In addition, Asiedu and Gu [7] have listed detailed model as one of cost estimation technique. Detailed model technique is an approach that calculates the product cost by using estimate labour time, labour rate, material quantities and prices to estimate the direct cost of product, and also using allocation rate to calculate indirect or overhead cost. This technique is the most accurate cost estimation technique and flexible approach, but it is time consuming and costly approach. Estimator should have detailed knowledge about the product from the process, material used and so on. Therefore, this technique is not suitable to estimate the cost for a complex system.

Cost Estimation Model

The methodology for life cycle costing or cost estimation model is designed to ensure that LCC analysis can be done efficiently and effectively. Until now, there are a number of cost estimation models that have been developed for various kinds of applications, which aimed to determine the product cost. Complete LCC analysis should include all costs of developing product for the entire life cycle. Korpi and Ala-Risku [9] noticed that based on their survey, only 3 out of 55 case studies on LCC analysis had included all costs from all product development stages.

The cost estimation task is a complex task because it requires balance between cost information and design decision [14]. Therefore, it is important to develop cost model as decision-aid tool in terms of cost aspect during the development process because it has the greatest impact on cost reduction. Layer et al. [13] has listed several requirements for cost estimation model, which are: 1) accuracy, 2) transparent description of cost structure, 3) design-concurrent use, 4) dynamic adaptivity, and 5) calculation of complex parts.

There are different techniques to develop cost estimation models for LCC analysis and the most general LCC models are conceptual, analytical and heuristic [15,16]. Zhang and Fuh [17] have categorized cost estimation into the following categories: 1) traditional detailed-breakdown cost estimation, 2) simplified breakdown cost estimation, 3) group technology (GT) based cost estimation, 4) cost estimation based on cost function or cost increase functions, and 5) activity-based cost estimation (ABC). It is usually being used for specific situation but it does not guarantee to produce optimal solution. General purposes of developed cost estimation model are used for performing LCC analysis and used to evaluate cost of certain operation or in specific phases of the product life cycle. Some previous cost estimation models by other researchers are shown in Table 1.

Table 1. Previous cost models

Author(s)	Model	Case study	Detail review
Kwon and Seo [6]	Hybrid life cycle costing model (HLCCM)	Product family	▪ Developed model was used to estimate the cost performance of product design alternatives. ▪ Cost performance was improved by using genetic algorithm and artificial neural network. ▪ Cloud computing-based collaborative design environment was proposed to allow users to estimate product data and other related information.
Seo et al. [14]	-	Electronic product	▪ The model used artificial neural network to predict the product's LCC. ▪ Feasibility test was conducted and focused on total life energy consumption. ▪ Training data were collected for 150 various types of electronic products from previous studies.
Zhang and Fuh [17]	Feature-based cost estimation	Packaging product – regular slotted carton (RSC)	▪ Cost estimation model was developed based on product's features. ▪ Product's features can be classified into the following categories: 1) material, 2) printing plates, 3) printing features, and 4) production requirement (lot size). ▪ Neural network has been used in this model: 1) to obtain cost-feature matrix according to product design specification, and 2) to calculate cost of new product.
Oh and Park [18]	Multistage integrated model	Printed circuit board (PCB)	▪ The model was used for decision making of the product and process design simultaneously at each stage. ▪ Cost estimation was done by identifying each cost value, including non-value added activity and intangible factor for process design alternatives. ▪ Dynamic programming method was used to select the optimal process design alternatives at each stage of operation. ▪ Cost model was used to calculate manufacturing cost.
Emblemsvåg [19]	Activity-based life cycle costing (LCC)	Platform supply vessel (PSV)	▪ Employed activity-based LCA model and the model work according to ABC principles. ▪ This model only focused on three activities: use, service on dock and repair.
Shehab and Abdalla [20]	Integrated framework PC-based system	Machining processes - socket	▪ The main functions of the model are to estimate product cost (manufacturing cost) and generate initial process planning, such as selection of machining processes. ▪ The intelligent knowledge-based system for modelling of product cost in the product development stage was developed and extended from the previous model, which also includes certain issues such as non-productive cost and set-up cost.
Günaydın and Doğan [21]	-	4-8 storey apartment buildings	▪ The model was developed to estimate the total cost for structural systems of reinforced concrete skeleton buildings in the early design phase by using artificial neural network (ANN).
Xu, Chen and Xie [22]	Framework for product lifecycle costing (PLC) system	New mobile phone with universal mobile telecommunica - tion system	▪ This model is a combination of 4 methodologies and tools – case reasoning method, activity-based costing method, dynamic programming, and object oriented modelling method. ▪ It functions as design support tool to estimate total cost of product.
Qian and Ben-Arieh [23]	Cost estimation model that link ABC with parametric cost	Rotational part	▪ This study was an extension from previous study which combines activity-based costing (ABC) with parametric cost of design and development activity. ▪ Parametric cost-representation method was tested in a controlled factory environment and it integrates with ABC model to obtain accurate and easy-to-compute cost estimation of the design and development of product.

Based on previous studies, there are many cost estimation models that have been developed for various purposes by using different cost estimation techniques. Most researchers did not perform complete LCC analysis in their model. Usually, the model only focuses on certain product development stage, such as at the design stage or production stage. A complete analysis should include the costs related to all activities in order to develop product from cradle-to-grave, including indirect cost. To the best of the authors' knowledge, none of the researchers had developed cost model to analyze LCC of membrane that will be used to filter wastewater from industry. Therefore, it could be a big gap for authors to explore this area. Further detail on proposed methodology of assessing LCC for membrane system in wastewater filtration will be discussed in the next sub-section.

Research Direction

Membrane technology has been used in many applications and industries. Thus, the development of cost model for calculating the LCC of membrane system can be done especially during the design stage. The proposed methodology will cover the complete cycle of membrane system and include all costs that relate to the membrane life cycle. The expected outcome from this study is a tool for assessing the LCC of membrane system. It can be a design-tool aid in terms of economic aspect to ensure that membrane system is economical to be implemented and to determine certain cost target based on the firm's goal. The proposed research methodology of the study can be divided into four stages. The first stage is data collection, followed by selection of cost estimation, calculating of LCC and lastly is the development of graphical user interface (GUI). Table 2 shows the proposed steps for the research.

Table 2. Proposed research steps

Stage	Proposed steps	Detail description
1	1. Collect relevant data 2. Define objective of proposed LCC analysis 3. Identify all activity (primary and secondary) 4. Mapping resources and activity	All data related to product manufacturing is listed and gathered based on the category to build cost structure.
2	5. Assemble cost and data to be used in analysis 6. Select cost estimation	Selection of suitable cost estimation technique can be referred to Niazi et al. (2006).
3	7. Develop cost calculation for each cost structure and LCC by using cost estimating technique	In order to calculate LCC of membrane, ABC method will be used due to limited number of historical data.
4	8. Develop cost estimation model (GUI) 9. Validation process	GUI is build to help end user to use this method for assessing LCC of membrane quickly and accurately.

Conclusion

The review on life cycle costing, cost estimation techniques and cost estimation models based on previous studies has been done. Based on the review, the suitable cost estimation technique is chosen in order to develop cost estimation model. The aim of this paper is to highlight the research direction on how to assess the LCC of membrane system for wastewater filtration. The tool can be used to assist in decision making related to aspects of product costing.

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