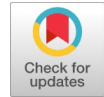# Development of Cost Estimation Model of the Membrane System

Nur Syamimi Jiran, Muhamad Zameri Mat Saman, Noordin Mohd. Yusof

Abstract: Apart from product quality, the manufacturing cost is an important element to compete in the competitive industry. Detail economic assessment is important to estimate the product cost accurately and avoid overestimating or underestimating that give bad impact to the firm. Membrane system; a compact, sustainable and cheaper wastewater treatment system compared to the traditional system. Yet, there is limited study analysing the economic aspect of the membrane system due to the limited historical data, a complicated process involved and deal with tangible overhead costs. Thus, this study aims to develop a cost model to estimate the total cost of the membrane system during its lifespan. Activity-based costing (ABC) method is used as cost estimation technique to calculating the overhead cost and added the direct costs to determine the life-cycle cost (LCC) of the membrane system by using Microsoft Excel while Microsoft Visual Basic is used to demonstrate a user-friendly cost estimation model. The proposed cost model is a simpler system because the end user is guided to get the LCC value without has to deal with a complicated equation. The proposed model cost is tested to estimating the LCC of HFMM in treating wastewater from the prototype stage until the disposal stage.

Keywords: Activity-based costing, Cost estimation model, Membrane system, Life cycle costing

I. INTRODUCTION

Increasing human population around the world generate increasing demand for the product thus create a highly competitive market among the manufacturing player. Previously, the manufacturer only concerns on reducing material acquisition cost, production and transportation cost only [1]. But, nowadays, in order to survive in this competitive market, the manufacturer has to consider reducing the total product cost or known as the product life cycle cost (LCC). Besides, consumer demand for quality but a reasonable low-cost product. Thus, cost estimation is a necessary task especially in estimating product cost at the early product stage because it can be reduced until 85% of the total product cost during this stage compared to other stages [2]. However, cost estimation at this stage is a tough, complex and not consistent process due to data availability and limited source of data [3].

Recently, membrane technology that used polymer membrane is widely utilized in various applications and industries [4] including in the water and wastewater industry particularly desalination and wastewater treatment system [5]. Membrane technology is proven as an effective and sustainable method to remove all micro-organisms present in the wastewater [6], [7]. Compared to the traditional wastewater system, membrane technology offer varies benefits including compact system with better output quality [8]-[10], required a minimum number of workers [11], [12] and did not produce any by-product from the filtering activity [13], [14].

Demand on the membrane technology keeps increasing and likely to continue in the future, but the LCC is an important concern to consider in implementing membrane technology. Consequently, cost assessment of the membrane technology needs to perform in order to provide an economic justification for a membrane technology project in monetary terms and able to evaluate several options based on the total costs and other benefits [12]. Cost analysis is important to ensure the membrane technology is a good option that balance both aspects, economic and environment hence accepted a sustainable product option [15]. However, estimating the total cost of the membrane technology is a tedious task because it deals with multiple processes which most of the data input is comes from other process output, involved with multiple tangible costs and some processes sharing the working space and equipment.

Therefore, computerized cost estimation model is needed to ensure cost estimation able to do effective and efficient manner due to its ability to deal with the manufacturing system that has multiple processes [16]. The user can estimate product cost without knowing the series of derived equations to determine the LCC of the membrane system. In addition, the proposed cost model is easy to use because the user is fully guided while performing the estimation. Several past studies had developed a computerized cost estimation model to estimate the cost of the membrane system. However, most of the study focus on estimating the investment cost of membrane technology [17]-[19] and the operating cost of various membrane application [12],[15],[20]-[23]. Most of the researches had explored the cost of membrane application and examined the membrane performance. Yet, limited research examined the total cost of the membrane system that covers the whole membrane system life cycle.

Different product cost and process have a different cost breakdown structure (CBS), so there is no single cost model the cost of varies product and process. Hence, this study aims that competent in estimating to develop a computerized cost

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model to estimate the LCC of the membrane system. Activity-based costing (ABC) method is used as the cost estimation method while a graphic user interface (GUI) to build the computerized cost model is developed by using the Microsoft Visual Studio. The target of the proposed cost model is to help membrane user to estimate the membrane system at an early stage as possible and able to do a comparison of several options of membrane system based on several factors before replaced the traditional system used in the organization.

II.   LITERATURE REVIEW

Membrane Technology

Membrane is a selective barrier that separates different pore size of liquid and gas that widely used in many industries depending on its flux rate. Membrane system has used to replace the traditional wastewater treatment system due to its ability to filter wastewater without produce any by-product from the separation activity to promote a sustainable solution [13],[14] and its ability to produce the higher output [8], [9]. Membrane system in the wastewater industry acts as a filter to filtering harmful effluent in the wastewater before its discharges to the drainage or it can be reused to promote water reused in any industry that has a high water demand such as the textile industry. Apart from saving the world from water pollution, membrane separation promoting water reuse to save a freshwater resource that keeps dwindling.

As a new technology, apart from the output produced, the LCC is the main concern for the manufacturer's stakeholder. There are some factors that may affect the cost of the membrane system that is, the mass balance of the separation output in term of flow rates and output's quality, the plant operation conditions, the system and module design, the mode of operation and other company's overheads [12]. Besides, There are two important elements in the membrane system that need to consider while designing the membrane plane which directly affects the membrane productivity, namely energy requirements and membrane's area [24]. The membrane system design testing is important because it may reduce as far as 30% of total investment cost and economic assessment is affecting about 30% of the total cost [12].

Cost Estimation

Cost estimation is a process of predicting the total product cost either in any product stage or for the whole product life cycle or known as LCC. Evaluating the product cost is important as a justification to support statement claimed a sustainable product is safe for the environment and provide economic benefit to the organization [25]. Cost estimation, especially LCC could act as an economic planning tool that helps to highlight any unexploited potential of any new investment in term of monetary and other benefits [16].

Cost estimation technique can be categorized into four main techniques, viz. intuitive, analogical, parametric and analytical [26]. Reference [27] had explained in detail each of the costing technique available. Each technique can be used for different cost problem based on data availability. Reference [28] had listed factors that need to consider while selecting the cost estimating technique including product data availability, amount of resource available, the timeframe setting and the degree of accuracy for each analysis. While according to [29], cost estimation technique is chosen based on the analysis stage, availability of product cost data either actual or similar product, number of cost driver needed, number of data set required and level of certainty accepted for the cost data input.

The cost estimation process should be done during the product design stage because the total product cost is depending on the decision at this stage and it can to save as much as 85% of the total product cost [2]. In addition, reducing the product cost is much easier to perform during this stage compared to another product stage [30]. However, cost estimation is a complicated and difficult task to perform during that stage. Cost estimation is normally prepared by the professional estimator which unfamiliar with some manufacturing process or did not have enough knowledge about the product. This could create a cost distortion which causes bad impact to the organization either loss profit due to underestimate or loss customer due to overestimating.

Recently, there is plenty of advanced manufacturing technology that helps the manufacturer to catch consumer demand, producing a high-quality product with possible low demand and fast distributing in the market. So, some manufacturing line could produce more than one type of product at one time or facilities shared by multiple product and process may occur in the factory. This situation may create a tangible overhead cost of the product and make the cost estimation process become more complicated and challenging. Apart from that, manual cost estimation is complicated because it could deal with multiple constraints including achieved multiple firm goals, able to demonstrate multiple outputs and functions and other factors that may interrupt and complicate the cost estimation process. Those factors indicate that computerized cost estimation is needed to ensure cost estimation could be done easily and produce accurate results as expected.

Cost Model

The cost model is a set of assumptions, rules, equations, and variables to describe the monetary flow of the system [31] in the form of a graphical user interface (GUI). A good cost model should have tolerable accuracy, clear detail of cost structure, suitable for design-concurrent use, dynamic adaptability and able to calculate simple and complex problem [32], yet able to demonstrate result in short time and have the ability to respond to any cost causality [33]. Besides, the computerized cost model is helping to reduce the management cost of estimating product cost, so it may further reduce the total product cost but increase product profitability [16].

There are various techniques can be employed to develop a cost model either based on conceptual, analytical or heuristic techniques [34], [35]. Many researchers had developed plenty of cost model for a different type of product and process to solve different type of cost analysis problem. However, until today none of the models had

become a cost model standard due to the difference in the problem nature, different in product typology and system and a different system of data collection [31]. Hence, the cost model usually developed to tackle one specific cost problem only. Normally, one cost model will apply one cost estimation technique to solve the cost problem, but some of the cost models used more than one cost estimation technique to get a more accurate and faster result [27].

Various cost models have been developed to estimating the cost for planning purposes, comparing several options and determine the impact of designs and operating conditions towards the membrane system in term of monetary and non-monetary benefits. Usually, the cost model is developed to estimate the investment cost of the membrane system. Most of the data come from the previously published research, real data from the membrane facilities and tender provided by the supplier or manufacturer [12]. Example of some developed membrane cost model is as follows. Reference [12] had evaluated the cost-effectiveness of reverse osmosis (RO) application in the dairy industry. Previously, [36] had used a cost model to examine the economic aspect of a nanofiltration (NF) process to recover detergents in the dairy industry. Reference [20] had developed a simplified cost model for estimating the cost of the water distillation process at different production scale. While [37] had developed a hybrid cost model for estimating LCC which combining genetic algorithm and artificial neural network to improve cost performance. Reference [38] had developed a cost model based on real data of microfiltration (MF) and ultrafiltration (UF) installations. Reference [15] had calculated the cost of water used in the agriculture irrigation by using MF and UF membrane technology along with the RO. A comprehensive technical and economic study had carried out by [39] which create four scenarios; single and integrated UF, loose NF, tight NF and RO membrane to treat textile dyebath wastewater in Turkey.

III. METHODOLOGY

Activity-based Costing

Based on the historical data availability, ABC is chosen as a cost estimation technique to calculate the overhead costs of the membrane system in this proposed cost model. The basic concept of ABC in measuring overhead costs are costs are generated the need for activity that consumes the resources [40], [41], [42] as shown in Fig. 1.

ABC is acknowledged as a reliable detail cost estimation technique because it uses detailed process information to estimate the overhead costs [43] thus it can accurately allocate overhead costs [44]. In ABC, the selection of cost driver is important because it may affect the accuracy of estimating the cost. A cost driver is any causal factor that may influence the activity's cost [45] and those factors could be identified through workers' interview or questionnaire and brainstorming session [46]. Resources consumed that include in this case study are quality control, material handling, space, equipment, set up, water, electricity, epoxy, nitrogen and chemical.

There are six steps in implementing ABC method, namely; identifying all activities, listing direct and

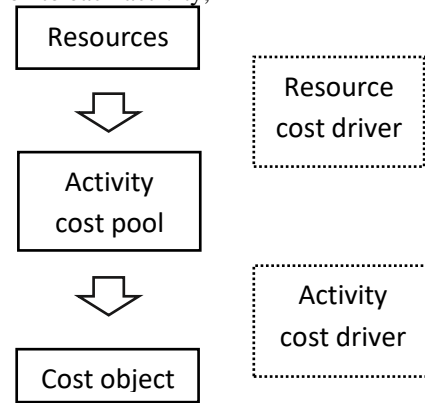overheads costs, identify and mapping resource consumption to each activity,

Fig. 1 The basic concept of activity-based costing

identify all cost drivers, calculating the cost pool rate and lastly, calculating the overhead costs. There are two cost allocation stages in the ABC method. During the first stage, all overhead costs were assigned to the activity centre or cost pool and the second stage, the overhead costs or known as cost object is allocated based on the cost of the activity centre.

In the proposed cost model, the derived equations to estimating the cost driver rate, cost pool rate, activity capacity, overhead cost, direct costs and the total cost for each product stage are developed in Microsoft Excel. There are 5 Excel workbooks used to calculate the cost for each product stage and the final workbook presents the LCC of the membrane system. Each workbook is linked from one to another in order to determine the LCC of the membrane system.

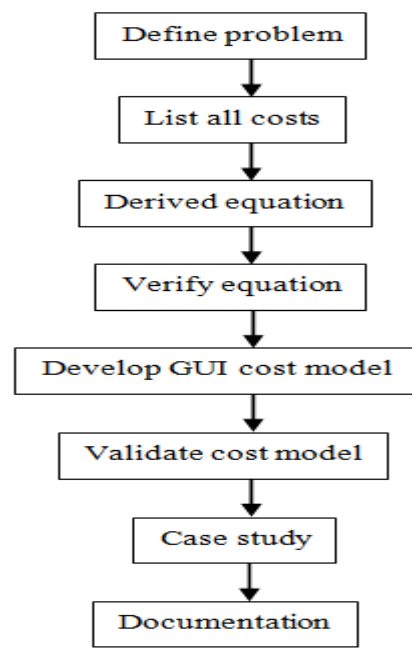### GUI of the Proposed Cost Model

Fig. 2 The GUI flowchart for the proposed cost model

The development of the GUI of the proposed cost model is shown in Fig. 2. The GUI of cost model is developed by

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using Microsoft Visual Basic aim to help the end user to predict the LCC of the membrane system in a simple way without the need to know or deal with the derived equations in Microsoft Excel. The proposed cost model is aimed to produce an accurate result in the fastest way so the user could estimate the cost since the early stage development with some basic membrane system information. The proposed cost model is unique because, apart from identifying the total cost of the membrane system in term of the LCC of the membrane, it also reveals some input that may help management to improve the production and operation in a way to reduce the total cost.

Define problem

Firstly, determine the user's problem that needs to be solved. In this case, the problem is manual cost estimation is a complicated and time-consuming process but it has plenty of benefits towards the organization. After that, identify and list all input, output and processing action used in the proposed cost model. Input is any features or information that need to key-in by the user. The output is the expected outcome from the proposed cost model while processing action is the process of translating the input into the output.

List all costs

Next, list all possible cost related to the membrane system throughout its lifespan. If possible, draw the CBS to ensure all costs are included.

Derived equation

After that, derived the equation used to calculate the cost object by using the chosen cost estimation technique. For the proposed cost model, ABC is used to calculate the overhead costs for each product stage. Microsoft Excel is used to store all derived equation from the step of calculating the resource cost driver until the final step to calculate the total cost of the membrane system. Each worksheet in every workbook and workbooks are named accordingly to avoid confusing and easier to search by other users if modification or upgrading is required.

Verify equation

Every equation used in the proposed cost model is verified by inserting random numbers into each input cell to ensure it produces an accurate result. Apart from that, the manual calculation is done for each equation to verify every equation.

Develop GUI

The proposed cost model is transforming the manual LCC cost estimation of membrane system into a user-friendly proposed software that developed by using Microsoft Visual Basic. The aim of the proposed cost model is to simplify the cost estimation process but able to produce an accurate result and solved the user's problem as defined in the first step of developing the GUI.

Validate model

Validation is a process of measuring the capability of the developed cost model to function well as a cost estimating tool. Cost model validation is done depends on the data availability or by using expert opinion if possible [44]. If there is sufficient historical data, the independent data point is used to validate the model [48]. Else, compare the result produced by another developed model that used a different type of cost estimation technique [48],[49]. The proposed cost model of the membrane system is validated by using comparing cost model result by using another developed cost model due to insufficient historical data.

Case study

The case study is carried out to demonstrate the capability of the proposed cost model in estimating the cost of the membrane system. The case study is used to test the proposed cost model to determine the LCC of the hollow fiber membrane module (HFMM).

Documentation

The final step is to ensure all related document is well maintained so any changes could be done accordingly.

The LCC Tool

The proposed cost model of the membrane system is named as LCC tool. The flow of the proposed cost model follows the procedure of ABC to estimating the total cost. There are 5 key options provided at the main page of the LCC tool; methodology, user guide, evaluation, setting and exit. The methodology explained the basic knowledge of the ABC that need to understand by the user before starting the estimating process. Some common terms used in the ABC method is explained in the simplest way.

The next option is user guide option that stored all related procedures that explained in detail, step-by-step from the beginning to start the evaluation until the pop-up result of the LCC of the membrane system. Besides that, all rules used in the LCC tool is also included in this user guide option. The user guide page of the LCC tool and an example of a user guide in the manufacturing stage shown in Fig. 3 and 4 respectively.

The next option is the evaluation option, the main function of the LCC tool. In this option, all calculation is occurring according to the ABC method. The evaluation of the LCC analysis is divided into the pre-manufacturing stage, manufacturing stage, usage stage and post-use stage before all costs; overhead cost, material cost and labour cost tabulate in the final page, named LCC page. The LCC analysis started with calculating the resource cost driver rate, followed by auto-calculated the resource overhead cost in the first stage cost allocation. Then, the overhead cost generated in the first stage is used to calculate the activity cost driver rate in the second stage cost allocation. The capacity of each activity is calculated based on its cost driver. Activity cost driver rate is calculated by dividing the resource overhead cost with the total capacity of each activity. Next, the cost per unit product is calculated because one manufacturing cycle producing 8 HFMMs. So, the cost per unit product is calculated to determine the cost for one HFMM. Add all cost per unit product to determine the overhead cost of the membrane system.

After that, the direct material and labour costs are

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calculated on the next page. Material costs are calculated based on total volume used to produce the HFMM while labour cost is calculated based on the number of workers involved directl.
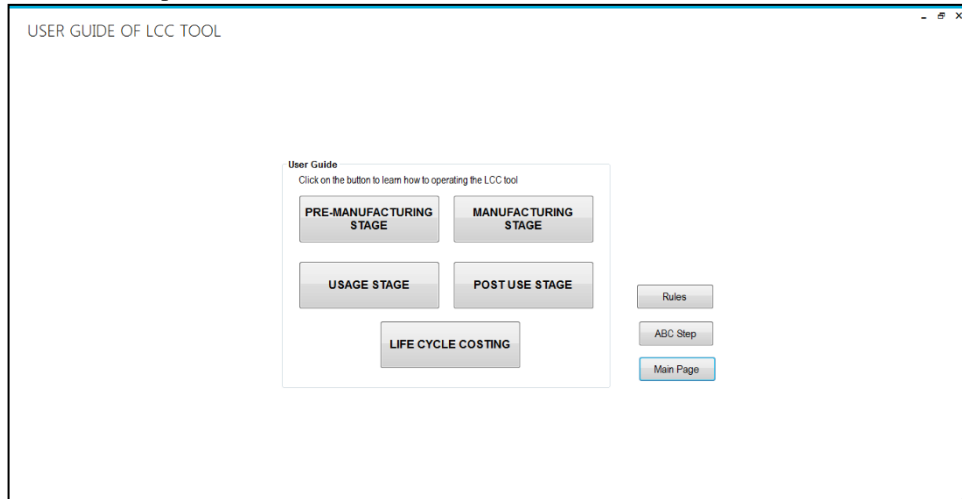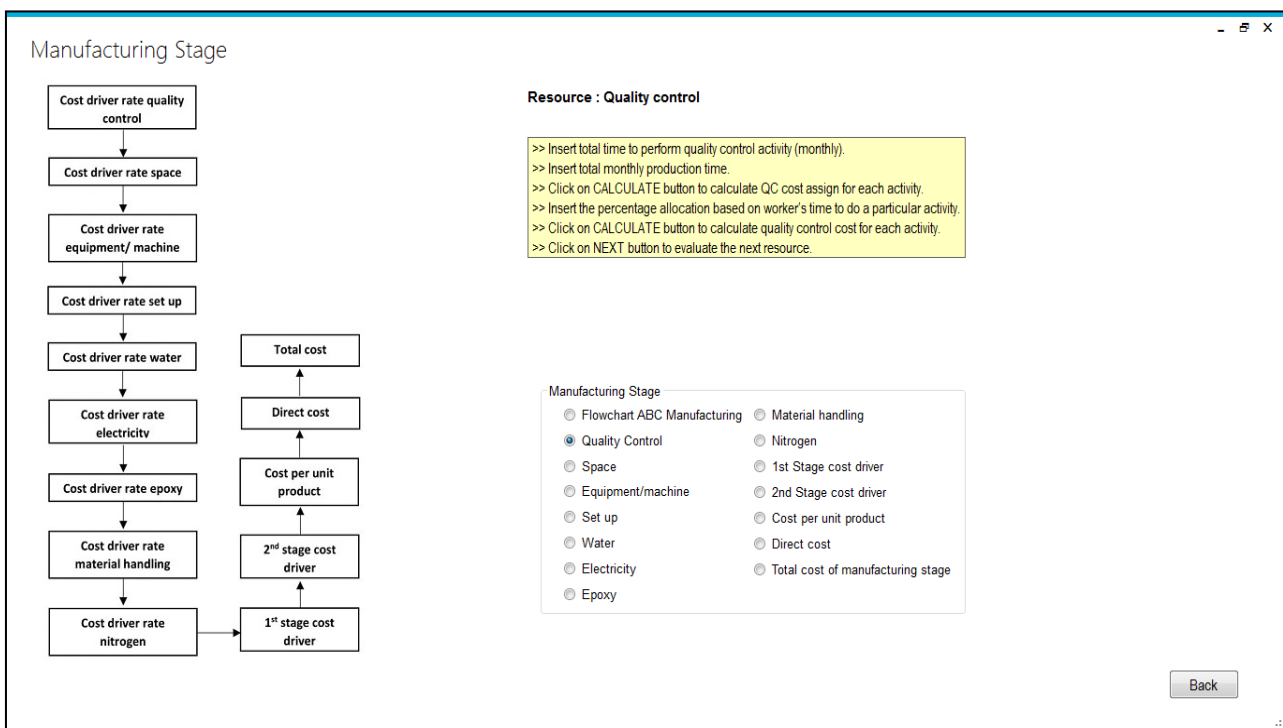

Fig. 3 User guide page

Fig. 4 An example page of a user guide in the manufacturing stage

to the process. In the LCC tool, labour cost only considers the wage of the workers. Lastly, the final page will show the total cost of the membrane system consists of the overhead, labour and material costs. This result will automatically link to the LCC page which summed all costs from the 4 product stages.

The setting option stored Microsoft Excel file used to recall in this LCC tool. The user is advised not to change this option to avoid any problem to the LCC tool. The final option is the exit button for the user to quit from the LCC tool. To ensure all result is secured, every change made in the LCC tool will automatically save in Microsoft Excel.

IV. CASE STUDY DESCRIPTION

The case study used in this study is the whole cycle of the HFMM from the stage of design and development of membrane module and system's prototype, the process of producing the HFMM, the usage of HFMM to treated wastewater until the final stage of the membrane replacement due to end-of-life (EOL).

In the pre-manufacturing stage, the membrane system is designed according to the purpose of the membrane system's application which is to treating wastewater. The

different raw material composition will produce different membrane morphology and pore size that affect the purpose of the membrane module. So, a proper selection of raw materials to produce the membrane module is required. After that, the prototype of the membrane module is developed until achieving the target output. The performance of the prototype membrane module is tested to measure its ability to filtering wastewater before continue to the next stage, the manufacturing stage.

The manufacturing stage involved the process of fabricating the HFMM until it ready to install in the membrane system. This stage starts with the process of preparing raw material to produce a dope solution. The dope solution is formulated from a combination between polymer, solvent, non-solvent and polymeric additive. The dope solution will undergo dry-wet phase inversion to produce a hollow fiber membrane (HFM). HFM is packed into a bundle, insert into tube sheet, seal both ends with epoxy to produce an

Table 1: The result of LCC of the HFMM

Product stage	Overhead cost	Labour cost	Material cost	Total cost
Design and prototype development	RM547.38	RM687.50	RM0.63	RM1,235.51
Membrane fabrication	RM222.97	RM0.63	RM0.49	RM224.09
Membrane operation and maintenance	RM9,622.90	RM1,375.00	RM0.00	RM10,997.90
Membrane EOL	RM937.94	RM375.00	RM0.00	RM1,312.94

HFMM. HFMM is tested by using a series of testing to measure its performance.

The next stage is the usage stage, which the HFMM is used based on its application. Filtering is the main activity in this stage while backwashing and chemical cleaning are a supporting activity that supports the productivity of the filtering activity. The cleaning procedure, cleaning interval and frequency will vary depending on the feed water quality, the treatment system design and operation, membrane flux rate and recovery rates [49].

The last stage is the post-use stage where the HFM meet its time-limited. The membrane is out of service, thus it needs to change with the new HFM and disposed of the older HFM. The tube sheet is cleaned and reused if it still in good condition, else it will be recycled. Membrane lifespan is depending on the membrane type, quality of feed stream and frequency of chemical cleaning but usually, it last for 5 to 10 years [50].

V. RESULTS AND DISCUSSION

The result from the ABC analysis in Table 1 shows that membrane operation and maintenance stage consumed the highest total cost compare to other product stages. So, it reveals that even though many researchers' claims that the membrane has cheaper manufacturing cost, the membrane operation is quite costly. It is important for membrane user to compare the operation cost of the membrane system with the previous system before continue to change the filtration

system. The membrane fabrication cost is cheap because membranes are produced in batch, so the cost of producing one membrane module could be cheaper than producing one membrane module for each manufacturing cycle. Cost for other stages are considered as high cost process because it used or deal with less number of membrane module for each cycle. For example, in this case study, only 4 membrane modules used in treating the wastewater during the membrane operation and maintenance. Apart from that, based on Table 1, it shows that the overhead cost during the membrane operation and maintenance are highest compared to other product stages.

ABC method is a detailed cost estimation technique that identified the source of activity that creates the cost object. Assigning the overheads to the product in a precise way to enable managers to have control over how the products consume resources and generate costs [42]. The resource is referring to any economic factors required by the activity
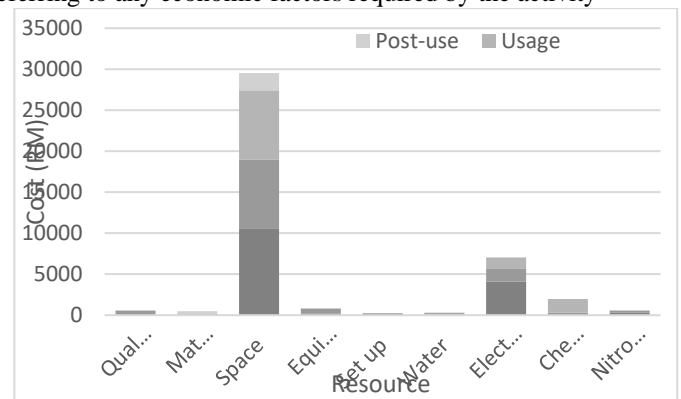

Fig. 5. Comparison of the resources consumption through the membrane lifespan

[50]. Resources include in this case study are quality control, material handling, space, equipment and machine, set up, water, electricity, chemical and nitrogen. The comparison of the resource consumption through the membrane lifespan is illustrated in Fig. 5. Space is recognized as the highest resource consumed followed by electricity. Resource space is an area that provided for any working area or storing purposes that measured in meter square (m^2). While electricity is referring to the power consumption used to make equipment and machine able to operate. Overhead of space is high due to land's price while for electricity, most of the equipment used throughout the membrane life cycle is electrical equipment. Other resources contribute to the total cost but the cost is not high compared to space and electricity. Membrane operation and maintenance are known as the highest cost thru the membrane lifespan. Therefore, a deep analysis on this stage is performed. Fig. 6 illustrates the resources consumption during membrane operation and maintenance based on the ABC analysis. The result shows that space contributes to the highest cost which is 73% of the total resource cost followed by chemical and electricity. Space is the area for the treatment plant and store. Whereas, the chemical is referring to the chemical substance used during the chemical cleaning activity and electricity is the

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power consumption used by the electrical equipment. Other resources including equipment and machine, water and material handling are recognized as low resource cost. Those
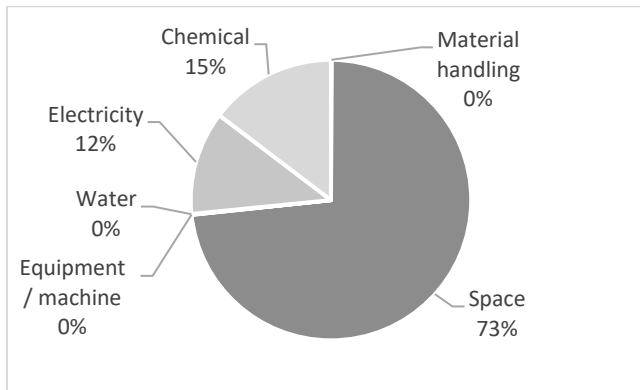

Fig. 6. Resources consumption in the membrane operation and maintenance stage

resources contribute RM4.99, RM7.60 and RM11.33 respectively for a month. That information could use by the management team to improve the plant operation at the same time reducing the total operation cost as possible. For example, as space contributes to the highest cost, relocating the factory could be considered in order to reduce the cost. Besides that, that information may help the organization to manage the resource to ensure it is used in the most optimum way to avoid any loss to the organization.

VI.   CONCLUSION

Sustainability becomes a common issue nowadays, so all new products and technology introduced to the market have to consider sustainability elements over its life cycle. However, the cost is an important element that needs to consider to ensure it has positive economic feedback to the organization too. Computerized cost estimation is developed to make the process easier and avoid human mistakes.

Hence, this paper shows the flow of developing a cost model to estimate the membrane system. A user-friendly interface, consist of the menu, user guideline, methodology and setting pushbutton had developed by using Microsoft Visual Basic make the cost estimation of the membrane system as an easier process. User is guided to insert the input to the system and completing the analysis. The derived equations to estimating the LCC had derived and stored in Microsoft Excel. This files had linked into the Microsoft Visual Basic so the user did not has to deal with all those equations in order to determine the LCC of the membrane system. The result from the LCC tool shows that membrane operation and maintenance is the most costing stages. A detail data collection while performing the ABC analysis helps to reveal that information which able to help in reducing the total cost of the membrane system. In addition, space is recognized as the most consuming resources which contribute to the highest overhead cost during the membrane life span. Based on that, it is agreed that ABC analysis used in the LCC tool could use to determine the total cost of the membrane system and it is also able to highlight other non-monetary information that may help the organization in improving the overall membrane system's performance and further reduce the total cost. The LCC tool gives benefit to

the environment in term of preventing water pollution and promoting water reused in the industry and also it gives economic benefit to the organization in term of helping to remove a non-productive activity, highlighting the most crucial activity that needs to carefully handle to avoid drastically increase the cost and other non-monetary benefits.

VII.   ACKNOWLEDGMENT

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