LIFE CYCLE ACTIVITY-BASED COSTING METHODOLOGY FOR WASTEWATER TREATMENT USING MEMBRANE SYSTEM

NUR SYAMIMI BINTI JIRAN

UNIVERSITI TEKNOLOGI MALAYSIA

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LIFE CYCLE ACTIVITY-BASED COSTING METHODOLOGY FOR WASTEWATER TREATMENT USING MEMBRANE SYSTEM

NUR SYAMIMI BINTI JIRAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Mechanical Engineering)

School of Mechanical Engineering
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Universiti Teknologi Malaysia

APRIL 2021

DECLARATION

I declare that this thesis entitled *"Life Cycle Activity-based Costing Methodology for Wastewater Treatment using Membrane System"* is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	NUR SYAMIMI BINTI JIRAN
Date	:	12 APRIL 2021

DEDICATION

To my parents Hj Jiran Siper and Hjh Zaiton Bidin who keep pushing me until the finishing line and to my lovely princess Faiha Alisha Muhamaad Fauzi; who will one day be better than me.

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ABSTRACT

Currently, the world is experiencing water crisis of declining clean water supply due to many factors such as human population growth, climate change and pollution. Membrane technology is known as a sustainable solution in preventing water pollution by treating wastewater effluent especially from the textile factory. Many researches on membrane performance and life cycle assessments have been carried out, but study on the economic aspect of membrane system using a detailed cost estimation method is limited. This study aimed to develop a life cycle costing (LCC) methodology for estimating the total cost of membrane system for wastewater treatment in small-scale textile factory using the activity-based costing (ABC) method. The outcome of this study may help in estimating the total cost at any membrane life cycle and determine the LCC of the membrane system. It can also serve as an economic justification and used as a decision-making aid as it reveals the monetary as well as other beneficial information of the product. The ABC method was used to compute overhead costs based on resource and activity cost drivers. Next, the total cost of the membrane system was calculated by adding overhead cost with direct material and labour costs. Three case studies were used to demonstrate the capability of the developed methodology in estimating the LCC and acting as a decision-making aid. The validation process was carried out by comparing results from the developed methodology with Fabrycky's parametric cost model and Kumar's parametric cost model. To produce accurate cost results, the cost error of the developed model should be less than 10%. Based on the results from case study 1, the cost of fabricating the hollow fiber membrane module (HFMM) was found to be lower (RM241.10 per unit HFMM) compared to the cost for membrane application (RM1,561.94). Results from case study 2 revealed that the cost of operation and chemical cleaning for the submerged membrane bioreactor (SMBR) was cheaper than the series HFMM although both options have the same operation time and total filtering cycle. Lastly, case study 3 showed that the combination of *Polyvinyl Chloride*, *N-Methyl-2-Pyrrolidone* and *Ethylene Glycol* had the cheapest material cost hence indirectly reducing the total cost of the membrane system. Apart from that, the ABC analysis also revealed an area of improvement that is useful for overall cost reduction. In conclusion, a methodology to estimate the LCC of membrane system throughout its lifespan using ABC method was successfully developed. This method is able to produce accurate result, avoid cost distortion and make cost estimation process easier compared to the traditional technique. Hence, it helps membrane user in estimating the total cost of the membrane system throughout its life cycle and monitoring the high-cost activities as well as high consumable resources to avoid increase in total cost. Subsequently, this method encourages the use of membrane as a sustainable system in the water and wastewater industries.

ABSTRAK

Dunia kini sedang mengalami krisis air iaitu pengurangan bekalan air bersih ekoran pelbagai faktor seperti pertumbuhan populasi manusia, perubahan iklim dan pencemaran. Teknologi membran telah dikenali sebagai penyelesaian mampan bagi mencegah pencemaran air menerusi kaedah rawatan sisa buangan terutamanya dari kilang tekstil. Banyak penyelidikan ke atas prestasi membran dan penilaian kitaran hayat telah dijalankan tetapi masih kurang kajian dari aspek ekonomi sistem membran tersebut dengan menggunakan kaedah penganggaran kos yang terperinci. Kajian ini bertujuan untuk membangunkan satu metodologi Kos Kitaran Hayat (LCC) bagi menganggar kos keseluruhan sistem membran untuk rawatan sisa buangan di kilang tekstil berskala kecil dengan menggunakan Kaedah Pengekosan Berasaskan Aktiviti (ABC). Hasil kajian ini boleh membantu menganggar jumlah kos keseluruhan pada mana-mana peringkat kitaran hayat membran dan menentukan LCC sistem membran tersebut. Ia juga boleh digunakan sebagai justifikasi ekonomi dan sebagai alat bantu membuat keputusan kerana ia mendedahkan maklumat kewangan dan maklumat penting yang lain mengenai produk terbabit. ABC digunakan bagi menganggar kos pasti berdasarkan pendesak-pendesak kos bagi setiap sumber dan aktiviti. Kemudian, kos keseluruhan sistem membran dikira dengan menambah kos pasti dengan kos bahan langsung dan kos buruh langsung. Tiga kajian kes telah digunakan bagi menunjukkan kebolehan metodologi yang dibangunkan dalam menganggar LCC dan bertindak sebagai alat bantu membuat keputusan. Proses pengesahan telah dilakukan dengan membandingkan keputusan daripada methodologi yang dibangunkan dengan model kos parametrik Fabrycky dan model kos parametrik Kumar. Untuk menghasilkan keputusan kos yang jitu, kesilapan kos bagi metodologi yang dibangunkan perlu kurang daripada 10%. Berdasarkan keputusan kajian kes 1, kos pembuatan modul membran serat berongga (HFMM) adalah lebih rendah (RM241.10 seunit HFMM) berbanding kos penggunaannya (RM1,561.94). Hasil daripada kes kajian 2 mendedahkan kos operasi dan kos pembersihan kimia bagi membran bioreaktor tenggelam (SMBR) adalah lebih murah berbanding siri HFMM walaupun kedua-duanya mempunyai masa operasi dan jumlah kitaran tapisan yang sama. Akhir sekali, keputusan kajian kes 3 menunjukkan kombinasi *Polyvinyl Chloride*, *N-Methyl-2-Pyrrolidone* dan *Ethylene Glycol* mempunyai kos bahan paling murah, maka secara tidak langsung mengurangkan kos keseluruhan sistem membran tersebut. Selain itu, analisis ABC juga mendedahkan kawasan yang boleh ditambah baik untuk mengurangkan keseluruhan kos. Kesimpulannya, metodologi untuk menganggarkan LCC sistem membran sepanjang kitaran hayatnya menggunakan kaedah ABC telah berjaya dibangunkan. Kaedah ini mampu menghasilkan keputusan yang lebih tepat, mengelakkan salah anggar kos dan membuat proses anggaran kos menjadi lebih mudah berbanding kaedah tradisional. Oleh itu, ia membantu pengguna membran untuk menganggar jumlah kos keseluruhan sistem membran sepanjang kitaran hayatnya dan memantau aktiviti kos yang tinggi serta sumber yang paling banyak digunakan untuk mengelakkan kenaikan kos keseluruhan. Seterusnya, kaedah ini dapat menggalakkan penggunaan membran sebagai sistem yang lestari untuk industri air dan air sisa.

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LIST OF ABBREVIATIONS

%	-	percent
±	-	Plus-minus
°C	-	Degree celcius
ABC	-	Activity-based Costing
AHP	-	Analytical Hierarchy Process
AMTEC	-	Advanced Membrane Technology Research Centre
ANN	-	Artificial Neural Network
ASEAN	-	The Association Of South East Asian Nations
CAD	-	Computer Added Design
CBS	-	Cost Breakdown Structure
CIP	-	Clean-In-Place
CSR	-	Corporate Social Responsibility
DMA_c	-	*Dimethylacetamide*
DMM	-	Domain Mapping Matrix
EG	-	*Ethylene Glycol*
EOL	-	End-Of-Life
Eq/mc	-	Equipment/Machine
FAMA	-	Agricultural Department And Federal Agriculture Marketing Authority
FTIR-ATR	-	Attenuated Total Reflection Fourier Transform Infrared Spectroscopy
g	-	gram
GA	-	Genetic Algorithm
GT	-	Green Technology
GUI	-	Grapical Use Interface
H_2O	-	Water
HCl	-	Hydrochloric Acid
HFM	-	Hollow Fiber Membrane
HFMM	-	Hollow Fiber Membrane Module
h	-	Hour

i.e.	-	that is
IWK	-	Indah Water Konsortium Sdn. Bhd.
ISO	-	International Organization For Standardization
KeTTHA	-	Ministry Of Energy, Green Technology And Water
ℓ	-	liter
LAP	-	*Lembaga Air Perak*
LCA	-	Life Cycle Assessment
LCC	-	Life Cycle Costing
MD	-	Membrane Distillation
MH	-	Material Handling
m^3	-	Cubic meter
m^2	-	Square meter
mℓ	-	Milliliter
min	-	Minute
ML	-	Machine Learning
MS	-	Microsoft
MSMA	-	New Stormwater Management Manual
MSW	-	Municipal Solid Waste
N_2	-	Nitrogen Gas
NEGTA	-	National Energy and Green Technology Awards
NF	-	Nano Filtration
NMP	-	*N-Methyl-2-Pyrrolidone*
NPV	-	Net Present Value
P/F	-	Find present value, given future value
PCB	-	Printed Board Circuit
pdf	-	Probability Density Function
PEG	-	*Polyethylene Glycol*
PES	-	*Polyethersulfone*
PLC	-	Programmable Logic Controller
PSV	-	Platform Supply Vessel
PVC	-	*Polyvinyl Chloride*
PVDF	-	*Polyvinylidene Fluoride*
PWP	-	Pure Water Permeability

QC	-	Quality Control
REHDA	-	Malaysian Real Estate And Housing Developers' Association
RM	-	Malaysian Ringgit
RO	-	Reverse Osmosis
SAJ	-	*Syarikat Air Johor*
sec	-	Seconds
SEM	-	Scanning Electron Microscopy
SIRIM	-	Standards And Industrial Research Institute Of Malaysia
S-LCA	-	Social Life Cycle Assessment
SMBR	-	Submerged Membrane Bioreactor
SME	-	Small-And-Medium Enterprise
SOP	-	Standard Operation Procedure
SVM	-	Support Vector Machines
SWM	-	South Waste Management
SYABAS	-	*Syarikat Bekalan Air Selangor Sdn. Bhd.*
TiO_2	-	Titanium Dioxide
TNB	-	*Tenaga Nasional Berhad*
U.N.	-	United Nation
U.S.	-	United States
UTM	-	Universiti Teknologi Malaysia
WIP	-	Work-In-Progress
wt%	-	Weight Percent

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Research

World sustainability directly depends on the human population and their activities. As the lifespan of products becomes shorter due to rapidly changing trends, a high amount of energy and raw materials are being over-consumed hence depleting resources for the next generation (Black et al, 2011). At the same time, the natural environment is being threatened by the revolting impacts of human activities including the overflowing of waste landfills, harmful gas emissions and various forms of pollution (Harte, 2007; Jaafar et al, 2007). Clean water is a vital element for human life but its sources are now facing the threat of depletion due to many factors (Kumar, Groth, & Vlacic, 2014; Kumari & Patil, 2019). The world is experiencing water shortage due to world climate change, high water demand from the industries, increasing human population, the dwelling of new water sources and water pollution (Piłatowska & Włodarczyk, 2018; Vegera, Malei, & Trubovich, 2018). Sewage discharge from the manufacturing and agricultural industry is a major factor contributing to the water crisis (Pang & Abdullah, 2013; United Nation (U.N.)-Water, 2011).

Water pollutant exacerbates the situation by contaminating large volumes of available water, rendering it unsuitable for human consumption. In Malaysia, there are several prominent problems related to clean water such as the prolonged water supply disruption around Kuala Lumpur and several regions in Selangor, the drastic reduction of the remaining amount of water in the dams caused by the dry spell in 2016 and the pollution of rivers resulting in raw water contamination. In early 2019, dozens of students and residents in Pasir Gudang suffered from the effects of the toxic waste dumped by irresponsible manufacturers that caused airborne pollution and also water contamination in the area, Sungai Kim Kim. At the end of 2019, another incident of illegal waste dumping in Sungai Semenyih caused residents nearby to endure smelly odours while many areas in Selangor suffered water disruption due to the forced shutdown of the Sungai Semenyih Water Treatment Plant. These problems primarily affected water supply for residential use. The continuous monitoring program by the Department of Environment Malaysia shows a declining trend in clean water river in Malaysia and the total number of slightly polluted and heavily polluted rivers keeps increasing every year due to many factors including, discharges from industry, sewage treatment plants, animal farms, agricultural activities and surface runoff (Afroz & Rahman, 2017). Hence, specific strategies and models focusing on wastewater treatment are needed to minimize the water pollution problem in Malaysia (Ujang & Buckley, 2002).

Membrane technology is acknowledged as an innovative technology that is widely used in many application and industries due to its advantages compared to traditional methods (Naveed, Bhatti, & Ali, 2006; Nicolaisen, 2003) including in the water and wastewater industry particularly desalination and wastewater treatment system (Goh & Ismail, 2018). Membrane technology has been proven to be an effective and sustainable method for removing all micro-organisms and eliminating all suspended solids present in wastewater (Capar, Yetis, & Yilmaz, 2006; Naveed et al, 2006) as well as producing better output quality of water (Drioli & Fontananova, 2004; Li et al, 2011; Ong & Chung, 2012), requiring only a minimum number of workers (Cheryan & Rajagopalan, 1998; Suárez et al, 2015) and yet keeping the environmental footprint to a minimum (Dasgupta et al, 2015; Molinari, Argurio, & Poerio, 2009; Yeo, Law, & Fane, 2006). With the current global water crisis, membrane technology can be used to purify municipal and industrial wastewaters for reuse or treatment before safely release into natural water stream (Mahmood, 2016).

As human activities of today will have an impact on the next generation in terms of raw material availability and future world conditions, the development of a sustainable product is needed to minimize the adverse impacts (Hemdi, 2013). The design of sustainable product should include cost considerations i.e. producing a quality product at a minimum cost throughout its lifespan (Ljungberg, 2007). Hence, the cost assessment via life cycle costing (LCC) analysis need to be performed before considering the implementation of membrane technology.

Apart from the quality of the product, cost is a critical aspect of business industries (Seo et al, 2002a) that may affect policies and strategies of the companies (Gupta & Galloway, 2003). Hence, it is important for decision-makers and industry players to understand the feasibility of projected plan (Salehi et al, 2014). Previously, membrane technologies have been rejected by small industries because it is claimed as expensive tools (Mulder, 2012; Pang & Abdullah, 2013). However, with recent technological innovations in membrane technologies, the cost of the membrane system is claimed to have decreased. This hence leads to an increase in the use of membrane systems for the wastewater treatment (Wang et al, 2014). To survive in the competitive market of today, manufacturers have to consider reducing the LCC of their product instead of only reducing cost of material acquisition, production and transportation (Seo et al, 2002a).

There are many techniques available for estimating product cost and plenty of cost models had been developed to facilitate the estimation process. Different products may entail different types of costs and every cost problem has different historical data viability, depth of analysis and goal of the analysis (Fixson, 2004). However, LCC analysis needs to be conducted as early as possible because estimating cost during the design stage could reduce the overall cost up to 85% (Dowlatshahi, 1992).

As sustainability has now become a global issue and a viable marketing strategy around the world, demands on membrane technology continue to increase and projected to keep growing into the future (Mahmood, 2016). Researches had been conducted on the potential and performance of the membrane system especially in relation to the environmental aspect (Kamali et al, 2019). However, very few had studied its economic aspect including the LCC of the membrane system due to variation in the raw wastewater characteristics, difficulties in gathering cost data and analyses that are time-consuming (Lau & Ismail, 2009; Lo, McAdam, & Judd, 2015).

Cost assessment needs to be performed to provide an economic justification in term of monetary value, to ensure that the membrane technology is a good option that balances both economic and environment aspects hence accepted as a sustainable product option (Bick et al, 2012) and act as an evaluation point in comparing several options based on the total cost and other benefits offered (Suárez et al, 2015). However, estimating the total cost of the membrane system at design stage is a tedious and complex task because it deals with multiple processes in which most of the data input comes from other process output, limited sources of data availability, multiple tangible costs and some processes sharing the working space and equipment (Tu, Xie, & Fung, 2007).

1.2 Problem Definition

At present, many sustainability assessments focus more on the environmental assessment as there is an international standard for it whereas limited international standards or guidelines are available for the social and economic assessment specially in the manufacturing industry (Costa, Quinteiro, & Dias, 2019; Kelly & Hunter, 2009; Korpi & Ala-Risku, 2008) due to difficulties in identifying the parameters involved in both elements (Hunkeler et al, 2008; Kelly et al, 2009). The lack of studies on LCC is caused by several factors including, lack of reliable historical cost data (Arditi & Messiha, 1999), differences in the nature of the problem (*Life cycle cost analysis,* 2016), uncertainties related to LCC assumptions (Dwaikat & Ali, 2018), and difficulties in obtaining cost parameters (Dwaikat et al, 2018). There are many ways others had employ to deals with insufficient data problem when conducting cost estimation activity including combining cost estimation methods, adopting other historical data and results and develop databases using machine learning (ML) based on historical data.

In the case of the economic assessment to determine the LCC of the membrane system, although some researchers had included economic assessment in their study, most had focused more on the basic economic calculations related to the initial and operational costs of the membrane system during the membrane application stage (Ang et al, 2017; Bick et al, 2012; Côté, Masini, & Mourato, 2004; Hitsov et al, 2018; Humeau et al, 2011; Keeley, Jarvis, & Judd, 2012; Samhaber & Nguyen, 2014; Suárez et al, 2015; Yoon, Lee, & Kim, 2004). Some common cost analysis involves expenditures related to investment, operation, maintenance, labour, energy and membrane replacement. Such assessment also typically only covers the application and usage stage (Korpi et al, 2008). Hence, those calculations are not a proper economic indicator to show the actual economic point of view of the product or system. Economic assessments should cover all stages of the product and include all costs related to the product throughout its lifecycle. Due to concerns on the use of the lifecycle engineering concept in designing products, the LCC of the product has become one of the elements that need to address well (Ahmad et al, 2018; Alting & Jøgensen, 1993; Asiedu & Gu, 1998; Hemdi, 2013; Lu et al, 2011).

The LCC analysis of the product should be carried out to determine the economical aspect of the product or system. LCC refers to all costs associated with the product or system to the defined lifecycle (Fabrycky & Blanchard, 1991). As membrane technology is a new trend in Malaysia, the LCC analysis should performed to determine the LCC value of the membrane system. The LCC analysis could be a justification to prove the economical point of the membrane system (Judd, 2017; Suárez et al, 2015) and in highlighting areas for cost reduction (Judd, 2017) to make the membrane system more attractive for implementation. Some companies that had implemented the membrane system are unsure about its cost-effectiveness. As the membrane system could be one of the best methods for filtering industrial wastewater (Drioli et al, 2004; Judd, 2017; Kamali et al, 2019; Mahmood, 2016; Owen et al, 1995; Vergili et al, 2012), an LCC analysis is important and should be performed in detail. A few studies found in literature had integrated LCC analysis and activity-based costing (ABC) method for application on other products and processes (Duran & Afonso, 2020; Kayrbekova, Markeset & Ghodrati, 2011; Pazarceviren & Dede, 2015; Rivero & Emblemsvåg, 2007; Yang, 2018), but hardly any had reported on the usage of the ABC method in the LCC assessment of the membrane system.

Since there is no standard procedure yet on how to perform the LCC of the membrane system, this study aims to develop a simple and effective methodology towards that end by using the ABC method. Using the ABC method, the cost of the product is estimated on the basis of the quantity of the resource consumed by each flow of activity in the production process. The ABC method is a detailed cost estimation system whereby the product cost is determined from its source making it suitable for dealing with indirect costs (Ben-Arieh & Qian, 2003; Carli & Canavari, 2013; Chouhan, Soral & Chandra, 2017; Esmalifalak, Albin & Behzadpoor, 2015; Gunasekaran, Marri & Grieve, 1999a; Gunasekaran & Sarhadi, 1998; Majid & Sulaiman, 2008; Wang & Han, 2013), able to produce reliable results (Majid et al, 2008; Tang, Wang, & Ding, 2012; Wang et al, 2013) and provide information related to specific activities (Baykasoğlu & Kaplanoğlu, 2008; Zhuang & Burns, 1992). ABC was developed to understand and control the indirect costs, as well as to highlight what trigger cost and how to manage those factors in order to control the product cost. Activity-based life cycle costing (ABLCC) analysis is more detailed and comprehensive as it captures costs from its source and covers the entire life-cycle of the product. The expected outcomes from the study will be a systematic methodology to measure LCC which can assist in decision-making process specially on the economic aspect. The purpose of this methodology is to measure the total cost involved in the membrane system's overall lifecycle.

1.3 Research Questions

The research questions for this study are as follows:

i. Is there a methodology for estimating the total cost of the membrane system for wastewater treatment in small-scale textile factories using a detailed cost estimation technique?

ii. How to determine the LCC of the membrane system?

iii. How to demonstrate the effectiveness of the methodology and validate the results from the methodology for estimating the LCC of the membrane system?

1.4 Research Objectives

The research objectives of this study are as follows:

i. To develop a methodology to calculate the total cost of the membrane system for wastewater treatment in small-scale textile factory using a detailed cost estimation technique i.e. the ABC method.

ii. To determine the LCC of the membrane system using the developed methodology.

iii. To demonstrate the effectiveness of the methodology using the case study technique and to validate the results by comparing it with another developed cost model.

1.5 Research Scopes

The scopes of the study are as follows:

i. Focus on the total cost of the membrane system from the pre-manufacturing stage, manufacturing stage, usage stage and post-use stage.

ii. The case study will focus on the hollow fiber membrane module (HFMM) used to treat wastewater from the textile manufacturing industry.

iii. The textile manufacturing industry chosen is a small-and-medium textile factory in Batu Pahat, Johor.

iv. For labour cost, this study only takes into consideration the workers' salaries; only a minimum total number of workers are taken into consideration.

1.6 Research Methodology

The research methodology of the study is shown in Figure 1.1 which is based on the research objectives and scope stated previously. A detailed explaination on the research methodoloy is presented in Chapter 3.

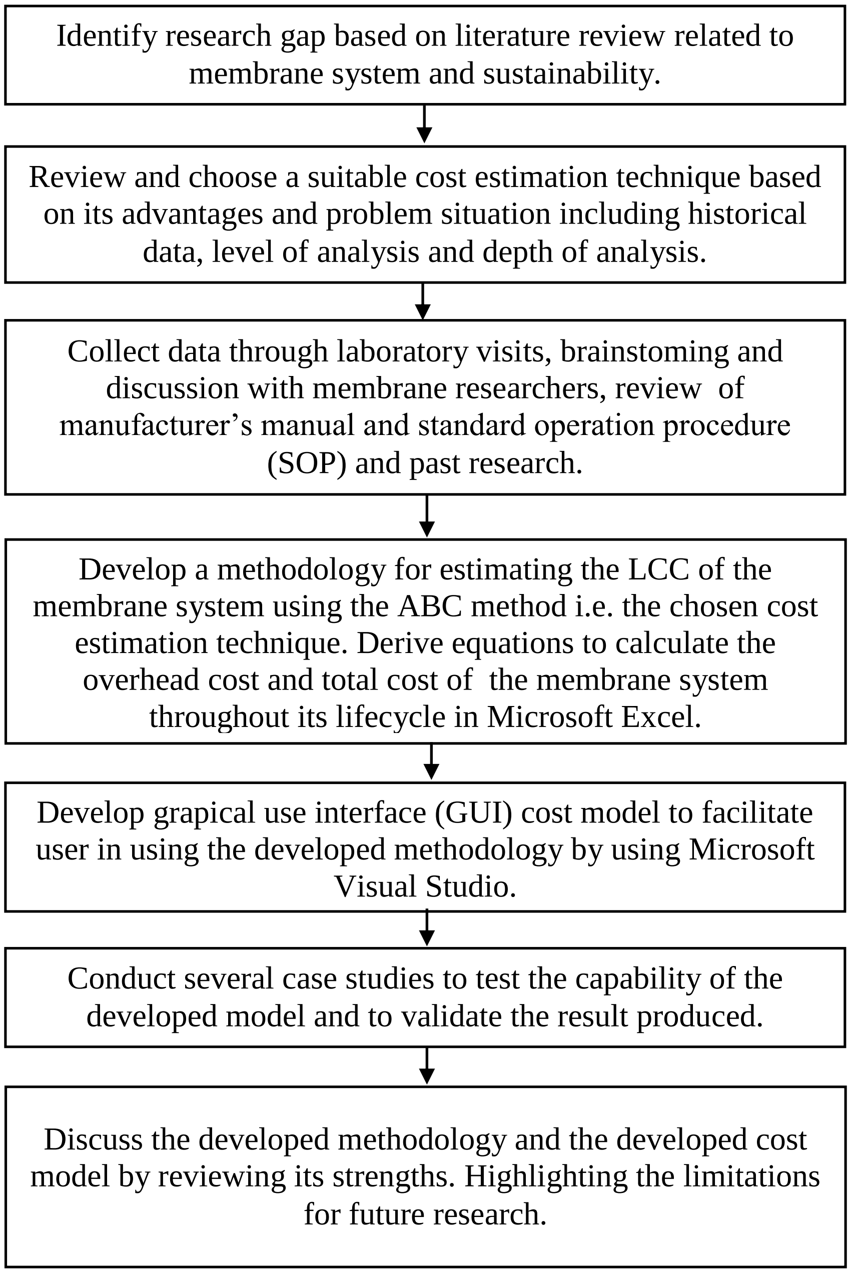

Figure 1.1 Research methodology of the study

1.7 Significance of the Research

Firstly, this study determines the total cost of the product throughout its lifespan i.e. covering the pre-manufacturing, manufacturing, usage and post-use stages using the ABC method, a detailed cost estimation technique. This is a new methodology that fulfills the research gap in the economic aspect of the sustainability concept i.e. LCC. This methodology integrates LCC and ABC in order to determine the LCC of the membrane system.

The developed methodology helps designers, researchers and manufacturers in estimating the total cost of the membrane system throughout its lifecycle including its LCC. Therefore, it can facilitate decision-making in terms of the economic aspect. The result from the developed methodology can be a reference point to decide whether the cost at any stage is within the company's preference before proceeding with the chosen membrane-type for filtration system. Estimating the LCC has many advantages despite being tricky as it involves tangible and intangible costs. Hence, a user-friendly cost model is needed to simplify the estimation process and to prevent miscalculations.

The outcome of the study is expected to facilitate researchers and practitioners in the manufacturing industry to estimate the LCC of any membrane-type and use it as an economic justification to prove that the membrane system is a sustainable and economic option in the wastewater filtration application. This is important because environmental activists had previously claimed that although membrane technology is a sustainable solution in preventing industrial water pollution, no detailed cost estimation that cover the LCC of the membrane system has been carried out. Hence, the developed methodology attempts to fill this gap. In addition, this could be an interactive point to promote the implementation of membrane technology in the water and wastewater industry as this technology has been proven to be sustainable with minimum cost. It helps in sustaining the environment and reducing the cost for the manufacturer as it is easy to modify into the existing treatment plant's system.

The results of the methodology can help the user in monitoring high cost activities and high consumable resources to avoid an increase in the total cost at any product stage. Apart from the monetary value, the ABC method also reveals areas that can improve the overall production and process flow as well as reduce the total cost.

1.8 Assumptions

The proposed methodology for estimating the LCC is implemented under several assumptions listed as follows:

i. Selection of resources, activity and cost drivers are based on brainstorming sessions with membrane researchers from the Advanced Membrane Technology Research Centre (AMTEC), UTM.

ii. All activities included in this study for every membrane lifespan is based on the basic flow at each cycle which is retrieved from the SOP prepared by AMTEC and past researchers.

iii. The economic life of equipment and machines are assumed to be 5 years or 43,800 hours for stainless steel equipment and 3 years or 26,280 hours for glass equipment when there is no information provided by the manufacturer.

iv. The operation time for the membrane manufacturing is assumed to be 26 days per month and 8 hours per day. This is based on the operation time applicable in AMTEC UTM and as used by other membrane researchers while fabricating the membrane module.

v. The operation time for the textile factory during the membrane application is assumed to be follow the case study company's working hour that is, 24 hours per day and 26 days per month.

vi. The labour cost only considers the workers' wage based on the minimum worker's wage in Malaysia.

vii. The recycling and disposal activity in the post-use stage will be handled by a third party such as Alam Flora and South Waste Management (SWM).

1.9 Thesis Structure

This thesis consists of seven chapters. Chapter 1 presents the background of the study, problem definition, research questions, research objectives, research methodology, research scopes, assumptions used and significance of the research.

Chapter 2 discusses and reviews relevant literatures which consists of several topics including, sustainability concept, sustainability developement, textile industry, sustainability assessment, LCC, cost estimation technique, the ABC method, cost model and membrane system. The basic procedure to conduct LCC analysis that is commonly used by others is explained. Several cost estimation techniques used to estimate the cost for various products and applications are reviewed and compared based on its advantages and limitations. The method for choosing the most suitable cost estimation technique for this study is also discussed. Based on that, the ABC method is chosen as the cost estimation technique. The basics of the ABC method are reviewed and its advantages and limitations are discussed in detail. Several developed cost models are reviewed as a guidance in developing the cost model for the membrane system. Lastly, this chapter explains basic information about the membrane system throughout its lifespan as the main case study in this research.

Chapter 3 explains the methodology of the research which includes the research framework and the theoretical methodology used in this study. Next, the development of the methodology to estimate the LCC using the ABC method is described in detail. Lastly, the developed software prototype, case study involved and method of validation used for the developed methodology is explained.

Chapter 4 describes in detail the development flow of the cost model to estimate the LCC of the membrane system. This includes defining the problem and listing the input, processing and output of the software. The software prototype for the LCC is presented with an illustration of the main page, methodology page, user guide page, evaluation page and setting page. Next, the flow of calculating the overhead cost in the GUI with sample calculation of each equation used in the developed methodology is presented. The case studies used in this study are also briefly discussed in this chapter.

Chapter 5 discusses the result and analysis of each case study. Some possible improvements based on the Pareto chart, value analysis and what-if analysis model are also listed for further analysis. Lastly, the results of the model validation are presented.

Chapter 6 discusses in detail the development of the methodology and also the proposed cost model software. The strengths and limitations of the developed methodology are also discussed in this chapter. Lastly, summarizes the conclusion of the study and lists some opportunities for future research.

REFERENCES

Abdulrazak, S. R. and Ahmad, F. S. (2014) ‘Sustainable development: a malaysian perspective’, *Procedia - Social and Behavioral Sciences, 164*, 237-241. doi:10.1016/j.sbspro.2014.11.072

Afroz, R. and Rahman, A. (2017) ‘Health impact of river water pollution in Malaysia’, *International Journal of Advanced and Applied Sciences, 4*(5), 78¬85.

Agyekum, E. O., Fortuin, K. P. J. and van der Harst, E. (2017) ‘Environmental and social life cycle assessment of bamboo bicycle frames made in Ghana’, *Journal of Cleaner Production, 143,* 1069-1080. doi:10.1016/j.jclepro.2016.12.012

Ahmad, A. L., Harris, W. A., & Ooi, B. S. (2002) ‘Removal of dye from wastewater of textile industry using membrane technology’, *Jurnal Teknologi, 36*(1), 31-44

Ahmad, S., Wong, K. Y., Tseng, M. L. and Wong, W. P. (2018) ‘Sustainable product design and development: A review of tools, applications and research prospects’, *Resources, Conservation and Recycling, 132,* 49-61. doi:10.1016/j.resconrec.2018.01.020

Ali, A., Quist-Jensen, C. A., Macedonio, F., & Drioli, E. (2016) ‘Optimization of module length for continuous direct contact membrane distillation process’, *Chemical Engineering and Processing: Process Intensification, 110,* 188-200. doi:https://doi.org/10.1016/j.cep.2016.10.014

Ali, N. a., Mohammad, A. W., & Ahmad, A. L. (2005) ‘Use of nanofiltration predictive model for membrane selection and system cost assessment’, *Separation and Purification Technology, 41*(1), 29-37. doi:https://doi.org/10.1016/j.seppur.2004.04.006

Alting, D. L. and Jøgensen, D. J. (1993) ‘The life cycle concept as a basis for sustainable industrial production’, *CIRP Annals, 42*(1)*,* 163¬167.

Ameli, M., Mansour, S. and Ahmadi-Javid, A. (2016) ‘A multi-objective model for selecting design alternatives and end-of-life options under uncertainty: A sustainable approach’, *Resources, Conservation and Recycling, 109,* 123-136. doi:10.1016/j.resconrec.2016.01.011

Ang, W. L., Nordin, D., Mohammad, A. W., Benamor, A. and Hilal, N. (2017) 'Effect of membrane performance including fouling on cost optimization in brackish water desalination process', *Chemical Engineering Research and Design, 117*, 401-413. doi:10.1016/j.cherd.2016.10.041

Arditi, D., & Messiha, H. M. (1999) 'Life cycle cost analysis (LCCA) in municipal organizations', *Journal of infrastructure systems, 5*(1), 1-10

Asiedu, Y. and Gu, P. (1998) 'Product life cycle cost analysis: State of the art review', *International Journal of Production Research, 36*(4), 883-908.

Avlonitis, S. A., Kouroumbas, K. and Vlachakis, N. (2003) 'Energy consumption and membrane replacement cost for seawater RO desalination plants', *Desalination, 157*(1–3), 151-158. doi:10.1016/S0011-9164(03)00395-3

Axelsson, R., Angelstam, P., Elbakidze, M., Stryamets, N. and Johansson, K.-E. (2011) 'Sustainable development and sustainability: Landscape approach as a practical interpretation of principles and implementation concepts', *Journal of Landscape Ecology, 4*(3), 5¬30.

Ayala, D., Ferre, V. and Judd, S. J. (2011) 'Membrane life estimation in full-scale immersed membrane bioreactors', *Journal of Membrane Science, 378*(1-2), 95-100.

Baker, R. W. (2004) *Membrane Technology and Applications* (Second ed.). England: John Wiley and Sons.

Balkema, A. J., Preisig, H. A., Otterpohl, R. and Lambert, F. J. D. (2002) 'Indicators for the sustainability assessment of wastewater treatment systems', *Urban Water, 4*(2), 153¬161.

Barringer, H. P. (2003) A life cycle cost summary. *International Conference of Maintenance Societies*. 20¬23 May. Perth, Australia, ICOMS:1-10.

Baykasoğlu, A. and Kaplanoğlu, V. (2008) 'Application of activity-based costing to a land transportation company: A case study', *International Journal of Production Economics, 116*(2), 308-324. doi: 10.1016/j.ijpe.2008.08.049

Ben-Arieh, D. and Qian, L. (2003) 'Activity-based cost management for design and development stage', *International Journal of Production Economics, 83*(2), 169¬183. doi: 10.1016/S0925-5273(02)00323-7

Bhojwani, S., Topolski, K., Mukherjee, R., Sengupta, D., & El-Halwagi, M. M. (2019) 'Technology review and data analysis for cost assessment of water treatment systems', *Science of The Total Environment, 651*, 2749-2761

Bick, A., Gillerman, L., Manor, Y. and Oron, G. (2012) ‘Economic assessment of an integrated membrane system for secondary effluent polishing for unrestricted reuse’, *Water, 4*(1), 219¬236.

Black, M. J., Whittaker, C., Hosseini, S. A., Diaz-Chavez, R., Woods, J. and Murphy, R. J. (2011) ‘Life Cycle Assessment and sustainability methodologies for assessing industrial crops, processes and end products’, *Industrial Crops and Products, 34*(2), 13321339.

Blocher, E. J., Stout, D. E. and Cokins, G. (2010) *Cost management: A strategic emphasis*. Includes index.

Bouhabila, E. H., Ben Aïm, R. and Buisson, H. (2001) ‘Fouling characterisation in membrane bioreactors’, *Separation and Purification Technology, 22–23,* 123-132. doi: 10.1016/S1383-5866(00)00156-8

Buecker, B. (2014) Micro- or Ultrafiltration and reserve osmosis: a popular combination for industrial treatment. *Water World*. Retrieved May 22, 2014, from https://www.waterworld.com/technologies/article/16211170/micro-or-ultrafiltration-and-reverse-osmosis-a-popular-combination-for-industrial-treatment

Capar, G., Yetis, U. and Yilmaz, L. (2006) ‘Reclamation of printing effluents of a carpet manufacturing industry by membrane processes’, *Journal of Membrane Science*, *277*(1–2), 120¬128. doi:10.1016/j.memsci.2005.10.022

Caputo, A. C., Pelagagge, P. M. and Salini, P. (2016) ‘Manufacturing cost model for heat exchangers optimization’, *Applied Thermal Engineering*, *94*, 513-533. doi:10.1016/j.applthermaleng.2015.10.123

Carli, G. and Canavari, M. (2013) ‘Introducing direct costing and activity based costing in a farm management system: A conceptual model’, *Procedia Technology*, *8*, 397-405.

Cheryan, M. and Rajagopalan, N. (1998) ‘Membrane processing of oily streams. Wastewater treatment and waste reduction’, *Journal of Membrane Science, 151*(1), 13¬28. doi: 10.1016/S0376-7388(98)00190-2

Chouhan, V., Soral, G., and Chandra, B. (2017) ‘Activity based costing model for inventory valuation’, *Management Science Letters, 7*(3), 135-144

Chung, T. S. N. (2008) *Fabrication of hollow-fiber membranes by phase inversion*, in Li, N. N., Fane, A. G., Ho, W. S. W. and Matsuura, T. (eds.), *Advanced Membrane Technology and Application.* John Wiley and Sons, pp. 821-839.

Ciardelli, G., Corsi, L., and Marcucci, M. (2001) ‘Membrane separation for wastewater reuse in the textile industry’, *Resources, Conservation and Recycling, 31*(2), 189-197.

Clark, C. E., Miller, A. and DuPont, B. (2019) ‘An analytical cost model for co-located floating wind-wave energy arrays’, *Renewable Energy, 132,* 885-897. doi: 10.1016/j.renene.2018.08.043

Cloete, S., Khan, M. N., and Amini, S. (2019) ‘Economic assessment of membrane-assisted autothermal reforming for cost effective hydrogen production with CO2 capture’, *International Journal of Hydrogen Energy, 44*(7), 3492-3510.

Costa, D., Quinteiro, P., and Dias, A. C. (2019) ‘A systematic review of life cycle sustainability assessment: Current state, methodological challenges, and implementation issues’, *Science of The Total Environment, 686*, 774-787. doi:https://doi.org/10.1016/j.scitotenv.2019.05.435

Côté, P., Masini, M., and Mourato, D. (2004) ‘Comparison of membrane options for water reuse and reclamation’, *Desalination, 167*, 1-11. doi:http://dx.doi.org/10.1016/j.desal.2004.06.105

Crinis, V. (2017) ‘Global commodity chains in crisis: The garment industry in Malaysia’, *Institutions and Economies,* 61-82.

Dasgupta, J., Sikder, J., Chakraborty, S., Curcio, S. and Drioli, E. (2015) ‘Remediation of textile effluents by membrane based treatment techniques: A state of the art review’, *Journal of Environmental Management, 147*, 55¬72. doi:10.1016/j.jenvman.2014.08.008

de Carvalho, J. F. (2011) ‘Measuring economic performance, social progress and sustainability using an index’, *Renewable and Sustainable Energy Reviews, 15*(2), 1073¬1079. doi:10.1016/j.rser.2010.11.040

de Paula, E. C., and Amaral, M. C. S. (2018) ‘Environmental and economic evaluation of end-of-life reverse osmosis membranes recycling by means of chemical conversion’, *Journal of Cleaner Production, 194*, 85-93. doi:https://doi.org/10.1016/j.jclepro.2018.05.099

Delogu, M., Zanchi, L., Maltese, S., Bonoli, A. and Pierini, M. (2016) ‘Environmental and economic life cycle assessment of a lightweight solution for an automotive component: A comparison between talc-filled and hollow glass microspheres-reinforced polymer composites’, *Journal of Cleaner Production, 139,* 548¬560. doi:10.1016/j.jclepro.2016.08.079

den Boer, J., den Boer, E. and Jager, J. (2007) 'LCA-IWM: A decision support tool for sustainability assessment of waste management systems', *Waste Management, 27*(8), 1032¬1045. doi:10.1016/j.wasman.2007.02.022

Dhillon, B. S. (1989) *Life cycle costing: Techniques, models and applications*. New York: Gordon and Breach Science Publishers.

Dong, J., Chi, Y., Zou, D., Fu, C., Huang, Q. and Ni, M. (2014) 'Energy–environment–economy assessment of waste management systems from a life cycle perspective: Model development and case study', *Applied Energy, 114*, 400¬408.

Dowlatshahi, S. (1992) 'Product design in a concurrent engineering environment: an optimization approach', *International Journal of Production Research, 30*(8), 1803¬1818. doi:10.1080/00207549208948123

Drioli, E. and Fontananova, E. (2004) 'Membrane Technology and Sustainable Growth', *Chemical Engineering Research and Design, 82*(12), 1557¬1562. doi:10.1205/cerd.82.12.1557.58031

Durairaj, S. K., Ong, S. K., Nee, A. Y. C. and Tan, R. B. H. (2002) 'Evaluation of life cycle cost analysis methodologies', *Corporate Environmental Strategy, 9*(1), 30¬39.

Duran, O., and Afonso, P. S. L. P. (2020) 'An activity based costing decision model for life cycle economic assessment in spare parts logistic management', *International Journal of Production Economics, 222*, 107499. doi:https://doi.org/10.1016/j.ijpe.2019.09.020

Dwaikat, L. N. and Ali, K. N. (2018) 'Green buildings life cycle cost analysis and life cycle budget development: Practical applications', *Journal of Building Engineering, 18*, 303¬311. doi:10.1016/j.jobe.2018.03.015

Ellis-Newman, J. (2003) 'Activity-based costing in user services of an academic library', *Library Trends, 51*(3), 333¬348.

Emblemsvåg, J. (2001) 'Activity-based life-cycle costing', *Managerial Auditing Journal,* 16**,** 17-27.

Emblemsvåg, J. (2003) *Life-cycle costing: Using activity-based costing and Monte Carlo methods to manage future costs and risks*. Hoboken, New Jersey: John Wiley and Sons.

Epstein M. J. (1996) *Measuring corporate environmental performance*. Chicago: Irwin Professional Publishing.

Esmalifalak, H., Albin, M. S., and Behzadpoor, M. (2015) ‘A comparative study on the activity based costing systems: Traditional, fuzzy and Monte Carlo approaches’, *Health Policy and Technology, 4*(1), 58-67. doi:https://doi.org/10.1016/j.hlpt.2014.10.010

Fabrycky, W. J. and Blanchard, B. S. (1991). *Life-cycle cost and economic analysis*. Prentice Hall.

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Koehler, A., Pennington, D. and Suh, S. (2009) ‘Recent developments in life cycle assessment’, *Journal of Environmental Management, 91*(1), 1¬21. doi:10.1016/j.jenvman.2009.06.018

Fixson, S. K. (2004) Assessing Product Architecture Costing: Product Life Cycles, Allocation Rules, and Cost Models. *ASME 2004 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. ASME, 857-868.

Fragkakis, N., Marinelli, M. and Lambropoulos, S. (2015) ‘Preliminary Cost Estimate Model for Culverts’, *Procedia Engineering, 123*, 153-161. doi: 10.1016/j.proeng.2015.10.072

Gagnon, B., Leduc, R. and Savard, L. (2012) ‘From a conventional to a sustainable engineering design process: different shades of sustainability’, *Journal of Engineering Design, 23*(1), 49¬74.

Ghaly, A., Ananthashankar, R., Alhattab, M., and Ramakrishnan, V. (2014) ‘Production, characterization and treatment of textile effluents: a critical review’, *Chemical Engineering & Process Technology Journal, 5*(1), 1000182.

Ghasemi, M., Daud, W. R. W., Ismail, A. F., Jafari, Y., Ismail, M., Mayahi, A., and Othman, J. (2013) ‘Simultaneous wastewater treatment and electricity generation by microbial fuel cell: performance comparison and cost investigation of using Nafion 117 and SPEEK as separators’, *Desalination, 325*, 1-6.

Giddings, B., Hopwood, B. and O'Brien, G. (2002) ‘Environment, economy and society: Fitting them together into sustainable development’, *Sustainable Development, 10*(4), 187¬196.

Gluch, P. and Baumann, H. (2004) ‘The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision-making’, *Building and Environment, 39*(5), 571¬580. doi:10.1016/j.buildenv.2003.10.008

Goh, P. S. and Ismail, A. (2018) 'A review on inorganic membranes for desalination and wastewater treatment', *Desalination, 434*, 60¬80.

Goh, Y. M., Newnes, L. B., Mileham, A. R., McMahon, C. A. and Saravi, M. E. (2010) 'Uncertainty in through-life costing–-review and perspectives', *IEEE Transactions on Engineering Management, 57*(4), 689-701.

Goh, Y. M., Newnes, L., McMahon, C., Mileham, A. and Paredis, C. J. (2009) A Framework for Considering Uncertainty in Quantitative Life Cycle Cost Estimation. *ASME 2009 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. Citeseer, 3-13.

Guinée, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T. and Rydberg, T. (2011) 'Life cycle assessment: Past, present, and future', *Environmental Science and Technology, 45*(1), 90¬96.

Gunasekaran, A., Marri, H. and Yusuf, Y. (1999b) 'Application of activity-based costing: some case experiences', *Managerial Auditing Journal, 14*(6), 286-293.

Gunasekaran, A., Marri, H. B. and Grieve, R. J. (1999a) 'Activity based costing in small and medium enterprises', *Computers and Industrial Engineering, 37*(1), 407-411.

Gunasekaran, A. and Sarhadi, M. (1998) 'Implementation of activity-based costing in manufacturing', *International Journal of Production Economics, 56*, 231-242.

Günaydın, H. M. and Doğan, S. Z. (2004) 'A neural network approach for early cost estimation of structural systems of buildings', *International Journal of Project Management*, *22*(7), 595-602.

Gundes, S. (2016) 'The use of life cycle techniques in the assessment of sustainability', *Procedia - Social and Behavioral Sciences, 216*, 916¬922. doi:10.1016/j.sbspro.2015.12.088

Gupta, M. and Galloway, K. (2003) 'Activity-based costing/management and its implications for operations management', *Technovation, 23*(2), 131¬138. doi:10.1016/S0166-4972(01)00093-1

Gupta, Y. P. (1983) *Life cycle cost models and associated uncertainties*. In Skwirzynski, J. K. (ed.), *Electronic Systems Effectiveness and Life Cycle Costing*. United Kingdom: Springer, pp. 535-549.

Hai, F. I., Yamamoto, K. and Fukushi, K. (2006) ‘Development of a submerged membrane fungi reactor for textile wastewater treatment’, *Desalination, 192*(1), 315-322.

Haifeng, L., Gopalkrishnan, V., Wee-Keong, N., Bin, S. and Xiang, L. (2007) Estimating product lifecycle cost using a hybrid approach. *2nd International Conference on Digital Information Management*. 28¬31 October, 393-398.

Harte, J. (2007) ‘Human population as a dynamic factor in environmental degradation’, *Population and Environment, 28*(4¬5), 223¬236.

Heijungs, R., Huppes, G. and Guinée, J. B. (2010) ‘Life cycle assessment and sustainability analysis of products, materials and technologies. Toward a scientific framework for sustainability life cycle analysis’, *Polymer Degradation and Stability, 95*(3), 422¬428.

Hemdi, A. R. (2013) *Fuzzy based sustainability indicator for product design and development process*. PhD Thesis, Universiti Teknologi Malaysia, Skudai.

Hennecke, F.-W. (1999) ‘Life cycle costs of pumps in chemical industry’, *Chemical Engineering and Processing: Process Intensification, 38*(4–6), 511-516. doi:10.1016/s0255-2701(99)00047-1

Hitsov, I., Sitter, K. D., Dotremont, C. and Nopens, I. (2018) ‘Economic modelling and model-based process optimization of membrane distillation’, *Desalination,* 436, 125-143. doi:10.1016/j.desal.2018.01.038

Holkar, C. R., Jadhav, A. J., Pinjari, D. V., Mahamuni, N. M., and Pandit, A. B. (2016) ‘A critical review on textile wastewater treatments: Possible approaches’, *Journal of Environmental Management, 182*, 351-366. doi:https://doi.org/10.1016/j.jenvman.2016.07.090

Hopwood, B., Mellor, M. and O'Brien, G. (2005) ‘Sustainable development: mapping different approaches’, *Sustainable Development*, 13(1), 38¬52.

Humeau, P., Hourlier, F., Bulteau, G., Massé, A., Jaouen, P., Gérente, C., Faur, L., and Le Cloirec, P. (2011) ‘Estimated costs of implementation of membrane processes for on-site greywater recycling’, *Water Science and Technology, 63*(12), 2949-2956. doi:10.2166/wst.2011.617

Hunkeler, D., Lichtenvort, K. and Rebitzer, G. (2008) *Environmental life cycle costing*. Pensacola, FL: SETAC.

Hussein, A. Y. (2009) *Development of product life-cycle cost analysis tool.* Master Thesis, Universiti Teknologi Malaysia, Skudai.

Idris, A., Hashim, R., Rahman, R. A., Ahmad, W., Ibrahim, Z., Razak, P. A., Zin, H. M., and Bakar, I. (2007) 'Application of bioremediation process for textile wastewater treatment using pilot plant', *International Journal of Engineering and Technology, 4*(2), 228-234.

Idris, A., Ismail, A. F., Noordin, M. Y., and Shilton, S. J. (2002). 'Optimization of cellulose acetate hollow fiber reverse osmosis membrane production using Taguchi method', *Journal of Membrane Science, 205*(1–2), 223-237. doi:http://dx.doi.org/10.1016/S0376-7388(02)00116-3

Ismail, A. F. and Kumari, S. N. (2004) 'Potential effect of potting resin on the performance of hollow fibre membrane modules in a CO2/CH4 gas separation system', *Journal of Membrane Science*, 236(1–2), 183-191. doi:10.1016/j.memsci.2004.02.023

International Organisation for Standardization (ISO) (2006) *ISO 14040 International Standard. In: Environmental Management – Life Cycle Assessment – Principles and Framework*. Geneva, Switzerland: International Organisation for Standardization.

International Society of Parametric Analysts (ISPA) (2008). *Parametric Estimating Handbook Fourth Edition*. Vienna: Institutional Society of Parametric Analysts Org. [online]. Available at: https://pmi-netherlands-chapter.org/images/stories/PMI-data/events-chaptermeetings/ISPA_PEH_4th_ed_Final.pdf (Accessed: 20 December 2018)

Jaafar, I. H., Venkatachalam, A., Joshi, K., Ungureanu, A.C., De Silva, N., Dillon Jr. O. W., Rouch, K. E. and Jawahir, I. S., (2007) *Product design for sustainability: a new assessment methodology and case studies*, in Kutz M, (ed.) *Handbook of environmentally conscious mechanical design*. John Wiley and Sons, pp. 25¬65.

Jalil, S., Ismail, A., and Hashim, S. (2004) 'Preparation and characterization of polyethersulfone hollow fiber nanofiltration membranes made from PES/NMP/PEG 400/WATER', *Jurnal Teknologi*, 1-19.

Jawahir, I. S., Rouch, K. E., Dillon, O. W., Joshi, K. J., Venkatachalam, A. and Jaafar, I. H. (2006). Total Life-cycle Considerations in Product Design for Manufacture: A Framework for Comprehensive Evaluation, *10th International Research/ Expert Conference Trends in the Development of Machinery and Associated Technology*. 11¬15 September. Lloret de Mar, Spain, 1¬10.

Jiran, N. S., Gholami, H., Mahmood, S., Mat Saman, M. Z., Yusof, N. M., Draskovic, V. and Jovovic, R. (2019) 'Application of activity-based costing in estimating the costs of manufacturing process', *Transformations in Business & Economics, 18*, 2B(47B), 839-860.

Judd, S. J. (2017) 'Membrane technology costs and me', *Water research, 122*, 1-9.

Kamali, M., Suhas, D. P., Costa, M. E., Capela, I., & Aminabhavi, T. M. (2019) 'Sustainability considerations in membrane-based technologies for industrial effluents treatment', *Chemical Engineering Journal, 368*, 474-494. doi:https://doi.org/10.1016/j.cej.2019.02.075

Kang, J.-G. and Brissaud, D. (2007) *A Product Lifecycle Costing System with Imprecise End-of-Life Data*, in Takata, S. and Umeda, Y. (eds.), *Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses*. Springer: London, pp. 467-472.

Kates, R. W., Parris, T. and Leiserowitz, A., (2005) 'What is sustainable development? Goal, indicators, value and practice', *Environmental engineering science*, 47, 8¬21.

Kaufman, R. J., (1970) 'Life cycle costing: a decision-making tool for capital equipment acquisition', *Cost and Management*, 44(2), 21¬28.

Kayrbekova, D., Markeset, T., & Ghodrati, B. (2011). 'Activity-based life cycle cost analysis as an alternative to conventional LCC in engineering design', *International Journal of System Assurance Engineering and Management, 2*(3), 218-225.

K Keeley, J., Jarvis, P., & Judd, S. (2012). 'An economic assessment of coagulant recovery from water treatment residuals', *Desalination, 287*, 132-137

Kelly, J. and Hunter, K. (2009) *Life Cycle Costing of Sustainable Design*. London: RICS Research.

Khayet, M., Feng, C., Khulbe, K. and Matsuura, T. (2002) 'Preparation and characterization of polyvinylidene fluoride hollow fiber membranes for ultrafiltration', *Polymer, 43*(14), 3879-3890

Koonce, D., Judd, R., Sormaz, D. and Masel, D. T. (2003) ‘A hierarchical cost estimation tool’, *Computers in Industry, 50*(3), 293-302. doi:10.1016/S0166-3615(03)00016-2

Korpi, E. and Ala-Risku, T. (2008) ‘Life cycle costing: a review of published case studies’, *Managerial Auditing Journal, 23*(3), 240¬261.

Kudoh, Y., Sagisaka, M., Chen, S. S., Elauria, J. C., Gheewala, S. H., Hasanudin, U., Khoo, H. H., Konishi, T., Romero, J., Sadamichi, Y., Shi, X. andSharma, V. K. (2011) *Sustainability Assessment of Biomass Utilisation in East Asian Countries*, in Finkbeiner, M. (ed) *Towards Life Cycle Sustainability Management*. Springer, Netherlands, pp. 413¬424.

Kuhlman, T. and Farrington, J. (2010) ‘What is Sustainability?’, *Sustainability, 2*(11), 3436¬3448.

Kumar, S., Groth, A. and Vlacic, L. (2014) ‘An analytical index for evaluating manufacturing cost and performance of low-pressure hollow fibre membrane systems’, *Desalination, 332*(1), 44¬51. doi:10.1016/j.desal.2013.10.013

Kumar, S., Groth, A., and Vlacic, L. (2016). ‘A tool for evaluation of lifecycle cost of water production for small-scale community projects’, *Water Policy, 18*(3), 769-782

Kumari, S. and Patil, Y. B. (2019) ‘Enablers of sustainable industrial ecosystem: framework and future research directions’, *Management of Environmental Quality: An International Journal, 30*(1), 61¬86.

Kwon, H. K. and Seo, K. K. (2013) ‘Development of a hybrid life cycle cost model for estimating product design alternatives in cloud computing based collaborative design environment’, *Advanced Material Research*. 658, 614-619.

Lau, W.-J. and Ismail, A. F. (2009) ‘Polymeric nanofiltration membranes for textile dye wastewater treatment: Preparation, performance evaluation, transport modelling, and fouling control — a review’, *Desalination, 245*(1–3), 321¬348. doi:10.1016/j.desal.2007.12.058

Layer, A., Brinke, E. T., Houten, F. V., Kals, H. and Haasis, S. (2002) ‘Recent and future trends in cost estimation’, *International Journal of Computer Integrated Manufacturing, 15*(6), 499-510. doi:10.1080/09511920210143372

Leong, J. Y. C., Balan, P., Chong, M. N., and Poh, P. E. (2019) ‘Life-cycle assessment and life-cycle cost analysis of decentralised rainwater harvesting, greywater recycling and hybrid rainwater-greywater systems', *Journal of Cleaner Production, 229*, 1211-1224. doi:https://doi.org/10.1016/j.jclepro.2019.05.046

Leslie, G., Mills, W., Dunivin, W., Wehner, M., and Sudak, R. (1998) Performance and economic evaluation of membrane processes for reuse applications. Paper presented at the *Proceedings of American Desalting Association Biennial Conference*. Williamsburg, VA, 1-8.

Li, F. Y., Li, Y., Chung, T.-S., Chen, H., Jean, Y. and Kawi, S. (2011) 'Development and positron annihilation spectroscopy (PAS) characterization of polyamide imide (PAI)–polyethersulfone (PES) based defect-free dual-layer hollow fiber membranes with an ultrathin dense-selective layer for gas separation', *Journal of Membrane Science, 378*(1¬2), 541¬550.

Life Cycle Cost Analysis (2006), in Giudice, F., La Rosa, G. and Risitano, A. (eds.), *Product Design for the Environment a Life Cycle Approach*. CRC Press, pp. 111-134.

Ljungberg, L. Y. (2007) 'Materials selection and design for development of sustainable products', *Materials and Design, 28*(2), 466¬479. doi:10.1016/j.matdes.2005.09.006

Lo, C., McAdam, E., and Judd, S. (2015) 'The cost of a small membrane bioreactor', *Water Science and Technology, 72*(10), 1739-1746.

Lu, B., Zhang, J., Xue, D. and Gu, P. (2011) 'Systematic lifecycle design for sustainable product development', *Concurrent Engineering, 19*(4), 307¬324.

Magram, S. F. (2009) 'A Review on Membrane Technologies and Associated Costs for Municipal Wastewater Reuse', *International Journal of Chemical Technology, 1*(2), 33-43.

Mahmood, S. (2016) *Methodology for assessing the sustainability of hollow fiber membrane system for wastewater treatment*. PhD Thesis, Universiti Teknologi Malaysia, Skudai.

Mahmood, S., Saman, M. Z. M. and Noordin, M. Y. (2013) 'Life cycle assessment of membrane system for wastewater treatment: A review and further research', In *Applied Mechanics and Materials*, 315, 186¬191.

Majid, J. A., and Sulaiman, M. (2008) 'Implementation of activity based costing in Malaysia: A case study of two companies', *Asian Review of Accounting, 16*(1), 39-55.

Marcucci, M., Ciabatti, I., Matteucci, A., & Vernaglione, G. (2003) ‘Membrane Technologies Applied to Textile Wastewater Treatment’, *Annals of the New York Academy of Sciences, 984*(1), 53-64. doi:10.1111/j.1749-6632.2003.tb05992.x

Mauchand, M., Siadat, A., Bernard, A. and Perry, N. (2008) ‘Proposal for tool-based method of product cost estimation during conceptual design’, *Journal of Engineering Design*, *19*(2), 159-172. doi:10.1080/09544820701802857

Mitcham, C. (1995) ‘The concept of sustainable development: its origins and ambivalence’, *Technology in Society, 17*(3), 311¬326. doi:10.1016/0160-791x(95)00008-f

Mo, Y., Chen, J., Xue, W. and Huang, X. (2010) ‘Chemical cleaning of nanofiltration membrane filtrating the effluent from a membrane bioreactor’, *Separation and Purification Technology, 75*(3), 407-414. doi:10.1016/j.seppur.2010.09.011

Mokthsim, N. and Salleh, K. O. (2014) ‘Malaysia's efforts toward achieving a sustainable development: issues, challenges and prospects’, *Procedia - Social and Behavioral Sciences, 120*, 299¬307. doi:10.1016/j.sbspro.2014.02.107

Molinari, R., Argurio, P. and Poerio, T. (2009) ‘Membrane processes based on complexation reactions of pollutants as sustainable wastewater treatments’, *Sustainability, 1*(4), 978¬993.

Moustafa, S. (2008). Process analysis & environmental impacts of textile manufacturing. *Dyes and Chemicals*.

Mulder, J. (2012) *Basic principles of membrane technology*: Springer Science and Business Media.

Mytilinou, V. and Kolios, A. J. (2019) ‘Techno-economic optimisation of offshore wind farms based on life cycle cost analysis on the UK’, *Renewable Energy, 132*, 439¬454.

Naveed, S., Bhatti, I. and Ali, K. (2006) ‘Membrane technology and its suitability for treatment of textile waste water in Pakistan’, *Journal of Research (Science), 17*(3), 155-164.

Ness, B., Urbel-Piirsalu, E., Anderberg, S. and Olsson, L. (2007) ‘Categorising tools for sustainability assessment’, *Ecological economics, 60*(3), 498¬508. doi:10.1016/j.ecolecon.2006.07.023

Newnes, L. B., Mileham, A. R., Cheung, W. M., Marsh, R., Lanham, J. D., Saravi, M. E. and Bradbery, R. W. (2008) ‘Predicting the whole¬life cost of a product at the conceptual design stage', *Journal of Engineering Design, 19*(2), 99¬112. doi:10.1080/09544820701803061

Niazi, A., Dai, J. S., Balabani, S. and Seneviratne, L. (2006) 'Product cost estimation: Technique classification and methodology review', *Journal of Manufacturing Science and Engineering, Transactions of the ASME, 128*(2), 563-575.

Nicolaisen, B. (2003) 'Developments in membrane technology for water treatment', *Desalination, 153*(1–3), 355¬360. doi:10.1016/s0011-9164(02)01127-x

Niren, P. and Jigisha, P. (2011) 'Textile wastewater treatment using a UF hollow-fibre submerged membrane bioreactor (SMBR)', *Environmental Technology, 32*(11), 1247-1257. doi:10.1080/09593330.2010.534821

No, J. J. and Kleiner, B. H. (1997) 'How to implement activity-based costing', *Logistics Information Management, 10*(2), 68-72.

Oh, C. J. and Park, C. S. (1993) 'An economic evaluation model for product design decisions under concurrent engineering', *The Engineering Economist, 38*(4), 275-297. doi: 10.1080/00137919308903104

Olawumi, T. O. and Chan, D. W. M. (2018) 'A scientometric review of global research on sustainability and sustainable development', *Journal of Cleaner Production, 183*, 231¬250. doi:10.1016/j.jclepro.2018.02.162

Ong, C., Lau, W., Goh, P., Ng, B., and Ismail, A. (2015) 'Preparation and characterization of PVDF–PVP–TiO2 composite hollow fiber membranes for oily wastewater treatment using submerged membrane system', *Desalination and Water Treatment, 53*(5), 1213-1223

Ong, N. S. (1995) 'Manufacturing cost estimation for PCB assembly: An activity-based approach', *International Journal of Production Economics, 38*(2–3), 159-172.

Ong, Y. K. and Chung, T.-S. (2012) 'High performance dual-layer hollow fiber fabricated via novel immiscibility induced phase separation (I2PS) process for dehydration of ethanol', *Journal of Membrane Science, 421*, 271¬282.

Ong, Y. K., Li, F. Y., Sun, S.-P., Zhao, B.-W., Liang, C.-Z. and Chung, T.-S. (2014) 'Nanofiltration hollow fiber membranes for textile wastewater treatment: Lab-scale and pilot-scale studies', *Chemical Engineering Science, 114*, 51-57. doi:10.1016/j.ces.2014.04.007

Owen, G., Bandi, M., Howell, J. A. and Churchouse, S. J. (1995) 'Economic assessment of membrane processes for water and waste water treatment', Journal of Membrane Science, 102(0), 77¬91. doi: 10.1016/0376-7388(94)00261-v

Pang, Y. L. and Abdullah, A. Z. (2013) 'Current status of textile industry wastewater management and research progress in malaysia: a review', *CLEAN – Soil, Air, Water, 41*(8), 751¬764. doi:10.1002/clen.201000318

Parameshwaran, K., Fane, A. G., Cho, B. D., and Kim, K. J. (2001) 'Analysis of microfiltration performance with constant flux processing of secondary effluent', *Water research, 35*(18), 4349-4358. doi:10.1016/s0043-1354(01)00182-8

Park, J. and Simpson, T. W. (2007) 'Toward an activity-based costing system for product families and product platforms in the early stages of development', *International Journal of Production Research, 46*(1), 99-130. doi:10.1080/00207540600825240

Pazarceviren, S. Y., and Dede, B. (2015) 'Life Cycle Costing Model Based On Target Costing and Activity-Based Costing Method and A Model Proposal', *European Scientific Journal*, 121-138.

Peruzzini, M., Gregori, F., Luzi, A., Mengarelli, M. and Germani, M. (2017) 'A social life cycle assessment methodology for smart manufacturing: The case of study of a kitchen sink', *Journal of Industrial Information Integration, 7*, 24¬32. doi:10.1016/j.jii.2017.04.001

Piłatowska, M. and Włodarczyk, A. (2018) 'Decoupling economic growth from carbon dioxide emissions in the EU countries', *Montenegrin Journal of Economics*, *14*(1), 7¬26.

Pilutti, M. and Nemeth, J. E. (2003) 'Technical and cost review of commercially available MF/UF membrane products', *Desalination*, 1-15.

Praneeth, K., Manjunath, D., Bhargava, S. K., Tardio, J., and Sridhar, S. (2014) 'Economical treatment of reverse osmosis reject of textile industry effluent by electrodialysis-evaporation integrated process', *Desalination*, *333*(1), 82-91. doi:10.1016/j.desal.2013.11.020

Qian, L. and Ben-Arieh, D. (2008) 'Parametric cost estimation based on activity-based costing: A case study for design and development of rotational parts', *International Journal of Production Economics,* 113**,** 805-818.

Rakmi, A. (1993). *Characterization and prospects for biological treatment of textile finishing wastewater*, in Yeoh, B. G., Chee, K. S., Phang, S. M., Isa, S., Idris,

A. & Mohamed M. (eds.), *Waste Management in Malaysia: Current Status and Prospects for Bioremedistion.* Malaysia, Ministry of Science, Technology and the Environment, pp. 99-108

Ratnatunga, J., Tse, M. S. C., and Balachandran, K. R. (2012) 'Cost Management in Sri Lanka: A Case Study on Volume, Activity and Time as Cost Drivers', *The International Journal of Accounting, 47*(3), 281-301. doi:http://dx.doi.org/10.1016/j.intacc.2012.07.001

Reich, M. C. (2005). 'Economic assessment of municipal waste management systems—case studies using a combination of life cycle assessment (LCA) and life cycle costing (LCC)', *Journal of Cleaner Production, 13*(3), 253-263. doi:10.1016/j.jclepro.2004.02.015

Rivero, E. J. R., and Emblemsvåg, J. (2007). 'Activity-based life-cycle costing in long-range planning', *Review of Accounting and Finance, 6*(4), pp.370-390

Roy, R., Souchoroukov, P. and Shehab, E. (2011). 'Detailed cost estimating in the automotive industry: Data and information requirements', *International Journal of Production Economics, 133*(2), 694-707.

Salehi, E., Madaeni, S., Shamsabadi, A. and Laki, S. (2014) 'Applicability of ceramic membrane filters in pretreatment of coke-contaminated petrochemical wastewater: Economic feasibility study', *Ceramics International, 40*(3), 4805¬4810

Saman, M., Hamid, W., Tap, M., and Sirat, R. (2007) *Ekonomi Kejuruteraan dan Perakaunan untuk Jurutera* (Vol. 13). Malaysia: Pearson Prentice Hall

Samhaber, W. M., and Nguyen, M. T. (2014) 'Applicability and costs of nanofiltration in combination with photocatalysis for the treatment of dye house effluents', *Beilstein Journal of Nanotechnology, 5*(1), 476-484.

Sartori, S., Latrônico, F. and Campos, L. (2014) 'Sustainability and sustainable development: a taxonomy in the field of literature', *Ambiente and Sociedade, 17*(1), 01¬22.

Schau, E. M., Traverso, M., Lehmannann, A., and Finkbeiner, M. (2011) 'Life cycle costing in sustainability assessment-A case study of remanufactured alternators', *Sustainability, 3*(11), 2268-2288. doi:10.3390/su3112268

Senán-Salinas, J., García-Pacheco, R., Landaburu-Aguirre, J., and García-Calvo, E. (2019) 'Recycling of end-of-life reverse osmosis membranes: Comparative LCA and cost-effectiveness analysis at pilot scale', *Resources, Conservation* *and Recycling, 150*, 104423. doi:https://doi.org/10.1016/j.resconrec.2019.104423

Seo, K. K., Park, J. H., Jang, D. S. and Wallace, D. (2002a) 'Approximate estimation of the product life cycle cost using artificial neural networks in conceptual design', *International Journal of Advanced Manufacturing Technology*, 19(6), 461¬471

Seo, K.-K., Park, J.-H., Jang, D.-S. and Wallace, D. (2002b) 'Prediction of the life cycle cost using statistical and artificial neural network methods in conceptual product design', *International Journal of Computer Integrated Manufacturing, 15*(6), 541¬554. doi:10.1080/09511920210143417

Shehab, E. M. and Abdalla, H. S. (2001) 'Manufacturing cost modelling for concurrent product development', *Robotics and Computer-Integrated Manufacturing, 17*(4), 341¬353. doi:10.1016/S0736-5845(01)00009-6

Shi, X., Tal, G., Hankins, N. P., and Gitis, V. (2014) 'Fouling and cleaning of ultrafiltration membranes: A review', *Journal of Water Process Engineering, 1*, 121-138. doi:http://dx.doi.org/10.1016/j.jwpe.2014.04.003

Shi, Y., Zhou, L., Xu, Y., Zhou, H., and Shi, L. (2018) 'Life cycle cost and environmental assessment for resource-oriented toilet systems', *Journal of Cleaner Production, 196*, 1188-1197. doi:https://doi.org/10.1016/j.jclepro.2018.06.129

Sidek, L. M., Ghani, A. A., Zakaria, N. A., Abdullah, R. and Desa, M. N. (2004). A life cycle costs (LCC) assessment of sustainable urban drainage system facilities. *Proceeding of the 1st International Conference on Managing Rivers in the 21st Century: Issues and Challenges*. 21–23 September. Penang, Malaysia: 329–343. Retrieved October, 2012, from: http://redac.eng.usm.my/http://redac.eng.usm.my/html/ publish/2004_21.pdf

Singh, R. K., Murty, H. R., Gupta, S. K. and Dikshit, A. K. (2012) 'An overview of sustainability assessment methodologies', *Ecological Indicators, 15*(1), 281¬299. doi:10.1016/j.ecolind.2011.01.007

Suárez, A., Fernández, P., Ramón Iglesias, J., Iglesias, E. and Riera, F. A. (2015) 'Cost assessment of membrane processes: A practical example in the dairy wastewater reclamation by reverse osmosis', *Journal of Membrane Science, 493*, 389¬402. doi:10.1016/j.memsci.2015.04.065

Tang, S., Wang, D., and Ding, F.-Y. (2012) ‘A new process-based cost estimation and pricing model considering the influences of indirect consumption relationships and quality factors’, *Computers & Industrial Engineering, 63*(4), 985-993. doi:http://dx.doi.org/10.1016/j.cie.2012.06.010

The, J. S., Yarlagadda, P. K. D. V., Karim, A. and Yan, C. (2013) ‘A framework for life cycle cost estimation of a product family at the early stage of product development’, *Advanced Material Research*, 605, 222-227.

Tsai, W.-H. and Kuo, L. (2004) ‘Operating costs and capacity in the airline industry’, *Journal of Air Transport Management, 10*(4), 269-275. doi:10.1016/j.jairtraman.2004.03.004

Tsai, W.-H., Chen, H.-C., Liu, J.-Y., Chen, S.-P. and Shen, Y.-S. (2011) ‘Using activity-based costing to evaluate capital investments for green manufacturing systems’, *International Journal of Production Research, 49*(24), 7275-7292. doi:10.1080/00207543.2010.537389

Tu, Y. L., Xie, S. Q. and Fung, R. Y. K. (2007) ‘Product development cost estimation in mass customization’, *IEEE Transactions on Engineering Management, 54*(1), 29¬40.

Turney, P. B. (2010) ‘Activity-based costing: An emerging foundation for performance management’, *Cost Management*, *24*(4), 33.

U.N.- Water (2011). *Brief Policy Water Quality*. Retrieved December, 2012, from: http://www.unwater.org/downloads/waterquality_policybrief.pdf.

Ujang, Z. and Buckley, C. (2002) ‘Water and wastewater in developing countries: present reality and strategy for the future’, *Water Science and Technology, 46*(9), 1¬9.

Ulrich, K. T. and Eppinger, S. D. (2003). *Product design and development*. Tata McGraw-Hill Education.

U.N. World Commission on Environment and Development (UNWCED) (1987). *Our Common Future*. Retrieved June, 2012, from: http://www.un-documents.net/wced-ocf.htm

Van der Bruggen, B., Vandecasteele, C., Van Gestel, T., Doyen, W. and Leysen, R. (2003) ‘A review of pressure-driven membrane processes in wastewater treatment and drinking water production’, *Environmental progress, 22*(1), 46-56.

Vandevivere, P. C., Bianchi, R., and Verstraete, W. (1998) ‘Review: Treatment and reuse of wastewater from the textile wet-processing industry: Review of emerging technologies’, *Journal of Chemical Technology & Biotechnology, 72*(4), 289-302. doi:10.1002/(sici)1097-4660(199808)72:4<289::aid-jctb905>3.0.co;2-#

Vegera, S., Malei, A. and Trubovich, R. (2018) ‘Accounting development of natural resources in organizations carrying out the disposal of municipal waste and biogas extraction in the context of the" green" economy’, *Entrepreneurship and Sustainability Issues*, *6*(1), 211-225.

Verduzco, L. E., Duffey, M. R., and Deason, J. P. (2007) ‘H2POWER: Development of a methodology to calculate life cycle cost of small and medium-scale hydrogen systems’, *Energy policy, 35*(3), 1808-1818.

Vergili, I., Kaya, Y., Sen, U., Gönder, Z. B. and Aydiner, C. (2012) ‘Techno-economic analysis of textile dye bath wastewater treatment by integrated membrane processes under the zero liquid discharge approach’, *Resources, Conservation and Recycling, 58*, 25-35. doi:10.1016/j.resconrec.2011.10.005

Verma, A. K., Dash, R. R. and Bhunia, P. (2012). ‘A review on chemical coagulation/flocculation technologies for removal of colour from textile wastewaters’, *Journal of Environmental Management, 93*(1), 154-168.

Waheed, B., Khan, F. I. and Veitch, B. (2011) ‘Developing a quantitative tool for sustainability assessment of HEIs’, *International Journal of Sustainability in Higher Education*, *12*(4), 355¬368.

Wang, M.-m. and Han, D.-p. (2013) *Measure strategic cost based on activity-based costing method*, in Qi, E., Shen, J., and Dou, R. (eds.), *The 19th International Conference on Industrial Engineering and Engineering Management*. Springer: Berlin Heidelberg, pp. 303-311.

Wang, Z., Ma, J., Tang, C. Y., Kimura, K., Wang, Q. and Han, X. (2014) ‘Membrane cleaning in membrane bioreactors: A review’, *Journal of Membrane Science, 468*, 276¬307. doi:10.1016/j.memsci.2014.05.060

Warsinger, D. M., Chakraborty, S., Tow, E. W., Plumlee, M. H., Bellona, C., Loutatidou, S., Karimi, L., Mikelonis, A. M., Achilli, A., Ghassemi, A., Padhye, L. P., Snyder, S. A., Curcio, S., Vecitis, C. D., Arafat, H. A. and Lienhard, J. H. (2018) ‘A review of polymeric membranes and processes for potable water reuse', *Progress in Polymer Science*. doi:10.1016/j.progpolymsci.2018.01.004

Weschenfelder, S. E., Mello, A. C. C., Borges, C. P. and Campos, J. C. (2015) 'Oilfield produced water treatment by ceramic membranes: Preliminary process cost estimation', *Desalination, 360,* 81-86. doi:10.1016/j.desal.2015.01.015

Woodward, D. G. (1997) 'Life cycle costing—Theory, information acquisition and application', *International Journal of Project Management, 15*(6), 335¬344. doi:10.1016/s0263-7863(96)00089-0

Xu, X., Chen, J. L. Q. and Xie, S. Q. (2006) 'Framework of a product lifecycle costing system', *Journal of Computing and Information Science in Engineering, 6*(1), 69-77.

Xu, Y., Fernandez Sanchez, J., and Njuguna, J. (2014) 'Cost modelling to support optimised selection of End-of-Life options for automotive components', *The International Journal of Advanced Manufacturing Technology, 73*(1), 399-407. doi:10.1007/s00170-014-5804-9

Yang, C.-H. (2018) 'An optimization portfolio decision model of life cycle activity-based costing with carbon footprint constraints for hybrid green power strategies', *Computers & Operations Research, 96*, 256-271.

Yeo, A. P. S., Law, A. W. K. and Fane, A. G. (2006) 'Factors affecting the performance of a submerged hollow fiber bundle', *Journal of Membrane Science*, *280*(1–2), 969¬982. doi:10.1016/j.memsci.2006.03.029

Yongqian, Z., Meng, C., Xuebo, Y. and Jin, Z. (2010) A manufacturing cost estimation method based on activity-based costing. *The 2010 International Conference on Mechanic Automation and Control Engineering*. IEEE, pp. 3476-3479.

Yoon, S.-H. (2015). *Membrane bioreactor processes: principles and applications*. CRC Press.

Yoon, T. I., Lee, H. S., and Kim, C. G. (2004) 'Comparison of pilot scale performances between membrane bioreactor and hybrid conventional wastewater treatment systems', *Journal of Membrane Science, 242*(1-2), 5-12.

Zakwan, N. M, Saman, M. Z. M. and Jarvis, R. (2006) Implementing of activity based costing in improving product performance – a case study. *The ACTM 2006: International Conference on Technology Management*, November 2006. UTHM, Malaysia.

Zhang, Y. F. and Fuh, J. Y. H. (1998) A neural network approach for early cost estimation of packaging products. *Computers and Industrial Engineering*, *34*(2), 433-450. doi:10.1016/S0360-8352(97)00141-1

Zhuang, L., and Burns, G. (1992) 'Activity-based Costing in Non-standard Route Manufacturing', *International Journal of Operations & Production Management*, *12*(3), 38-60. doi:doi:10.1108/01443579210008114

Zwicker, C., Hammerstingl, V., Possin, C. and Reinhart, G. (2016) 'Life cycle cost estimation of robot systems in an early production planning phase', *Procedia CIRP*, *44*, 322-327. doi: 10.1016/j.procir.2016.02.117

LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Jiran, N.S.**, Gholami, H., Mahmood, S., Saman, M.Z.M., Yusof, N.M., Draskovic, V., Javovic, R. (2019), Application of Activity-Based Costing in Estimating the Costs of Manufacturing Process, Transformations in Business & Economics, Vol. 18, No 2B (47B), pp.839-860. (**Q3, IF:1.058**)

Indexed Journal

1. **Jiran, N.S.**, Saman, M.Z.M. and Yusof, N.M. (2019). Development of the Cost Estimation Model of the Membrane System. International Journal of Recent Technology and Engineering, 8(5C), pp. 645-653. (**Indexed by SCOPUS**)

1. **Jiran, N.S.**, Zainol, Z.N, Saman, M.Z.M. and Yusof, N.M. (2019). Cost Assessment on the Application of Hollow Fiber Membrane Module in Wastewater Treatment System of Textile Industry. International Journal of Recent Technology and Engineering, 7(6S5), pp. 1023-1030. (**Indexed by SCOPUS**)

2. **Jiran, N. S.**, Mahmood, S., Saman, M. Z. M., & Noordin, M. Y. (2014). Review on Methodology for Life Cycle Costing of Membrane System for Wastewater Filtration. *Advanced Materials Research, 845*, 713-719. (**Indexed by SCOPUS**)

3. Mahmood, S., **Jiran, N. S.**, Saman, M. Z. M., & Noordin, M. Y. (2014). *Determination of Parameters for Sustainability Assessment of Hollow Fiber Membrane Module Life Cycle.* Advanced Materials Research, 845, 724-729. (**Indexed by SCOPUS**)

4. **Jiran, N. S.**, Saman, M. Z. M., Mohd Yusof, N., & Zakuan, N. (2014). Life Cycle Costing Model for Hollow Fibre Membrane Module: A Review and Further Research. *Applied Mechanics and Materials, 660,* 1020-1025 (**Indexed by SCOPUS**)

Non-Indexed Conference Proceedings

1. **Jiran, N. S.**, Saman, M. Z. M., & Yusof, N. M. (2019). Life Cycle Costing Model for the Membrane System. *Asia Proceedings of Social Sciences*, *4*(1), 64-67. (Proceeding of the 3rd Asia International Multidisciplinary Conference, Johor, Malaysia, May 2019)

2. **Jiran, N. S.**, Mat Saman, M. Z. and Mohd Yusof, N. (2013). Life Cycle Costing of the Membrane System for Wastewater Treatment: a Review and Further Research. In 4th International Graduate Conference on Engineering, Science and Humanities (IGCESH 2013), ISSBN 1823-3287 (2013) Vol. 4, 16-17 April 2013, pp.233-240