COST BREAKDOWN STRUCTURE FOR LIFE CYCLE COST OF WATER PUMP

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Specially dedicated to my parents, family, husband and children and I love all of you. And to my late mother, this is for you. My journey of PhD begins with you. Thanks to all for being supportive.

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ABSTRACT

Life Cycle Costing (LCC) is an essential concept that is useful in reducing cost along a lifespan of an asset or equipment. LCC concepts have been introduced to water distribution system management; which is aimed to attain the lowest network provision and operating cost. However, there is slow adoption of LCC due to the lack of framework or mechanism to collect and store the data in a systematic way. Thus, a guideline is needed in order to widely encourage the application of LCC in the water industry especially in pump purchasing decision making. However, a Cost Breakdown Structure (CBS) is a pre-requisite before performing the LCC. Thus, the objective of this study are to identify the cost element needed for estimating the LCC for treated water pump in Malaysia; the next objective is to determine the weightage of most budget spent and important phase in life cycle stages for treated water pump and to develop a CBS for treated water pump in Malaysia. In the first stage, cost elements were collected based on literature review. Next, a questionnaire survey was conducted and the data were analyzed using Analytical Hierarchy Process (AHP). Then, a CBS for treated water pump is developed and verified based on the consensus among experts of Malaysian water industry during the Delphi study. The findings indicate that the CBS for LCC treated water pump in Malaysia is classified into four phases which are; 1) initial cost (planning), 2) operating cost, 3) maintenance and repair cost and 4) disposal and upgrading cost. The AHP weightage comes with the result that operating cost is the biggest expenditure and needs to be more considered along the lifespan of treated water pump. The outcome from this study contributes to a systematic and structured data cost to develop the LCC for water pumps in Malaysia. Also, the result of the AHP can be used to help Malaysia's water industry practitioners to allocate budget wisely in the future. Furthermore, the results of this study may be a beginning for the Malaysia's water industry to implement LCC using the developed CBS.

ABSTRAK

Kos kitar hayat (LCC) adalah konsep penting yang berguna dalam pengurangan kos sepanjang jangka hayat aset atau peralatan. Konsep LCC telah diperkenalkan ke dalam pengurusan sistem pengagihan air; bertujuan mencapai peruntukan rangkaian dan kos operasi terendah. Meskipun begitu, wujud halangan yang menjadikan penggunaan LCC agak perlahan iaitu kekurangan rangka kerja atau mekanisme untuk mengumpulkan dan menyimpan data secara sistematik. Maka, bagi menggalakkan penggunaan LCC secara meluas dalam industri air terutamanya sebelum keputusan pembelian pam, satu garis panduan diperlukan. Walau bagaimanapun, struktur pecahan kos (CBS) adalah prasyarat sebelum melaksanakan LCC. Oleh itu, objektif kajian ini adalah untuk mengenal pasti elemen kos yang diperlukan bagi menganggarkan LCC untuk pam air terawat di Malaysia; juga objektif seterusnya untuk menentukan fasa yang paling banyak memerlukan belanja dan fasa penting sepanjang kitaran hayat bagi pam air terawat dan objektif terakhir, untuk membangunkan CBS untuk pam air terawat di Malaysia. Pada peringkat pertama kajian, elemen kos dikumpulkan berdasarkan kajian literatur. Selanjutnya, tinjauan soal selidik telah dijalankan dan data dianalisis dengan menggunakan proses hierarki analitik (AHP). Kemudian, CBS untuk pam air terawat dibangunkan dan disahkan oleh persetujuan bersama di kalangan pakar industri air Malaysia semasa kajian Delphi. Hasil kajian menunjukkan bahawa CBS untuk LCC pam air terawat Malaysia diklasifikasikan kepada empat fasa iaitu; 1) kos awalan (perancangan), 2) kos operasi, 3) kos penyelenggaraan dan pembaikan dan 4) pelupusan dan peningkatan kos. Hasil keputusan pemberat dari AHP menunjukkan bahawa kos operasi adalah kos yang paling tinggi dan perlu dipertimbangkan sepanjang hayat pam air terawat. Hasil daripada kajian ini menyumbang kepada kos data yang sistematik dan berstruktur untuk membangunkan LCC bagi pam air di Malaysia. Juga, keputusan AHP boleh digunakan bagi membantu pengamal industri air Malaysia dalam peruntukan belanjawan yang bijak pada masa hadapan. Selain itu, hasil kajian ini berupaya menjadi permulaan bagi industri air Malaysia untuk melaksanakan LCC menggunakan CBS yang dibangunkan.

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LIST OF ABBREVIATIONS

AHP	-	Analytical Hierarchy Process
CAPEX	-	Capital Expenditure
CBS	-	Cost Breakdown Structure
CI	-	Consistency Index
CR	-	Consistency Ratio
CSF	-	Critical Success Factor
JKR	-	Jabatan Kerja Raya
KKH	-	Kos Kitar Hayat
LCC	-	Life Cycle Costing
LCCBS	-	Life Cycle Cost Breakdown Structure
MPAM	-	Manual Pengurusan Aset Menyeluruh
OPEX	-	Operating Expense
RCI	-	Random Consistency Index
SPK	-	Struktur Pecahan Kos
SPAN	-	Suruhanjaya Perkhidmatan Air Negara

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CHAPTER 1

INTRODUCTION

1.1 Background of the Research

Asset management is noticeable by its highly structured approach to identify assets and to be familiar with the assets very well (Harlow, 2001). Besides, it can be defined as a set of processes managing assets through their life cycles and must be practicably implemented in a systematic way. Asset management also mentioned as an holistic approach to run infrastructures that combines engineering principles with well business practices, economic theory and information management as well as the traditional operational matters related to the maintenance of assets (USEPA, 2006). However, the asset management process should draw out from design, procurement and installation to achieve even better value through operation, maintenance and retirement of the complete life cycle (Schuman, 2005). Thus, all life cycles within a system must be included. Asset life-cycle considers the design, construction, commissioning, operating, maintaining, repairing, modifying, replacing and the disposal of assets (Ambrose et al. 2008).

Delivering a quality water service to public requires the pipe networks and the supporting pump and treatment system as the facilities (Brighu, 2008). However, Nicklow et al. (2009) indicates that the water distribution system progressively deteriorates over time with internal corrosion and depositions, leading to the loss of lifting capacity in pipes and directly increasing the pump pressure and energy costs, pressure hesitancy, faulty pressure at customers' premises and problems with water quality. This is why the system of water supply infrastructures throughout the world became deteriorated (Watson et al., 2001; Engelhardt et al., 2003; Rahman and Vanier, 2004). Hence, water utilities must analyse asset condition, performance, remaining life and risks to facilitate improved asset maintenance investment decision-making (Urquhart, 2006).

Considering the issue of deterioration and high cost in water asset, Engelhardt et al. (2003) proposed Life Cycle Costing (LCC) concept to water distribution system management, which aims at attaining the lowest network provision and operating cost when all private and societal parties consider achieving the standards enforced by regulation. Based on Too (2010), LCC is an essential concept in asset management where all costs are reduced. It begins with the initial investment through operation and maintenance, and ends up with disposal. LCC or Whole Life Cycle Cost (WLCC) is sometimes considered as the exercises to identify, track, quantify and calculate the lifetime of an asset. In such a way, LCC has been defined as a decision support tool to prioritise alternatives (Engelhardt et al., 2003). In addition, The American Public Works Association stated that it is crucial for the industry to move from a low bid procurement strategy to LCC strategy (Ambrose et al., 2008). In short, the significances of the strategic level in asset management are the cost optimisation, performance and risk at the design, procurement and decision-making of the infrastructure based on the LCC (Too et al. 2006).

The LCC method is ordinarily applied in pump machinery management. The data required for LCC are costs incurred along the life span of an asset starting from the design until disposal (Brighu, 2008). Currently, the theory of purchasing pumps in the department is to choose a pump only on the basis of the least price quoted and not a pump with low LCC. This is not economical in the long term as a cheap pump may not have a good life cycle rather compared to a pump chosen based on low LCC. This happens when there is a lack of awareness in LCC among pump users. Pump System Matter™ created by The Hydraulic Institute (HI) along with some guidance from the US Department of Energy and other organisations has led the North American pump manufacturers to put their effort in creating awareness and promoting educated decision-making based on life cycle costs among pump system users (Tutterow et al., 2006). Moreover, many water facilities in pump system have their life cycle costs dominated by energy and maintenance costs (Tutterow et al., 2006).

To decide whether to purchase new pumps or to prolong the pump's life even though they are usually purchased as individual component, pump will only provide service when it is operating as part of a system (Frenning, 2001). To ensure the efficiency of a pump, it must be consciously matched with its effective lives to obtain the lowest energy and maintenance costs (Frenning, 2001). Moreover, by understanding all the components making up the total cost of a pump system, the energy, operation, and maintenance costs of a pump can be essentially reduced. Thus, LCC has to be considered when designing a system to achieve the aforementioned objective (Hodgson et al., 2002).

Previous study claimed that the success implementation of LCC is based on the availability of data. According to Barringer (2003) and Smit (2009), LCC is a data driven process.. However, Barringer (2003) argued that LCC is lack of data and reliable information (Bull, 1993; Goh et al., 2010). This issue therefore brings difficulties in forecasting beyond a long period of time specifically for component life cycle and performance, future operating and maintenance plans and cost as well as the discount rate. Besides, Hodgson et al. (2002) suggested that all of these costs were hidden from the objective when making decision. As a result, LCC implementation became slow as there is a lack of trusted past data of LCC (Korpi, 2008).

In order to develop a comprehensive LCC, one has to list and recognise all kinds of assumptions related to the system as there is little information on operational, system life and support organisations. Similarly, when it comes to maintain proper audit track, it is essential to record and document all changes to data and assumptions during the estimating process. Moreover, Goh et al., (2010) added that the quantity of data needed in LCC is enormous and complex, which caused high time consumption in collecting LCC data. Furthermore, LCC is assumed to have little frameworks (Lindholm et al., 2004) or mechanisms to collect and store the data (Bakis et al., 2003; Schade, 2007).

El-Haram et al., (2002) in their study have developed a framework to collect LCC data in building industry. They tried to solve the main barriers to the succesfully implement WLC (also referred as LCC) despite the lack of reliable and consistent data elements including capital cost, facilities management and disposal cost. They also explained how to develop a consistent and flexible framework to collect data for WLC of buildings by looking at the breakdown of cost elements included in LCC. Their study aimed at giving value to all the project team members such as designer, facilities manager, contractor, supplier, and the entire person involved in the project management by concerning the development of Cost Breakdown Structure (CBS) prior making LCC estimation.

Cost Breakdown Structure (CBS) is generally used to confirm that all related cost elements of the system are recognised, convinced and considered. This term may reflect a structured list of all items needed during the LCC process. However, the LCC adoption is lack of generic breakdown structure. In a word, CBS is crucial before applying LCC model. However, not all pump users and asset managers in water industry are aware with LCC. Even Korpi et al. (2008) has conducted a review on constructions with the leasing industry that applied LCC. He had reviewed about 55 published case studies of LCC. The review involved a total of 38 cases from the year 2000 until the year 2007, which produced the list of LCC implementation's areas including construction, transportation, manufacturing, energy, research and real estate. It was observed that there is only one study of LCC in real estate with none in water industry.

1.2 Problem statement

In Malaysia, LCC concept is introduced through the manual of MPAM (Manual Pengurusan Aset Menyeluruh), which began on 2009 to manage the assets of Malaysia's government including the water distribution system. Currently, LCC is being actively applied in the construction industry. The alternative was shown by the Public Works Department (PWD); they were urged to guide practitioners to implement LCC in the asset of infrastructure buildings especially in new construction projects in Malaysia. Thus, the Public

Works Department (PWD) has published a guideline in 2012 specially to introduce LCC with the cost elements and the guideline named “Garis Panduan Kos Kitaran Hayat” (KKH). Thus, the same alternative is going to be implement in water industry. However, LCC is actively applied within construction industry (Korpi et.al, 2008). Also happens in Malaysia the basis of purchasing pumps in the department is by choosing a pump only with the least price quoted and not a pump with low LCC (PAAB, 2015). Not only that, Malaysia also lack with framework and mechanisme to collect and store the LCC data or mechanisms to collect and store the data (Lindholm et al., 2004; Bakis et al., 2003; Schade, 2007; PAAB, 2015).

Thus, in order to solve the LCC “data issue” (lacking of framework and mechanisme to collect and store data), the development of Cost Breakdown Structure (CBS) is need to be concern prior making LCC estimation (El-Haram et al., 2002; Jeong et al. 2012; Smit, 2012). At the same time, a LCC framework is a helpful idea to encourage many researchers and practitioners to practice LCC. CBS might counter the problems by enhancing the CBS to increase and standardise the use of LCC (El-Haram et al., 2002; Jeong et al. 2012). Not to mention, the proposed framework is purposively used to collect cost data and to ensure consistency and flexibility of data collection (El-Haram et al., 2002). By doing so, all cost elements can be included without any ignoration (Kishk et al., 2003). Smit (2012) has also explained how NATO develops the generic life cycle cost breakdown structure in the framework for LCC in multinational defence programme. Nevertheless, LCC must be carefully broken down to avoid the “epistemic uncertainty” or uncertainties in results if there is lack of definition in developing the CBS or in excluding any less important cost elements (Goh et al., 2010).

Thus, in this study, the focus of LCC is to develop CBS in Malaysia water industry so that there will be a framework and mechanisme to store the LCC data systematically. Plus, the CBS mainly on the treated water pump as this pump is the highest expenditure spent in most water treatment plant. The highest expenditure is contributed by the energy cost by looking at the bill of electricity consumption (PAAB, 2015). This fact came from the Water Asset

Management Company (WAMCO) established on 5th May 2006 as a wholly owned company under the Minister of Finance Incorporated. PAAB forms a part of the Federal Government's efforts to restructure the water services industry in the country to achieve better efficiency and quality (PAAB, 2015). Plus, according to report of Water Services Industry Performance published by Suruhanjaya Perkhidmatan Air Malaysia (SPAN) in 2009, the high rate in energy cost was created by the water treatment by 56% in the year 2009. The high electricity tariff was resulted due to many old and inefficient treatment plants that are in operation. Besides, treated water pump stations were declared as the largest consumers of energy in water treatment plant (Headquarters, Department of the Army, 1992). Apart from that, SPAN has also put the KPI on PAAB to calculate the LCC for every water asset leased to the water operator companies migrated to PAAB (PAAB, 2015).

In the meantime, the complexity of asset management is often collaborated with lack of finance, skills and information disrupting the processes of acquiring, commissioning, maintaining, overhauling, and replacing assets at optimum time. A number of decisions such as what assets to acquire, when to carry out maintenance and when to renew or replace assets is to be answered in asset management (Asian Development Bank, 2013). Yet, hundreds of billions of dollars are spent to manage assets all around the world (Frolov et al., 2010). Mostly, the operating cost (for depreciation, maintenance and energy) is driven by the asset base. Plus, the annual expenses for new assets and asset renewal are significant.

According to Lim et al. (2007), high economic cost and environmental issue occur in water treatment, water supply and wastewater treatment. Hence, water and sanitation are hardly to receive any funding due to the pressure caused by struggling economies, large debts and a host of other socio-political matters to the government. The priority was put on the other basic social services such as education and health rather than water and sanitation. Generally, the expenditure in many developing countries on low cost water and sanitation is around 1% and 3% of the government budgets (Annamraju et al., 2001; Lim et al., 2007). Therefore, water supply budgets are often claimed to be underutilised or ineffectively used (Hunter et.al, 2010) due to complicated decision, which leads to the difficulties in managing the financial as the lifespan of the assets is longer than normal borrowing periods and where revenues are defenceless on asset valuations. At the same time, the same issue of funding has occurred in the Malaysian water industry, which often turns out to be a critical issue.

To address this, PAAB has ensured the availability of the long term funding (The Report Malaysia, 2010). Based on Economic Unit Planning (2006), the development budget is planned through the Malaysia Five-Year Plans, which is in the Ninth Malaysia Plan (2006-2010) where the current financial structure supports the water resource development but lack of the financial support from the government to increase the capacity of enforcement bodies. Thus, to create an effective asset management, the tools required were proposed including decision-making techniques, maintenance strategies and plans, operational strategies and plans, capital works strategies, financial and funding strategies. In water and wastewater utilities where physical assets make up at least 85% of their total asset, the proficient financial management expertise is essential to the asset-concentrated service businesses (Asian Development Bank, 2013). Thus, effective strategic financial plans for the water sector should highlight their prospects to reduce costs (OECD 2009). As a long-term commitment, asset management still needs a plenty of enhancements to achieve good asset management practices (Asian Development Bank, 2013). Therefore, there is a need to concern between what is required and what funds available to be adopted. This will attract the funders on their investments in water and wastewater infrastructures, which further ensures the adequate management and maintenance of the water asset in long term sustainability and security (Environmental Finance Centre New Mexico Tech, 2006; Asian Development Bank, 2013).

1.3 Objectives of the Research

Based on the problem statement, the main purpose of this study is to provide the systematic LCC Cost Breakdown Structure (CBS) for treated water pump in Malaysia. Hence, the following objectives were formulated including:

1. To identify the cost element needed for estimating LCC for treated water pumps in Malaysia.
2. To identify the weightage of each LCC main cost element in life cycle phases for treated water pump in Malaysia.
3. To develop cost breakdown structure (CBS) for treated water pumps in Malaysia.

1.4 Scope of the Research

The water industry in Malaysia is trying its best to apply asset management in its practice. Nevertheless, asset management especially for the above-ground assets is not commonly practiced in the water industry. Meanwhile, LCC approach is among the core components of asset management process and widely used in many areas of industry or equipment. To implement LCC, there also many processes involved; but this study is only focus to discover the cost elements needed to perform LCC specifically for water pump. LCC cost elements are basically differ from one to another areas and equipment, which need adjustment before being used. The critical cost elements first is identified from literatures then selected for the development of CBS by interviewing the experts through Delphi study. The study was conducted in the states under migration of PAAB, which are Johor, Malacca and Penang. The CBS developed only deal with the treated water pumps, which is a general CBS, so that it can be referred to any studies conducted for improvement in the future.

1.5 Research Methodology

To achieve the stated objectives, this research was carried out using the following methodologies:

1. Literature review;
2. Interview research question;
3. Questionnaire surveys;
4. Analytical Hierarchy Process (AHP); and
5. Delphi method;

1.5.1 Literature Review

The literature review is based on the previous studies related or similar to that of LCC implementation or treated water pump. The cost elements required for the development of LCC model are selected by looking at the frequency it is cited. Next, the most cited cost elements are validated by the opinion of the experts and practitioners through interview session during Delphi Analysis. Once validated, it is included in the Cost Breakdown Structure (CBS) before developing the model. In addition, the review of previous literature also covers the readiness and critical success factors determining the LCC readiness and its implementation factors. Then, these studies are picked to be included in the questionnaire survey based on their suitability to be applied together to overcome the LCC barriers.

1.5.2 Interview question

The Delphi questionnaires used in this research is in a form of interview questions. The interview is conducted during the Delphi process by four rounds. The selected experts are involved along the Delphi rounds to validate the cost elements to develop CBS.

1.5.3 Questionnaire surveys

Questionnaire surveys were used in this study to achieve the third and fourth objectives based on CBS developed to determine which of the phase in lifespan of treated water pump that affect the budget allocation. At the same time, it guides the decision makers to properly allocate future budget based on LCC of treated water pumps in Malaysia. The objective of using questionnaire in the third objective is to collect the information and opinions among the experts regarding to the most spent budget along the lifespan of treated water pump. This questionnaire is distributed during the last round of Delphi process.

Another survey is conducted to achieve the fourth objective to determine the readiness level among Malaysian water industry towards the implementation of LCC and CBS developed. However, the survey conducted at this level is in the form of response survey, which is called Likert-scale questionnaire.

1.5.4 Analytical Hierarchy Process (AHP) approach

As the financial issue arisen in the water industry leads to the deterioration of water assets, which is crucial in ensuring the better management of budget allocation. Garcia et al. (2004) mentioned that the reason behind the difficulty in allocating the cost is that water services require great capital investments that are fixed, which is equal to the quantity of water consumed.

Hence, the limited budget needs to be in proper allocation to solve this issue. A decision making tool can help water utility managers in making their financial decision. One of the decision tools applied in many industries currently is Analytic Hierarchy Process (AHP). AHP is known as an effective tool for priority setting since it combines empirical and system approaches in solving problems. According to Vaidya et al. (2006), AHP is a tool invented to make decision hierarchy and is widely used as a multiple criteria decision-making tools. AHP is able to assist decision maker in water asset management and industries to allocate their limited budget into efficient budget management by looking into the priority of cost spent along the life cycle of a plant or equipment.

1.5.5 Delphi method

Delphi method is used to collect the data and validate the collected data where the experts' opinions are used with the Delphi undergoing four rounds. Jeong et al. (2012) mentioned that Delphi method is an analysis that involves expert's opinions and advices to collect certified opinions and to produce a combined judgment. The idea of applying Delphi method is to ensure the validity and neutrality of CBS development. Agreed by Okoli et al. (2004), this method in various past studies was not only applied for "Forecasting and Issue Identification/ Prioritisation", but also in the "Concept/Framework Development". This has actually supported the reason of selecting Delphi method as this research objective is to develop Cost Breakdown Structure (CBS) for treated water pump.

1.6 Significance of the Research

The significance of the study commonly outlines the importance, practice and future of the study. Thus the significances of this research can be seen in four aspects:

a) The result contributes to the academic world in term of the compilation of cost elements needed to estimate LCC for water pump in Malaysia;
b) The result contributes in the future research to calculate the LCC of water pump with the real value and numbers;
c) Results from this study can be used as guideline for developing the Cost Breakdown Structure (CBS) for Life Cycle Cost (LCC) for water pump in Malaysia;

d) Results from this study also propose a systematic and structured data cost to develop LCC for water pumps in Malaysia;

e) The results of the analytical study on the identifing the weightage of each LCC main cost element in life cycle phases for water pump in Malaysia can be use to help the Malaysia's water industry practitioners to allocate budget wisely in future;

f) The results of this study may be a beginning for the Malaysia's water industry to implement LCC using the CBS developed.

g) The result will contributes consultants, water asset managers, municipalities, and others a relevant overview of all the key factors essential for making the better decision to lower the cost over the total lifetime of a pump system.

1.7 Organisation of the Study

This thesis is divided into six chapters;

Chapter 1 introduces the whole picture of the study consisting research background, problem statement, objectives of the study, scope of the study, methodology, significance of the study and the organisation of the study.

Chapter 2 highlights the review on the concept of asset management and its relations with LCC. Furthermore, an overview on cost elements cited in previous study of LCC is presented, which is used to develop the interview questions during the first round of Delphi method. It describes the cost elements involved to develop a CBS for LCC model. Subsequently, the LCC concepts and its descriptions are explored by looking at the literature and past studies.

Chapter 3 describes the methods involved in this study. A number of literatures are reviewed to select the best method for this study. Next, the proper selection of the best knowledgeable experts involved in the Delphi interview session is explained. The Analytical Hierarchy Process (AHP) method is described as well as its purposes in this study are reviewed.

Chapter 4 reports the data collected and analysis conducted based on the responses from interview session during the Delphi study. Besides, this chapter reports the result from AHP calculation to determine the weightage for each main cost and CBS developed for treated water pump. Then, the result from all the data analyzed is presented at the end of this chapter.

Chapter 5 discusses the findings from the analysis of the questionnaires and experts' opinions in answering the objectives of the study. The discussion refers the results of analysis of the experts' opinions from Delphi analysis to the the Analytical Hierarchy Process (AHP) result presented in Chapter 4 and next , to the development of cost breakdown structure (CBS). This chapter discusses the agreement or contradiction and difference between the outcomes of the literature review, the results derives from Analytical Hierarchy Process (AHP) and the results of the experts' opinions during Delphi study.

Chapter 6 highlights the main conclusion where all objectives for this study are achieved with several contributions explained. The direction for future study is also explored at the end of this chapter.

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Table of cost elements from previous studies			
No.	**Cost Elements**	**Reference/s**	**Frequencies**
1.	Discount Rate	Rangaraju et.al (2008); Schade, J.(2013); Shahata et.al, (2013); The Australian Asset Management Collaborative Group (AAMCoG) (2008); The Research and Technology Organisation (RTO) of NATO (2007),Witik et al. (2011),Massarutto et al.(2011),Gluch et.al, (2004),Korpi et.al, (2008), Kim et al. (2010),Afrane, G., & Ntiamoah, A. (2012) Halwatura et.al, (2009), Olubodun et.al, (2010),König et.al, (2012), Brighu,(2008),Babashamsi, P., Yusoff, N. I. M., Ceylan, H., Nor, N. G. M., & Jenatabadi, H. S. (2016).	14
2.	Maintenance costs	Schade, J. (2009),Shahata et.al, (2013), The Australian Asset Management Collaborative Group (AAMCoG) (2008), Fonseca et.al, (2011),Johansson (2005), Australian National Audit Office (2001),Treasury, (2004),The Research and Technology Organisation (RTO) of NATO (2007),Shankar Kshirsagar et.al, (2010),Gluch et.al, (2004), Tysseland (2008), Ong et al. (2012), Wong et al. (2003), Kim et al. (2010),Singh et.al, (2005), Li et.al, (2014).Halwatura et.al, (2009), Liu et.al, (2008), Asiedu et.al, (1998), Perera et.al, (1999). Liu et.al, (2009), Olubodun et.al, (2010), Krishnaiah et.al, (2012). Patra et.al, (2009). Selman et.al, (2005), Naguib (2009). Humphries et.al, (2004). Sinisuka et.al, (2013),Brighu (2008), Utne (2009),Babashamsi, P., Yusoff, N. I. M., Ceylan, H., Nor, N. G. M., & Jenatabadi, H. S. (2016),Dogan, and Aydin (2011),Kleyner, A., & Sandborn, P. (2008).	29

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No.	Cost Elements	Reference/s	Frequencies
3.	End of life cost (disposal and demolition)	Schade, J. (2009),The Australian Asset Management Collaborative Group (AAMCoG) (2008), Australian National Audit Office (2001),The Research and Technology Organisation (RTO) of NATO (2007), Shankar Kshirsagar et.al, (2010), El-Haram (2002), Barringer et.al, (1996), Witik et al. (2011),Gluch et.al, (2004),Korpi, E and Ala-Risku, T. (2008), Kim et al. (2010),Singh (2005), Liu et.al, (2008), Olubodun et.al, (2010), Fabrycky and Blanchard (1991), Liu et.al, (2008),Asiedu et.al, (1998),Perera et.al (1999), Tech (2006),Li et.al, (2014),Selman et.al, (2005), Humphries et.al, (2004), Sinisuka et.al, (2013), Hong, T., Han, S., & Lee, S. (2007), Kleyner, A., & Sandborn, P. (2008).	22
4.	Construction cost	Schade, J. (2009), Fonseca et.al, (2011), Gluch et.al, (2004), Korpi et.al, (2008), Kim et al. (2010), Liu et.al, (2008), Humphries et.al, (2004), Dogan and Aydin (2011), Ngapuli I. Sinisuka et.al, (2013).El-Haram (2002), Fabrycky and Blanchard (1991).	10
5.	Investment cost	Schade, J. (2009),Fonseca et.al, (2011), Hinow, M., Waldron, M., Müller, L., Aeschbach, H., & Pohlink, K. (2008).	3
6.	Operation cost	Shahata et.al, (2013),The Australian Asst Management Collaborative Group (AAMCoG) (2008), Fonseca et.al, (2011), Australian National Audit Office (2001), Treasury, (2004), The Research and Technology Organisation (RTO) of NATO (2007), Shankar Kshirsagar et.al, (2010), Frenning (2001), Tysseland (2008), Halwatura et.al, (2009), Olubodun et.al, (2010), Singh et.al, (2005), Brighu (2008), Li et.al, (2014), Fabrycky and Blanchard (1991), Utne (2009), Hinow, M., Waldron, M., Müller, L., Aeschbach, H., & Pohlink, K. (2008), Massarutto et al. (2011), Goedecke et al.(2007), Krishnaiah et.al, (2012), Patra et.al, (2009), Selman et.al, (2005), Sinisuka et.al, (2013), Mahlia, T. M. I., Saidur, R., Husnawan, M., Masjuki, H. H., & Kalam, M. A. (2010), Mahlia, T. M. I.,	26

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No.	Cost Elements	Reference/s	Frequencies
6.	Operation cost	Razak, H. A., & Nursahida, M. A. (2011), Shahata & Tarek Zayed (2013), Silalertruksa et al.(2012), Standard, N. (1996).	
7.	Replacement/ repair cost	Shahata et.al, (2013), Fonseca et.al, (2011), Shankar Kshirsagar et.al, (2010), Wong et al. (2003), Afrane, G., & Ntiamoah, A. (2012), Barringer et.al, (1996), Olubodun et.al, (2010), Shahata & Tarek Zayed (2013), Ong, H. C., Mahlia, T. M. I., Masjuki, H. H., & Honnery, D. (2012), Coffelt, D. P., & Hendrickson, C. T. (2010).	10
8.	Initial cost / Project cost (Acquisition cost/ project planning and preparation of asset, cost of raising funds and feasibility studies)	The Australian Asset Management Collaborative Group (AAMCoG) (2008), Fonseca et.al, (2011), Johansson (2005) , Australian National Audit Office (2001), Treasury, (2004), The Research and Technology Organisation (RTO) of NATO (2007), Shankar Kshirsagar et.al,(2010),Woodward, (1997), Wong et al. (2003),Singh et.al, (2005), Halwatura et.al, (2009), Brighu (2008),Barringer et.al, (1996), Goedecke et al. (2007), Hinow, M., Waldron, M., Müller, L., Aeschbach, H., & Pohlink, K. (2008), Naguib (2009), Sinisuka et.al, (2013), Babashamsi, P., Yusoff, N. I. M., Ceylan, H., Nor, N. G. M., & Jenatabadi, H. S. (2016), Selman et.al, (2005),Teo, E. A. L., & Harikrishna, N. (2005).	20
9.	Development cost	Fonseca et.al, (2011),The Research and Technology Organisation (RTO) of NATO (2007)Gluch et.al,(2004),Liu et.al, (2008),Liu et.al, (2009).Kleyner, A., & Sandborn, P. (2008).	6
10.	Renewal cost	The Australian Asset Management Collaborative Group (AAMCoG) (2008), Fonseca et.al, (2011),Humphries et.al, (2004),Barringer et.al, (1996), Hinow, M., Waldron, M., Müller, L., Aeschbach, H., & Pohlink, K. (2008).	5
11.	Rehabilitation cost	Fonseca et.al, (2011),Singh et.al, (2005), Babashamsi, P., Yusoff, N. I. M., Ceylan, H., Nor, N. G. M., & Jenatabadi, H. S. (2016), Curran, S. (2011).	4

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No.	Cost Elements	Reference/s	Frequencies
12.	Financing cost/ Capital cost (loan repayments / cost of tying up capital)	Fonseca et.al, (2011), Australian National, Audit Office (2001),Halwatura et.al, (2009),Olubodun et.al, (2010), Patra et.al, (2009), Li et.al, (2014), Curran, S. (2011), Coffelt, D. P., & Hendrickson, C. T. (2010), Standard, N. (1996).	9
13.	Utilities cost	Shankar Kshirsagar et.al, (2010), Barringer et.al, (1996),	2
14.	Service Cost / Overhaul	Shankar Kshirsagar et.al, (2010),Kleyner, A., & Sandborn, P. (2008), Standard, N. (1996).	3
15.	Energy Cost	Johansson (2005), Australian National Audit Office (2001),Witik et al. (2011),vGluch et.al, (2004), Korpi(2008), Brighu (2008), Barringer et.al, (1996), Asiedu et.al, (1998), Perera et.al, (1999). Frenning (2001),Woodward, (1997), Patra et.al, (2009), Naguib (2009), Humphries et.al, (2004), Sinisuka et.al, (2013), Folgado, R., Peças, P., & Henriques, E. (2010), König, H., & De Cristofaro, M. L. (2012).	16
16.	Energy consumption	Mahlia, T. M. I., Razak, H. A., & Nursahida, M. A. (2011), Standard, N. (1996).	2
17.	Material cost	The Research and Technology Organisation (RTO) of NATO (2007), Witik et al. (2011), Gluch et.al, (2004), Humphries et.al, (2004), Sinisuka et.al, (2013), Liu et.al, (2008), Asiedu et.al, (1998),Perera et.al, (1999), Folgado, R., Peças, P., & Henriques, E. (2010), Silalertruksa et al. (2012),	10
18.	Training Cost	The Research and Technology Organisation (RTO) of NATO (2007), Fabrycky and Blanchard (1991), Woodward, (1997), Humphries et.al, (2004), Sinisuka et.al, (2013).	5
19.	Procurement Cost	The Research and Technology Organisation (RTO) of NATO (2007), Afrane, G., & Ntiamoah, A. (2012)	2
20.	Operating personnel cost	The Research and Technology Organisation (RTO) of NATO (2007),Humphries et.al, (2004).	2

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No.	Cost Elements	Reference/s	Frequencies
21.	Spare parts consumption cost/ spare part cost	The Research and Technology Organisation (RTO) of NATO (2007), Shankar Kshirsagar et.al, (2010), Tysseland (2008), Humphries et.al, (2004), Barringer et.al, (1996), Nilsson, J., & Bertling, L. (2007), Standard, N. (1996).	7
22.	Installation cost	Humphries et.al, (2004), Woodward, (1997), Standard, N. (1996).	3
23.	Environmental cost	Witik et al. (2011), Goedecke et al. (2007), Li et.al, (2014).	3
24.	Insurance cost	Gluch et.al, (2004), Resurreccion, E. P., Colosi, L. M., White, M. A., & Clarens, A. F. (2012), Jeong et.al, (2012),	3
25.	Service life	Wong et al. (2003), Halwatura et.al, (2009), Khaled Shahata & Tarek Zayed (2013), König, H., & De Cristofaro, M. L. (2012).	4
26.	Inspection cost	Sinisuka et.al, (2013), Hong, T., Han, S., & Lee, S. (2007), Kleyner, A., & Sandborn, P. (2008).	3
27.	Preventive maintenance and corrective maintenance costs	Selman et.al, (2005), El-Haram (2002), Hong, T., Han, S., & Lee, S. (2007), Nilsson, J., & Bertling, L. (2007), Standard, N. (1996).	5
28.	Corrective maintenance cost	Hong, T., Han, S., & Lee, S. (2007), Standard, N. (1996).	2
29.	Logistic cost	Dogan, N. Aydin (2011), Barringer et.al, (1996).	2
30.	Facility cost	Sinisuka et.al, (2013), Liu et.al, (2008), Asiedu et.al, (1998), Perera et.al, (1999).	4
31.	Design cost	El-Haram (2002), Jeong et.al, (2012), Asiedu et.al, (1998),Perera et.al, (1999), Kleyner, A., & Sandborn, P. (2008).	5
32.	Demolition	El-Haram (2002), Jeong et.al, (2012)	2
33.	Site clearance	El-Haram (2002),	1
34.	Equipment work/ cost	Jeong et.al, (2012), Kleyner, A., & Sandborn, P. (2008), Standard, N. (1996).	3
35.	Waste disposal/ waste cost	Jeong et.al, (2012),Barringer et.al, (1996),Asiedu et.al, (1998), Perera et.al, (1999).	4
36.	Downtime cost	Liu et.al, (2008), Asiedu et.al, (1998), Perera et.al, (1999), Kmenta, S., & Ishii, K. (2000).	4

APPENDIX A

No.	Cost Elements	Reference/s	Frequencies
37.	Product testing & evaluation	Fabrycky and Blanchard (1991), The Research and Technology, Organisation (RTO) of NATO (2007).	2
38.	Quality control	Fabrycky and Blanchard (1991), Utne (2009),	2
39.	Initial training cost	Utne (2009),Barringer et.al, (1996),	2
40.	Decommissioning cost	Utne (2009), Frenning (2001)	2
41.	Commissioning & Installation cost	Barringer et.al, (1996), Woodward, (1997), Standard, N. (1996).	3
42.	Scheduled & unscheduled maintenance costs	Barringer et.al, (1996), Hinow, M., Waldron, M., Müller, L., Aeschbach, H., & Pohlink, K. (2008), Nilsson, J., & Bertling, L. (2007).	3
43.	Failure cost	Hinow, M., Waldron, M., Müller, L., Aeschbach, H., & Pohlink, K. (2008), Kleyner, A., & Sandborn, P. (2008).	2
44.	Labour cost	Barringer et.al, (1996), Asiedu et.al, (1998) , The Research and Technology Organisation (RTO) of NATO (2007), Kleyner, A., & Sandborn, P. (2008), The Research and Technology Organisation (RTO) of NATO (2007), Witik et al. (2011), Dogan, N. Aydin (2011), Folgado, R., Peças, P., & Henriques, E. (2010), Silalertruksa et al. (2012),	9
45.	Overhead cost	Barringer et.al, (1996),Perera et.al, (1999).	2

APPENDIX B
QUESTIONNAIRE

To determine the weightage of most budget spent and important phase in life cycle stages for treated water pump.

Question: What are the highest cost spent along the pump life span/ operation?
You may highlight the number that represents the intensity of importance to compare the cost.

Intensity of importance	Definition
1	Equal Importance
2	Weak
3	Moderate importance
4	Moderate Plus
5	Strong Importance
6	Strong Plus
7	Very Strong or demonstrated importance
8	Very very strong
9	Extreme importance

Factor	Factor weighting score																	Factor
	Spent Most than								Equal	Spent Less than								
Initial Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Operating cost**
Initial cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Disposal& Upgrading cost**
Initial cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Maintenance & Repair cost**
Operating cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Disposal& Upgrading cost**
Operating cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Maintenance & Repair cost**
Maintenance & Repair cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Disposal& Upgrading cost**

APPENDIX C
Interview Questions

Expert Opinion on the Cost Elements For Cost Breakdown Structure of Treated Water Pump

UTM
UNIVERSITI TEKNOLOGI MALAYSIA
RESEARCH UNIVERSITY

LIFE CYCLE COST FOR WATER TREATMENT PLANT (TREATED WATER PUMP)

I'm conducting a research for the above subject. Your input is critical to the success of this research.
Thank you for your time and all your response and cooperation are really highly appreciated.

Nurul Wahida Binti Rosli, Doctoral student.
Jabatan Pengurusan Harta, Fakulti Geoinformasi dan Harta Tanah,
Universiti Teknologi Malaysia,
81310 UTM Skudai,
Johor Bahru, Johor

Section A: Respondent details.

Please provide correct information for each item (*required).

I. What is your name?

II. What is your position in this company?

III. How many years of experience in water industry

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xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Section B: Knowledge on Life Cycle Cost (LCC).

Please (√) to answer question1.

1. Do you ever hear of the theory of LCC?

----

2. If yes, where do you get the information? (Please specify.)

If no/ never heard of LCC theory, please proceed to another section.

Section C: Cost Element involves during the Capital phase (CAPEX) of a TREATED WATER PUMP OF WTP.

Question 1 needs you to tick (√) in the box ☐ to answer all questions.

Based on your experience and knowledge within water industry, which all of these are included during the CAPEX OF A TREATED WATER PUMP OF WTP?

Below are the cost elements that need for Life Cycle Cost for TREATED WATER PUMP. The cost elements may not limit to what we been listed. You may add more lists of cost elements if related to the CAPEX of TREATED WATER PUMP.

1.

No.	**Cost Element/s**	**Please tick (√) if related**
1.	Construction cost	
2.	Research and Development (R&D) cost	
3.	Land Acquisition cost	
4.	Land Inspection and Survey	
5.	Site Preparation Cost	
6.	Excavation work , piling work	
7.	Design cost	
8.	Drawing cost	
9.	Authority Fee	
10.	Installation equipment cost	
	What the quipment? ……………………………………………………… ……………………………………………………… ………………………………………………………. ………………………………………………………	
11.	Material purchase cost	
	What the material purchase? ……………………………………………………... ……………………………………………………… …………………………………………………….. ……………………………………………………...	
12	Testing Procedure cost	
13	Utility Detection & Mapping (UMP)	
14	Professional Consultant cost/ Consultancies Fees	
15	Labor cost	
16	Equipment Purchasing Cost	
17	Town Planning cost	

18.	Tendering preparation cost	
19.	Conceptual Design Report (CDR)	
20.	Interest during construction	
21.	Testing and commissioning	

2. Other cost. Please state/specify if there is other cost/s involves during CAPEX
phase based on experience /knowledge.

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xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx x

Section D: Cost Element involves during the Capital phase (OPEX) A TREATED WATER PUMP OF WTP in Malaysia.

Question 1 needs you to tick (√) in the ☐ box to answer all questions.

1. Based on your experience and knowledge within water industry, which all of these are included during the OPEX (OPERATION & MAINTENANCE) of A TREATED WATER PUMP OF WTP.

In the next page is the list of cost elements that needed for operation of Life Cycle Cost for TREATED WATER PUMP. The cost elements may not limited to what we been listed. You may add more lists of cost elements if related to the OPEX of TREATED WATER PUMP.

No.	Cost Element/s	Please tick (√) if related
1.	Electricity cost	
2.	Chemical cost/ coagulant cost	
3.	Cleaning cost	
4.	Laboratory Test cost	
5.	Lease	
6.	Insurance	
7.	Raw Water Purchase cost	
8.	Storage cost	
9.	Labor cost	
10	Waste disposal cost	
11	Supervision cost	
12	Administration cost	
13	Service cost	
14	Repair cost	
15	Replacement cost	
16	Installation of a new equipment cost	
17	Tooling cost	
18	Renewal cost	
19	Rehabilitation cost	
20	Inspection cost	
21	Lubrication cost	
22	Material Maintenance cost	

2. Other cost. Please state/specify if there is other cost/s involves during operation activities based on your experience /knowledge.

____

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3. In the next page is the list of cost elements that needed for operation of Life Cycle Cost for TREATED WATER PUMP. The cost elements may not limited to what we been listed. You may add more lists of cost elements if related to the MAINTENANCE of TREATED WATER PUMP.

No.	Cost Element/s	Please tick (√) if related
1.	Labor cost	
2.	Supervision cost	
3.	Administration cost	
4.	Training cost	
5.	Overhaul cost	
6.	Spare part cost What is/are the spare part that always needed in water treated pump? ………………………………………………… …………………………………………………. ……………………………………………………	
7.	Tooling cost	
8.	Material maintenance cost What is/are the material/s that always needed in water treated pump? ………………………………………………… …………………………………………………. ……………………………………………………	
9.	Miscellaneous cost. Please specify. ………………………………………………………. ……………………………………………………… ……………………………………………………..	
10.	Others (Please specify) ……………………………………………………..	
11.	Others (Please specify) ……………………………………………………..	

Section E: Cost Element involves during the End of Life of a TREATED WATER PUMP OF WTP.

Question 1 needs you to tick (√) in the ☐ box to answer all questions.

1. Based on your experience and knowledge within water industry, which all of these are included during the End of Life) of a TREATED WATER PUMP OF WTP. Below are the cost elements that need for Life Cycle Cost for TREATED WATER PUMP. The cost elements may not limited to what we been listed. You may add more lists of cost elements if related to the End-of-Life of TREATED WATER PUMP.

No.	Cost Element/s	Please tick (√) if related
1.	**Upgrade cost**	
2.	**Sells of a equipment**	
3.	**Demolition cost**	
4.	**Site and Land Clearance / Clean up**	
5.	**Disposal cost**	

2. Other cost. Please state/specify if there is other cost/s involves during operation and maintenance activities based on your experience /knowledge.

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

Thank you for your time and opinions. If you have any inquiry, please email me at wahidawinn@yahoo.com.my or contact my handset at 017-7445141.

Nurul Wahida binti Rosli
Doctoral Student
Department of Property Management
Faculty of Geoinformation and Real Estate
Universiti Teknologi Malaysia
Skudai
Johor.

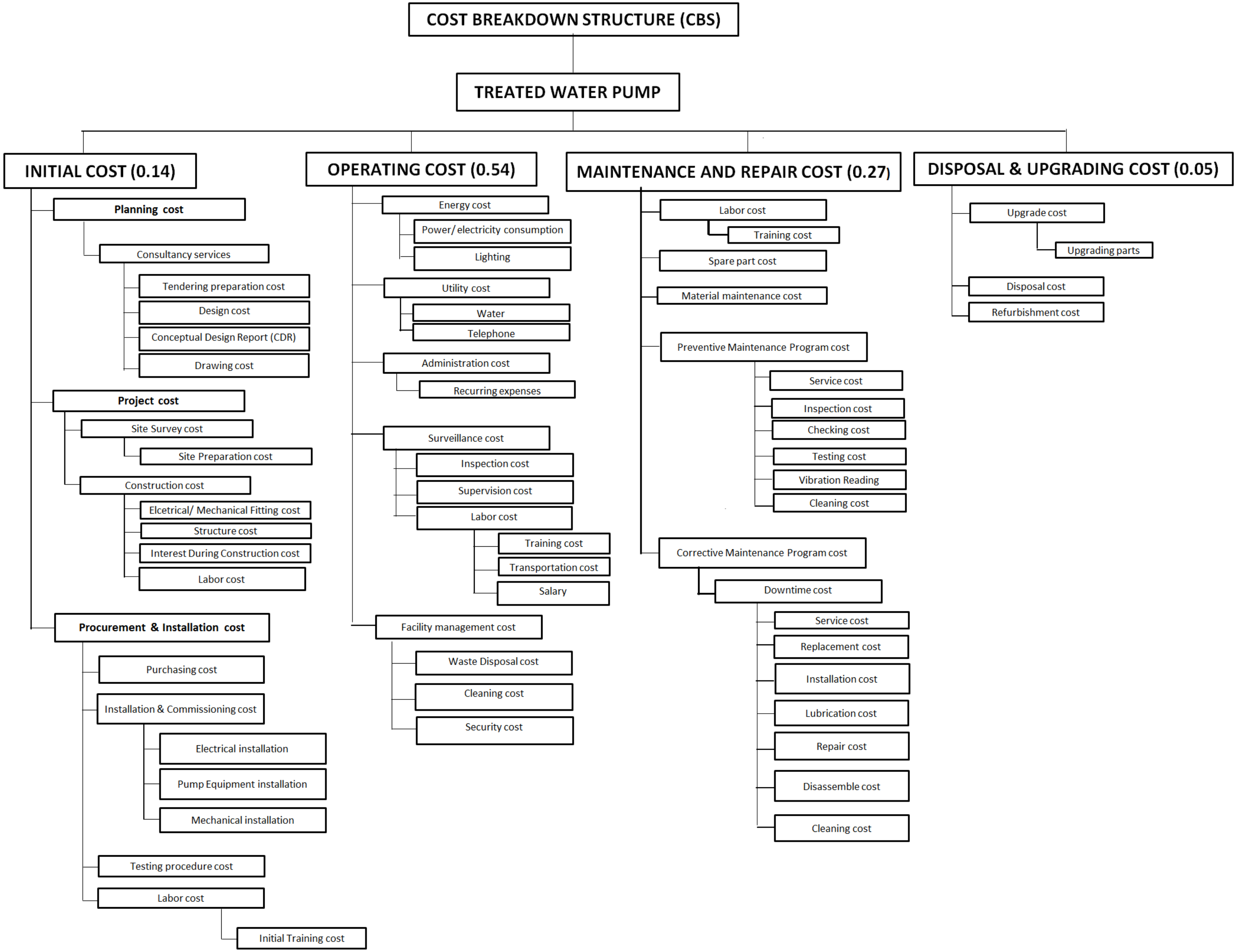
APPENDIX C1

FINAL DRAFT OF

COST BREAKDOWN STRUCTURE

TREATED WATER PUMP

IN MALAYSIA


COST BREAKDOWN STRUCTURE (CBS)
TREATED WATER PUMP
INITIAL COST (0.14)
Planning cost
Consultancy services
Tendering preparation cost
Design cost
Conceptual Design Report (CDR)
Drawing cost
Project cost
Site Survey cost
Site Preparation cost
Construction cost
Elcetrical/ Mechanical Fitting cost
Structure cost
Interest During Construction cost
Labor cost
Procurement & Installation cost
Purchasing cost
Installation & Commissioning cost
Electrical installation
Pump Equipment installation
Mechanical installation
Testing procedure cost
Labor cost
Initial Training cost
OPERATING COST (0.54)
Energy cost
Power/ electricity consumption
Lighting
Utility cost
Water
Telephone
Administration cost
Recurring expenses
Surveillance cost
Inspection cost
Supervision cost
Labor cost
Training cost
Transportation cost
Salary
Facility management cost
Waste Disposal cost
Cleaning cost
Security cost
MAINTENANCE AND REPAIR COST (0.27)
Labor cost
Training cost
Spare part cost
Material maintenance cost
Preventive Maintenance Program cost
Service cost
Inspection cost
Checking cost
Testing cost
Vibration Reading
Cleaning cost
Corrective Maintenance Program cost
Downtime cost
Service cost
Replacement cost
Installation cost
Lubrication cost
Repair cost
Disassemble cost
Cleaning cost
DISPOSAL & UPGRADING COST (0.05)
Upgrade cost
Upgrading parts
Disposal cost
Refurbishment cost

APPENDIX D

AHP CALCULATION

RESPONDENT 1:

COST CATEGORY	IC	OC	MR	DU	PRIORITY VECTOR	WEIGHTAGE %	WEIGHTED SUM MATRIX	CONSISTENCY MEASURE
IC	1	0.167	2	8	0.220	22%	0.997	4.529
OC	6	1	3	8	0.553	55%	2.746	4.967
MR	0.5	0.333	1	8	0.188	19%	0.790	4.193
DU	0.125	0.125	0.125	1	0.038	4%	0.159	4.128
	7.625	1.625	6.125	25.000	1.000	100%	λ max	4.454
Consistency Index	0.151							
Consistency ratio	0.168							

RESPONDENT 2:

COST CATEGORY	IC	OC	MR	DU	PRIORITY VECTOR	WEIGHTAGE %	WEIGHTED SUM MATRIX	CONSISTENCY MEASURE
IC	1	0.333	0.500	6	0.190	19%	0.771	4.059
OC	3	1.000	1	8	0.409	41%	1.690	4.135
MR	2.0	1.000	1	7	0.357	36%	1.456	4.080
DU	0.167	0.125	0.143	1	0.044	4%	0.178	4.017
	6.167	2.458	2.643	22.000	1.000	100%	**λ max**	4.072
Consistency Index	0.024							
Consistency ratio	0.027							

RESPONDENT 3:

COST CATEGORY	IC	OC	MR	DU	PRIORITY VECTOR	WEIGHTAGE %	WEIGHTED SUM MATRIX	CONSISTENCY MEASURE
IC	1	0.2	1	3	0.173	17%	0.718	4.155
OC	5	1	1	9	0.471	47%	2.069	4.396
MR	1	1	1	7	0.309	31%	1.283	4.149
DU	0.333	0.111	0.143	1	0.047	5%	0.201	4.260
TOTAL	7.333	2.311	3.143	20.000	1.000	100%	λ max	4.240
Consistency Index	0.080							
Consistency ratio	0.089							

RESPONDENT 4:

COST CATEGORY	IC	OC	MR	DU	PRIORITY VECTOR	WEIGHTAGE %	WEIGHTED SUM MATRIX	CONSISTENCY MEASURE
IC	1	0.125	0.250	2	0.077	8%	0.324	4.189
OC	8	1.000	2	8	0.513	51%	2.224	4.338
MR	4.0	1.000	1	8	0.365	36%	1.551	4.254
DU	0.500	0.125	0.125	1	0.046	5%	0.194	4.254
TOTAL	13.500	2.250	3.375	19.000	1.000	100%	**λ max**	4.259
Consistency Index	0.086							
Consistency ratio	0.096							

RESPONDENT 5:

COST CATEGORY	IC	OC	MR	DU	PRIORITY VECTOR	WEIGHTAGE %	WEIGHTED SUM MATRIX	CONSISTENCY MEASURE
IC	1	0.111	0.167	3	0.083	8%	0.339	4.062
OC	9	1	1	8	0.459	46%	1.984	4.326
MR	6	1	1	8	0.413	41%	1.734	4.200
DU	0.333	0.125	0.125	1	0.045	5%	0.182	4.024
	16.333	2.236	2.292	20.000	1.000	100%	λ max	4.153
Consistency Index	0.051							
Consistency ratio	0.057							

RESPONDENT 6:

COST CATEGORY	IC	OC	MR	DU	PRIORITY VECTOR	WEIGHTAGE %	WEIGHTED SUM MATRIX	CONSISTENCY MEASURE
IC	1	0.143	0.167	4	0.097	10%	0.397	4.093
OC	7	1	1	8	0.434	43%	1.874	4.322
MR	6	1	1	9	0.428	43%	1.819	4.255
DU	0.25	0.125	0.111	1	0.042	4%	0.168	4.019
	14.250	2.268	2.278	22	1	100%	λ max	4.172
Consistency Index	0.057							
Consistency ratio	0.064							

RESPONDENT 8:

COST CATEGORY	IC	OC	MR	DU	PRIORITY VECTOR	WEIGHTAGE %	WEIGHTED SUM MATRIX	CONSISTENCY MEASURE
IC	1	0.333	9	8	0.330	33%	1.377	4.169
OC	3	1	9	9	0.569	57%	2.468	4.340
MR	0.111	0.111	1	1	0.050	5%	0.201	4.010
DU	0.125	0.111	1	1	0.051	5%	0.205	4.036
	4.236	1.555	20.000	19.000	1.000	100%	λ max	4.139
Consistency Index	0.046							
Consistency ratio	0.051							

RESPONDENT 7:

COST CATEGORY	IC	OC	MR	DU	PRIORITY VECTOR	WEIGHTAGE %	WEIGHTED SUM MATRIX	CONSISTENCY MEASURE
IC	1	0.111	0.125	3	0.073	7%	0.299	4.064
OC	9	1	2	9	0.525	52%	2.274	4.334
MR	8	0.5	1	9	0.361	36%	1.577	4.366
DU	0.333	0.111	0.111	1	0.041	4%	0.163	4.025
	18.333	1.722	3.236	22.000	1.000	100%	λ max	4.197
Consistency Index	0.066							
Consistency ratio	0.073							

RESPONDENT 9:

COST CATEGORY	IC	OC	MR	DU	PRIORITY VECTOR	WEIGHTAGE %	WEIGHTED SUM MATRIX	CONSISTENCY MEASURE
IC	1	0.5	5	8	0.359	36%	1.500	4.183
OC	2	1	4	9	0.489	49%	2.038	4.171
MR	0.2	0.250	1	3	0.109	11%	0.435	4.010
DU	0.125	0.111	0.333	1	0.044	4%	0.179	4.054
	3.325	1.861	10.333	21.000	1.000	100%	λ max	4.104
Consistency Index	0.035							
Consistency ratio	0.039							

RESPONDENT 10:

COST CATEGORY	IC	OC	MR	DU	PRIORITY VECTOR	WEIGHTAGE %	WEIGHTED SUM MATRIX	CONSISTENCY MEASURE
IC	1	0.111	0.2	3	0.089	9%	0.361	4.068
OC	9	1	2	9	0.564	56%	2.409	4.271
MR	5	0.5	1	5	0.297	30%	1.274	4.287
DU	0.333	0.111	0.2	1	0.050	5%	0.202	4.023
	15.333	1.722	3.400	18.000	1.000	100%	λ max	4.162
Consistency Index	0.054							
Consistency ratio	0.060							

Final results computed for each cost category

COST CATEGORY	IC	OC	MR	DU	PRIORITY VECTOR	WEIGHTAGE %	CONSISTENCY MEASURE
IC	1	0.186	0.54	3.976	0.145	14	4.046
OC	5.37	1	1.876	8.54	0.538	54	4.167
MR	1.85	0.533	1	5.385	0.268	27	4.066
DU	0.251	0.117	0.186	1	0.049	5	4.014
	8.471	1.836	3.602	18.901	1.000	100	4.073
CI (Consistency Index)	0.024						
CR (Consistency ratio)	0.027						

COST CATEGORY	RESPONDENT/S									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
INITIAL COST	0.220	0.190	0.173	0.077	0.083	0.097	0.073	0.330	0.359	0.089
OPERATION COST	0.553	0.409	0.471	0.513	0.459	0.434	0.525	0.569	0.489	0.564
MAINTENANCE AND REPAIR COST	0.188	0.357	0.309	0.365	0.413	0.428	0.361	0.050	0.109	0.297
DISPOSAL AND UPGRADING COST	0.038	0.044	0.047	0.046	0.045	0.042	0.041	0.051	0.044	0.050
CONSISTENCY INDEX	**0.151**	0.024	0.080	0.086	0.051	0.057	0.066	0.046	0.035	0.054
CONSISTENCY RATIO	**0.168**	0.027	0.089	0.096	0.057	0.064	0.073	0.051	0.039	0.060

- Reciprocal of Maintenance and Repair Cost Compared to Operation Cost

$$= \frac{1}{1.876}$$

$$= \mathbf{0.53}$$

Calculation steps for group judgment matrix using weighted geometric mean method (WGMM).

- Initial Cost Compared to Operation Cost:

$$\sqrt[9]{0.333 \times 0.2 \times 0.125 \times 0.111 \times 0.143 \times 0.111 \times 0.333 \times 0.5 \times 0.111} = \mathbf{0.186}$$

- Reciprocal of Operation Cost Compared to Initial Cost $= \frac{1}{0.186}$

$$= \mathbf{5.37}$$

- Initial Cost Compared to Maintenance and Repair Cost:

$$\sqrt[9]{0.5 \times 1 \times 0.25 \times 0.167 \times 0.167 \times 0.125 \times 9 \times 5 \times 0.2} = \mathbf{0.54}$$

- Reciprocal of Maintenance and Repair Cost Compared to Initial Cost $= \frac{1}{0.54}$

$$= \mathbf{1.85}$$

- Initial Cost Compared to Disposal and Upgrading Cost:

$$\sqrt[9]{6 \times 3 \times 2 \times 3 \times 4 \times 3 \times 8 \times 8 \times 3} = \mathbf{3.976}$$

- Reciprocal of Disposal and Upgrading Cost Compared to Initial Cost $= \frac{1}{3.976}$

$$= \mathbf{0.251}$$

- Operation Cost Compared to Maintenance and Repair Cost:

$$\sqrt[9]{1 \times 1 \times 2 \times 1 \times 1 \times 2 \times 9 \times 4 \times 2} = \mathbf{1.876}$$

- Operation Cost Compared to Disposal and Upgrading Cost:

$$\sqrt[9]{8 \times 9 \times 8 \times 8 \times 8 \times 9 \times 9 \times 9 \times 9} = \mathbf{8.541}$$

- Reciprocal of Disposal and Upgrading Cost Compared to Operation Cost $= \frac{1}{8.541}$

$$= \mathbf{0.117}$$

- Maintenance and Repair Cost Compared to Disposal and Upgrading Cost:

$$\sqrt[9]{7 \times 7 \times 8 \times 8 \times 9 \times 9 \times 1 \times 3 \times 5} = \mathbf{5.385}$$

- Reciprocal of Disposal and Upgrading Cost Compared to Maintenance and Repair Cost $= \frac{1}{5.385}$

$$= \mathbf{0.186}$$

Group judgment matrix derived from WGMM:

COST CATEGORY	IC	OC	MR	DU	WEIGHTAGE %
IC	1	0.186	0.54	3.976	14%
OC	5.37	1	1.876	8.54	54%
MR	1.85	0.533	1	5.385	27%
DU	0.251	0.117	0.186	1	5%
					100%

APPENDIX E

RESULT OF DELPHI ANALYSIS

Results of Delphi analysis during Initial Phase

INITIAL PHASE (previously proposed as CAPEX in questionnaire in the first round)		
Respondents ID	**Round of Delphi**	**Main Analysis**
1.	1	• The list of the questionnaires is rearranged on the spot based on PAAB current practice.
2.	1	• The list of questionnaires is identified and explained on the spot based on PAAB current practice. • To add and follow the actual and specific sequence of initial phase practiced in PAAB.
3.	1	• To add and follow the actual and specific sequence of initial phase practiced in PAAB.
4.	1	• No modification on the whole list of CBS elements in questionnaire.
5.	1	• No modification on the whole list of CBS elements in questionnaire.
6.	1	• The list of questionnaires is identified and explained on the spot based on SAJH current practice. • Installation equipment cost is chosen. • Material purchase cost is chosen. • Testing procedure cost is chosen. • Labour cost is chosen. • Equipment purchasing cost is chosen. • Commissioning cost is chosen.
7.	1	• The list of the questionnaire is identified and explained on the spot based on SAJH current practice.
8.	1	• No modification on the whole list of CBS elements in questionnaire.
9.	1	• No modification on the whole list of CBS elements in questionnaire.

INITIAL PHASE (previously proposed as CAPEX in questionnaire in the first round)		
Respondents ID	**Round of Delphi**	**Main Analysis**
10.	1	• The list of the questionnaire is identified and explained on the spot based on SAMB current practice. • Construction cost is chosen. • Research & Development (R&D) cost is chosen. • Excavation and piling work costs are chosen. • Design cost is chosen. • Drawing cost is chosen. • Installation equipment cost is chosen. • Material purchase cost is chosen. • Testing procedure cost is chosen. • Consultancy fee/ cost is chosen. • Labour cost is chosen. • Equipment purchasing cost is chosen. • Tendering preparing cost is chosen. • Conceptual Design Report (CDR) cost is chosen. • Interest during construction cost is chosen. • Testing & Commissioning cost is chosen.

INITIAL PHASE		
Respondents ID	**Round of Delphi**	**Main Analysis**
1.	2	• Restructure the hierarchy. • To include the initial training cost under labour cost
2.	2	• To change the title “CAPEX” to “Initial” phase. • To include the Initial training cost under labour cost.
3.	2	• Restructure the hierarchy into the right sequence based on PAAB current practice. • To eliminate the R&D cost.
4.	2	• Restructure the hierarchy into the right sequence based on PAAB current practice. • To eliminate the excavation cost.
5.	2	• No modification.
6.	2	• No modification.
7.	2	• No modification.
8.	2	• No modification.
9.	2	• To eliminate the excavation cost.
10.	2	• To change the title “CAPEX” to “Initial” phase. • To include the initial training cost under labour cost.

INITIAL PHASE		
Respondents ID	**Round of Delphi**	**Main Analysis**
1.	3	• No modification.
2.	3	• No Modification.
3.	3	• No Modification.
4.	3	• No Modification.
5.	3	• No Modification.
6.	3	• No Modification.
7.	3	• No Modification.
8.	3	• No Modification.
9.	3	• No Modification.
10.	3	• No Modification.

INITIAL PHASE		
Respondents ID	**Round of Delphi**	**Main Analysis**
1.	4	• Verification of Hierarchy level.
2.	4	• Verification of Hierarchy level.
3.	4	• Verification of Hierarchy level.
4.	4	• Verification of Hierarchy level.
5.	4	• Verification of Hierarchy level.
6.	4	• Verification of Hierarchy level.
7.	4	• Verification of Hierarchy level.
8.	4	• Verification of Hierarchy level.
9.	4	• Verification of Hierarchy level.
10.	4	• Verification of Hierarchy level.

Results of Delphi analysis during the Operation Phase.

OPERATION PHASE		
Respondents ID	**Round of Delphi**	**Main Analysis**
1.	1	• No modification.
2.	1	• Restructure the classification of items under the operation cost.
3.	1	• No modification.
4.	1	• Eliminate the chemical cost/ coagulant cost.
5.	1	• No modification.
6.	1	• Eliminate the laboratory test cost. • Eliminate the repair cost.
7.	1	• Eliminate the repair cost. • Eliminate the rehabilitation cost.
8.	1	• Electricity cost is chosen. • Cleaning cost is chosen. • Labor cost is chosen. • Supervision cost is chosen. • Service cost is chosen. • Repair cost is chosen. • Replacement cost is chosen.
9.	1	• Installation of new equipment cost is chosen. • Rehabilitation cost is chosen. • Inspection cost is chosen. • Lubrication cost is chosen. • Material maintenance cost is chosen.

OPERATION PHASE		
Respondents ID	**Round of Delphi**	**Main Analysis**
10.	1	• Electricity cost is chosen. • Chemical/ coagulant cost is chosen. • Laboratory cost is chosen. • Raw water purchase is chosen. • Waste Disposal cost is chosen. • Administration cost is chosen. • Tooling cost is chosen. • Cleaning cost is chosen. • Labor cost is chosen. • Supervision cost is chosen. • Service cost is chosen. • Repair cost is chosen. • Replacement cost is chosen. • Installation of new equipment cost is chosen. • Rehabilitation cost is chosen. • Inspection cost is chosen. • Lubrication cost is chosen. • Material maintenance cost is chosen.

OPERATION PHASE		
Respondents ID	**Round of Delphi**	**Main Analysis**
1.	2	• Eliminate utility cost. • Eliminate raw water purchase cost.
2.	2	• Eliminate the downtime cost.
3.	2	• No modification.
4.	2	• No modification.
5.	2	• No modification.
6.	2	• Eliminate the raw water purchase cost
7.	2	• Eliminate the raw water purchase cost. • Restructure the hierarchy level.
8.	2	• Restructure the hierarchy level.
9.	2	• Eliminate the chemical cost. • Eliminate the raw water purchase cost.
10.	2	• Restructure the hierarchy level.

OPERATION PHASE		
Respondents ID	**Round of Delphi**	**Main Analysis**
1.	3	• No Modification.
2.	3	• No Modification.
3.	3	• No Modification.
4.	3	• No Modification.
5.	3	• No Modification.
6.	3	• No Modification.
7.	3	• No Modification.

OPERATION PHASE		
Respondents ID	**Round of Delphi**	**Main Analysis**
8.	3	• No Modification.
9.	3	• No Modification.
10.	3	• No Modification.

OPERATION PHASE		
Respondents ID	**Round of Delphi**	**Main Analysis**
1.	4	• Verification of Hierarchy level
2.	4	• Verification of Hierarchy level.
3.	4	• Verification of Hierarchy level.
4.	4	• Verification of Hierarchy level.
5.	4	• Verification of Hierarchy level.
6.	4	• Verification of Hierarchy level.
7.	4	• Verification of Hierarchy level.
8.	4	• Verification of Hierarchy level.
9.	4	• Verification of Hierarchy level.
10.	4	• Verification of Hierarchy level.

Result of Delphi Method Analysis on the Maintenance and Repair Phase.

MAINTENANCE AND REPAIR PHASE		
No.	**Round of Delphi**	**Main Analysis**
1.	1	• To subdivide and add more items under preventive maintenance (suggested referring the maintenance task/ schedule from water operators).
2.	1	• No modification.
3.	1	• To subdivide and add more items under preventive maintenance (suggested referring the maintenance task/ schedule from water operators).
4.	1	• Labour cost is chosen. • Supervision cost is chosen. • Overhaul cost is chosen. • Spare part cost is chosen. • Material maintenance cost is chosen. • To add more items under preventive maintenance and corrective maintenance (suggested referring the maintenance task/ schedule from water operators).
5.	1	• Add items to labour cost.
6.	1	• Labor cost is chosen. • Supervision cost is chosen. • Overhaul cost is chosen. • Spare part cost is chosen. • Material maintenance cost is chosen.

MAINTENANCE AND REPAIR PHASE		
No.	**Round of Delphi**	**Main Analysis**
7.	1	• Labour cost is chosen. • Supervision cost is chosen. • Overhaul cost is chosen. • Spare part cost is chosen. • Material maintenance cost is chosen.
8.	1	• Labour cost is chosen. • Supervision cost is chosen. • Overhaul cost is chosen. • Spare part cost is chosen. • Material maintenance cost is chosen.
9.	1	• Labour cost is chosen. • Supervision cost is chosen. • Overhaul cost is chosen. • Spare part cost is chosen. • Material maintenance cost is chosen. • Administration cost is chosen. • Training cost is chosen;
10.	1	• Add more items under preventive maintenance and corrective maintenance.

MAINTENANCE AND REPAIR PHASE		
Respondents ID	**Round of Delphi**	**Main Analysis**
1.	2	• No modification.
2.	2	• No modification.
3.	2	• Eliminate the utility cost. • To subdivide the items under energy cost.
4.	2	• No modification.
5.	2	• No modification.
6.	2	• To add the training cost under the items of Labour cost.
7.	2	• To add the training cost under the item of labour cost.
8.	2	• To add the training cost under the items of labour cost.
9.	2	• Eliminate the cleaning cost. • Eliminate the lubrication cost under the items of preventive maintenance cost.
10.	2	• No modification.

MAINTENANCE AND REPAIR PHASE		
Respondents ID	**Round of Delphi**	**Main Analysis**
1.	3	• No Modification.
2.	3	• No Modification.
3.	3	• No Modification.
4.	3	• No Modification.
5.	3	• No Modification.
6.	3	• No Modification.
7.	3	• No Modification.
8.	3	• No Modification.
9.	3	• No Modification.
10.	3	• No Modification.

MAINTENANCE AND REPAIR PHASE		
Respondents ID	**Round of Delphi**	**Main Analysis**
1.	4	• Verification of Hierarchy level.
2.	4	• Verification of Hierarchy level.
3.	4	• Verification of Hierarchy level.
4.	4	• Verification of Hierarchy level.
5.	4	• Verification of Hierarchy level..
6.	4	• Verification of Hierarchy level.
7.	4	• Verification of Hierarchy level.
8.	4	• Verification of Hierarchy level.
9.	4	• Verification of Hierarchy level.
10.	4	• Verification of Hierarchy level.

Result of Delphi Method Analysis during the Disposal and Upgrading Phase.

DISPOSAL AND UPGRADING PHASE		
No.	**Round of Delphi**	**Main Analysis**
1.	1	• No modification.
2.	1	• No modification.
3.	1	• No modification.
4.	1	• No modification.
5.	1	• No modification.
6.	1	• No modification.
7.	1	• No modification.
8.	1	• Refurbishment cost is chosen.
9.	1	• Upgrade cost is chosen. • Disposal cost is chosen. • Refurbishment cost is chosen.
10.	1	• Upgrade cost is chosen. • Refurbishment cost is chosen. • Disposal cost is chosen. • Adding upgrading parts under the items of upgrading cost.

DISPOSAL AND UPGRADING PHASE		
No.	**Round of Delphi**	**Main Analysis**
1.	2	• No modification.
2.	2	• No modification.
3.	2	• No modification.
4.	2	• No modification.
5.	2	• No modification.
6.	2	• No modification.
7.	2	• No modification.
8.	2	• No modification.
9.	2	• No modification.
10.	2	• No modification.

DISPOSAL AND UPGRADING PHASE		
No.	**Round of Delphi**	**Main Analysis**
1.	3	• No Modification.
2.	3	• No Modification.
3.	3	• No Modification.
4.	3	• No Modification.
5.	3	• No Modification.
6.	3	• No Modification.
7.	3	• No Modification.
8.	3	• No Modification.
9.	3	• No Modification.
10.	3	• No Modification.

DISPOSAL AND UPGRADING PHASE		
No.	**Round of Delphi**	**Main Analysis**
1.	4	• Verification of Hierarchy level.
2.	4	• Verification of Hierarchy level.
3.	4	• Verification of Hierarchy level.
4.	4	• Verification of Hierarchy level.
5.	4	• Verification of Hierarchy level.
6.	4	• Verification of Hierarchy level.
7.	4	• Verification of Hierarchy level.
8.	4	• Verification of Hierarchy level.
9.	4	• Verification of Hierarchy level.
10.	4	• Verification of Hierarchy level.