DEVELOPMENT OF A GENERIC LIFE CYCLE COST BREAKDOWN STRUCTURE FOR WATER TREATMENT PLANT IN MALAYSIA WATER INDUSTRY

Nurul Wahida Rosli[1], Abdul Hakim @ MiswanMohamed[2] , Mat Naim Abdullah @ Mohd Asmoni[3], Izran Sarrazin Mohammad[4] & Alan Chong Kim Wing[5]

[1,2,3,5]*Department of Real Estate, Faculty of Geoinformation and Real Estate*
[4]*Centre for Real Estate Studies, Institute for Smart Infrastructure & Innovative Constructuion*
Universiti Teknologi Malaysia
81310 UTM Johor Bahru, Johor, Malalysia
Email: wahidarosli9@gmail.com

Abstract

Life cycle cost (LCC) is increasingly important in the management and operation of assets. LCC helps to determine the total cost of owning and operating a facility over a period of time. Currently in Malaysia, LCC is actively applied in construction industry. While LCC has the potential to be implemented to the water industry, it faces challenges such as the lack of reliable and consistent data in the elements for LCC. In order to overcome these barriers, a consistent data structure called Cost Breakdown Structure (CBS) is needed before applying LCC. Thus, the purpose of this paper is to discuss the development of LCC cost breakdown structure (CBS) for treated water pump in Malaysia using the Delphi method. The results gathered from expert opinions during Delphi process are developed into a data structure. This proposed data structure could assist water industry practitioners in the preparation of implementing LCC and also acts as a basis for collecting LCC data in a consistent manner. Recommended future research is to develop CBS for other types of pumps and also implement LCC calculation through the proposed CBS.

Keywords: *cost breakdown structure, life cycle cost, Delphi method, water industry*

1.0 INTRODUCTION

The challenges in Malaysia's water supply sector are the poor efficiency and effectiveness of the water supply systems and inadequacy of funding (Kim, 2012). However, Economic Planning Unit (2008) reported that the total allocation for water infrastructure under successive Malaysia Plans was increased from time to time throughout the period of 1976 to 2005. Yet, the Eleventh Malaysia Plan (2016-2020) had mentioned that the challenge in water supply is to raise the financial sustainability of the water services (Economic Planning Unit, 2015). Other than that, the water industry also had issues with the high operation cost (Economic Planning Unit, 2015). Thus, in order to efficiently manage the water supply services especially in asset management, Lemer (1998) mentioned that decision makers should focus on the required expenditure and how to spend on infrastructure. From a business perspective, it is of critical importance that the long-term management of assets or infrastructures is in a cost-effective manner. This requires a life-cycle approach to establish their management strategies (Richardson *et al*., 2011). Based on Cashin (2006), one of asset management key objectives is to achieve the lowest life cycle cost. Asset management considers capital, operations, maintenance, repair, renewal and replacement as investment decisions (Albee and Byrne, 2007). Cox (2005) declared that asset management is capable to allocate capital and operational expenditure to achieve short-term value and long-term sustainability.

Nevertheless, Life Cycle Cost (LCC) had been introduced in Malaysian construction industry and practiced by Public Works Department (PWD). The department was urged to guide practitioners to implement LCC in asset of infrastructure buildings especially in new construction projects in Malaysia. In 2012, PWD published a guideline to introduce the methods and cost elements associated in the application of LCC namely "Garis Panduan Kos Kitaran

Hayat" (KKH). Following the objective of Malaysian Plans to improve public assets, LCC should be applied in critical infrastructures such as the water industry. However, previous papers in the field of LCC stated that the main barrier in implementing LCC is the lack of reliable and consistent data on the elements of LCC (Bull, 1993; Goh *et al*., 2010). Thus, it led to a lack of acceptable LCC standards.

The only list that compiles all the variety of cost factors in LCC is cost breakdown structure (CBS). CBS is the key driven process needed before developing the LCC model (Bakis *et al*., 2003). Smit (2009), in the paper entitled *"NATO Initiative to Improve Life Cycle Costing",* also mentioned that both types of LCC model which is estimated by empiric methods and parametric formula uses CBS as its basis. In another study by El-Haram *et al.* (2002), the researchers also described the process of categorizing the data elements required in the development of CBS before making the LCC estimation.

2.0 LIFE CYCLE COST (LCC) AND PUMP SELECTION ISSUE

In water distribution systems worldwide, one of the most expensive items in the water distribution is the pumping system (Tarquin *et al*., 1989; López-Ibáñez *et al.*, 2011). Approximately 90 percent of power consumed at water treatment facilities is attributed to pumping. Furthermore, treated water pumping stations was declared as the largest consumer of energy in water treatment plant (Headquarters, Department of the Army, 1992).

In addition, according to Water Services Industry Performance Report 2009, published in Malaysia by Suruhanjaya Perkhidmatan Air (SPAN), the high rate of energy cost recorded an increase of 56% in 2009 was attributed to water treatment. The higher electricity tariff was due to higher consumption of electricity and costs of operations from old and inefficient treatment plants that continued to operate until today. Additionally, there is a need to calculate the LCC for water distribution system in Malaysia as SPAN has tasked a set of key performance indicators (KPI) on Pengurusan Aset Air Berhad (PAAB) to calculate the LCC for every water asset under PAAB. Previously, the water assets were leased to the water operator companies and subsequently transferred to PAAB (PAAB, 2015).

Thus, in order to solve the issue of deterioration and the high cost in water asset, Engelhardt *et al*. (2003) proposed Life Cycle Costing (LCC) concept to water distribution system management with the purpose to attain the lowest operating cost. Based on Too (2010), LCC is an essential concept in asset management which can lead to cost reduction. It begins with the initial investment, through operation and maintenance, and ends up with disposal. LCC, which is also referred as Whole Life Cycle Cost (WLCC), is sometimes considered as exercises to identify, to track and quantify and costs over the lifetime of an asset. In addition, The American Public Works Association stated that it is crucial that the industry switch from a low bid procurement strategy to LCC strategy (Ambrose *et al*., 2008). They also noted that within the United States, most public infrastructures were built through some form of low-bid procurement system that was unable to produce the most effective or efficient system whenever there was consideration of total maintenance, repair, and rehabilitation.

The LCC method is ordinarily applied for pumping machinery management. The data required for LCC are costs incurred along the life span of an asset starting from the design until the disposal (Brighu, 2008). However, the rule of thumb in purchasing pumps in the department (also in Malaysia; PAAB, 2015) is to choose a pump based on the most inexpensive price quoted and not a pump with low LCC. This is not economical in the long term run as the cheaper pump may not have longer life cycle compared to a pump chosen based on low LCC. This situation occurs when there is lack of awareness for LCC among pump operators. (Tutterow *et al*., 2006).

The proper selection of pump materials may prevent the pump to be damaged by corrosion. However, if the selection is overlooked, the pump may be rendered useless in a very short amount of time. Lemer (1998) concurred by stating that the utility had saved money by selecting equipment that came with lower LCC.

It has also been affirmed that the concept of LCC modeling is a really strong and useful tool that offers important opportunities to lower the cost associated with operating pumping equipment.

Moreover, by understanding all the components that made up the total cost of a pumping system, it provides an opportunity to essentially reduce energy, operational, and maintenance costs of a pump. Thus, if one might respond to these benefits, then one is designing the system based on LCC (Hodgson *et al*., 2002).

Thus, this paper discussed on the application of LCC for treated water pump in Malaysia water industry. The focus on treated water pump is due to the component recorded the highest expenditure in most water treatment plant which is evidently proven through bill of electricity consumption (PAAB, 2015). The objective of the research is to develop cost breakdown structure (CBS) for water treated pump. Water industry could benefit from the identified the cost elements as they act as a precursor in applying LCC and subsequently tackling issues regarding pump selection.

3.0 COST BREAKDOWN STRUCTURE (CBS): THE DEFINITION

According to Bakis *et al*., (2003), CBS is a crucial concept in LCC. In addition, based on The Australian Asset Management Collaborative Group (AAMCOG, 2008), LCC can be broken down into CBS elements. It is also considered as a tool that is capable of computing and defining LCC. Hence, it is able to assist decision makers in the process of decision-making. In short, CBS is the key driven process needed before developing the LCC model.

CBS reflects the many different types of activities which form the life cycle of a system while LCC is a compilation of a variety of cost factors resulting from the categories which form the CBS. CBS provides a mathematical framework which can be used to calculate the overall LCC (Parker, 1991). CBS also symbolized the way of LCC are categorized and presented (Bakis *et al.*, 2003). Meanwhile, Kishk *et al*., (2003) mentioned CBS may be considered as another way of categorizing cost.

Thus, CBS can be regarded as a reflection of cost data or cost elements needed with the LCC analysis. Similarly, CBS is also defined as a systematic list of all cost items related to LCC of a system. It has to be applied in LCC to assure that all appropriate costs are linked together with the system (RTO TR-SAS–069, 2009).

4.0 LIFE CYCLE COST (LCC) PROCESS AND COST BREAKDOWN STRUCTURE (CBS)

Based on NATO RTO SAS-028 (2003), the first step is to prepare the CBS before attempting to develop framework for LCC analysis. In a study by Barringer (2003), the calculation of LCC included CBS as the third step of eleven (11) steps listed in the LCC process. Figure 1 shows the steps in LCC process adapted by Barringer (2003):

Additionally, in RTO TR-SAS-054, (2007), CBS is used as the first stage in the LCC management activities which consist of four processes; 1) Cost Planning, 2) Cost Estimating, 3) Cost Budgeting and lastly, 4) Cost Assessment and Control. In this situation, CBS is associated with the "Cost Planning" process. "Cost Planning" process affects the decision making on the facility or equipment. During this process, many decisions need to be evaluated. For example, the decision to lease or construct new facility/equipment, or to refurbish the existing building, or build a new sustainable building for solution.

Based on Smit (2012), NATO Research and Technology Organization (RTO) which aims to develop a LCC framework, stated that the framework should include a generic CBS to be used for LCC analysis in all stages of life cycle of a systems. The decision to develop the framework was due to the lack of guidelines to conduct LCC analysis in multinational defense acquisition programs. Thus, CBS was defined as a first step in the framework before defining the methods and models to develop guideline for LCC.

It is absolutely common to develop or picture a CBS as a tree structure (RTO TR-

SAS–069, 2009). RTO-SAS-069 (2009) and Smit (2012) stated that LCC can be broken down in a number of styles. For example CBS categorized by time (year, month, or life cycle stage); by product (systems, subsystems, components); by type of costs (direct, indirect, linked, variable or fixed); by resources (personnel, equipment, consumables); by organization; by process/activity (management, engineering, maintenance, etc.); by unit, service branch, etc.; by nation and public or private industry. Sometimes, the identified cost categories can be useful at all design stage (Kishk *et al*., 2003). According to Bakis *et al*., (2003), CBS elements are usually in hierarchical form in order for the costing at different levels to be described in detail while the complexity will depend on the scope and objectives of the LCC exercise.

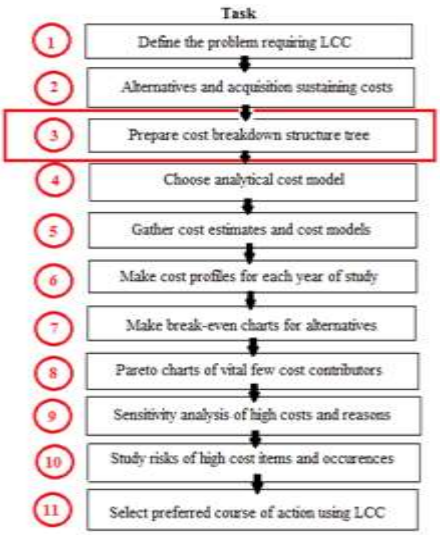


Figure 1: LCC Process
Source: Barringer (2003)

5.0 CBS: THE PREVIOUS RESEARCH

El-Haram *et al*., (2002) are among of the researchers that discussed on the classification of CBS in his study. The researchers proposed a data structure that could benefit all parties in a project such as the designer, facilities manager, contractor, supplier, etc. Instead of using LCC terms, they selected the Whole Life Cost (WLC) terms in the study. WLC is defined as a technique to examine and determine all the costs in monetary terms, and also as an economic and engineering evaluation tool to choose among variety of design/build, operation, and maintenance cost throughout a period of time. They applied WLC to evaluate and optimize the LCC of a building in order to select the most appropriate and cost-effective for the design option.

El-Haram then highlighted the way the CBS was categorized to suit with the project phases which consisted of three phases. The three phases are; 1) Capital Cost; 2) Facility Management Cost; and 3) Disposal Cost. Figure 2 below shows the CBS developed by El-Haram (2002).

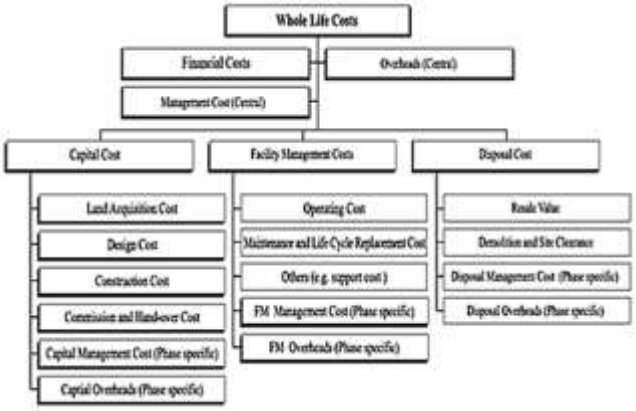


Figure 2: CBS of the cost of each phase of project.
Source: El-Haram (2002).

The study concluded that with the CBS development, all cost data would be easier to be listed and defined. It also provided information on users that would be using the data, required cost depending on level of building, and selection of data source

Similar to Jeong *et al*., (2012), in *"*Life Cycle Cost Breakdown Structure Development of Buildings through Delphi Analysis*",* their proposed CBS was categorized into four stages which are; 1) Planning and Design, 2) Construction, 3) Maintenance and lastly, 4) Waste Disposal. This study differs from the previously mentioned studies as the CBS was developed using Delphi method.

Table 1: Life cycle phases associated with industries.

Industries	Life cycle phases
Constructions	- Planning - **(Dhillon, 2010; Jeong *et al*., (2012).** - Acquisition/ Capital - **(El-Haram *et al.*, 2002 ; Dhillon, 2010).** - Design- **(Dhillon, 2010, Jeong *et al*., 2012).** - Construction - **(Dhillon, 2010; Jeong *et al.*, 2012).** - Facility Management cost - **(El-Haram *et al*., 2002).** - Operating - **(Dhillon, 2010).** - Maintenance – **(Dhillon, 2010; Jeong *et al.*, 2012).** - Disposal - **(El-Haram *et al*., (2002; Dhillon, 2010).** - Waste Disposal - **(Jeong *et al*., 2012).**
Energy	- Acquisition/ Capital - **(Jeong *et al*., 2002 ; Dhillon, 2010).** - Operating - **(Dhillon, 2010).** - Maintenance- **(Dhillon, 2010).**
Transportation	- Research &Development (R&D) - **(Dhillon, 2010).** - Acquisition/Capital - **(Dhillon, 2010).** - Production - **(Dhillon, 2010).** - Operating - **(Dhillon, 2010).** - Maintenance - **(Dhillon, 2010).**
Asset	- Planning - **(Langdon, 2007).** - Design - **(Langdon, 2007).** - Construction - **(Langdon, 2007).** - Operating - **(Langdon, 2007).** - Maintenance - **(Langdon, 2007).** - Disposal - **(Langdon, 2007).**
Multinational defence programme	- Concept - **(Smit, 2012).** - Development – **(Smit, 2012).** - Production - **(Smit, 2012).** - Utilization - **(Smit, 2012).** - Support - **(Smit, 2012).** - Retirement - **(Smit, 2012).**

This method verified the cost elements through experts in order to ensure its objectivity and validity which subsequently leads to higher accuracy of LCC estimation. Then, it was concluded that the CBS developed in the study can be continuously applied to shorten the time required in LCC estimation and enabled the calculation of construction work to be more economical and efficient.

Based on the previous research mentioned above, every CBS is different for every area or industry because the data required for each CBS depends on the life cycle stages of an asset or equipment or a project (Lindholm *et al.*, 2004; Smit, 2012). These different data also influence the LCC in various stages of the life cycle. In short, CBS cost elements and data required in LCC are based on the life cycle stages of the type of LCC intentions. Table 1 shows the Life cycle phases associated with industries which also describes the stages involved in CBS development for different area or industries.

Earles (1976) stated that there is no standard LCC model. RTO-TR-058 reported that most of the issues in LCC implementation were related to a lack of generic breakdown structure which was also known as CBS. It is essentially to understand the reason for the lack of standardisation in LCC model. One of the main reasons is that there are differences in the behaviour of cost elements as LCC is comprised of different life cycle phases (Lindholm *et al*., 2004). Therefore, RTO TR-SAS–069, (2009) stated that, any CBS must be as constant as possible with each system nationally. In conclusion, CBS creates a standard glossary to identify and grouping the cost of a system or an asset.

6 .0 DEVELOPMENT PROCESSES OF COST BREAKDOWN STRUCTURE (CBS)

According to El-Harem (2002), it is essential to create or develop a CBS that defined all the relevant cost categories and elements during the life cycle phases before applying LCC. The researchers then proposed CBS to be categorized into five levels using a top-down hierarchy of the data structure as follows: 1) project level; 2) phase level; 3) category level; 4) element level; and lastly 5) task level. Figure 3 shows the way El-Haram categorized the building cost into five levels in his study.

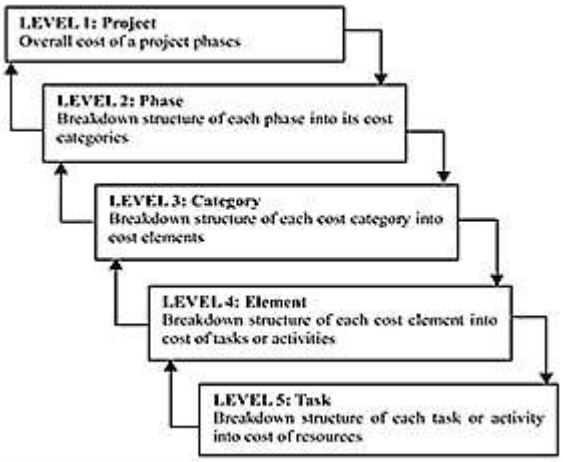


Figure 3: Levels of CBS data structure.
Source: El-Haram (2002).

Table 2: Water Industry Experts selected as the respondents for Delphi Method Participation.

Respondents ID	State	Companies	Positions
1.	Kuala Lumpur	Pengurusan Aset Air Berhad (PAAB)	Water asset top management person
2.	Kuala Lumpur	Pengurusan Aset Air Berhad (PAAB)	Water asset top management person
3.	Kuala Lumpur	Pengurusan Aset Air Berhad (PAAB)	Water asset top management person
4.	Penang	Perbadanan Bekalan Air Pulau Pinang (PBAPP)	Operation Officer
5.	Penang	Perbadanan Bekalan Air Pulau Pinang (PBAPP)	Maintenance Officer
6.	Johor	Syarikat Air Johor Holdings (SAJH)	Water Operator
7.	Johor	Syarikat Air Johor Holdings (SAJH)	Maintenance Officer
8.	Johor	Syarikat Air Johor Holdings (SAJH)	Operation Officer
9.	Melaka	Syarikat Air Melaka Berhad (SAMB)	Maintenance & Operation Officer
10.	Melaka	Syarikat Air Melaka Berhad (SAMB)	Planning Officer

Delphi technique can be applied to validate and verify the CBS. The same application has been carried out by Jeong (2012) in his study to develop the CBS in the construction industry. The researcher obtained the required results for the CBS after four rounds of data collection extracted from expert opinions.

This research will discuss the application of Delphi method with a total of four rounds to be completed by selected experts within the water industries. The experts come from four different states and companies of water industries in Malaysia. They have experience averaging from 5 to 20 years in the water industries. Table 2 shows the Water Industry Experts selected as the respondents for Delphi Method Participation.

The experts included in this research have 10-20 years of experience in a broad range of professional backgrounds such as water operator, water asset manager or even water industry practitioners, respectively.

7 .0 DELPHI METHOD

The Delphi study for this research is based on the study conducted by Jeong *et al.,* (2012). Similarly, they also aimed to estimate LCC but in the building industry instead of water assets. Delphi method was used to develop the CBS before arriving with the LCC estimation for the buildings. Delphi method was conducted for four rounds to validate and ensure the accuracy of the response from the experts. In order to provide meaningful results, a researcher has to know when it is the perfect time or the number of rounds to stop. It is a crucial step because once the researcher stops the Delphi round too soon, the samples collected might be insufficient (Schmidt, 1997).

The Delphi method in this research starts with the process of reviewing the literature of previous researches in LCC or any researches related to water pumps. The purpose for the literature review is to determine the cost elements that would be listed and included as interview research questions in the first round's questionnaire.

The process would continue until a consensus on CBS of LCC treated water pump is

achieved. At the same time, feedbacks given during the rounds of data collection have to be considered. If the consensus is achieved within three rounds, the only three rounds of Delphi method are required in this research. In short, the round of Delphi in this research would stop when the CBS developed is agreeable and satisfies the requirement of the experts. Figure 4 shows the Research process involved in Jeong *et al.* (2012) study. The same process is applied in this research.

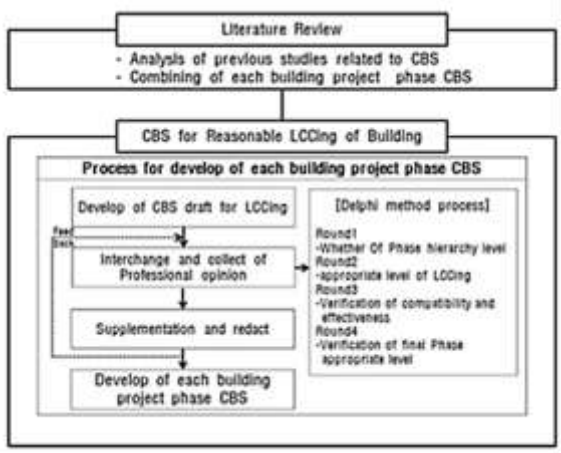


Figure 4: The research process.
Source: Jeong *et al.*, (2012)

7.1 First Round of Delphi Method

During the "First Round" of Delphi method of this research, the selected expert would be interviewed and asked on questions related to the list of cost elements cited from the literature review.

7.2 Second Round of Delphi Method

The "Second Round" is to collect and organize the suggestions and construct the second questionnaire. The second questionnaire for this research would be a draft for the CBS. It is developed based on completed questionnaire distributed during the First Round of Delphi. At this moment, the hierarchy of CBS is formed but it still requires adjustment as the CBS has not been verified and finalized as a CBS for treated water pump in Malaysia. Furthermore, the choices made by the experts/respondents on the LCC elements needed to be taken into consideration for the next round of Delphi process.

7.3 Third Round of Delphi Method

When the required information is gathered in "Second Round" of Delphi, the response from "Second Round" would be the second draft of CBS. The second draft of CBS would be distributed during the "Third Round" of Delphi. At this moment, the CBS draft would be narrowed down into a more detailed and refined structure which reveals the most significant cost element. At the same time, the respondents may question the cost elements arrangement on whether it is positioned accordingly in the right the phase. This "Third Round" is where the respondents carefully itemised and detailed all the cost elements. Based on Jeong *et al*. (2012), most of the respondents commented “No Modification” in the third round in their Delphi method.

Round	Experts	Main Analysis
1	A	No modifications
	B	No modifications
	C	No modifications
	D	Subdivision of small scale classification
	E	No modifications
	F	No modifications
2	A	No modifications
	B	No modifications
	C	No modifications
	D	Add of item to asbestos research expenditure
	E	No modifications
	F	Unnecessary of small scale classification
3	A	No modifications
	B	No modifications
	C	Required of small scale classification
	D	No modifications
	E	No modifications
	F	No modifications
4	A	Verification of Hierarchy level
	B	Verification of Hierarchy level
	C	Verification of Hierarchy level
	D	Verification of Hierarchy level
	E	Verification of Hierarchy level
	F	Verification of Hierarchy level

Figure 5: Result of Delphi method analysis on Waste Disposal Phase.
Source: Jeong *et al*., (2012)

Thus, the "Forth Round" is the final round of the Delphi method which is the verification of their CBS Draft. The same processes are being applied in this research where the Delphi round is concluded when there is “No Modification” being commented in the CBS draft. Figure 5 shows the example of “No Modification” from Result of Delphi method analysis on Waste Disposal Phase adopted from Jeong study.

Therefore, in reference to Jeong (2012)'s study, this research reached the consensus during the third round of Delphi; when there is no modification required for the CBS draft.

7.4 Fourth Round of Delphi Method

The "Forth Round" of Delphi would be the final round of Delphi once the research question is answered. This occurs when consensus is reached or agreeable CBS is achieved. In this research, if there is no modification specified in the previous draft of CBS distributed during the Third Round of Delphi, the "Forth Round' of Delphi would be the verification process (Jeong *et al.*, 2012).

8.0 RESULTS OF DELPHI ANALYSIS OF TREATED WATER PUMP PHASE DELPHI METHOD

The results from the Delphi Analysis are presented below. It covers all the stages (Initial phase, Operation phase, Maintenance and Repair Phase and Disposal and Upgrading phase) that are involved in a life span of Treated Water Pump in Malaysia. After going through the four rounds of Delphi process and a consensus was achieved by all the respondents and experts, a final CBS hierarchy for Treated Water Pump covering the Initial phase, Operation phase, Maintenance and Repair phase and Disposal and Upgrading phase is developed. However, a hierarchy cannot be referred as CBS without subdividing the elements into group of classification.

This has been stated by El-Haram *et al.* (2002) that all appropriate cost categories in all the life cycle phases should be included from the beginning in order to adopt or build a CBS.

As this research is using the Delphi approach, it has to take into account all the expert opinions and experienced water operators' knowledge. Consequently, every phase might not have the same segment patterns but would still reflect the categorization proposed in El-Haram‘s study. After going through all of the four rounds of Delphi process, the output is a flow chart of conceptual LCC model and LCC framework as shown in the Figure 6.

Based on Figure 6, it describes the outcome from four rounds of Delphi process. The CBS final structure consists of 3 levels in a top-down order namely; project, phase, and category. The developed life cycle CBS is limited to projects for treated water pumps in the Malaysian water industry.

Then, the next level is to break down the structure into its cost phase. The respondents agreed and achieved a consensus to divide the structure into four phases which are: 1) Initial Cost Phase; 2) Operating Cost Phase; 3) Maintenance and Repair Cost Phase and; 4) Disposal and Upgrading Cost Phase. All of these phases successively described the generic life cycle stages of a treated water pump in Malaysia. From the result, the treated water pump’s operator can get a quick glance of the phases that a treated water pump might go through along its life span.

Then, the CBS structure is broken down into the cost category level where every phases have their own sub-category cost. The "Initial Cost Phase" is developed and divided into three sub-categories of cost which are; 1) Planning Cost; 2) Project Cost; and 3) Procurement & Installation Cost. Meanwhile, the "Operating Cost Phase" is broken down into five sub-categories of cost which are: 1) Energy Cost; 2) Utility Cost; 3) Administration Cost; 4)

Surveillance Cost; and 5) Facility Management Cost. Subsequently, the "Maintenance and Repair Cost Phase" is also been broken down into five sub-categories which consist of: 1) Labor Cost, 2) Spare Part Cost; 3) Material Maintenance Cost; 4) Preventive Maintenance Program Cost; and 5) Corrective Maintenance Program Cost.

Finally, the last phase of the structure; "Disposal and Upgrading Cost Phase" is broken down into three categories which are: 1) Upgrade Cost; 2) Disposal Cost; and 3) Refurbishment Cost.

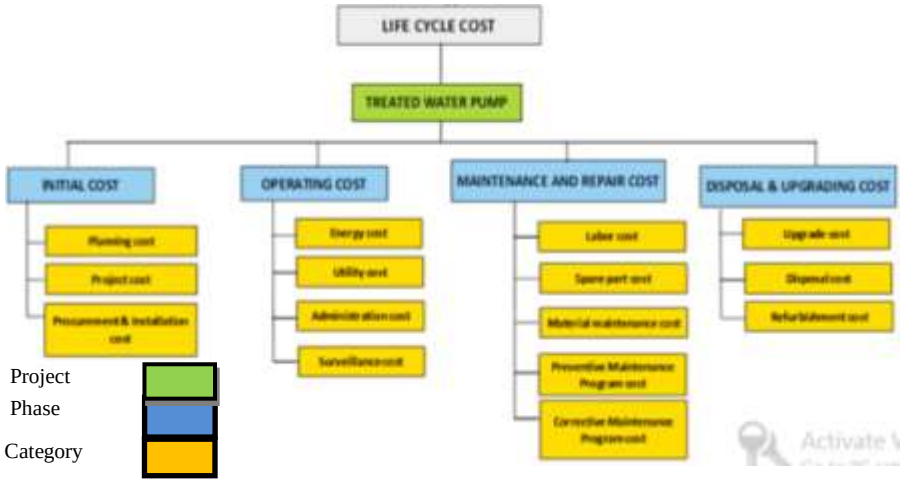


Figure 6: Developed Model of Life Cycle Cost Breakdown Structure for Treated Water Pump (Level Project, Phase and Category.

8.1 Delphi analysis results of Initial Cost Phase

Next, the CBS structure is broken down into the element level based on their tasks or activity. It is influenced by the category cost for each phase. The elements might not be limited to this CBS element level only as every company/ type of treated water pump has different kind of tasks. In the next section, the CBS structure for every phase level is explained for every type of the cost into element level and task level.

The "Initial Cost Phase" is developed and divided into three (3) categories of cost which are; 1) Planning Cost; 2) Project Cost; and 3) Procurement & Installation Cost.

Then, "Planning Cost" is sub-divided into one element which is "Consultancy Services" which consists of three tasks; 1) Tendering Preparation Cost, 2) Design Cost, and 3) Conceptual Design Report (CDR).

Meanwhile, "Project Cost" is sub-divided into two elements which are 1) Site Survey Cost and 2) Construction Cost. "Site Survey Cost" is contains one task which is "Site Preparation Cost". Meanwhile, "Construction Cost" is divided into three tasks which are; 1) Electrical/ Mechanical Fitting Cost, 2) Structure Cost, 3) Interest during Construction Cost and 4) Labor Cost.

As for "Procurement & Installation Cost", the phase is sub-divided into four (4) elements of 1) Purchasing Cost, 2) Installation & Commissioning Cost, 3) Testing and Procedure Cost and 4) Labor Cost. However, only "Installation Cost" and "Labor Cost" are divided into their own task level. "Installation Cost" consists of tasks such as; 1) Electrical

Installation, 2) Pump Equipment Installation, and 3) Mechanical Installation.

The CBS for "Initial Phase" is attached in Appendix A.

8.2 Delphi analysis results of Operating Cost Phase

The "Operation Cost phase" is developed and divided into five categories which are: 1) Energy Cost, 2) Utility Cost, 3) Administration Cost, 4) Surveillance Cost and 4) Facility Management Cost.

The "Energy Cost" is sub-divided into element levels which consist of two elements which are; 1) Power/electricity Consumption, and 2) Lighting.

Meanwhile the "Utility Cost" is sub-divided into element levels which consist of two elements which are; 1) Water and 2) Telephone. These two elements represent the bill of Water and Telephone consumption.

As for the "Administration Cost", only one element involved is "Recurring Expenses". "Recurring Expenses" can be referred as the sales, general, and administrative expenses. The common examples for "Recurring Expenses" are rent, salaries, and money spent on office supplies.

The "Surveillance Cost" is sub-divided into three element level which are; 1) Inspection Cost, 2) Supervision Cost and 3) Labor Cost. However, experts agree that "Labor Cost" needs to be sub-divided into three tasks which are; 1) Training Cost, 2) Transportation Cost, and 3) Salary.

As for the "Facility Management Cost", it is sub-divided into three element levels which are, 1) Waste Disposal Cost, 2) Cleaning Cost, and 3) Security Cost.

The CBS for "Operation Phase" is attached in Appendix B.

8.3 Delphi analysis results of Maintenance and Repair Cost Phase

The "Maintenance and Repair Cost Phase" is developed and divided into five categories which are: 1) Labor Cost, 2) Spare Part Cost, 3) Material Maintenance Cost, 4) Preventive Maintenance Cost and 4) Corrective Maintenance Cost.

The "Labor Cost" only has one element only which is "Training Cost".

Meanwhile the "Spare Part Cost" is not sub-divided into any elements. The experts stated that it is a well-known fact for all treated water pumps to have different spare parts which only the operator personnel would be familiar with. Thus, there is no task under "Spare Part Cost".

Same goes for the "Material Maintenance Cost". It is not divided into any elements because experts agreed that different treated water pump has different material. As this CBS is presented in a generic form, it is understood that this CBS would require modification to suit the needs and situation for future use. Thus, there is no fixed list under the "Material Maintenance Cost".

Experts agreed that the "Preventive Maintenance Cost" needs to be sub-divided into six tasks which are; 1) Surveillance Cost, 2) Inspection Cost, 3) Checking Cost, 4) Testing Cost, 5) Vibration Reading and 6) Cleaning Cost.

As for the "Corrective Maintenance Cost", it contains one element only which is "Downtime Cost". The "Downtime Cost" can be further sub-divided into seven tasks of level which are; 1) Service Cost, 2) Replacement Cost, 3) Installation Cost, 4) Lubrication Cost, 5) Repair Cost, 6) Disassemble Cost, and 7) Cleaning Cost.

The CBS for "Operation Phase" is attached in Appendix C.

8.4 Delphi analysis results of Disposal and Upgrading Cost Phase

The "Disposal and Upgrading Cost Phase" is developed and divided into three categories which are: 1) Upgrade Cost, 2) Disposal Cost and 3) Refurbishment Cost.

However, all the experts agreed that only the "Upgrade Cost" should be sub-divided into task level which is "Upgrading Parts". The experts stated that treated water pump usually goes through the upgrading process rather than disposal. It is because upgrading process can improve the efficiency usage of the pump and also to prolong its life span.

The CBS for "Disposal and Upgrading Phase" is attached in Appendix D.

9.0 DISCUSSION

From the outcome, there are four phases of Treated Water Pump in Malaysia, which are 1) Initial Cost Phase; 2) Operating Cost Phase; 3) Maintenance and Repair Cost Phase and; 4) Disposal and Upgrading Cost Phase. All of these phases actually reflect the life span of treated water pump in Malaysia. Furthermore, it reflects the phases that need to be considered in order to prolong the lifespan of the treated water pump. The whole generic Cost Break down Structure, which is attached in Appendix E, displays the entirety of the required cost elements and describes the cost data structure for the entire life span of treated a water pump.

To validate the outcome, the triangulation of data is used. The cost elements in CBS are compared and viewed with previous literatures related with LCC.

The discussion delves into the LCC calculation formula and then compared with the CBS developed in this research.

Based on Hennecke (2006), the elements of pump LCC are as follows:

1. Initial cost;
2. Installation and commissioning cost;
3. Energy costs;
4. Operating cost;
5. Maintenance and repair costs;
6. Downtime and loss of production cost;
7. Environmental cost; and
8. Decommissioning and disposal cost

All of these elements are presented in a formula in Figure 7:

Elements of Life Cycle Costs (LCC)

$$LCC = C_{ic} + C_{in} + C_e + C_o + C_m + C_s + C_{env} + C_d$$

C_{ic} = initial cost
C_{in} = installation and commissioning cost
C_e = energy costs
C_o = operating cost
C_m = maintenance and repair costs
C_s = down time and loss of production cost
C_{env} = environmental cost
C_d = decommissioning and disposal cost

Figure 7: The Elements of Pump LCC.
Source: Hennecke, (2006).

Table 3: Comparison of cost elements between the LCC formulas and the developed CBS.

No.	Based on Hennecke, (2006)	Based on the experts opinion (CBS developed)
1.	Initial cost	Included
2.	Installation and commissioning cost	Included
3.	Energy costs	Included
4.	Operating cost	Included
5.	Maintenance and repair costs	Included
6.	Downtime and loss of production cost	Included (Mentioned as Downtime cost)
7.	Environmental cost	Not Included
8.	Decommissioning and disposal cost.	Included (Mentioned separately)

Based on the Table 3, it can be concluded that most of the cost elements stated by Hennecke (2006) and his formula of LCC for pump are included in the CBS developed in this

research. However, "Environmental Cost" is excluded as it has been agreed by the expert that the CBS has included the basic cost elements that are incurred during the treated water pumps' operation and maintenance. Furthermore, they believe that if the "Environmental Cost" is added into the CBS, it would turn into the Environmental Life Cycle Assessment instead. This is supported by the definitions given by Finnvedenetal. (2009), whereas the Life Cycle Assessment is a method to assess the environmental effects and resources used over a product's life cycle, i.e., from raw material acquisition, through production and use phases, to waste management.

9.1 Initial Cost Phase

According to Hennecke, (2006) the initial cost of pump would only cover the purchase cost and the acquisition cost. Currently, the guiding principle for purchasing pumps in the department is to choose a pump on the basis of the least price quoted and not a pump with low LCC. However, the decision of purchasing pump based on LCC will be more economical in the long term as the cheaper pump may not have longer life cycle compared to a pump chosen based on low LCC (Tutterow *et al*., 2006). This statement shows that the CBS proposed is aligned with the literature as the "Initial Cost Phase" is crucial in every pump purchasing decision.

9.2 Operating Cost Phase

Frenning (2001) stated that operation cost includes the labor cost of standard system observation. He added that "Labor Costs" which are linked to the operation of a pumping system, are "Operation Costs". The purchase and operation of pumping systems is a significant budget for most facilities (Woodland, 2006). Bankston *et al*., (1994) concurred by stating that a cost analysis which includes the initial cost of capital investment, annual fixed cost and operating cost should be carried out before choosing a pump that will suit the needs of a pumping system. Thus, the CBS proposed in this research is aligned with the literature because it has incorporated the element of operation cost into consideration.

9.3 Maintenance and Repair Cost Phase

Maintenance can be defined as any activity or actions that involve management role and the technical aspects carried out to keep, preserve or recover a thing to its original condition (Wood, 2009). Many water facility pumping system have their life cycle costs dominated by energy and maintenance costs (Tutterow *et al*., 2006). Maintenance costs consist of direct labor, fuel power, materials, and equipment and purchased services. In fact, almost 75% of the total life cycle cost of a typical pumping system is assumed for energy and maintenance costs (Woodland, 2006).

9.4 Disposal and Upgrading Cost Phase

This is the cost incurred at the end of an asset's functioning life in disposing of the asset (Woodward, 1997). In the majority of cases, most experts involves in the Delphi rounds agreed that pump needs to be upgraded in order to be more optimized and efficient.

10.0 CONCLUSION

This paper reports the development of generic Cost Breakdown Structure (CBS) of treated water pump, the findings and the discussion. This generic CBS data structure could be used by practitioners or even facility managers in water industry for the collection of consistent data for LCC estimation. This framework is a generic data structure that reflects the list of data needed before estimating the LCC for treated

water pump. According to Bakis *et al*., (2003), CBS could based on the different cost standards depending on specific countries.

Thus, in future, the implementation may require certain modification to suits or fit the specific features of certain pump in other countries. This is because every CBS is different for every area or industry as the data required for each CBS is dependent on the life cycle stages of an asset or equipment or a project (Lindholm *et al*., 2004; Smit, 2012). The outcome from this study gathered from expert opinions during Delphi process, is a proposed data structure that can be beneficial to all the water industry practitioners before implementing LCC. It serves as a basis of collecting LCC data in a consistent manner. Recommended future research is to develop CBS in other types of pumps and also to implement LCC calculation by using the proposed CBS to collect the data.

REFERENCES

AAMCoG (2008): Public Sector Asset Performance Measurement and Reporting, Australian Asst Management Collaborative Group (AAMCoG) and Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM).

Albee, S. and Byrne, R. (2007), "A global vision for driving infrastructure asset management improvement", Leading-edge asset management: Reports and abstracts book, 17-19 October 2007, Lisbon, pp. 27.

Ambrose, M., Burn, S., DeSilva, D., & Rahilly, M. (2008, September). Life cycle analysis of Water Networks. In Plastics Pipe XIV: Plastics Pipes Conferences Association (Vol. 22).

Bakis, N., Amaratunga, R. D. G., Kagioglou, M., & Aouad, G. (2003).An integrated environment for life cycle costing in construction.

Bankston, J. D., & Baker, F. E. (1994).―Selecting the Proper Pump‖. Southern Regional Aquaculture Center.

Barringer, H. P. & Weber, D. P., (1996).―Life Cycle Cost Tutorial. Houston, Gulf Publishing Company and Hydrocarbon Processing.

Brighu, U. (2008). Asset management in urban water utilities: Case study in India.

Bull, J. W. (1993). ―The Way Ahead for Life Cycle Costing in the Construction Industry‖.In Bull, J. W. (ed.) Life Cycle Costing for Construction. Blackie Academic & Professional, Glasgow, UK.

Cashin, G. (2006), *"Asset management in the context of operation and maintenance contracts"*, Water Asset Management International, vol. 2, no. 4, pp. 12.

Cox, J. (2005). New developments in investment planning and project evaluation: optimising expenditure to meet multiple objectives with limited resource. Water Asset Management International, 1(2), 9-15.

Dhillon, B. S. (2009). Life cycle costing for engineers. CRC Press.

Economic Unit Planning (EPU) (2006).The Ninth Malaysia Plan. Economic Planning Unit, Putrajaya.

Economic Planning Unit (EPU) (2015). The Eleventh Malaysia Plan, Economic Planning Unit, Putrajaya.

El-Haram, M. A., Marenjak, S., & Horner, M. W. (2002). Development of a generic framework for collecting whole life cost data for the building industry. Journal of Quality in Maintenance Engineering, 8(2), 144-151.

Engelhardt, M., Savic, D., Skipworth, P., Cashman, A., Saul, A., & Walters, G. (2003).*Whole life costing: Application to water distribution network.* Water Science and Technology: Water Supply, 3(1-2), 87-93.

Earles,D.R. (1976). ―Techniques For A Multifaceted Discipline‖. Def. MgmtJl 3847.

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., ...&Suh, S. (2009). Recent developments in life cycle assessment. Journal of environmental management, 91(1), 1-21.

Frenning, L (Ed.). (2001). ―Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems‖. Hydraulic Institute,

Europump, and the US Department of Energy‘ s Office of Industrial Technologies (OIT).

Headquarters Department Of The Army, (1992). ―Water Supply: Pumping Stations. Technical Manual. No. 5-813-6. TM 5-813-9. Washington, DC, 6 October 1992.

Hennecke, F. (2006). “A Comparative Study Of Pump Life Cycle Costs”. Paper Technology, 47(7), 20.

Hodgson, J., & Walters, T. (2002, February).Optimizing pumping systems to minimize first or life-cycle cost.In Proceedings Of The International Pump Users Symposium (pp. 1-8).

Goh, Y. M., Newnes, L. B., Mileham, A. R., McMahon, C. A., &Saravi, M. E. (2010). ―Uncertainty in Through-Life Costing–-Review and Perspectives. Engineering Management, IEEE Transactions on, 57(4), 689-701.

Jeong, J. H., Shin, H. W., Ryu, H. G., Kim, G. H., & Kim, T. H. (2012). *Life Cycle Cost Breakdown Structure Development of Buildings through Delphi Analysis.* Journal of the Korea Institute of Building Construction, 12(5), 528-538.

Kim, C.T. (2012). « Malaysian water sector reform - Policy and performance PhD thesis, Wageningen University, Wageningen, NL (2012).

Kishk, M., Al-Hajj, A., Pollock, R., Aouad, G., Bakis, N.And Sun, M., (2003).Whole life costing in construction: a state of the art review. Available from Open AIR@RGU. [online]. Available from: http://openair.rgu.ac.uk.

Lindholm, A., & Suomala, P. (2004). ―The possibilities of life cycle costing in outsourcing decision making‖. Frontiers of E-business Research, 226-241.

Lemer, A.C. (1998) . ―Progress Toward Integrated Infrastructure-Assets-Management Systems: GIS and Beyond‖. Innovat ions in Urban Infrastructure Seminar of the APWA International Public Works Congress, Las Vegas, Nevada, pp. 724,

López-Ibáñez, M., Prasad, T. D., & Paechter, B. (2011). Representations and evolutionary operators for the scheduling of pump operations in water distribution networks. Evolutionary computation, 19(3), 429-467. m)

Parker, K. R. (1991).*A generic life-cycle cost model for an embedded controller* (Doctoral dissertation, Texas Tech University).

PengurusanAset Air Berhad (PAAB), (2015).

Public Works Department (PWD) (2012). GarisPanduan Kos KitaranHayat - Life Cycle Cost LCC. Pekeliling Am Bil 2 Tahun 2012. SuratArahan KPKR Bil.23/2012.

Richardson, S. J., &Hodkiewicz, M. R. (2011).Modeling tool to support budgeting and planning decisions for pump overhauls. Journal of Water Resources Planning and Management, 137(4), 327-334.

RTO TR-058 / SAS-028; “Cost Structure and Life Cycle Costs for Military Systems”; RTO-SAS-028. Task Group Technical Report; September 2003.

RTO TR-SAS-054, (2007).―Methods and models for life cyclecosting‖.RTO-SAS054Task Group Technical Report.

RTO TR-SAS–069, (2009).―Code of Practice for Life Cycle Cost ing‖. Task Group Technical Report; September 2009.

Schmidt R.C. (1997). ―Managing Delphi surveys using nonparametric statistical techniques‖. Decision Sciences 28, 763±774.

Smit, M.C. (2009). ―NATO Initiatives to Improve Life Cycle Costing‖. Papers presented at the NATO-RTO Systems Analysis and Studies Panel (SAS).Report number: RTO-MP-SAS-080.

Smit, M. C. (2012). ―A North At lantic Treaty Organisation framework for life cycle costing‖. International Journal of Computer Integrated Manufacturing, 25(45), 444-456.

Tarquin, A. J., & Dowdy, J. (1989).Optimal pump operation in water distribution. Journal of Hydraulic Engineering, 115(2), 158-168.

Too, E. G. (2010).A framework for strategic infrastructure asset management. In

Definitions, concepts and scope of engineering asset management (pp. 31-62). Springer London

Tutterow, V., &Asdal, R., McKane, A. T (2006). Pump Systems Matter. World Pumps, 2006(481), 44-46.

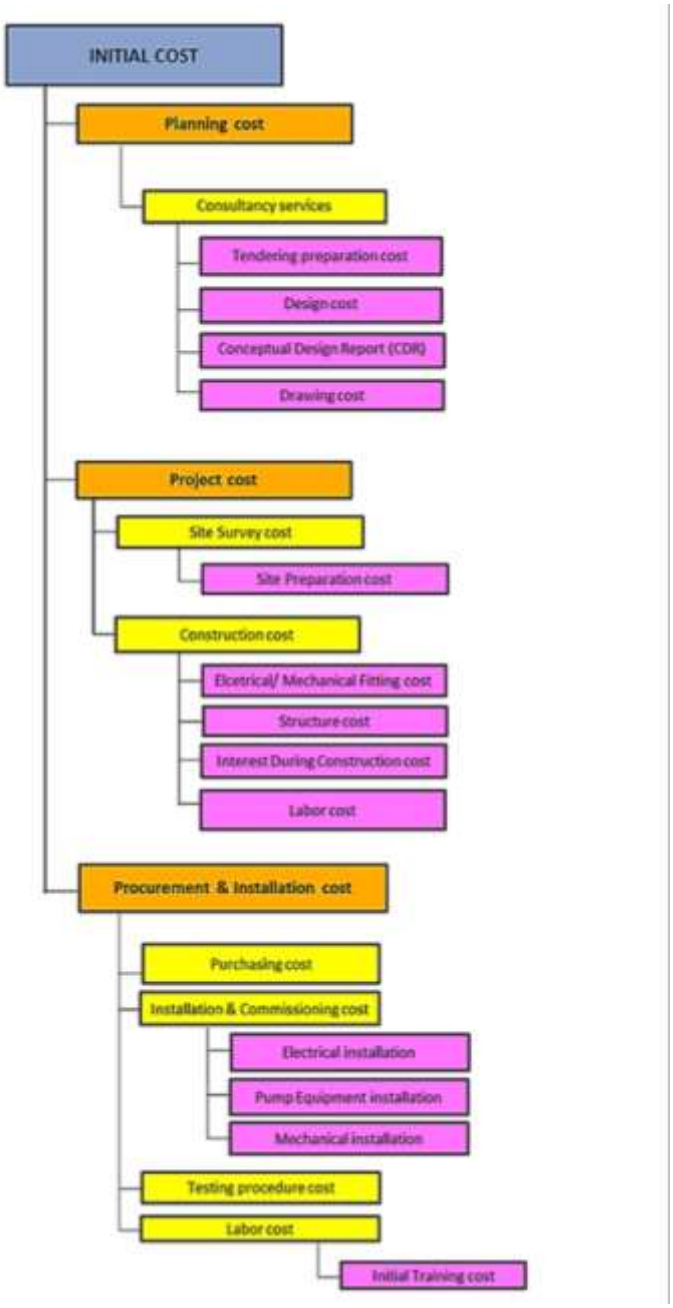
Wood, B. (2009). *Building Maintenance*. Singapore: Wiley-Blackwell.

Woodland Park, C. O. (2006). Taking Another Look at Pumping Systems: Opportunities Go Well Beyond Just Energy Savings.pumpsystemsmatter.org

Woodward, D. G. (1997).*Life cycle costing—theory, information acquisition and application.* International journal of project management, 15(6), 335-344.

Water Services Industry Performance Report (2009).Copyright of Suruhanjaya Perkhidmatan Negara (SPAN) 2009.

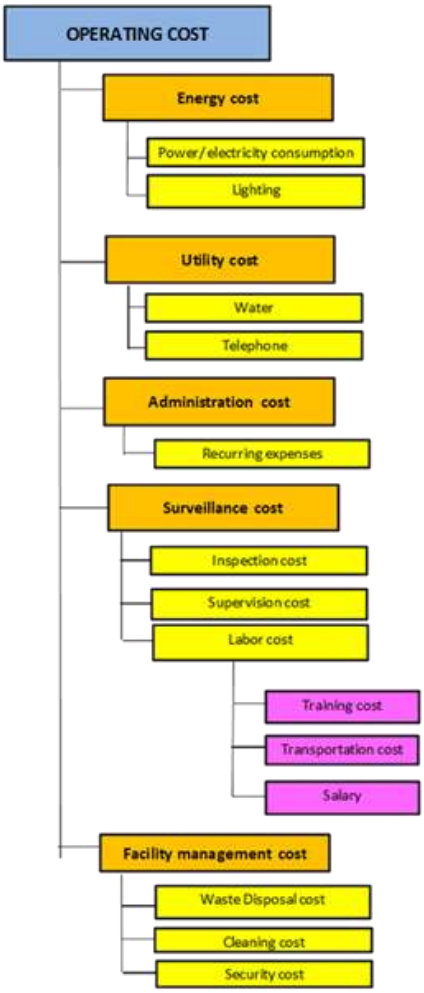
APPENDIX A
Cost Breakdown structure of Initial Phase Cost



Note:

	Phase level
	Category level
	Element level
	Task level

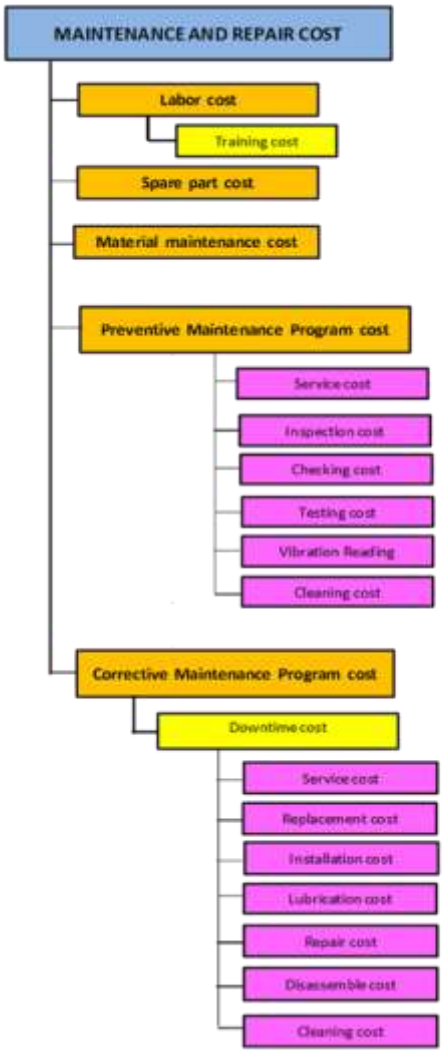
APPENDIX B
Cost Breakdown structure of Operation Phase cost



Notes:

	Phase level
	Category level
	Element level
	Task level

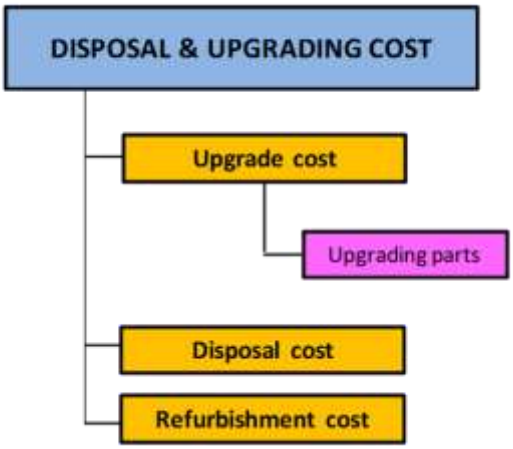
APPENDIX C
Cost Breakdown structure of Maintenance and Repair Phase cost



Note :

	Phase level
	Category level
	Element level
	Task level

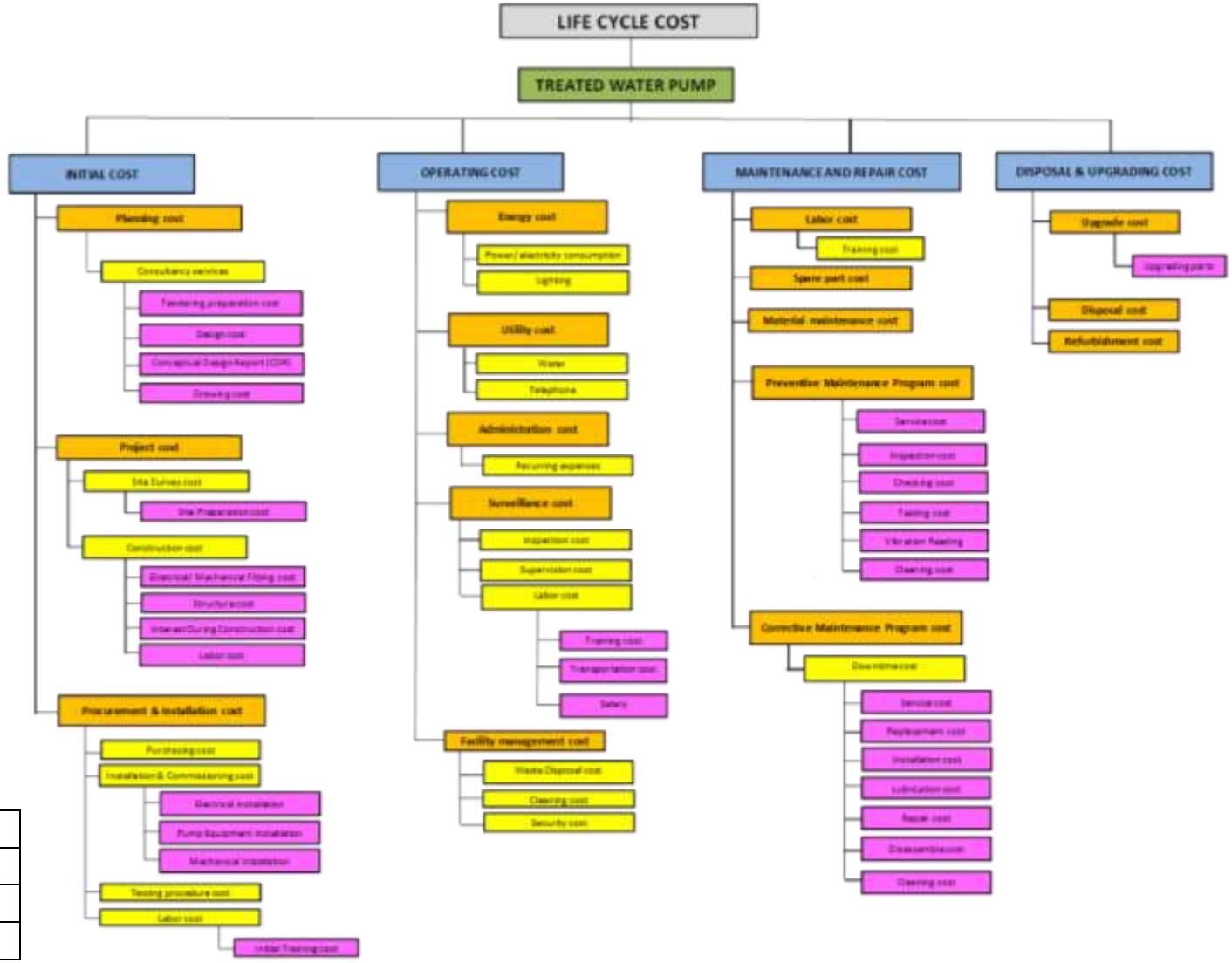
APPENDIX D
Cost Breakdown structure of Disposal and Upgrading Phase cost



Note :

	Phase level
	Category level
	Element level
	Task level

APPENDIX E
Cost Breakdown Structure of Treated Water Pump in Malaysia



Note:

	Phase level
	Category level
	Element level
	Task level