University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Master in Offshore Technology / Industrial Asset Management	Spring semester, 2013 Open
Writer: Ming Chuin Teng	………………………………………… (Writer's signature)
Faculty supervisor: Tore Markeset **External supervisor(s):** Roar Gabrielsen	
Title of thesis: Life Cycle Cost for Modification Project	
Credits (ECTS): 30	
Key words: Life Cycle Cost, Modification, Front-End Loading Studies, Operation & Maintenance	Pages: ……50…………… + Enclosure: …1……… Stavanger, June 2013

Life Cycle Cost for Modification Project

by

Ming Chuin Teng

Thesis submitted in fulfillment of
the requirements for the MASTER DEGREE in
OFFSHORE TECHNOLOGY
Specialization: Industrial Asset Management

University of Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY
Department of Mechanical and Structural Engineering and Material Science
Center of Industrial Asset Management
2013

ABSTRACT

Life Cycle Costing is a commonly used method for evaluating various alternatives and hence, choosing the best solution. This method is not fully utilized in the Front End Loading studies performed by one of the operating company in cooperation with their contractor for the modification of their existing facilities in an oil field.

In most of the cases, the proposed technical solutions are often chosen mainly based on the initial acquisition cost, technical compliances and previous experiences. The complete life cycle cost, which shall typically include solution integration, operation and maintenance cost are often neglected. It is important to consider the complete life cycle cost as much as possible. Without having thorough understanding of the associated cost incurred in the life cycle, it is just like viewing only the top of the iceberg by overlooking the hidden cost.

The operating company aims to implement the life cycle cost calculation as part of the standard procedures while performing studies in the early phase for their modification projects. It forms a basis for selecting the best technical solutions economically.

The purpose of this paper is to propose a practical solution and life cycle cost evaluation for selecting the best technical solution for modification projects. It enables the company to properly document the criteria and calculation as supporting document for decision making in the project. A practical case study is carried out and simplified LCC calculation method is proposed.

It is also recommended that LCC analysis to be extended to bid evaluation while purchasing new critical equipment during the project execution phase.

ACKNOWLEDGEMENT

The thesis would not be completed without the help and support from the wonderful people around me.

I would like to thank my faculty supervisor, Professor Tore Markeset, for his valuable guidance for accomplishing this thesis. Without his professional advices and supervision, this thesis would have remained as a dream.

My deepest gratitude also goes to my managers in Aibel AS, Mrs. Betty Marie Lystad and Mr. Ingar Hære, for getting the opportunities to work my thesis with the operating companies. I would like to thank them for trusting me that I can handle the difficulties to cope with my works and thesis at the same time.

I would also like to thank Mr. Roar Gabrielsen, Dr. Sukhvir Singh Panesar and Dr. Rajesh Kumar from ConocoPhillips AS and other involving companies, for their valuable input and professional suggestions to the thesis in more industrial and practical approach. Without them trusting me and giving me the chance for writing the thesis with them, I would not have completed this thesis within the given period.

I would also like to thank Mr. Kjetil Øxnevad, Managing Director of the involving supplier, for his professional advices and practical information for me to complete the calculation for demonstrating the case study.

I also thank all professors who passed on their knowledge to us throughout the period of my study in University of Stavanger. My sincere thankfulness also goes to all classmates and friends from Norway, Singapore and Malaysia for giving me the mental support and encouragement at all times. They have been the motivation for keeping me fighting for my goals.

My special thanks go to Miss Changhui Mao who has been taking great care of me since I arrived in Norway. She was the only person that I know when I first arrived and has continuously sharing me her experience and giving me constructive advice in both my career and personal goals. Without her, my life in Norway would have been very tough and I might have given up before completing this thesis.

Last but not least, I would like to thank my family and relatives for their unconditional love and support throughout my life. They have accompanied us to go through the toughest moments. I owe my deepest gratitude to my mum, Madam Yet Good Ho, the most important person in my life who has provided me with best education, continuous supports and encouragement at all times. I thank my siblings for taking great care of my mum when I am unable to do so, that allows me to focus on my study without any worries. I would like to thank my father, the late Mr. Jock Joh Teng, for his love and blessings.

Ming Chuin Teng

Stavanger, Norway

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

CBS	Cost Breakdown Structure
FEL	Front End Loading
FWM	Fresh Water Maker
LCC	Life Cycle Cost
NPV	Net Present Value
NCS	Norwegian Continental Shelf
OEM	Original Equipment Manufacturers
PV	Present Value

DEFINITIONS

According to ISO 15663-1 (2000), the following terms are defined as:

Cost driver
– Major cost element which if changed will have a major impact on the life-cycle cost of an option

Cost element
– Identifiable part of the life cycle cost of an option which can be attributed to an activity

Life cycle
– All development stages of an item of equipment or function, from when the study commences up to and including disposal

Life cycle cost
– Discounted cumulative total of all costs incurred by a specified function or item of equipment over its life cycle

Life cycle costing
– Process of evaluating the difference between the life cycle costs of two or more alternative options

Net present value
– Sum of the total discounted costs and revenues

Sensitivity analysis
– Process of testing the outcome of a life cycle costing in order to establish whether the final conclusion is sensitive to changes in assumptions

1. INTRODUCTION

Having a net production of approximately 147,000 barrels of oils per day in year 2011, the operating company is one of the largest foreign operators in the Norwegian Continental Shelf. The company discovered the first field in the NCS which is located at the southern part of North Sea and there are a total number of close to 30 installations are currently in the operations (Anonymous, 2013a).

According to Aibel (2013), the company Aibel AS had been awarded a long term contract by the operating company to carry out the modification and installation projects for their oilfield since summer in year 2002. The scope of work for the contract includes the engineering, procurement, fabrication, installation and completion for the modification and installation of the equipment/system.

1.1 Background and Problem Statements

The entire process has been split into various phases and sub-projects according to the scale of each sub-project. As shown in Figure 1, the typical phases involved in the modification project are mainly Front End Loading studies (i.e. FEL 0, FEL 1, FEL 2 and FEL 3) and project execution (i.e. engineering, procurement, installation and completion). Prior moving into the actual project execution phase, the FEL study team carries out the concept or feasibility studies with respect to various possible solutions which fulfill the needs and requirements of the modification.

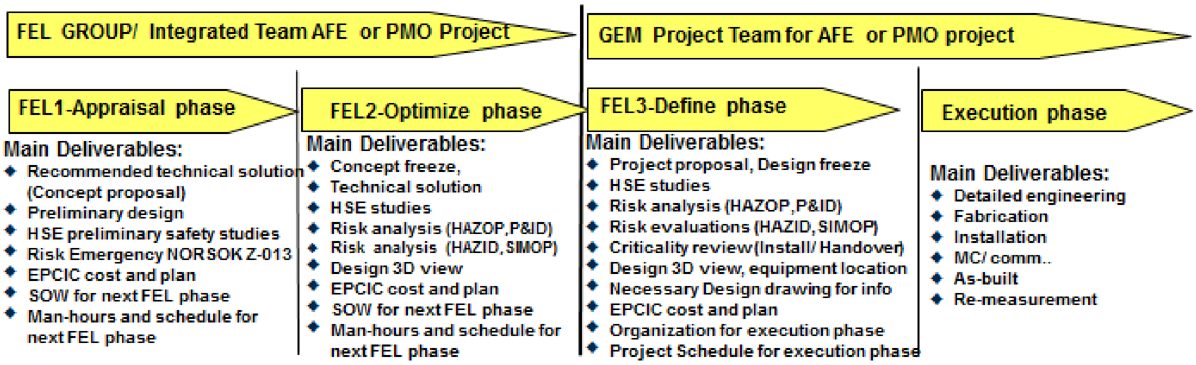


Figure 1: Front End Loading Work Process (Anonymous, 2013)

Currently, the selection of the best technical solution are mainly based on the initial procurement price, frame agreement contract with suppliers, technical compliances with standard and regulations, earlier experience with Original Equipment Manufacturer, personal experience with the system and etc. This approach was challenged against the lack of consideration of complete Life Cycle Cost including the integration cost with existing facilities, operation and maintenance cost as well as the cost associated with environmental impact. As a result, the chosen technical solution might be ended up with enormous amount of sustaining cost during the operation phase.

Hence, it is proposed to incorporate practical evaluation of LCC during the early phase of the modification, ideally during the FEL 1 study phase. Appropriate documentations and LCC calculations should also be generated and included as part of the study report in order to further support the recommended solutions for better managerial decision. It aids the company to select a more appropriate and economic solution in the long run with adequate consideration of cost drivers.

Most of the literature shows the existing standards and methods for carrying out LCC analysis are not effective for the modification project as most of the information required are lacking at such early stage. Hence, this thesis focuses on the modification project carried out for the oil and gas platform located in the Norwegian Continental Shelf (NCS) with limited time, space and resources. On such basis, the thesis will focus on the following problems:

- What are the important criteria or drives for choosing the best technical solutions?
- What are the appropriate cost drivers to be considered?
- What criteria or factors to be applied in LCC calculation?
- Why is it important to consider LCC in the modification projects?
- What kind of equipment or systems should LCC analysis be applied for?
- How to implement the LCC evaluation in the early phase of modification project in a practical manner?

1.2 Objectives and Scopes

The main scope of this thesis is to study and propose a practical method for the operating company to consider more detailed evaluation of LCC of the critical equipment/systems in their early stage of the modification projects. It also aims to propose practical calculation method, with a case study, to obtain the LCC of the proposed alternatives and hence, assist the project management team for choosing the most suitable technical solution economically.

The sub-objectives of the thesis work involve:

a. Identify the important criteria/drivers for selecting of best critical equipment/technical solution
b. Study and discuss appropriate cost drivers for consideration
c. Discuss and recommend the criteria/factors in LCC calculation with case study
d. Describe the method of implementation of LCC evaluation in FEL studies and its benefits
e. Discuss and recommend practical implementation of LCC in the modification project and need of LCC analysis on equipment

The scope of this thesis also involves a practical case study that is currently being investigated by the operating company and their contractor, i.e. the replacement of Fresh Water Maker in the existing living quarter. The output of the LCC estimation should be taken into consideration for selecting the most appropriate technical solution together with the advantages and disadvantages of proposed technical solutions.

1.3 Limitation and Challenges

The research scope of this thesis focuses only on the application of LCC evaluation for the critical or major equipment and systems in the modification project of existing Norwegian oil and gas platforms. The detail LCC evaluation method will be proposed for selection of various technical solutions. It is aimed to recommend a practical solution for selecting suitable technical solution with consideration of limited time and personnel resources.

Additionally, it is not practical and cost effective for performing LCC evaluation if the overall cost of the investment has no significant impact as compared with the total investment cost. Further research is encouraged for normalizing or simplifying the LCC calculation method generally for most equipment or systems within the facilities.

While preparing the thesis, below challenges have been encountered:

- Difficult to obtain or estimate the operation and maintenance cost due to uncertainties and accuracy of the information and data.
- Difficult to obtain cost estimation for every single cost component as it is normally estimated based on works involved by each disciplines
- Difficult to acquire in-depth information from suppliers related to operation and maintenance aspects as they are not willing to put much effort or lacking of defined requirements at this stage
- Uncertainties exist due to the limited information and detail engineering performed. Possible changes in the design and process requirements may affect the estimated value.

1.4 Organization of Thesis

This thesis is divided in to eight sections in total with the following outlines:

Section 1 – This section covers the introduction and scopes of the thesis. It also describes the background information and its limitations for preparing the thesis.

Section 2 – This section is written based on various researches and literature review concerning LCC. It presents the background, concept of LCC and its applications. It also provides essential information needed and typical procedures for carrying LCC analysis.

Section 3 – In this section, the practical use and implementation of LCC technique on modification project of existing facilities had been discussed and presented. Practical case study of choosing the most appropriate technical solution for replacement of FWM package on existing living quarter with regards to LCC matters is investigated and reported.

Section 4 – This section addresses the result obtained from the previous section in order to facilitate decision making in the project. The result is calculated based on various assumption and only includes critical cost elements due to time and resources constraints.

Section 5 – These sections draws the conclusion from the findings of thesis and provides recommendations for future work and study.

Section 6 – It provides the list of references and sources that had been used for preparing the thesis.

Section 7 – Appendix presents the standard checklist to be used for LCC analysis in general.

2. METHODOLOGY / LITERATURE REVIEW

This section of the thesis presents an overview and introduction of life cycle cost based on literature review and interviews with experts in this area.

2.1 Background

It is recognized that, in most cases, systems are planned, designed, manufactured, installed and operated with neglecting the concern for affordability and the total system value over its intended life cycle which is widely known as Life Cycle Cost (Blanchard & Fabrycky, 2011). Major costs such as operating and maintenance cost are often deferred to the later phase. As consequences, the total cost of the system is increased significantly. Typical life cycle stages are shown in Figure 2.

Figure 2: Typical Life Cycle Stages of Facilities/ Systems (Davis Langdon Management Consulting, 2007)

As an example shown in Figure 3, life cycle cost is the total discounted cost of ownership of a product/equipment throughout its defined life cycle, i.e. including design and development cost, initial acquisition cost, operating and maintenance cost, facility integration & installation cost, facility management cost and disposal cost (Barringer & Weber, 1996; ISO 15663-1, 2000; Ellis, 2007). This LCC concept and definition are always misunderstood by many organization and managers as they tend to equate this with the acquisition cost. Often, the manager always assumes that there will be no significant differences between the total costs among the alternatives for simplicity reason (Ahmed, 1995). The potentially huge cost of future expenditures that had been ignored results in reduced value for the total asset of the organization. It is also acknowledged that the manager might be aware of such potential increase in total ownership costs during operation, but they choose to ignore them (Ahmed, 1995).

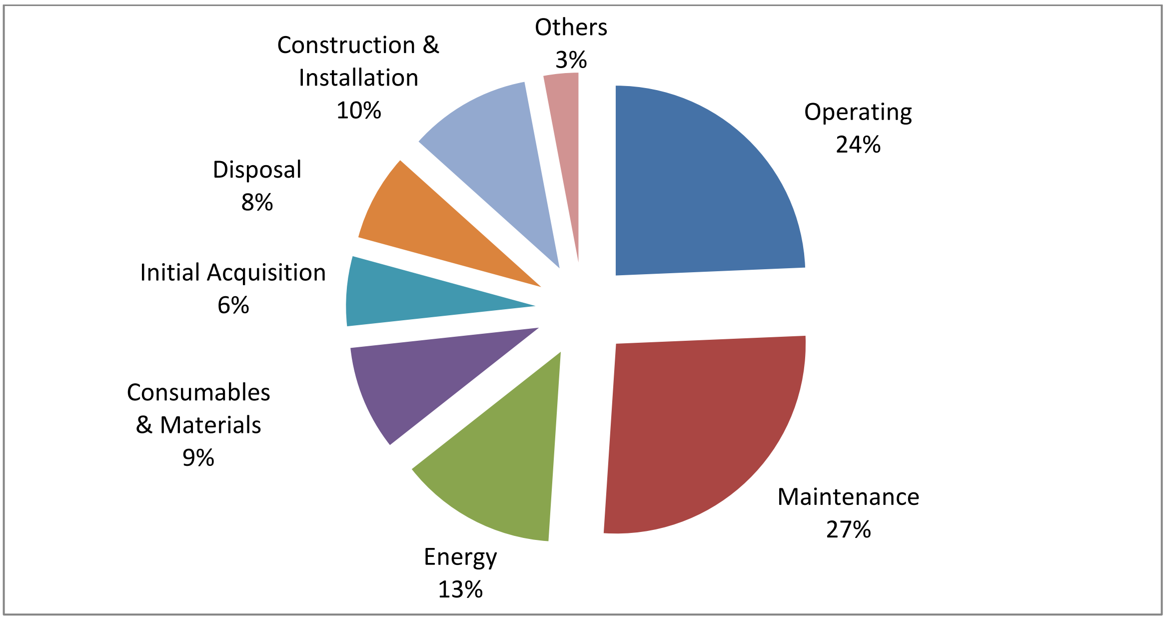


Figure 3: Typical Life Cycle Cost

Among all of the above mentioned cost components in LCC, the acquisition cost is the most identifiable components and therefore, had been widely as the primary criteria while performing the equipment or supplier selection (Blanchard & Fabrycky, 2011). In most of the cases, managerial decisions from project management team are often superficially made based only on such criteria and other associated cost concerning operating and maintenance are frequently ignored. The bad financial decisions made are, in many cases, the consequences of ignoring those hidden cost (Barringer, 1998). It also implies from the famous quote from John Ruskin: “It's unwise to pay too much, but it's foolish to pay too little. When you pay too much, you lose a little money - that's all. When you pay too little, you sometimes lose everything, because the thing you bought was incapable of doing the thing it was bought to do”. According to Barringer & Weber (1996), this also forms the basis of the operating principle of LCC analysis. In fact, good project management practice is to minimize the total project cost and not the initial procurement cost (Ellis, 2007).

In fact, the initial acquisition cost represents only the tip of an iceberg as illustrated in Figure 4. The underlying and hidden parts of the iceberg always incur enormous cost in the later phase of the project. Hence, it is crucial that the complete LCC had been considered and evaluated with care in order to minimize the total project cost.

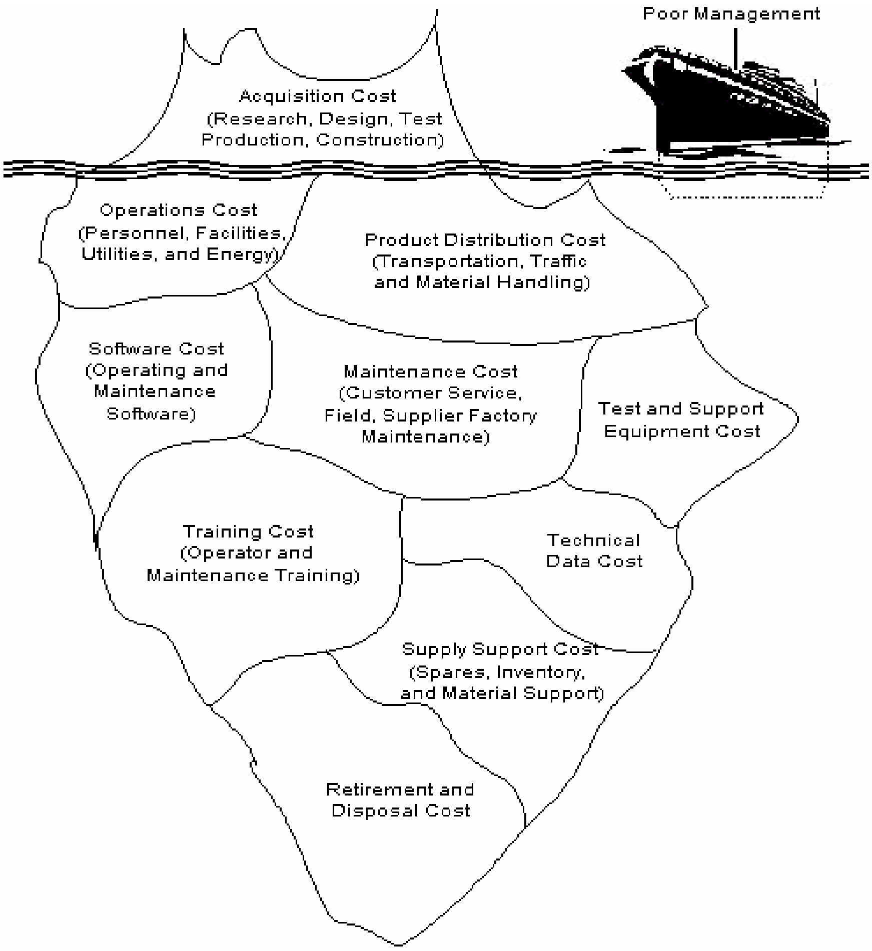


Figure 4: Total Cost of Visibility (Blanchard & Fabrycky, 2011)

Figure 5 shows that the major part of LCC are fixed and committed in the early stage of a project and the chances of reducing the project LCC is getting lesser in later phase. Reduction of the gap between the cost committed and cost expended has become the goals of the project.

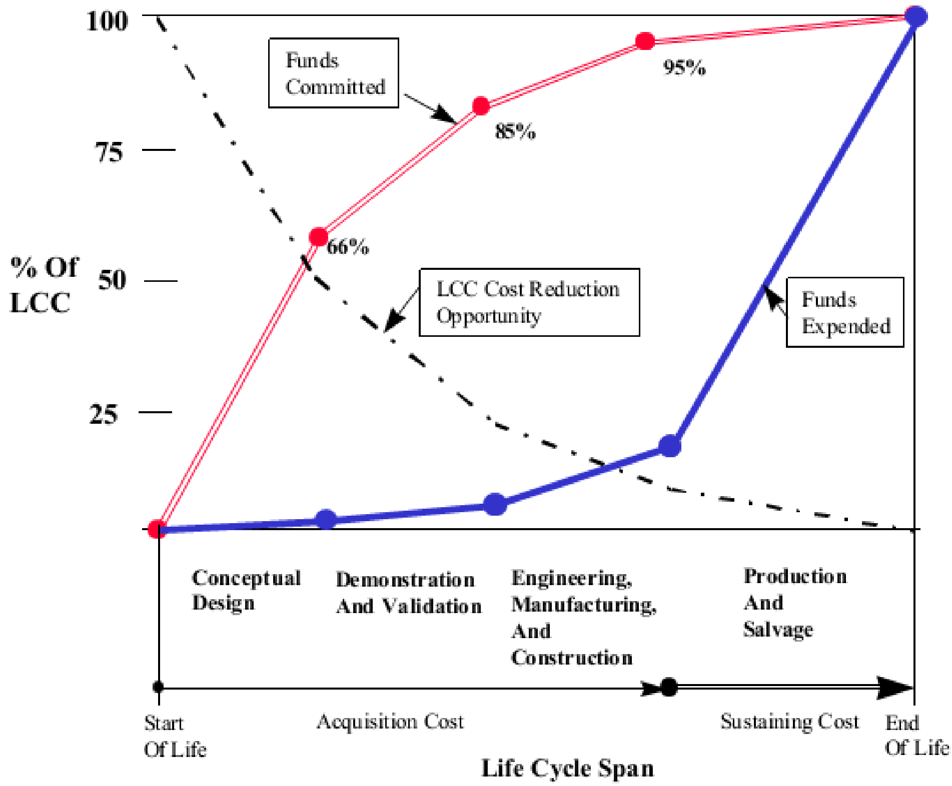


Figure 5: Funding Trends by Commitment and Expenditure (Barringer & Weber, 1996)

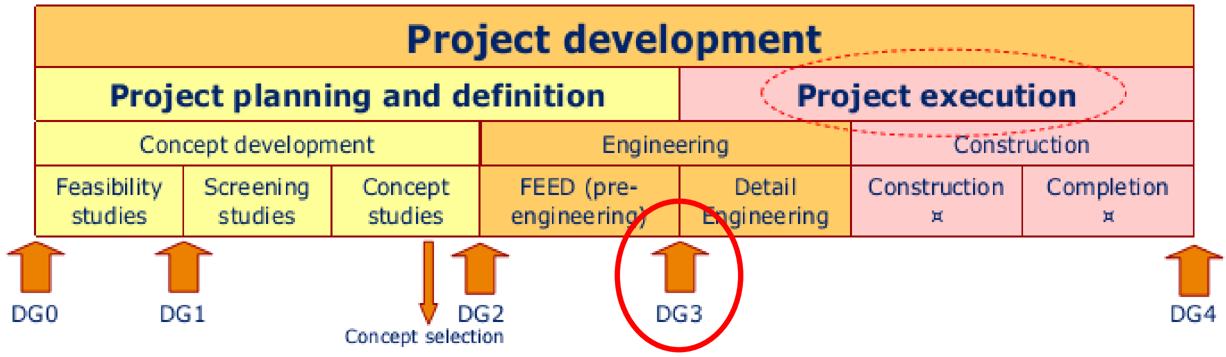


Figure 6: Decision Gates in Project Development (Odland, 2011)

In the event of project development, various decision gates have to be checked and completed before proceeding to the next phase. Typical decision gates allocation is shown in Figure 6 above. Several analysis approaches are normally used to assist decision making, those are NPV method, IRR analysis, payback period method, and etc. LCC analysis can be commonly used for DG3 and also for supplier evaluation. DG3 is the main focus of the study area for this thesis, i.e. performing LCC evaluation in FEL phase before executing the project (detail engineering).

The practical applications of LCC and its calculation method are further discussed and presented in the following sections.

2.2 Application of LCC

The predicted LCC is commonly used for evaluating and selecting the most economic approach and solution among various alternatives in the long run. The LCC analysis assists engineers to better justify their selection of technical solution based on the total cost within a defined life cycle period, and document as a supporting document to facilitate decision making by the management. It leads to better decision making for solution selection that minimize the total project cost by considering overall associated cost instead of only the acquisition cost (Barringer & Weber, 1996; Blanchard & Fabrycky, 2011; NORSOK O-CR-001, 1996). Acquisition cost typically includes procurement price, administrative cost, engineering cost, installation cost, training cost, facilities integration cost and logistics.

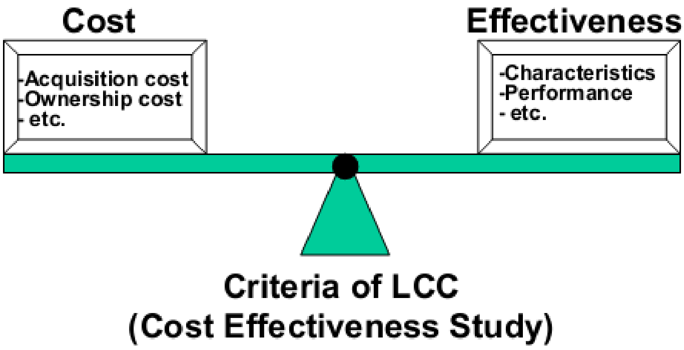


Figure 7: Cost effectives studies in LCC (Kawauchi & Rausand, 1999)

According to Barringer (1997) and Kawauchi & Rausand (1999), the goal of performing LCC analysis is to select the solution with the best system effective as shown in Figure 7. Cost effectiveness may also be defined as the measure of the system with respect to their ability to fulfill the requirements and LCC (Blanchard & Fabrycky, 2011):

$$Cost\ Effectiveness = \frac{System\ Effectiveness}{LCC}$$

As shown in Figure 8, the preferred measure is to select the system with highest effectiveness and lowest LCC.

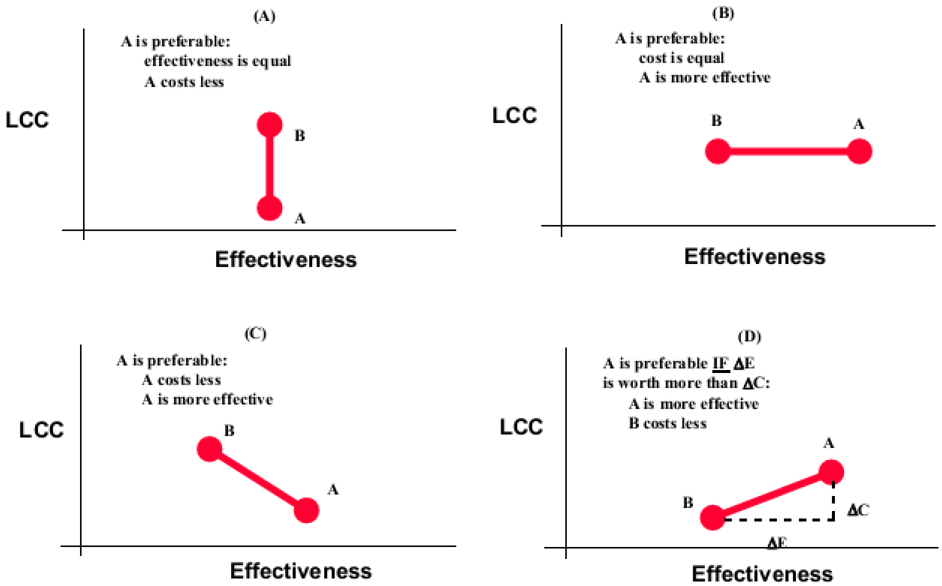


Figure 8: Possible Results from Trade-off Studies (Barringer, 1998)

According to Fabrycky & Blanchard (1991), system effectiveness is related to the ability of a system to fulfill their desired requirements and it includes performance, capacity, availability, readiness, reliability, maintainability, supportability, and etc. It is commonly defined as the probability of the designed system that successfully meeting the demand operational requirements while operating under specified time and conditions, and hence, it is also a measure of its value that are received from operation (Fabrycky & Blanchard, 1991; Barringer, 1998). The value of effectiveness falls between 0 and 1.

Typically,

$$Effectiveness = \text{Availability * Reliability * Maintainability * Capability}$$

Each component stated in the formula above is explained and defined as below:

<u>Availability</u>

As defined by Dhillon (2006) and Barringer (1998), availability is the probably of a system that it is available for use. It is a measure of how frequent a system is up for running and it allows estimating of uptime for a system within a given interval. It is typically expressed as:

$$Availability = \frac{Uptime}{Uptime + Downtime}$$

where Uptime = Mean Time between Failure (MTBF) = 1 / λ

Downtime = Mean Time to Repair (MTTR)

λ = Failure Rate, total number of failures per total operating period

<u>Reliability</u>

"Reliability is a measure of the probability for failure-free operation during a given interval, i.e. it is a measure of success for a failure free operation", as defined by Barringer (1998). Fabrycky & Blanchard (1991) defined that reliability is the probability where a system operates in satisfactory manner in a specified interval and under specified conditions.

$$Reliability = \exp\left(\frac{-t}{MTBF}\right) = \exp(-\lambda\, t)$$

where λ = constant failure rate = 1 / MTBF

<u>Maintainability</u>

Maintainability is defined as the probability that a failed system that restores to its operational state, i.e. how long it takes to complete repair/maintenance (Dhillon, 2006). It is the characteristics of the design of system or equipment in installation that deals with the ease, economy, safety and accuracy in scheduled or unscheduled maintenance. The degree of maintainability often affects the length of repair/maintenance time that relates to system downtime. This characteristic should always be considered in the early phase but always neglected. According to earlier research (Blanchard, et al., 1995), the idea of "design it now and fix it later" will turn out to be very costly because changing the system in later phase is a very expensive activity (Also reference to Figure 5 mentioned in Section 2.1)

$$Maintainability = 1 - \exp\left(\frac{-\,t}{MTTR}\right) = 1 - \exp(-\,\mu\, t)$$

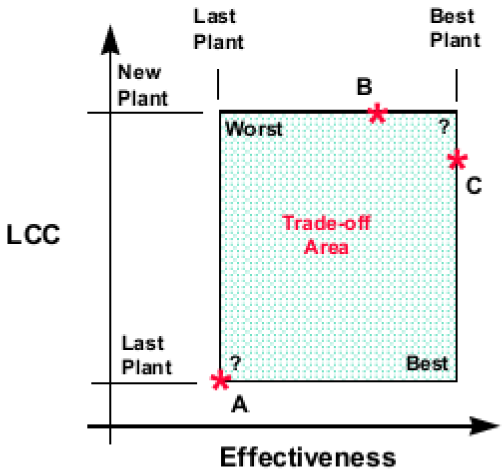
where μ = Constant Maintenance Rate

Capability

Capability measures the system capability to perform its intended function on a system basis, i.e. to compare the productive output to the productive input. It tells how well the system performs (Barringer, 1998)Goal of LCC Analysis

As mentioned in the earlier sections, the application of LCC strives to obtain the solution selection which gives the maximum effectiveness with the lowest LCC. There must be some trade-off between the criteria with deep consideration. By performing the LCC study and analysis while evaluating the possible alternatives, it helps to identify the cost drivers and include them in the estimation for alternatives as practical as possible. Hence, this helps preventing any 'surprise' of cost incurred from operating and maintenance the system.

In Figure 9, an example shows that the best alternative is Option C. Option A gives the least effectiveness; therefore, this option is not preferred even though it is the cheapest option. It has better effectiveness than Option B but with lower LCC.



Parameter	A Last Plant	B New Plant	C Best Plant
Availability	0.95	0.95	0.98
Reliability	0.3	0.4	0.6
Maintainability	0.7	0.7	0.7
Capability	0.7	0.8	0.6
Effectiveness	0.14	0.22	0.25
LCC	80	100	95

Figure 9: Goals of LCC Analysis (Barringer, 1998)

According to Barringer (2003), LCC takes care of the business perspective with highlighting economic competitiveness and system effectiveness for the lowest cost of ownership in long term. Typical conflicts commonly faced while executing project are presented by Barringer (2003) as follows:

- Project Engineering wants to minimize capital costs as the only criteria
- Maintenance Engineering wants to minimize repair hours as the only criteria
- Production wants to maximize uptime hours as the only criteria
- Reliability Engineering wants to avoid failures as the only criteria
- Accounting wants to maximize project net present value as the only criteria
- Shareholders want to increase stockholder wealth as the only criteria

LCC is implemented as a decision making tool to harmonize the above mentioned conflicts by concentrating on the cost, facts and time.

On the other hand, it is also important that both engineers and managers are aware of the benefits of conducting LCC analysis as earlier as possible for a project. According to ISO 15663-1 (2000), the principle benefits for LCC application are identified as follows:

- Reduce ownership cost
- Align between engineering decision and corporate/business objectives
- Defined common objective criteria for various parties to manage and optimize business transactions
- Reduce the risk of operating expenditure surprise
- Change the criteria for option selection
- Maximize the value of current operating experience
- Provide framework to compare options at all stages of development
- Provide mechanism where major costs drivers can be identified, targeted and reduced

Nonetheless, the level of details of the LCC study depends on the external factors such as the given time frame for the analysis, the financial means of carrying out the analysis, the availability of the resources such as expert involvements and the availability of information as input to the study (RTO, 2007). According to RTO (2007), it is worthwhile to establish the boundaries regarding the cost before starting the process. As such, cost elements that fell outside of the boundaries will be eliminated from consideration.

2.3 General LCC Application

The LCC analyses are generally used for the following applications:

a. Design optimization

This is to study and identify the LCC for various system designs, for both green and brown field, in order to select the most optimal and most economical solution throughout its life cycle.

Figure 10 shows the typical optimization process presented in NORSOK Z-016 (1998). This process can be iterated for further selection and definition in later phase of the projects.

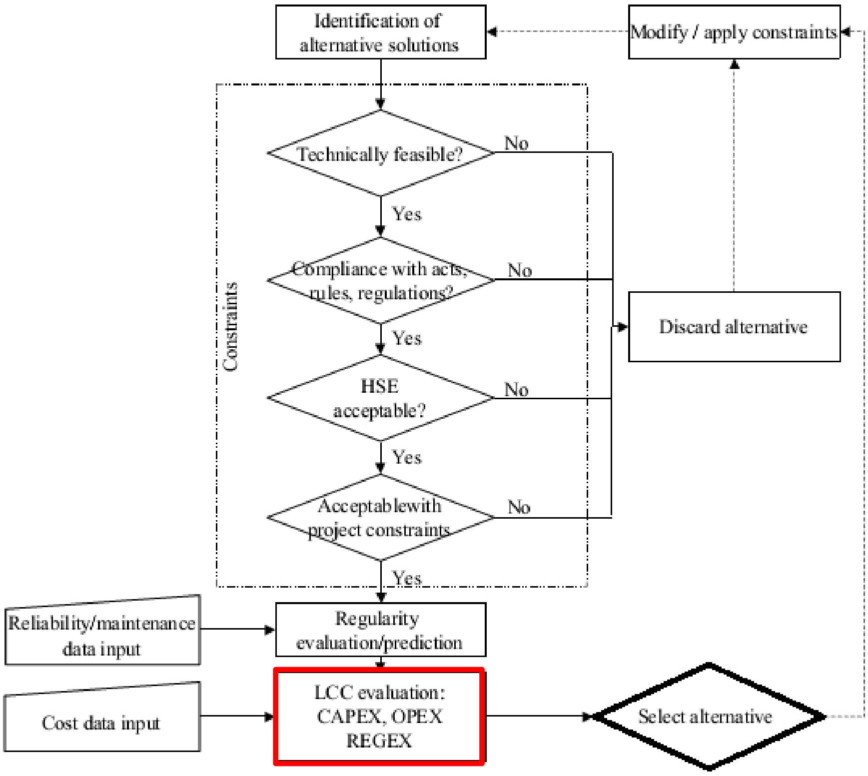


Figure 10: Optimization Process (NORSOK Z-016, 1998)

b. Bid Evaluation

This is to evaluate the alternatives proposed by various suppliers and to select the best proposal with consideration of the LCC but not only the procurement cost, as illustrated in Figure 11. This figure shows the typical example of variation between two proposals as different options and the trade-off to be considered. The option with cheaper initiation cost has higher operating & maintenance cost and disposal cost. LCC analysis can be applied to verify which option is the best economical solution.

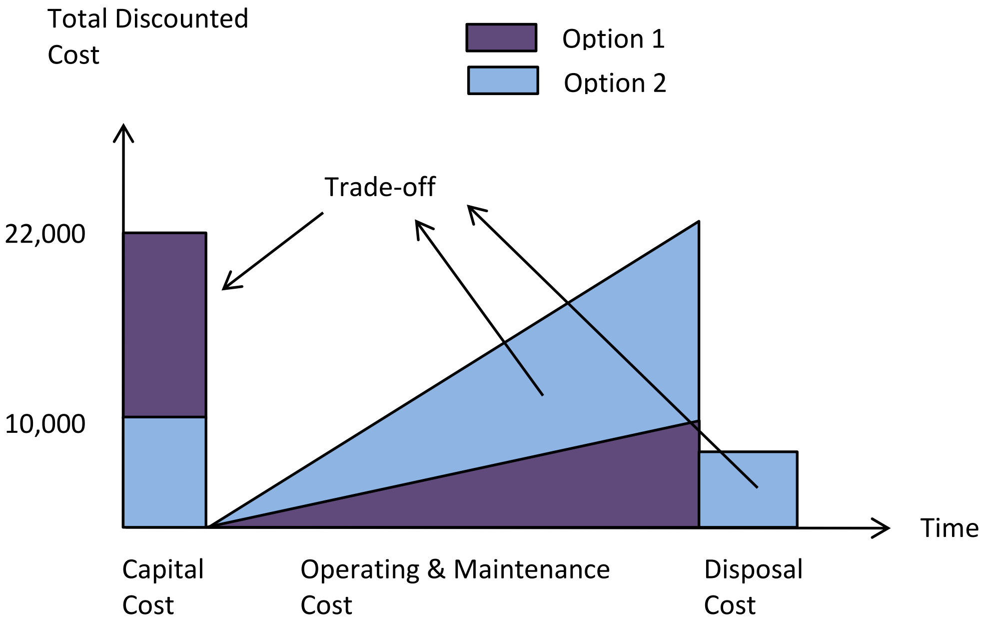


Figure 11: Trade-off for LCC (Lapašinskaitė & Boguslauskas, 2005)

Figure 12 shows the LCC evaluation process upon receiving different bid proposals from different suppliers.

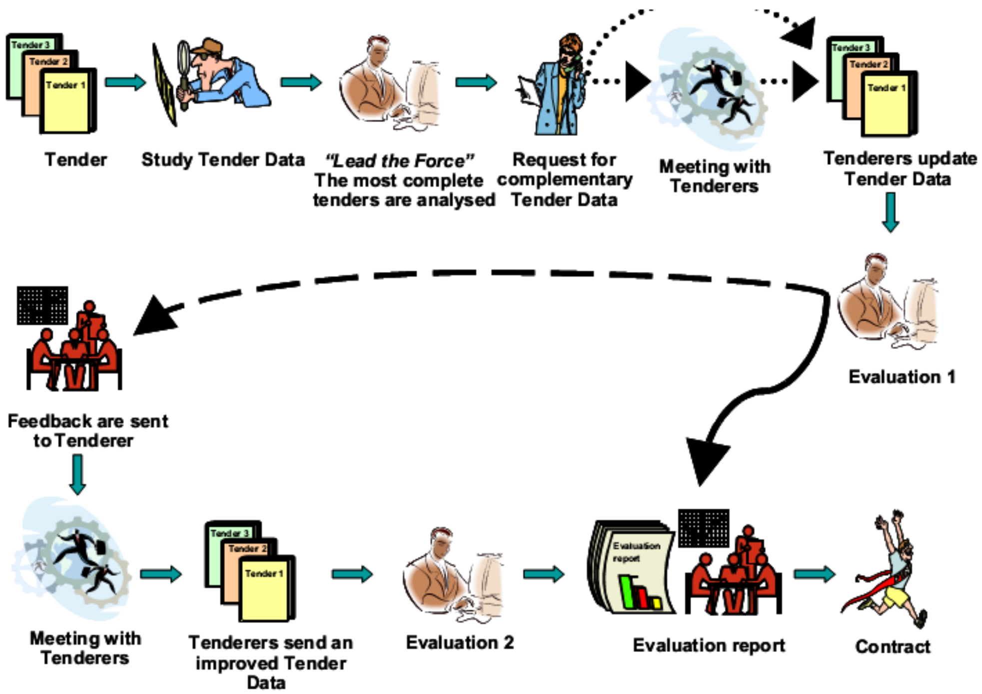


Figure 12: LCC and Bid Evaluation Process (RTO, 2007)

c. <u>Affordability studies</u>

It investigates and studies the impact of LCC for various alternatives of a system or project in a long term strategy and operating results.

d. Source selection studies

It presents and compares various LCC of products from various suppliers and their goods and services. The results allow the decision maker to select the suppliers in the most economical approach.

e. Design trade-offs

This enables the system designer to obtain the optimized design with best performance/effectiveness, time and LCC, as shown in Figure 7 shown earlier.

f. Evaluate repair or replacement selection for breakdown equipment

This provides a basis for comparing and evaluating the pros and cons to aids selecting the best options, i.e. to repair or to replace, for the old or breakdown equipment in existing facilities. The availability of spare parts and engineering documentation forms part of the evaluate criteria to access if repair of system is more cost effective.

g. Identification of forecast cost drivers and cost effectiveness improvement

This assists the project team to understand the cost drivers within the investment and achieves the most suitable manners in long term financial planning.

Various research studies had proven the above discussion (Fabrycky & Blanchard, 1991; Barringer & Weber, 1996; NORSOK O-CR-001, 1996; Kawauchi & Rausand, 1999).

Details of the process for performing LCC analysis are discussed in further section.

2.4 Life Cycle Costing Process

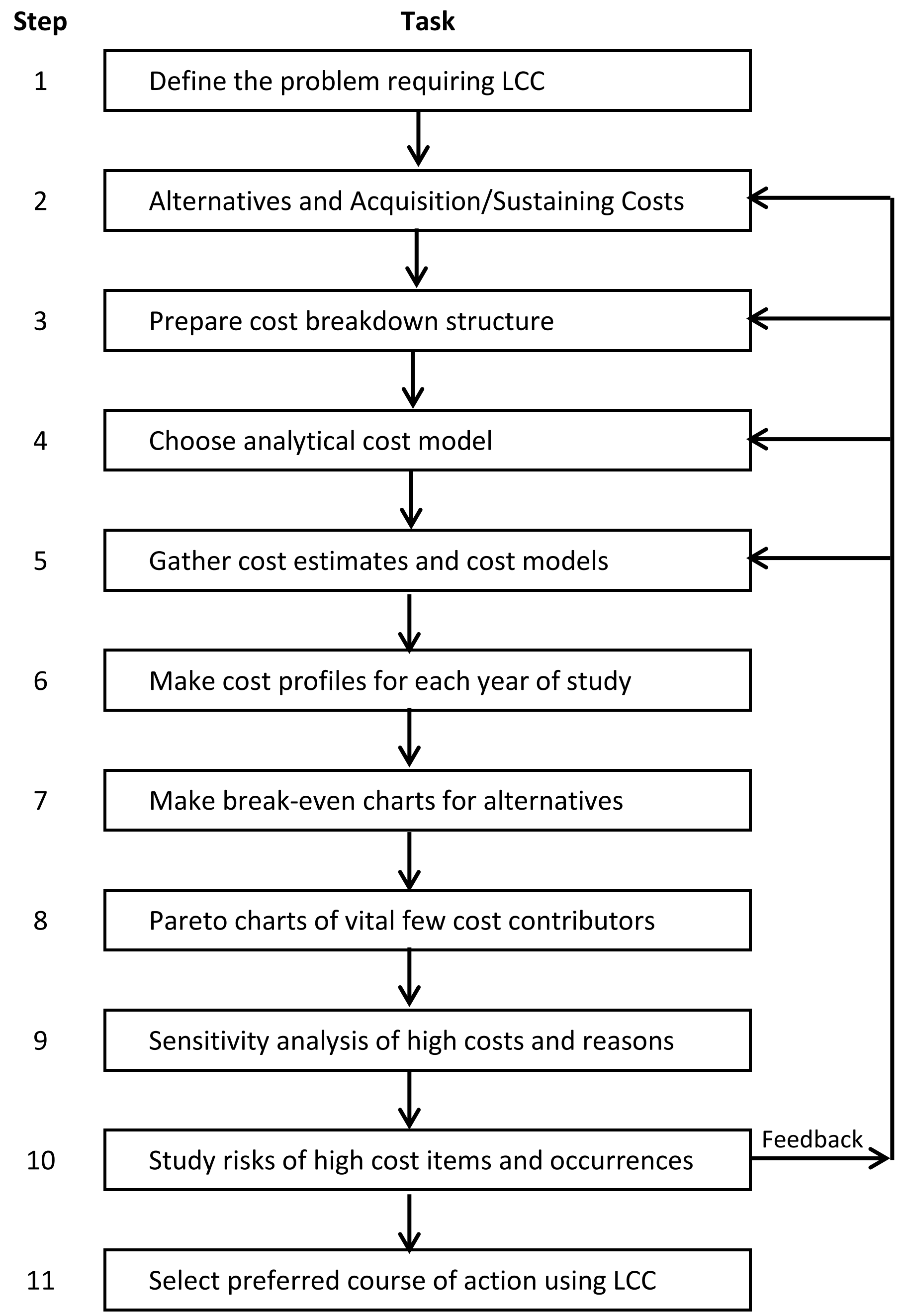


Figure 13: Process Flow for LCC Calculation (Barringer, 1998)

Various researches had presented many ways of conducting LCC analysis for different industry at different phases. Above figure presents the typical steps for the LCC process and commonly used in the oil and gas industry. However, these steps can be altered and iterated according to the objectives and resources available based on the actual situation at that stage.

With reference to Figure 13, the typical steps are further elaborated below (Barringer & Weber, 1996; ISO 15663-1, 2000):

Step 1: Define the problem requiring LCC

It is the very first step while performing LCC analysis, hence, it is crucial that the problem or business case is correctly defined. This step involves identification of the objective of LCC analysis and to define the time period for conducting the study. Problems and scenarios to be analyzed and important financial criteria are also identified in this step.

Step 2: Alternatives and acquisition/sustaining cost

It is the stage where the engineer team conducts study and brainstorms for the alternatives solution in technical aspects that fulfill the requirements.

Step 3: Prepare cost breakdown structure / tree

This step identifies the possible cost elements involved and develops cost breakdown structure for further evaluation. The critical cost drivers and solution selection criteria are also identified at this stage.

Before starting this process, the common cost for all alternatives should be identified. These are normally excluded in the consideration.

According to Ahmed (1995), a cost breakdown structure should fulfill below necessities:

- It should list down the major costs or activities which had been defined clearly to avoid misinterpretation of the costs.
- It should be designed with possibility to find out the impact of cost changes in such area by not influencing others
- For proper reporting and controlling purposes, it should be compatible with the requirements concerning data.

Step 4: Choose analytical cost model

Further from earlier step, an appropriate cost model should be chosen according to the project complexity and available resources.

Step 5: Gather cost estimates and cost models

It is the stage involves data acquisition and collection regarding operating and maintenance data and other associated cost. The outcome obtained from this step facilitates complete evaluation considering both the financial and technical aspects.

Step 6: Make cost profiles for each year of study

Based on the data and information collected from earlier steps, a cost profiles for each alternatives will be produced for each year of study throughout the defined life cycle.

Step 7: Make break-even charts for alternatives

Break even charts are prepared for critical issues and simplifies the details into time and money.

Step 8: Pareto charts of vital few cost contributors

Verify and identify the key cost contributors. These cost contributors are ranked accordingly for further investigation.

Step 9: Sensitivity analysis of high costs and reasons

This step facilitates study and identification of how the cost contributors vary and affects the total cost. If a little change in the cost contributor results in huge change in the total ownership cost, it has to be taken note and focus to reduce the risk of over budgeting.

Step 10: Study risks of high cost items and occurrences

"A LCC analysis that does not include risk analysis is incomplete at best and can be incorrect and misleading at worst" (Craig, 1998). The uncertainty and risk associated with high cost items have to be identified and handled. The feedback should then be provided to the team. Monte Carlo Simulation is widely used for handling the uncertainties and provides more accurate analysis.

Step 11: Select preferred course of action using LCC

It is the final step for LCC analysis that the most suitable alternatives are chosen. The complete cycles allows the engineering team to present facts and figures obtained from the LCC for better visualization and consideration by the management team.

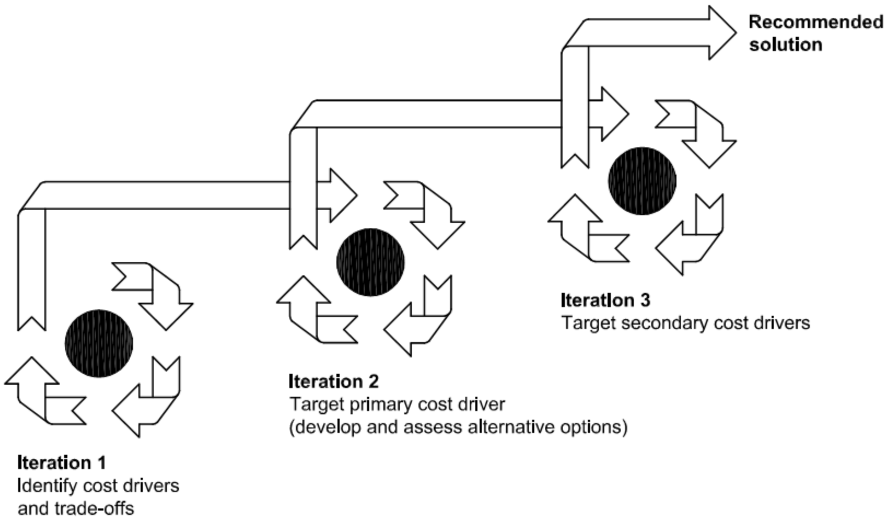


Figure 14: The iterative process of LCC analysis (ISO 15663-1, 2000)

Early introduction in the feasibility study phases has higher degree of influence power to the design of the system and minimize the risk of having high operating and maintenance cost in later stage of the development. The outcome from the LCC analysis in earlier phase can also be used as the basis for LCC analysis for next phase. Figure 14 illustrates the typical iterative process of LCC analysis.

2.5 Cost Breakdown Structure & Cost Drivers for the Project

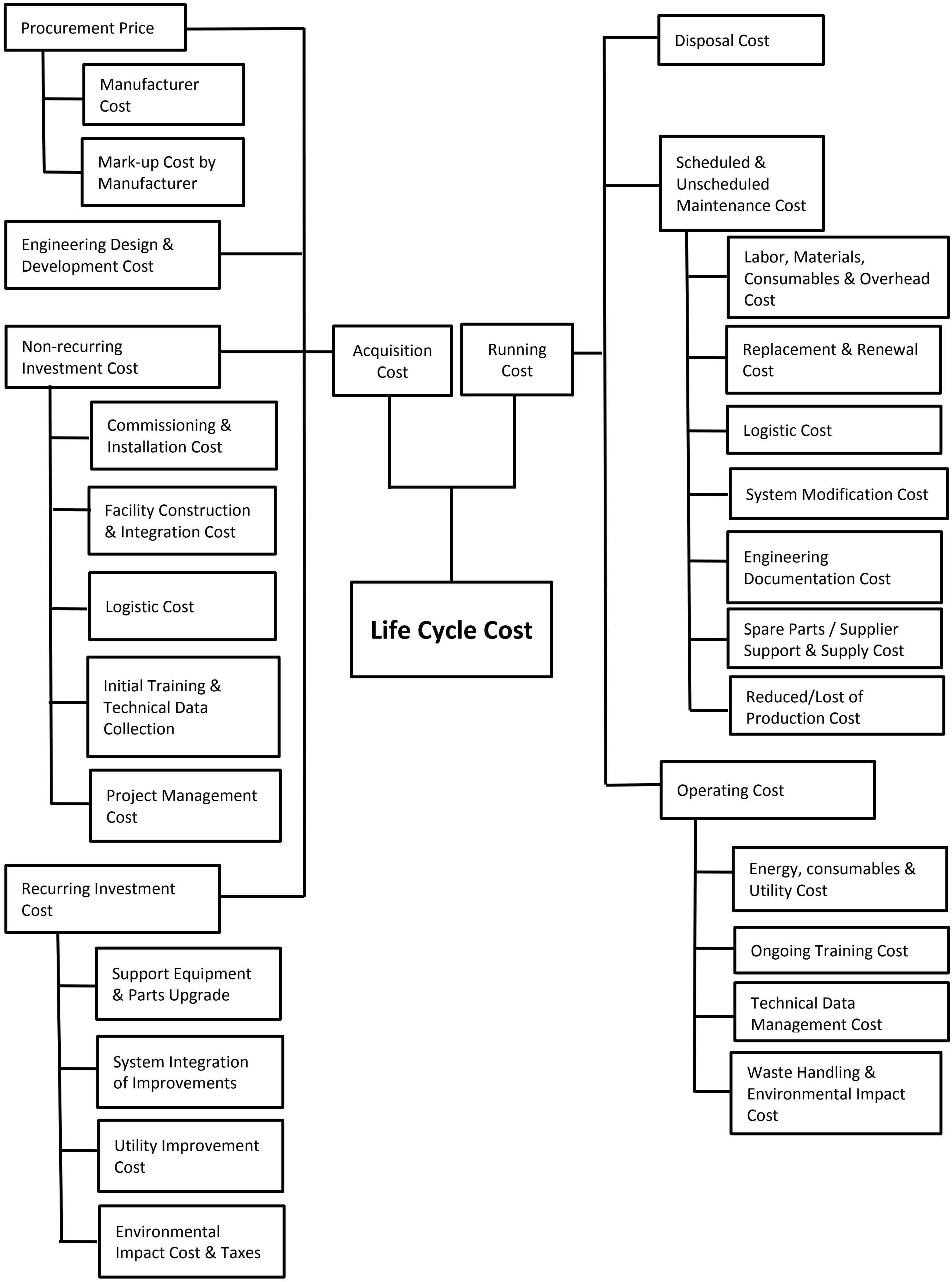


Figure 15: Cost Break-Down Structure of LCC Tree (Adapted from Barringer & Weber, 1996)

The cost breakdown structure tree as illustrated above is often used as the basis for obtaining and comparing the LCC of various alternatives as it links the objectives and activities with their associated costs and resources.

Once the cost components had been identified and the structure tree had been developed, a better visibility of cost contributing elements are provided. It is relatively important that the most critical cost drivers for the project or investment are identified at this stage in order to perform LCC analysis more accurately.

It can be noted that below cost components are commonly identified as the major cost drivers for a project:

- Operation cost

  It typically involves operational administrative expenses, functional operating expenses and consumable cost (Dhillon, 2006).

- Maintenance cost

  It includes cost of repairs and spare parts, cost of maintenance facilities, cost of labor, cost of consumables, cost of personnel replacement and cost of equipment downtime (Dhillon, 2006). These are the costs to maintain the operability and performance of the system.

- Utility cost

  It normally involves the cost of power and other utilities.

The above findings will be further elaborated and discussed in the following sections.

2.6 Limitation of Life Cycle Costing

According to Barringer & Weber (1996), below examples are identified as the common limitation of LCC analysis:

a. The application of LCC and its method is subjective based on individual perceptions, knowledge and experience. There is no absolutely right or wrong conclusion derived from LCC analysis.

b. LCC requires large amount of data input from various areas to achieve maximum accuracy. However, it is practically challenging, i.e. expensive and difficult, to obtain the required information from the database and operating condition as input to the calculation.

c. Limited time and resources are the common problem faced while acquiring information and performing LCC analysis. During the project execution, the evaluation process is always being shortened and sped up due to the short time limit allocated for the team.

It is important to fully understand the limitations of LCC analysis and necessarily consider appropriate assumptions for best results. Kayrbekova (2011) also acknowledged the above limitation. According to Kayrbekova (2011), simplified LCC analysis can be performed to compare the characteristics of the differences in various alternatives.

3. IMPLEMENTATION OF LCC ANALYSIS

The main objective of this thesis is to present a practical solution for implementing LCC approach and analysis in the early phase of modification project for operating, possibly in FEL 1 phase. The results of LCC analysis will form part of the concept study optimization report prepared by the study group in FEL phase and submitted to the project management team for decision making regarding suitable technical solution in their investment.

By implementing LCC analysis in the early phase of the study, it reduces the possibility of having enormous unexpected cost arisen from integration, operating and maintenance aspects. It has proven that the integration cost for the modification and operating & maintenance cost are sometimes being neglected. LCC analysis ensures including of key cost drivers in the cost estimation while selecting the alternatives

Due to the limited time allocated and availability of resources while carrying out the concept study, the process of LCC analysis discussed in Section 2 will be modified to a more practical approach. Below steps are proposed to be implemented as part of the concept study procedure or general guidelines:

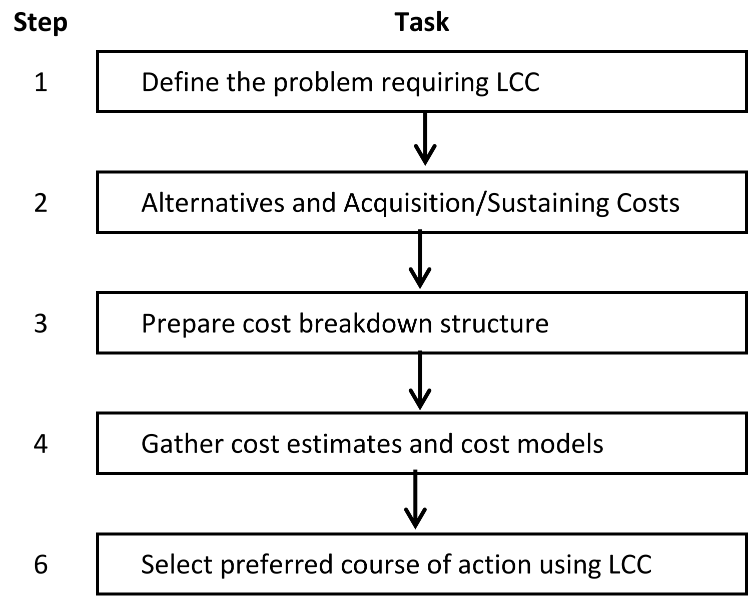


Figure 16: Proposed Steps of LCC Process for Modification Projects

It has been acknowledged that operating and maintenance costs are the main cost contributing elements in the system life cycle. According to Dhillon (2006), these costs are account for as much as 75% of the total project LCC and approximately 65% of the estimated life cycle costs are committed in the early phase of the project.

Nonetheless, it is very difficult and impossible to predict or estimate all the associated cost due to the uncertainties and indirect costs caused by possible changes in the execution phase. Hence, the LCC analysis in the early phase should practically consider only the critical and major cost drivers for the project where those costs can be predicted or estimated from the database, experience or supplier’s information (Fabrycky & Blanchard, 1991).

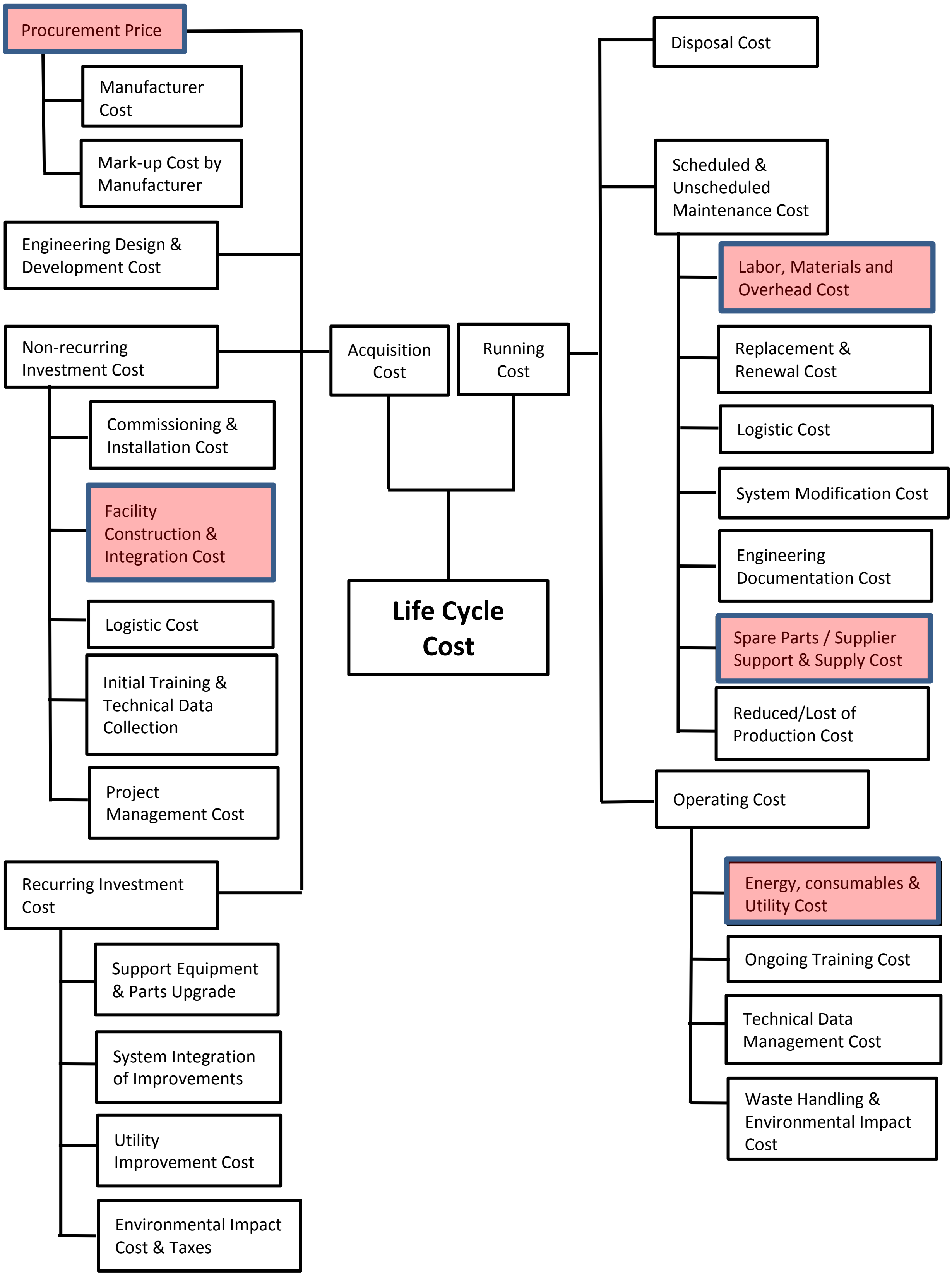


Figure 17: CBS Highlighting Possible Major Cost Drivers

With reference to Figure 17, it shows that the critical cost drivers for a project are:

- Procurement Price
- Facility Construction Cost
- Integration Cost
- Labor, Materials and Overhead Cost
- Energy, Consumables & Utility Cost
- Spare Parts / Supplier Support & Supply Cost

However, as mentioned earlier, there are certain challenges for getting the estimate of the above mentioned cost elements. Those are predicted mainly based on the preliminary information from the suppliers and sometimes not available.

The challenges presented in ISO 15663-3 (2001) while selecting technical solutions based on vendor's information are:

- Supplier collects performance data on equipment and its spares requirements in different manners
- The solution based on different equipment or techniques may have different forms of performance
- The performance data and failure predictions are normally based on small sample

As a result, it can be very much costly and time consuming for performing LCC analysis. Therefore, it is necessary to evaluate the need for LCC analysis against various projects before starting it. A coarse evaluation can be performed to decide if it is cost and time effective to carry out the LCC analysis for each project or system.

Various assumptions as mentioned below have to be made to simplify the problems:

1. As this is concerning modification performed in the existing facilities, the life cycle of the equipment/system is defined according to the remaining life of the platform in its life cycle.
2. Failure or additional maintenance cost due to human error is not considered.
3. The maintenance personnel are performing the task continuously.
4. The disposal costs for old facilities that to be replaced and new facilities are not being considered as it will be similar among the alternatives.
5. There is no intention to recycle/sell the existing facilities, hence, no salvage cost is being considered.

3.1 LCC Analysis for Technical Solution Selections

This section presents and describes the method of using LCC to select the best economical and technical acceptable solutions in the modification project. Detailed calculation method is presented in the next section as case study.

Step 1: Determine the need for LCC

As described in the earlier section, it is essential to determine the need for carrying LCC analysis at this very first step. It is a waste of resources if the project team has to perform such analysis for a minor modification project such as upgrading of slurry mud transfer pump.

Below criteria are deemed to be the most critical factors:

- Scale of the Project
- Continuous service time in operation, i.e. 100% running time
- Criticality of Equipment/System to be repaired or replaced and its Service
- Current Trend of Maintenance Cost & Rate of Degradation/Failure for Existing Facilities

Step 2: Define the problem requiring LCC

The objective of LCC analysis, life cycle period and project constraints must be first identified. In addition, the engineering facts and information had to be sorted and presented. Possible future problems/challenges, various scenarios and important financial criteria needs to be understood also in this step. It is also important to consider the remaining lifetime of the platform as this factor have certain influence while selecting the appropriate technical solution.

It is recommended to list out the critical and minimum technical requirements that must be fulfilled for the design of the system in terms of its function and operation. This assists the analyst and study group to understand the factors while performing LCC analysis.

Additionally, the system functional requirements, operational & maintenance philosophy and support philosophy need to be developed in this stage based on the available resources and information. The key factors that affect the overall project shall be understood (Kayrbekova, 2011).

It is always wise to ask the following questions before going into details for LCC analysis:

- Will the LCC analysis have any impact on the project? If yes, what are the impacts and what are the advantages?
- What costs are to be considered in LCC analysis?
- Do we have sufficient data to estimate LCC?
- What other possible costs are to be considered?
- What is the remaining lifetime of the platform where modification needs to be performed?

Step 3: Alternatives and acquisition/sustaining cost

A brainstorming session should be conducted to propose and present the possible alternatives solution. As a minimum, the proposed alternatives should fulfill the minimum technical requirements. The proposals of technical solutions are mainly based on personal knowledge & experience and limitation of the resources. Additional in this step, it is also necessary to identify the possible risks associated with each alternative. Risk reducing measures and its cost should be considered and implemented as far as possible.

At this stage, it is also possible to start requesting budgetary quotation for all alternatives in order to facilitate further investigation and discussion in future steps. Figure 18 below shows some examples of alternatives solutions.

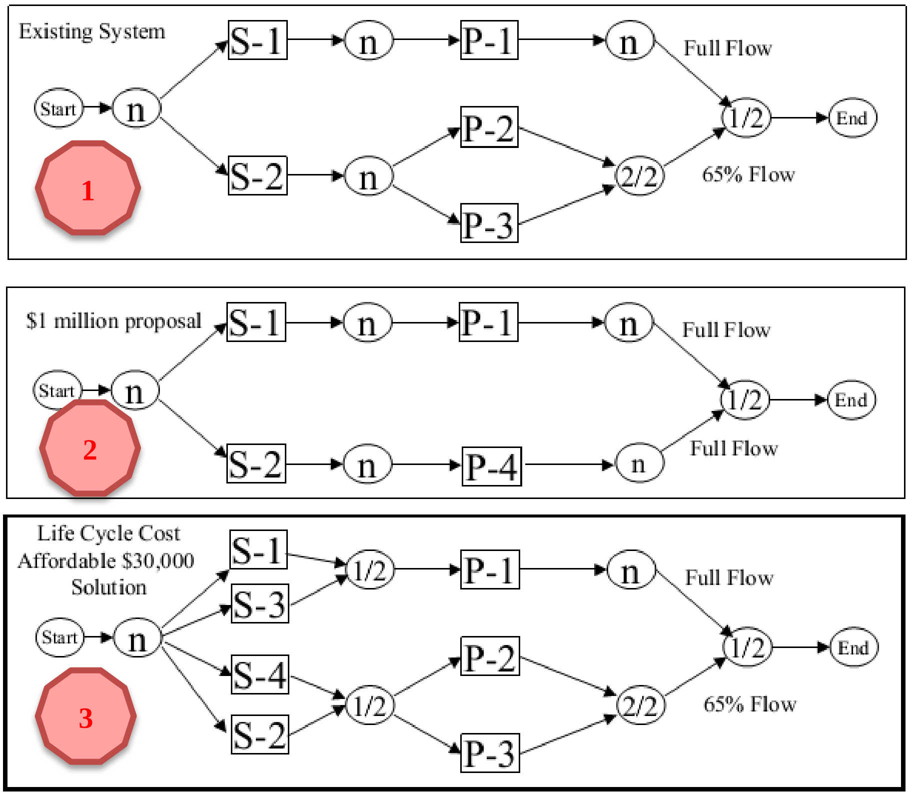


Figure 18: Example of Life Cycle Alternatives (Barringer, 2000)

Step 3: Prepare cost breakdown structure / tree

A simple version of cost breakdown structure is to be developed for each alternatives based on the critical cost driver presented in Section 3. Identification of possible cost drivers is helpful for handling the budget and estimate of the project cost in more efficient and effective way.

Step 4: Gather cost estimates and cost models

This is the most difficult and complicated step as all collected data and information have to be consolidated at this point. It could be tough to obtain some insight information about possible operating and maintenance cost at this moment. The information obtained from the supplier might not be true and it has to be considered with certain contingencies. One should always be reminded that uncertainties due to changes and unwanted events do exist.

Additionally, the common reasons that lead to inaccurate LCC analysis are: omission of data, use of incorrect or inconsistent data, misinterpretation of information/data and etc. (Kayrbekova, 2011).

It is common that the project management allocates project reserve and contingencies to compensate the possible losses due to inaccuracy of input data, project uncertainties and associated risks.

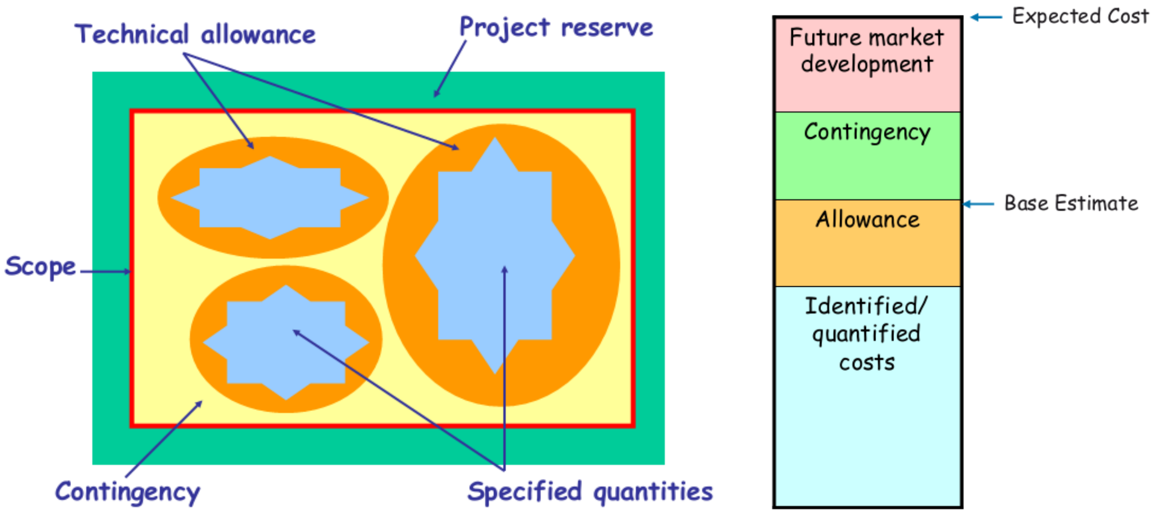


Figure 19: Project Reserves, Base Estimates and Expected Cost (Odland, 2011)

In order to compare the alternatives, the time value of money has to be considered as the costs have to be compared as the same basis. Therefore, all the future LCC related cost should be discounted to the present value (Barringer, 1998; Markeset & Kumar, 2000).

While gathering the cost estimates for each relevant cost elements, it is part of the standard procedures to contact various suppliers to obtain preliminary quotations with available information. The following questions are suggested to ask the suppliers:

- What is the energy consumption of the system? Are there any associated operating costs to be considered?
- What are the main activities involved regarding maintenance? What items or components need to be replaced and their estimated cost?
- What are the estimated hours and number of personnel needed for carrying out maintenance?
- What is the technical life-time for the system?

A summary of the LCC for each alternative shall be presented in this step by using the simplified version of LCC spreadsheet from Barringer (2000).

Step 5: Select preferred course of action using LCC

Based on the summary obtained from earlier step, it is normal to choose the alternatives with the lowest NPV of Life Cycle Cost. It always makes sense if the project decides to buy more equipment at higher acquisition price with better electrical power efficiency as it reduces the electrical power consumption and achieves huge saving in the cost.

Further elaboration will be presented with case study in the following section to provide a better visibility for estimation of LCC for different alternatives.

3.2 Case Study Example

This section provides the background information of the study and presents the findings from the case study. A practical calculation method is recommended for use to implement the LCC study in the early phase of modification project.

The numbers and figures used for calculation are based on the project experience but have been altered for the purpose to be used in this thesis only. Hence, it should be noted that these are not to be applied in actual projects.

3.2.1 Background

The operating company is performing a study for replacing the existing FWM in EKOK Platform in the Great Ekofisk Area. This platform is expected to continue its operation until year 2028. Hence, the life cycle of existing FWM should be extended to match the platform life cycle. This package had been operated well for 25 years and the quality of drinking water is still within the acceptable range. It is a package with high complexity and consists of substantial amount of pumps, heat exchangers, filters, separators, pipes and instrumentations.

Recently, it has been reported that there is an increase in the downtime and difficulty arisen while buying the obsolete spare parts for replacement/maintenance. Most of the parts are in titanium and this makes the sourcing of the spare parts even tougher in the next 15 years. In addition, due to the aging effect, it can be expected that the failure will continuously increase. As a result, preventive maintenance activities have to be scheduled in a shorter interval to prevent failure occurs as shown in Figure 20. It is also acknowledged by Lapašinskaitė & Boguslauskas (2005) that the longer exploitation period is, the higher the maintenance costs are. Therefore, the operating company decided to perform a study to evaluate two alternatives that replacing the existing package in order to "extend" its life cycle and to resolve the problems of getting necessary spare parts which will soon be obsolete.

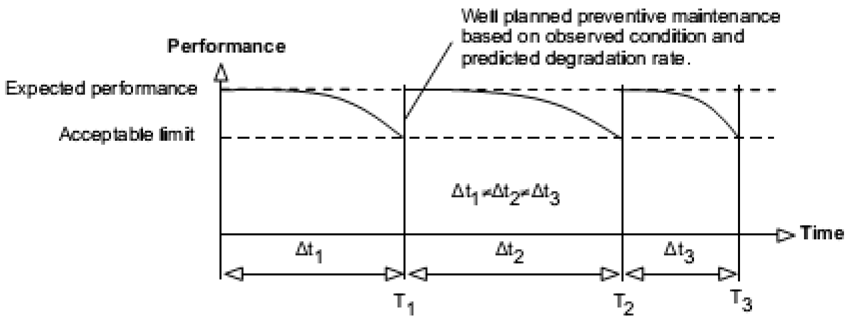


Figure 20: Predictive Maintenance based on Observed Performance Degradation (Kayrbekova, 2011)

The capacity of fresh water storage tank is currently sufficient to supply the drinking water for approximately 2 days in the case of failure occur. The supply boat will have to be used to transport the drinking water to the platform but the water may be contaminated by impurities in the tank or the pipes. In the event of severe weather conditions, the service of the supply boat will be interrupted and hence causing de-manning of the platform that results loss of production.

The technology used in the existing package is evaporation. Salts are separated from the sea water and be processed and filtered to be drinking water. For this technology, scale inhibitor injection and acid cleaning of the evaporator are needed to maintain the water quality and its performance. Additionally, there might be risk involved that this technology might become obsolete from the market in few years later.

In the current market, a new type of technology, Reverse Osmosis, has been widely used for similar functions and produces equivalent quality of fresh water. The sea water is forced through membrane typed filters in order to remove the salt contents. Due to less maintenance required, less moving parts and acid cleaning/scale inhibitor free, this new technology had gained their values in the offshore industry.

This section of the thesis presents a practical method for carrying out LCC analysis for the alternative technical solutions and the output will form the basis for solution selection. Some findings presented in project proposal report (Anonymous, 2013b) are taken as basis for the case study and the scope of case study is limited to the current findings from the FEL study.

Several meetings with the operating company and the contractor had been carried out to discuss the available information and expected results from the LCC analysis and to achieve the objective of performing LCC. Valuable information and study report was provided in order to perform the LCC calculation for comparing the two proposed alternatives. Additionally, the supplier of FWM with reverse osmosis technology was also being interviewed in order to identify the main differences and to obtain in-depth information regarding operation and maintenance approach for both alternatives. They have provided valuable information and advices regarding LCC and cost to be considered.

3.2.2 LCC Analysis

<u>Step 1: Determine the need for LCC</u>

As this is a complex package with substantial amount of equipment, the operating & maintenance cost have been identified as significant. In addition, the FWM is designed for continuous operation, i.e. 2 x 100%. As per Table 1 below presented in NORSOK Z-016 (1998), the LCC evaluation should be performed for systems critical to production, safety, environment or other operation. Hence, LCC analysis should be performed for this FWM Package at this phase.

Table 1: Overview of regularity activities in life cycle phases (NORSOK Z-016, 1998)

	Life cycle phase								
Activity	Feasibility study	Conceptual design	Engineering	Procurement	Fabrication/ construction	Commissioning	Preparation for operation	Operation	Modification
Regularity management	***	***	***	***	***	***	***	***	***
Regularity analyses	**	***	***	*	-	-	*	*	**
Reliability/availability/LCC evaluation of systems critical to production, safety, environment or other operations	**	**	***	*	*	-	**	*	**
Maintenance and operational planning	-	*	**	**	-	-	***	**	*
Design reviews	*	**	**	*	-	-	-	-	**
Reliability/qualification testing of selected items	-	*	*	*	*	*	*	-	-
Data collection and analysis	-	*	*	-	-	*	*	***	-

Step 2: Define the problem requiring LCC and propose alternatives solutions

A preliminary study and investigation had been carried to present the problem with the existing Fresh Water Package. The current objective of this study is to select most economical technical solution instead of select based on the acquisition cost only. It is the objective of the project that the package can be replaced in a swift and smooth way with minimum supply boat delivery during the change-over period.

It is part of the general procedure of the operating company to investigate and evaluate the various alternatives where functional specifications/requirements, problems, estimates of engineering and installation cost, disposal cost of existing cost and etc. are identified. However, this study normally excludes LCC analysis considering the operation and maintenance aspects. Hence, the section of the thesis extends the study scope to include such evaluation and the output of this analysis will be included as part of the estimate.

In this case study, there are two proposed technical solutions:

i. Evaporation technology

   Using the same technology as the current facilities, hence, there will be minimum impact on operational philosophy. However, this technology requires a lot of heating and consumes considerable amount of energy and the energy cost involved is significant. Additionally, the chemical cleaning of evaporator has to be carried out as regular maintenance activities. Chemical consumption, chemical handling, maintenance labor cost are considerable.

   TECHNICAL LIFE CYCLE = 25 Years

ii. Reversed Osmosis technology

   This is a new technology evolved after the installation of current facilities with less chemical handling during operation. Acid cleaning and scale inhibitors dosing can be eliminated. However, there is a need for changing the membrane with an interval of 18-24 months interval but the energy consumption is much lower as compared to the existing configuration. Other than the regular maintenance of mechanical equipment, the package will be functioning as new after each changeover of the membranes and filter cartridges. Hence, less maintenance activities will be involved but more spares to be procured.

   TECHNICAL LIFE CYCLE = 25 Years

Below table shows the major differences identified for both alternatives and cost to be considered as part of LCC:

Table 2: Comparison between Evaporation and Reverse Osmosis Technology

	Evaporation	**Reverse Osmosis**
Main Component	Evaporator (Plate Heat Exchanger)	Membranes
Energy Consumption	Considerable, directly proportional to volume of fresh water produced as heating is required to remove salt contents in seawater	Normal energy consumption for moving parts
Key Maintenance activities	• Requires scale inhibitor to prevent deposition of salt • Requires acid cleaning for the washing shell & plate heat exchanger	• Replacement of Membranes every alternate years
Maintenance Costs (Excludes mechanical maintenance)	• Chemical handling cost • Chemical cost for cleaning in place • Yearly chemical cleaning labor cost • Filter cartridges replacement cost	• Membrane replacement cost • Filter cartridges replacement cost
Integration Cost	Minimum, no much changes involved in other system	Considerable amount, various changes need to be done in other systems and control philosophy

a. Impacts and Advantages of LCC Analysis

LCC analysis will have certain impact on the project. As the replacement of the FWM Package might be involved new technology where the integration cost might be dominant as compared to the existing technology. By performing LCC, it helps the study team to ensure the most critical factors and cost drivers have been taken into calculation to minimize the significant cost impacts in later phase of the project.

b. Availability of Cost Information and Estimation

As highlighted in Section 3, in order to conduct LCC analysis effectively and efficiently, it is important to consider the availability of getting the information for estimating the cost. In such early phase of the study, it should be acknowledge that suppliers will not put in too much effort to provide operation and maintenance related cost to the company. Hence, it is recommended to include below costs for the analysis:

- Procurement Price

  This cost can be estimated by requesting budgetary quotation from suppliers based on the minimum technical requirements, operating conditions and basic scope of supply for the package. The estimated delivery time of the package may also be taken into consideration as there is allowable time frame for installation due to weather conditions in North Sea.

- Facility Construction Cost

  This cost is normally estimated by all disciplines involved in the project and estimation team. A summary of estimated cost are obtained by combining the estimated man hours needed to perform their work for engineering design in each disciplines, estimated material take-off for the construction and the estimated man hour for the construction.

- Integration Cost

  This cost is relevant to the integration cost with the existing platform design and software used. If the modification project involves only replacement of the package with an identical skid (i.e. “Plug and Play”), there will be zero or minimum integration cost concerning modification of the existing system such as safety system, control system and etc. However, if the modification involves new technology, there will be impacts or changes on not only the existing operation philosophy or other systems but also the documentations and software needs to be updated. Figure 21 shows the better illustration of the major integration cost involved with respect to this case study:

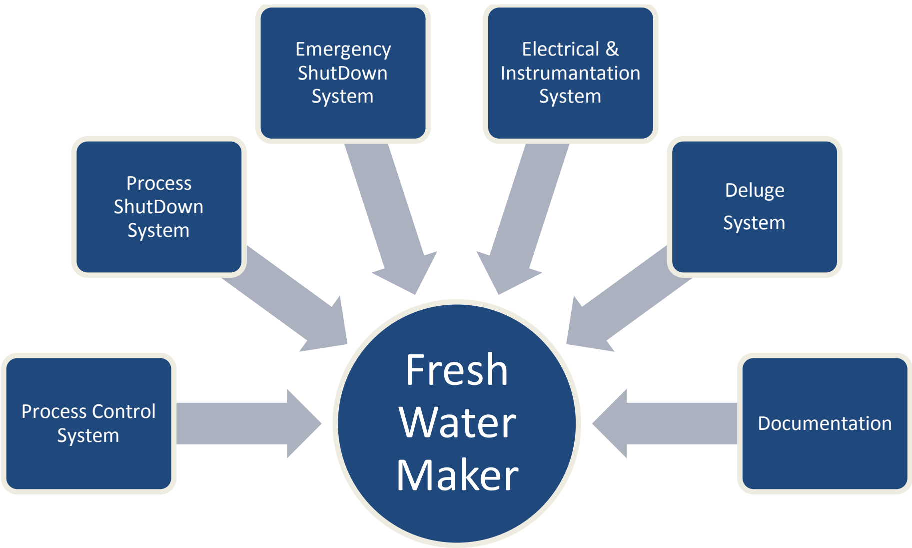


Figure 21: Major Integration Cost Components related to Fresh Water Maker

- Labor, Materials and Spare Parts Cost

  This cost may be estimated from the information obtained from the suppliers. It is possible to obtain the typical recommendation from supplier regarding the estimated man hours required to perform each maintenance, recommended spare parts required and maintenance interval required. However, it should be noted that the information might be typical for general products supplied by vendor and contingencies should be included for estimation purposes.

- Energy, consumables & Utility Cost

  These costs can be estimated from the power requirements for the package and the required consumables for the alternatives. However, the utility cost might end up being similar among alternatives and thus, it can be neglected.

Step 3: Prepare cost breakdown structure tree

According to ISO 15663-2 (2001), the function of the system and the interrelations with other system should also be evaluated in order to find out the relevant cost elements. The following items may be considered for evaluation:

- Output requirements
- Power requirements
- Requirement of utilities/support systems
- Downstream effect of efficiency, resistance and etc.
- Regularity requirements for the system
- Maintenance concept/workload
- Consequences of failure

However, this section covers only the key cost contributors due to limited available for the FEL study. It is assumed that the engineering cost, disposal cost, commissioning & decommissioning cost and etc. will be similar for both alternatives, hence, these cost are not being considered. The training cost for new operational philosophy is considered negligible.

As presented in Section 3, below figure is modified to illustrate the cost breakdown structure tree with key cost contributors to be considered in this analysis. Theoretically, the integration cost falls under acquisition. In order to ensure such cost had been considered, it is highlighted as a main category as shown in the figure.

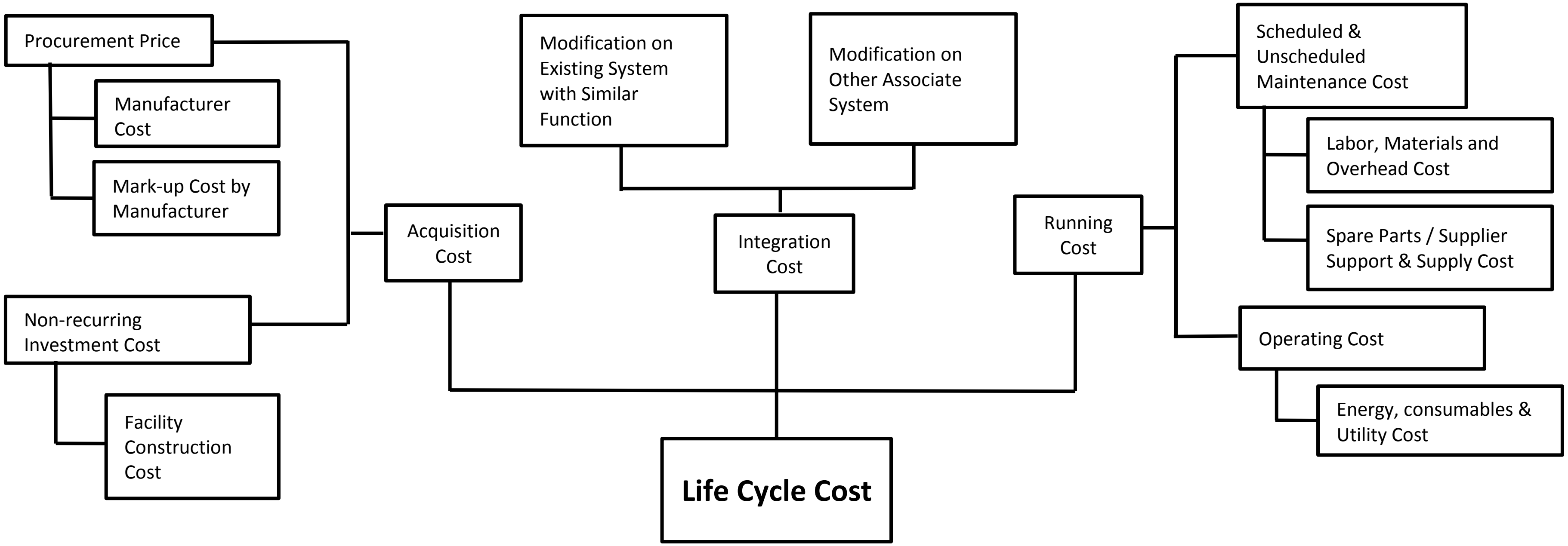


Figure 22: Key Cost Contributors for Life Cycle Cost in Case Study

Figure 22 above is proposed based on the cost components that had been identified in the check-list shown in Table 3 with high level of impact to LCC. The level of impacts are determined based on the past experience and previous estimation done for earlier projects which are similar and compared within each functional level.

Table 3: Check List of LCC Parameters with Level of Impacts (Adapted from Thabit, 1984)

LCC Parameters			Predicted Level of Impact on LCC Comparison Cost		
		Cost Components			
	Cost Elements				
Functional Level			High	Moderate	Low
CAPITAL					
	Equipment Procurement				
		Main Units	√		
	Installation & Integration				
		Foundations		√	
		Changes in Other Systems	√		
	Commissioning				
		Local Resources			√
		Contractors		√	
		Material			√
	Supporting Services				
		Initial Spares	√		
		Documentation			√
		Training		√	
		Maintenance Facilities		√	
		Spare Units or Assembles		√	
	Logistics				
		Supply Boats & Vessel	√		
OPERATION					
	Personnel				
		Operators			√
		Supervisors			√
	Materials				
		Oil & Greases		√	
	Energy				
		Main Supply: Gas or Electricity	√		
		Utilities: Air, Water, Lighting		√	

LCC Parameters			Predicted Level of Impact on LCC Comparison Cost		
		Cost Components			
	Cost Elements				
Functional Level			High	Moderate	Low
OPERATION					
	Services				
		Equipment Statuary Inspections		√	
		Training			√
		Manuals			√
		Safety and Fire Fighting Equipment		√	
MAINTENANCE					
	Personnel				
		Routine Work		√	
		Preventive Maintenance & Inspection	√		
		Corrective Maintenance & Overhaul	√		
	Materials				
		Spare Parts	√		
		Consumable Materials		√	
		Special Tools			√
	Services				
		Workshop Charges		√	
		Training			√
		Test Equipment and Documentation		√	
		Modification			√
DISPOSAL					
	Decommissioning				
		Contractors		√	
	Logistics				
		Supply Boats & Vessel		√	

Step 4: Gather cost estimates

Some of the cost as shown in Step 3 can be directly estimated such as procurement price and spare parts cost.

During the FEL phase, it is common that the equipment supplies are engaged to aid performing the study and provide budgetary quotations based on the preliminary technical requisition stating the key design and operation requirements. The typical recommended spare part cost, the expected maintenance interval and power & utilities consumption are normally requested from suppliers during the enquiry stage. However, some suppliers reserve their right to disclose such information and it can be challenging to estimate the operation and maintenance cost. If such information is available, simplified calculation can be performed to estimate the maintenance cost.

Additionally, the equipment installation and integration cost may contribute significantly to the overall project cost. This depends on the size and complexity of the equipment that might affect planning and carrying out offshore activities due to weather condition and handling capacity of the crane and etc. Hence, the weight and the size of the equipment often play an important role in the evaluation stage. In most of the modification project, it is encouraged to maintain the same or similar operational philosophy to minimize the impact to the existing facilities.

In this particular case study, the impact of the existing control philosophy and additional facility integration cost should definitely be considered while implementing the new technology of Reverse Osmosis.

Below is the summary of collected and estimated cost information based on single supplier information and history form the database:

- Procurement Price

The procurement price typically includes engineering services, component cost, production cost, assembly cost, testing and inspection, software & programming cost, documentation, preservation cost and delivery for the package procured from the supplier. The supplier is responsible for providing equipment/system that fulfills all specified requirement and conditions during its operation.

A rough estimation for the two alternatives is shown below:

Evaporation - NOK 45,000,000

Reverse Osmosis - NOK 45,000,000

- Facility Construction Cost & Integration Cost

The choice of the alternatives will have significant impact on this cost as described in earlier section. During the FEL study, it is generally taken by all relevant disciplines while estimating their scope of work and required hours for such modification. The changes in different aspects required by each alternative will be studied and considered in the cost estimation. Hence, it is difficult to provide a separate cost for such cost. However, this cost will be included in the checklist as shown in Section 7.1 while performing LCC analysis which serves as a general guideline to ensure inclusion of necessary cost components.

- Labor, Materials and Spare Parts Cost

These costs for the 1st year are estimated based on supplier information as detailed below:

Evaporation

Scheduled Preventive Maintenance	
Labor Cost	
No. of Maintenance Personnel	2
No. of Hours Required	30
Hourly Rate, NOK	900
Total Labor Cost, NOK	**54,000**

Recommended Spare Parts Cost	
Filter, NOK each	5,000
Number of Filter Required	3
Total Parts Cost, NOK	**15,000**

Reverse Osmosis

Scheduled Preventive Maintenance	
Labor Cost	
No. of Maintenance Personnel	2
No. of Hours Required	25
Hourly Rate, NOK	900
Total Labor Cost, NOK	**45,000**
Recommended Spare Parts Cost	
Filter, NOK each	5,000
No. of Filter Required	8
Membrane, NOK each	10,000
No. of Membrane Required	12
Total Parts Cost, NOK	**160,000**

- Energy & Consumables Cost

In this case study, only the energy cost and consumables cost might have considerable impacts to the LCC cost. This is because the energy consumption and chemical consumables varies significantly in both alternatives. Other costs such as utility and lubrication cost are considered similar for both alternatives, hence, not being evaluated.

Examples for calculation for the 1st year are shown below:

Evaporation

Energy Cost	
Energy Consumption, kWh	220
Electricity Cost, NOK / (yr-kWh)	1,000
Total Energy Cost, NOK per year	**220,000**

Consumable Cost	
Chemical - Scale Inhibitor, each time	10,000
Chemical - Acid Cleaning, each time	10,000
Total Chemical Cost, NOK per year	**20,000**

Reverse Osmosis

Energy Cost	
Energy Consumption, kWh	55
Electricity Cost, NOK / (yr-kWh)	1,000
Total Energy Cost, NOK per year	**55,000**

The detailed calculation is presented in the following Section.

Step 5: Select preferred course of action using LCC

The selection of the preferred alternatives is done based on the combined evaluation of the LCC and the effectiveness of the system. In practical, not only practical issues & its constraints but also the advantages & disadvantages for both alternatives have to be taken into consideration before making the final decision.

The main responsibility of FEL group in both the operating company and their contractor is to perform the investigation on the feasibility on proposed solution and furnish preliminary cost estimation for the alternatives. The result of the study will be presented as a report to the project management with summary of the conclusions and facts that had been identified during the study.

The project management will make decision to go for the best economical solutions with consideration of factors in all aspects.

Details of the conclusion for this case study are presented in Section 4 with more explanation and discussion.

3.2.3 Calculations

In order to consider time value of money, below equation is used to discount the future cost to Present Value, PV:

$$PV = F\left[\frac{1}{(1+i)^n}\right]$$

where F = Future Cost at the end of n^{th} year,

i = Discount Rate = 7%

n = number of years = 13 years

Information used in the calculation are obtained from the proposal report (Anonymous, 2013b), based on preliminary supplier information and data history in the database of current system. Due to the limited time and capacity, this LCC evaluation between two alternatives are consolidated using the data obtained from current FWM (Evaporation Technology) and the similar package (Reverse Osmosis Technology) that had been delivered to Statoil.

The calculation is performed based on the following assumptions:

Description	Assumptions	Remarks
Investment Year	Year 2014	Execution phase
Start of Operating	Year 2015	End of Year 2015
Expected End of Platform Lifetime	Year 2028	
Life Cycle Time of FWM	13 years	
Discount Rate, yearly	7%	
Tax Provision	38%	
Inflation Rate, yearly	5%	
Technical Lifetime of FWM with Evaporation Technology	25	Increase maintenance hours and cost to maintain package performance due to degradation
Technical Lifetime of FWM with Reverse Osmosis Technology	25	

In addition to above cost assumptions, below are the assumptions made for both alternatives of proposed solution:

Assumptions (Both Alternatives)	
1	For comparison purposes, the initial procurement prices for both alternatives are assumed to be the same.
2	Energy consumption increases by 8% per year after 8th Year
3	No. of Maintenance Personnel increases by 1 person after 10th Year
4	The electricity cost is assumed to be NOK 1000 per year per kWh
5	The estimated costs are based on the preliminary information available and are used for carrying out LCC analysis in this case study only.
6	Straight-line depreciation is considered over the period of 13 years

Evaporation		Reverse Osmosis	
1	Preventive maintenance activities includes acid cleaning for FWM	1	More maintenance hours are required if change of membrane is required
2	Chemical price and consumption are assumed.	2	It is assumed that change interval for membrane is 24 months

It shall also be noted that the budgetary proposal of FWM with Evaporation technology was not requested. Due to the fact that the incurred integration cost and bulk material costs for using the same technology are lesser, it is assumed that the total project cost (excluding equipment procurement cost) is reduced by approximately 30%. The reduction of such costs is due to less modifications need to be carried out in other systems.

The consolidated and summary tables shown in this section are proposed to be used as general and practical guidelines in the early phase of modification for the operating company and these are adapted from various LCC analysis examples in earlier researches in order to be applied practically and effectively considering availability of information and time frame (Fabrycky & Blanchard, 1991; Barringer & Weber, 1996; NORSOK O-CR-002, 1996)

Table 4: Estimated LCC Summary - Alternative 1: Evaporation

Life Cycle Cost Worksheet							
Discount Rate (%) -->	7%	*Project Life ->*	13	*Tax Provision (%) -->*	38%		
- 80,180,577	<--NPV (in NOK)						
Acquisition Costs:	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Procurement - Equipment	45,000,000						
Procurement – Bulk Materials	5,500,000						
Total Project Cost (Excludes Equipment Acquisition Costs)	52,500,000						
Total Acquisition Costs, NOK	**103,000,000**						

Running Costs:	**1**	**2**	**3**	**4**	**5**	**6**
Energy Consumption Cost	220,000	231,000	242,550	254,678	267,411	280,782
Preventive Maintenance Cost	40,000	42,000	44,100	46,305	48,620	51,051
Labor Man Hour Cost	54,000	56,700	59,535	62,512	65,637	72,365
Total Running Costs, NOK	314,000	329,700	346,185	363,494	381,669	404,198

Year	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Running Costs:							
Energy Consumption Cost	294,821	325,040	358,357	395,088	435,585	480,232	529,456
Preventive Maintenance Cost	53,604	56,284	59,098	62,053	65,156	68,414	71,834
Labor Man Hour Cost	79,783	87,960	96,976	106,916	176,813	194,936	214,917
Total Running Costs, NOK	428,207	469,285	514,431	564,058	677,554	743,582	816,208

Table 5: NPV Calculation for Alternative 1 - Evaporation

NPV Calculations:	0	1	2	3	4	5	6
Total Acquisition Cost	103,000,000						
Total Running Costs		14,000	329,700	346,185	363,494	381,669	404,198
Straight-line Depreciation		7,923,077	7,923,077	7,923,077	7,923,077	7,923,077	7,923,077
Profit Before Taxes		-8,237,077	-8,252,777	-8,269,262	-8,286,571	-8,304,746	-8,327,275
Tax Provision @ 38% Of Profit Before Tax		3,130,089	3,136,055	3,142,320	3,148,897	3,155,803	3,164,365
Net Income (Profit before Tax + Tax Provision)		-5,106,988	-5,116,722	-5,126,942	-5,137,674	-5,148,942	-5,162,911
Cash Flow (Net Income + Depreciation)	-103,000,000	2,816,089	2,806,355	2,796,135	2,785,403	2,774,134	2,760,166
Discount Factors @ i = 7%, $\frac{1}{(1+i)^n}$	1.0000	0.9346	0.8734	0.8163	0.7629	0.7130	0.6663
Present Value, NOK	**-103,000,000**	**2,631,859**	**2,451,179**	**2,282,479**	**2,124,970**	**1,977,920**	**1,839,215**

NPV Calculations:	7	8	9	10	11	12	13
Total Running Costs	428,207	469,285	514,431	564,058	677,554	743,582	816,208
Straight-line Depreciation	7,923,077	7,923,077	7,923,077	7,923,077	7,923,077	7,923,077	7,923,077
Profit Before Taxes	-8,351,284	-8,392,361	-8,437,508	-8,487,135	-8,600,631	-8,666,659	-8,739,285
Tax Provision @ 38% Of Profit Before Tax	3,173,488	3,189,097	3,206,253	3,225,111	3,268,240	3,293,330	3,320,928
Net Income (Profit before Tax + Tax Provision)	-5,177,796	-5,203,264	-5,231,255	-5,262,024	-5,332,391	-5,373,329	-5,418,356
Cash Flow (Net Income + Depreciation)	2,745,281	2,719,813	2,691,822	2,661,053	2,590,686	2,549,748	2,504,721
Discount Factors @ i = 7%, $\frac{1}{(1+i)^n}$	0.6227	0.5820	0.5439	0.5083	0.4751	0.4440	0.4150
Present Value, NOK	**1,709,623**	**1,582,956**	**1,464,173**	**1,352,745**	**1,230,816**	**1,132,119**	**1,039,370**

*NPV = Sum of Present Values from year 0 to 13.

Table 6: Estimated Cost Breakdown for Each Cost Element – Alternatives 1

	Alternative 1 (Evaporation)												
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Material & Spare Parts Cost for Maintenance													
Filter	15,000	15,750	16,538	17,364	18,233	19,144	20,101	21,107	22,162	23,270	24,433	25,655	26,938
Chemical	20,000	21,000	22,050	23,153	24,310	25,526	26,802	28,142	29,549	31,027	32,578	34,207	35,917
Other Spares	5,000	5,250	5,513	5,788	6,078	6,381	6,700	7,036	7,387	7,757	8,144	8,552	8,979
Total Material Cost per yr, NOK	40,000	42,000	44,100	46,305	48,620	51,051	53,604	56,284	59,098	62,053	65,156	68,414	71,834

Energy Cost													
Power Consumption, kWh	220	220	220	220	220	220	220	231	243	255	267	281	295
Electricity Cost, NOK / (yr-kWh)	1,000	1,050	1,103	1,158	1,216	1,276	1,340	1,407	1,477	1,551	1,629	1,710	1,796
Total Electrical Cost per yr, NOK	220,000	231,000	242,550	254,678	267,411	280,782	294,821	325,040	358,357	395,088	435,585	480,232	529,456

Preventive Maintenance Labor Cost													
No. of Maintenance Personnel	2	2	2	2	2	2	2	2	2	2	3	3	3
No. of Hours Required, per person	30	30	30	30	30	32	33	35	36	38	40	42	44
Offshore Hourly Rate, NOK / hr	900	945	992	1,042	1,094	1,149	1,206	1,266	1,330	1,396	1,466	1,539	1,616
Total Labor Cost per yr, NOK	54,000	56,700	59,535	62,512	65,637	72,365	79,783	87,960	96,976	106,916	176,813	194,936	214,917

Table 7: Estimated LCC Summary - Alternative 2: Reverse Osmosis

Life Cycle Cost Worksheet							
Discount Rate (%) -->	7%	*Project Life)-->*	13	*Tax Provision (%) -->*	38%		
-98,263,399	<--NPV (in NOK)						
Acquisition Costs:	0	1	2	3	4	5	6
Procurement - Equipment	45,000,000						
Procurement – Bulk Materials	7,500,000						
Total Project Cost (Excludes Equipment Acquisition Costs)	76,000,000						
Total Acquisition Costs, NOK	**128,500,000**						

Running Costs:						
Energy Consumption Cost	55,000	57,750	60,638	63,669	66,853	70,195
Preventive Maintenance Cost	40,000	54,000	44,100	58,905	48,620	64,281
Labor Man Hour Cost	45,000	66,150	49,613	72,930	54,698	81,210
Total Running Costs, NOK	**140,000**	**177,900**	**154,350**	**195,505**	**170,171**	**215,687**

Year	7	8	9	10	11	12	13
Running Costs:							
Energy Consumption Cost	73,705	81,260	89,589	98,772	108,896	120,058	132,364
Preventive Maintenance Cost	53,604	70,176	59,098	76,639	65,156	83,729	71,834
Labor Man Hour Cost	66,335	98,487	80,447	119,440	146,344	217,277	177,479
Total Running Costs, NOK	**193,644**	**249,923**	**229,135**	**294,852**	**320,396**	**421,064**	**381,677**

Table 8: NPV Calculation for Alternative 2 – Reverse Osmosis

NPV Calculations:	0	1	2	3	4	5	6
Total Acquisition Cost	128,500,000						
Total Running Costs		140,000	177,900	154,350	195,505	170,171	215,687
Straight-line Depreciation		9,884,615	9,884,615	9,884,615	9,884,615	9,884,615	9,884,615
Profit Before Taxes		-10,024,615	-10,062,515	-10,038,965	-10,080,120	-10,054,786	-10,100,302
Tax Provision @ 38% Of Profit Before Tax		3,809,354	3,823,756	3,814,807	3,830,446	3,820,819	3,838,115
Net Income (Profit before Tax + Tax Provision)		-6,215,262	-6,238,760	-6,224,159	-6,249,674	-6,233,967	-6,262,187
Cash Flow (Net Income + Depreciation)	-128,500,000	3,669,354	3,645,856	3,660,457	3,634,941	3,650,648	3,622,428
Discount Factors @ i = 7%, $\frac{1}{(1+i)^n}$	1.0000	0.9346	0.8734	0.8163	0.7629	0.7130	0.6663
Present Value, NOK	**-128,500,000**	**3,429,303**	**3,184,432**	**2,988,023**	**2,773,079**	**2,602,862**	**2,413,777**

NPV Calculations:	7	8	9	10	11	12	13
Total Running Costs	193,644	249,923	229,135	294,852	320,396	421,064	381,677
Straight-line Depreciation	9,884,615	9,884,615	9,884,615	9,884,615	9,884,615	9,884,615	9,884,615
Profit Before Taxes	-10,078,259	-10,134,538	-10,113,750	-10,179,467	-10,205,011	-10,305,679	-10,266,292
Tax Provision @ 38% Of Profit Before Tax	3,829,738	3,851,124	3,843,225	3,868,197	3,877,904	3,916,158	3,901,191
Net Income (Profit before Tax + Tax Provision)	-6,248,521	-6,283,414	-6,270,525	-6,311,270	-6,327,107	-6,389,521	-6,365,101
Cash Flow (Net Income + Depreciation)	3,636,095	3,601,202	3,614,090	3,573,346	3,557,508	3,495,094	3,519,514
Discount Factors @ i = 7%, $\frac{1}{(1+i)^n}$	0.6227	0.5820	0.5439	0.5083	0.4751	0.4440	0.4150
Present Value, NOK	**2,264,377**	**2,095,932**	**1,965,826**	**1,816,508**	**1,690,147**	**1,551,864**	**1,460,473**

*NPV = Sum of Present Value from year 0 to 13

Table 9: Estimated Cost Breakdown for Each Cost Element – Alternatives 2

	Alternative 2 (Reverse Osmosis)												
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Material & Spare Parts Cost for Maintenance													
Filter	40,000	42,000	44,100	46,305	48,620	51,051	53,604	56,284	59,098	62,053	65,156	68,414	71,834
Membrane	0	12,000	0	12,600	0	13,230	0	13,892	0	14,586	0	15,315	0
Other Spares	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Material Cost per yr, NOK	40,000	54,000	44,100	58,905	48,620	64,281	53,604	70,176	59,098	76,639	65,156	83,729	71,834

Energy Cost													
Power Consumption, kWh	55	55	55	55	55	55	55	58	61	64	67	70	74
Electricity Cost, NOK / (yr-kWh)	1,000	1,050	1,103	1,158	1,216	1,276	1,340	1,407	1,477	1,551	1,629	1,710	1,796
Total Electrical Cost per yr, NOK	55,000	57,750	60,638	63,669	66,853	70,195	73,705	81,260	89,589	98,772	108,896	120,058	132,364

Preventive Maintenance Labor Cost													
No. of Maintenance Personnel	2	2	2	2	2	2	2	2	2	2	3	3	3
No. of Hours Required, per person	25	35	25	35	25	35	28	39	30	43	33	47	37
Offshore Hourly Rate, NOK / hr	900	945	992	1,042	1,094	1,149	1,206	1,266	1,330	1,396	1,466	1,539	1,616
Total Labor Cost per yr, NOK	45,000	66,150	49,613	72,930	54,698	81,210	66,335	98,487	80,447	119,440	146,344	217,277	177,479

Table 10: Summary for Material & Spare Parts Cost

Evaporation		Reverse Osmosis	
No. of Filter	3	**No. of Membrane**	12
Cost of Each Filter Cartridge, NOK / each	5,000	**Cost of Membrane, NOK / each**	10,000
Total Cartridge Cost per Change, NOK	**15,000**	**Total Membrane Cost per change, NOK**	**120,000**
Chemical Cost, scale inhibitor	10,000	**No. of Filter**	8
Chemical Cost, acid cleaning	10,000	**Cost of Each Filter Cartridge**	5,000
Total Chemical Cost , NOK / year	**20,000**	**Total Cartridge Cost per Change**	**40,000**

4. DISCUSSION

This section summarizes and concludes the findings presented in Section 3. It shall be noted that the case study was performed based on the assumption that the FWM with evaporator technology is the same configuration as the existing skid and the budgetary quotation for such skid was not available.

Based on Table 5 and 7, The NPV obtained from the LCC analysis for both alternatives are:

Evaporation Technology = **- NOK 80,180,577**

Reverse Osmosis = **- NOK 98,263,399**

According to the findings of the LCC analysis, it can be shown that the FWM with existing technology is preferred based on the NPV at the 7% discount rate. There are no considerations of revenues and savings in the analysis, hence, the alternative with minimum loss will be the most attractive approach.

The output of this LCC analysis should be combined with the estimation proposed by the FEL group regarding Design and Engineering Estimate. As mentioned earlier, the integration cost is found to be challenging to be quantified as separate component and this cost had been included in the Design & Engineering Estimate.

Hence, both estimations should be combined in order to complete the LCC analysis. Table 11 presents the list of cost elements that had been considered in the LCC analysis based on the limited time and information available in the early phase of the modification project.

Table 11: Cost Elements Considered in Case Study Example

Have the below cost be considered and included in estimation?	Evaporation	Reverse Osmosis
Design & Engineering Cost	Yes	Yes
Documentation - New and Update where applicable	Yes, Minimum	Yes
Equipment Procurement Price	Yes	Yes
Bulk Material Procurement Price	Yes, Minimum	Yes
Construction & Installation Cost (Includes material and labor cost)	Yes	Yes
Integration Cost - Changes for replacement	Yes	Yes
Integration Cost - Changes in other system for replaced system	Yes, Minor	Yes
Mechanical Completion & Commissioning Cost (Include material and labor cost)	Yes	Yes
Commissioning & Start-Up Spares	Yes	Yes
Operating & maintenance spares cost	Yes	Yes
Operating & maintenance labor cost (e.g. Preventive/Corrective Cost)	Yes	Yes
Consumables cost - Maintenance	Yes	Yes
Consumables cost - Operation	Yes	Yes
Energy cost	Yes	Yes
Logistics Cost	Yes	Yes

It might be interesting to note that the NPV of FWM with Reverse Osmosis is lesser if the integration cost and bulk material cost are not being considered, as shown in Table 12.

Table 12: Comparison of NPV

Net Present Value	Evaporation	Reverse Osmosis
With Integration & Bulk Material Cost	- NOK 80,180,577	- NOK 98,263,399
Without Integration & Bulk Material Cost	- NOK 36,350,009	- NOK 35,162,496

From Table 5, it can be seen that the project cost with integration cost for the same technology as original skid is approximately 51% of the total acquisition cost. On the other hand, the project cost with integration cost for implementing new technology is approximately 59% of the total acquisition cost.

The above finding shows that the integration cost while carrying out modification or change technology used in the projects or systems is very important. It often leads to wrong interpretation if the important cost drivers are not being included. By properly performing LCC analysis at the right time and right phase, the total project cost can be greatly reduced or controlled and the chances of getting "surprise" in future cost can be reduced. The same theory applies to the operation and maintenance cost.

Due to the following reasons, the FWM with the new technology (Reverse Osmosis) costs more than the existing technology in LCC perspective:

1. The integration cost for changing the technology for FWM is significant due to the changes/modification in other systems and updates of documentation are needed to be carried out.
2. The spare or replacement parts, such as membrane, are more costly than the existing technology although the energy consumption is low and no cleaning-in-place is required.

Nonetheless, the LCC analysis provides better overview and consideration while selecting the technical solutions to ensure the possible costs that will be incurred in the later stage of the project are being included in the analysis. It has been misunderstood that the technical solution with the lowest initial procurement price appears to be the best alternatives. The influence of various cost drivers in NPV should be best concluded by running LCC analysis at certain level of details. It had also been proven that the operating and maintenance cost are more dominant than the initial cost in the operation phase. By doing such analysis, it helps minimizing the level of "surprise" in the operating expenditures at the later stage.

LCC analysis performed in the case study presented in this thesis concluded that the existing technology is more cost effective as compared to the new technology. However, there is always some practical information or issues that should also be considered before making the decision. It is the matter if it is worth for making such changes while the existing technology will not only save times and resources but also achieve the same level of effectiveness as compared to the new technology. The advantages and disadvantages of both technical solutions should also be presented and considered by the project management or decision maker.

Possible advantages of Reverse Osmosis over Evaporation might be the following:

- The availability of the spares or replacements parts is better as this technology is rather new. Hence, it will have less possibility that the parts will be obsolete before year 2028.
- The risk of lacking service support from supplier is lower as the existing technology might be outdated before year 2028.
- Great saving in energy consumption which is in strong preference among offshore industry and better recovery
- Better effectiveness and efficiency in the long run as the new technology was invented with the aims of improving those from old technology

All current procurement procedures implemented by the operating company at the moment relied very much on the initial procurement price, e.g. 70% weightage for commercial and 30% weightage for technical aspects. It often leads to the circumstances that the follow-on engineering and execution cost or operation and maintenance costs are in fact much more than the other options. One of the reasons could be that some suppliers often reduce their price with lower quality in order to be awarded for the contract. In addition, the nominated suppliers with frame agreement contract should always be used if applicable. There are proven cases that some of the nominated suppliers had not been executed the job with complete effort and often incurs additional and significant expenses in order to rectify the issues. This may due to the increased workload with limited resources available in their company.

As such, it is strongly advisable to include LCC analysis as earlier as possible in the project and to consider the potential risks before making decision while selecting the final solution or suppliers.

5. CONCLUSIONS AND RECOMMENDATIONS

The technique of LCC analysis had been implemented in conjunction with the engineering aspects to obtain the overall cost that considers both the time value of money and technical aspect fulfillments. The LCC concept highlights very much not only on the availability and maintainability related issues but also the cost associated with spare parts and their availability. It also conveys the crucial message to the decision maker that one should not focus only on the initial investment amount and ignores the possible cost occurrence later.

It is recognized that the LCC techniques are used as a supporting tool for decision making. It cannot be used solely for making decision because there are various factors need to be taken into consideration in practical manner based on the discussion in earlier sections. This is important especially when the lifetime of the platform or facilities also plays an important role in the modification project as such.

The thesis presented a practical solution for implementing LCC concept and analysis during the early phase of the study. However, this approach is also recommended to be used during the project execution phase, i.e. supplier bid evaluation for procurement for critical equipment or system. Currently, almost all equipment or systems are evaluated mainly based on the initial procurement and delivery lead time. The significant potential cost relating to operation & maintenance and environmental cost are chosen to be ignored. A good project planning should be performed to include sufficient time for carrying LCC analysis for critical equipment.

The case study presented in this thesis and the LCC analysis relates more to the mechanical equipment and system. Hence, the process of LCC can be modified to suit systems/equipment for all disciplines.

Additionally, it is also recommended to have the LCC procedure properly developed as part of the standard procedure or guidelines in the system. Management as decision makers should also be provided with sufficient training and courses to have better understanding of LCC. By doing so, it helps to create great saving in terms of operation and maintenance cost in the long run.

6. REFERENCES

Ahmed, N. U., 1995. A design and implementation model for life cycle cost management system. *Information & Management,* Volume 28, pp. 261 - 269.

Aibel, 2013. *Homepage of Aibel AS.* [Online] Available at: http://aibel.com/en/projects/gem [Accessed 10 January 2013].

Anonymous, 2013a. *Homepage of Operating Company.* [Online] [Accessed 10 January 2013].

Anonymous, 2013b. *Project Propsal - Fresh Water Maker Package,* Stavanger: Operating Company.

Barringer, H. P., 1997. *Life Cycle Cost & Reliability for Process Equipment.* Houston, American Petroleum Institute.

Barringer, H. P., 1998. *Life Cycle Cost and Good Practices.* San Antonio, Barringer & Asociates Inc..

Barringer, H. P., 2000. *Why You Need Practical Reliability Details To Define Life Cycle Costs For Your Products and Competitors Products.* [Online] Available at: http://www.barringer1.com/lcc.htm [Accessed 15 March 2013].

Barringer, H. P., 2003. *A Life Cycle Cost Summary.* Perth, Maintenance Engineering Society of Australia.

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

Blanchard, B. S. & Fabrycky, W. J., 2011. *Systems Engineering and Analysis.* 5th ed. New Jersey: Pearson Education Inc..

Blanchard, B. S., Verma, D. & Peterson, E. L., 1995. *Maintainability: A Key to Effective Serviceability and Maintenance Management.* 3rd ed. New York: John Wiley & Sons, Inc..

Craig, B. D., 1998. *Quantifying the consequence of risk in life cycle cost analysis.* Stavanger, s.n.

Davis Langdon Management Consulting, 2007. *Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology - Literature Review,* s.l.: s.n.

Dhillon, B., 2006. *Maintainability, Maintenance, and Reliability for Engineers.* New York: CRC Press.

Ellis, B. A., 2007. *Life Cycle Cost,* Baltimore: The Jethro Project.

Fabrycky, W. J. & Blanchard, B. S., 1991. *Life Cycle Cost and Economic Analysis.* New Jersey: Prentice Hall.

ISO 15663 - 2, 2001. *Petroleum and natural gas industries - Life Cycle Costing - Part 2: Guidance on application of methodology.* [Online] Available at: http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=28626 [Accessed 30 January 2013].

ISO 15663 - 3, 2001. *Petroleum and natural gas industries - Life Cycle Costing - Part 3: Implementation Guidelines.* [Online]. Available at: http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=28627 [Accessed 30 January 2013].

ISO 15663-1, 2000. *Petroleum and natural gas industries - Life Cycle Costing - Part 1: Methodology*. [Online] Available at: http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=28625 [Accessed 30 January 2013].

Kawauchi, Y. & Rausand, M., 1999. *Life Cycle Cost (LCC) analysis in oil and chemical process industries,* s.l.: s.n.

Kayrbekova, D., 2011. *Activity-Based Life-Cycle Cost Analysis,* Stavanger: Universtiy of Stavanger.

Kopi, E. & Ala-Risku, T., 2008. Life Cycle Costing: a review of published case studies. *Managerial Auditing Journal,* 23(3), pp. 240-261.

Lapašinskaitė, R. & Boguslauskas, V., 2005. The maintenance Cost Allocation in Product Life Cycle. *ECONOMICS OF ENGINEERING DECISIONS,* 44(4), pp. 17-23.

Markeset, T. & Kumar, U., 2000. *Application of LCC Techniques in selection of mining equipment and technology.* Athens, National Technical University of Athens.

NORSOK O-CR-001, 1996. *Life Cycel Cost for Systems and Equipment.* [Online] Available at: http://www.standard.no/no/Fagomrader/Petroleum/NORSOK-Standard-Categories/O-Operation/O-CR-001/ [Accessed 30 January 2013].

NORSOK O-CR-002, 1996. *Life Cycle Cost for Production Facility.* [Online] Available at: http://www.standard.no/no/Fagomrader/Petroleum/NORSOK-Standard-Categories/O-Operation/O-CR-002/ [Accessed 30 January 2013].

NORSOK Z-016, 1998. *Regularity Management & Reliability Technology*. [Online] Available at: http://www.standard.no/en/sectors/Petroleum/NORSOK-Standard-Categories/Z-Regularity--Criticality/Z-016/ [Accessed 20 February 2013].

Odland, J., 2011. *Project Management,* Stavanger: University of Stavanger.

RTO, 2007. *Methods and Models for Life Cycle Costing,* Neuilly: NORTH ATLANTIC TREATY ORGANIZATION.

Thabit, S. S., 1984. A Study of the technique of Life Cycle Costing as applied to the appraisal of oilfield power supply systems. *Engineering Costs and Production Economics,* Volume 7, pp. 305 - 312.

7. APPENDIX

7.1 Check list

Below check list is proposed to be included as general guideline to consider relevant cost as practical as possible while performing LCC analysis in the early phase of the modification project:

Table 13: Check List of Cost Element in LCC estimation

Have the below cost be considered and included in estimation?	Yes / NA
Design & Engineering Cost	
Documentation - New and Update where applicable	
Equipment Procurement Price	
Bulk Material Procurement Price	
Construction & Installation Cost (Includes material and labor cost)	
Integration Cost - Changes for replacement	
Integration Cost - Changes in other system for replaced system	
Mechanical Completion & Commissioning Cost (Include material and labor cost)	
Commissioning & Start-Up Spares	
Operating & maintenance spares cost	
Operating & maintenance labor cost (e.g. Preventive/Corrective Cost)	
Consumables cost - Maintenance	
Consumables cost - Operation	
Additional maintenance cost for operation after exceeding technical life time	
Energy cost	
Logistics Cost	
Decommissioning Cost	
Disposal Cost	