CRANFIELD UNIVERSITY

OKECHUKWU PETER OKAFOR

DEVELOPMENT OF A LIFE CYCLE COST ESTIMATING FRAMEWORK FOR OIL REFINERIES

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MSc by Research Thesis

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DEVELOPMENT OF A LIFE CYCLE COST ESTIMATING FRAMEWORK FOR OIL REFINERIES

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ABSTRACT

This study is concerned with the understanding of some vital features of various life cycle costing methodologies and tools. Integrating these features with the refinery technical processes would assist in the development of a life cycle costing framework for oil refineries. The aim of this research is to develop a comprehensive life cycle cost estimating framework for the evaluation of not only the total cost and system effectiveness of new refineries but also the revamping, and maintenance of the existing refineries.

Several conceptual life cycle costing models relating to various life cycle stages were reviewed, and their attachment to specific life cycle activities assessed. Furthermore, the literature review and the industry survey identified that a vital requirement for the development of a life cycle costing framework is the establishment of a structured conceptual life cycle costing model and a cost breakdown structure that will depict major cost categories and cost elements in the LCC framework. Consequently, a standard conceptual life cycle costing model and its cost breakdown structure were developed and integrated into a proposed LCC framework for oil refineries.

A combination of the literature review findings and industry survey were also used to ascertain the current life cycle costing practice. It was identified that there is a lack of a practical framework to compare two or more options of refinery schemes for system effectiveness. This led to the development of a novel life cycle cost estimating framework that could be used in the evaluation of the total cost and system effectiveness of a new refinery when there is no performance data.

Finally, the framework's applicability and effectiveness was demonstrated through its application on a case study. The validation of the proposed framework and the cost estimates development within the case study was successfully carried out by experts from the industry and academia. Consequent upon the research findings, key areas for future work were identified. The implementation of the findings of this research within the industry could provide the much needed long-term benefit that comes with the formalisation of life cycle costing practice.

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LIST OF ABBREVIATIONS

BPSD	Barrels per stream day
CAPEX	Capital Expenditure
CBS	Cost Breakdown Structure
COT	Commercial-off-the-shelf
FCC	Fluid Catalytic Cracking
FEED	Front End Engineering Design
IEC	International Electro-technical Commission
ISBL	Inside Battery Limits
ISO	International Organisation for Standardisation
LCC	Life Cycle Costing
LCCA	Life Cycle Cost Analysis
LPG	Liquefied Petroleum Gas
MCDM	Multi-Criteria Decision Making
MOD	Ministry of Defence
NATO	North Atlantic Treaty Organisation
NPV	Net Present Value
OPEX	Operating Expenditure
OP	Operating Profile
OREDA	Offshore reliability database
ORT	Oil Refinery Technology
OSBL	Outside Battery Limits
R&D	Research and Development
ROI	Return on Investment
RTO	Research and Technology Organisation
UST	Unitised Smart-Tailored Refinery

CHAPTER 1 INTRODUCTION

1.1 Background

In the oil refining industry, global competition and rising cost of ownership have created awareness and interest in total life cycle cost assessment that will support the decision making process (Iwawaki *et al*, 2002). Furthermore, increasing energy demand in the developing countries of Asia-Pacific and Africa are some of the life cycle costing challenges facing new investments in refining capacity (Tashiro and Ogawa, 2003). In as much as no new refineries are currently being constructed in Europe, several other refinery projects are still in progress in other parts of the world because of the rising energy demand.

Independent Project Analysis (2009) states that in several regions of the world, such as Northern Alberta, Canada, the Middle East, parts of Asia, and Latin America large investments in new refining assets are still ongoing. Independent Project Analysis as a company added 238 refining projects to its database in 2009 and this represents approximately $14 billion in capital investment. In addition, Nigeria is to spend approximately $2.4 billion (N 388.11 billion) on petrol imports in the first quarter of 2011 (Nigerian Punch Newspaper, 2011). Nigeria, according to the Punch Newspaper source consumes about 32 million litres of petrol per day. Nigeria has a refining capacity of 445,000 barrels per day but the Nigerian National Petroleum Corporation (NNPC) had recently shut the Nation's four refineries as a result of pipeline vandalism and other technical problems, leaving the country to depend completely on fuel importation.

The financial viability of projects in the oil refining industry is often assessed on the basis of minimum investment cost, while the operating costs have played little role in the decision making process. This has discountenanced a potentially huge cost and has resulted in higher ownership costs. Early application of life cycle costing analysis is bound to influence the design change of a plant and provides explanation of the relationship between cost and design parameters that could enhance total cost reduction. Moreover, the application and formalisation of life cycle costing practice could provide the oil refining industry the leverage to mitigate the challenges of energy demand, and rising cost of ownership.

Life cycle costing (LCC) refers to all costs associated with a product, from conception to disposal (Waghmode *et al*, 2010). Life cycle costing provides the tools to manage in-service costs, and presents decision making scenarios in a financial perspective to attain the lowest long term cost of ownership (Barringer, 2003). The US Department of Defense encouraged the development and practical use of life cycle costing in the 1970s to enhance its cost effectiveness in granting competitive tenders (Kawauchi and Rausand, 1999).

While life cycle costing techniques have been used for the economic evaluation of some generic refinery components (pumps, reactors, heat exchangers) that exist in other industrial plants, the development of a high level life cycle costing framework for the holistic evaluation of oil refinery complexes is yet to be established. It therefore, becomes apparent that there is a need to develop a comprehensive life cycle costing framework for the evaluation of not only the total cost and system effectiveness of new refineries, but also the revamping, and maintenance of the existing refineries.

1.2 Research Motivation

In spite of the establishment of a life cycle costing (LCC) methodology (BS ISO 15663-1&2: 2000) for the economic appraisal of oil and gas upstream/offshore facilities, the adoption and application of life cycle costing in the oil and gas industry remains limited (Vorarat and Al-Hajj, 2004). Furthermore, only a few studies have considered the life cycle costing of some generic refinery components like pumps (Waghmode *et al*, 2010), and reactor effluent air coolers (Iwawaki *et al*, 2002) that exist in other industrial plants. It is therefore, noteworthy that no detailed studies have addressed or considered the development of a high level life cycle costing framework for a downstream facility such as the oil refinery.

1.3 Problem Statement

"For many years the oil and gas industry has assessed the financial viability of projects on the basis of minimum capital cost (CAPEX), whereas operating costs (OPEX) have played little part in the decision making process"(Vorarat and Al-Hajj, 2004). This omission has now been recognised by the oil and gas industry (EN ISO 15663-1&2: 2006). With a decline in the last four decades in the number of new technologies, attention has now been shifted towards the revamping, upgrading, and maintenance of existing facilities and the construction of new refineries using already established technologies (Gary *et al*, 2007; Speight, 2011; Lucas, 2000). Moreover, the gap between the 'Procurement Division' and 'Operation and Maintenance Division' in the oil and gas industry is quite wide (Kawauchi and Rausand, 1999). Generally, the procurement division is the primary decision maker in purchasing an asset and whose major concern is in minimising investment cost, and not life cycle cost. Consequently, this research is being proposed to address the following research question: ***"How could a life cycle cost estimating framework be developed to evaluate not only the total cost and system effectiveness of new refineries but also the revamping, and maintenance of the existing refineries?"***

1.4 Research Aim

Consequent upon the aforementioned life cycle costing challenges in the oil refining industry, the aim of this research is:

"To develop a comprehensive life cycle cost estimating framework for the evaluation of not only the total cost and system effectiveness of new refineries but also the revamping, and maintenance of the existing refineries".

1.5 Thesis Structure

Chapter 1- Introduction: The research aim was presented based on the research problem statement. The author in this section acquaints the reader with the past and present issues about the research themes. The thesis structure was also presented in order to familiarise the reader with the sequence of events leading to the accomplishment of the research aim.

Chapter 2- Literature Review: The author presents a critical review of the literature that will assist in understanding the research concepts. The literature review findings will be used in the development of ideas that will address the identified research gap.

Chapter 3- Research Aim, Objectives and Methodology: The objectives for satisfying the overall research aim are presented. The development of the research methodology was accomplished through a careful analysis of available approaches and strategies. The methodological approach and strategy was selected based on the nature of the research objectives.

Chapter 4- Framework Development: The author examines the research requirements for the development of a conceptual life cycle costing model, and cost breakdown structure for oil refineries. Consequently, a refinery conceptual life cycle costing model and its cost breakdown structure were modelled and integrated into an overall life cycle costing framework for oil refineries. The proposed novel framework will be used for the evaluation of not only the total cost but also the system effectiveness of oil refineries when there is no performance data.

Chapter 5- Detailed case study: The author describes how the proposed framework will be used to predict the operating costs associated with an effective refinery scheme selected through a screening process (Multi-criteria decision making approach) in one of the steps within the framework.

Chapter 6- Validation: The validation of the framework will be conducted simultaneously in two ways. First, the suitability of the framework will be investigated through its application on a case study. Thereafter, a validation questionnaire will be used to extract experts' opinions regarding the framework's applicability. Second, the experts will have the opportunity to assess the reasonableness of the assumptions used, and the effectiveness of the cost estimates.

Chapter 7- Discussion, future work, and conclusions: This chapter presents discussion on the research findings, research limitations, future work, key research contributions, and the overall conclusions of the research showing how the research objectives have been accomplished.

The following Chapter presents a critical review of the literature relating to this study.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

The purpose of the literature review is to collect and critically review published works and data on current studies associated with life cycle costing methodologies and tools. This will establish the extent of existing knowledge in order to provide the background to the topic and to support the logic of the research. On completion of this chapter, the scope of current theory and practice would have been identified. This, then, will be used as the basis for the definition of the research gap that requires further investigation and creation of new ideas towards the development of a comprehensive life cycle costing framework for oil refineries. Figure 2.1 represents the overall structure of this Chapter.

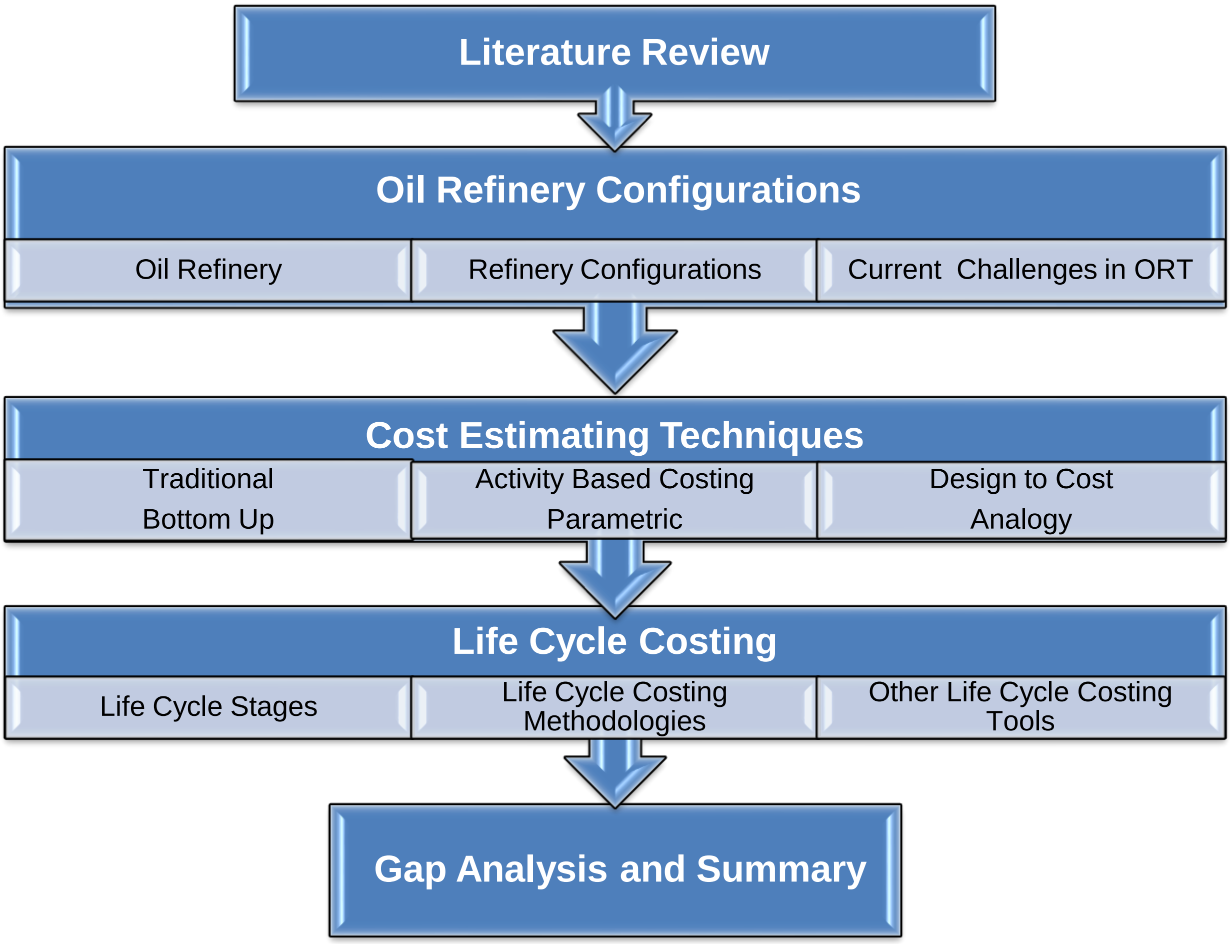

Figure 2.1 Literature Review Structure

2.2 Oil Refinery Configurations

2.2.1 Oil Refinery

Speight (2011) defines an oil refinery as "a group of integrated manufacturing plants which vary in number with the variety of products produced and which are selected to give balanced production of saleable products, in amounts that are in accord with the demand for each". According to Cleveland and Szostak (2006), it is an installation that manufactures finished petroleum products from crude, unfinished oils, natural gas liquids, and other hydrocarbons. An oil refinery is an industrial process plant where crude oil is processed and refined into more useful petroleum products, such as gasoline, diesel fuel, asphalt base, heating oil, kerosene, and liquefied petroleum gas (Gary and Handwerk, 2001; Leffler, 1985). The core refining process is simple fractional distillation (Figure 2.2).

The aggregation of the foregoing definitions means that an oil refinery is an industrial plant that refines crude oil into useful petroleum products.

Raw and unprocessed crude oil is not very useful in the form it comes out of the ground. Hence, it needs to be broken down into parts and refined before use. Since it is made up of a mixture of hydrocarbons, the first and basic refining process is aimed at separating the crude oil into its fractions. Crude oil is heated and put into a still by the use of a distillation column where different products boil off and can be recovered at different temperatures. The lighter products which are liquefied petroleum gas (LPG), naphtha and gasoline (petrol) are recovered at the lowest temperatures. Middle distillates are jet fuel, kerosene, distillates such as home heating oil and diesel fuel come next. Finally, the heaviest products (residual fuel oil) are recovered, sometimes at temperatures over 500^{o}C. The simplest refinery stops at this point (Cleveland and Szostak, 2006).

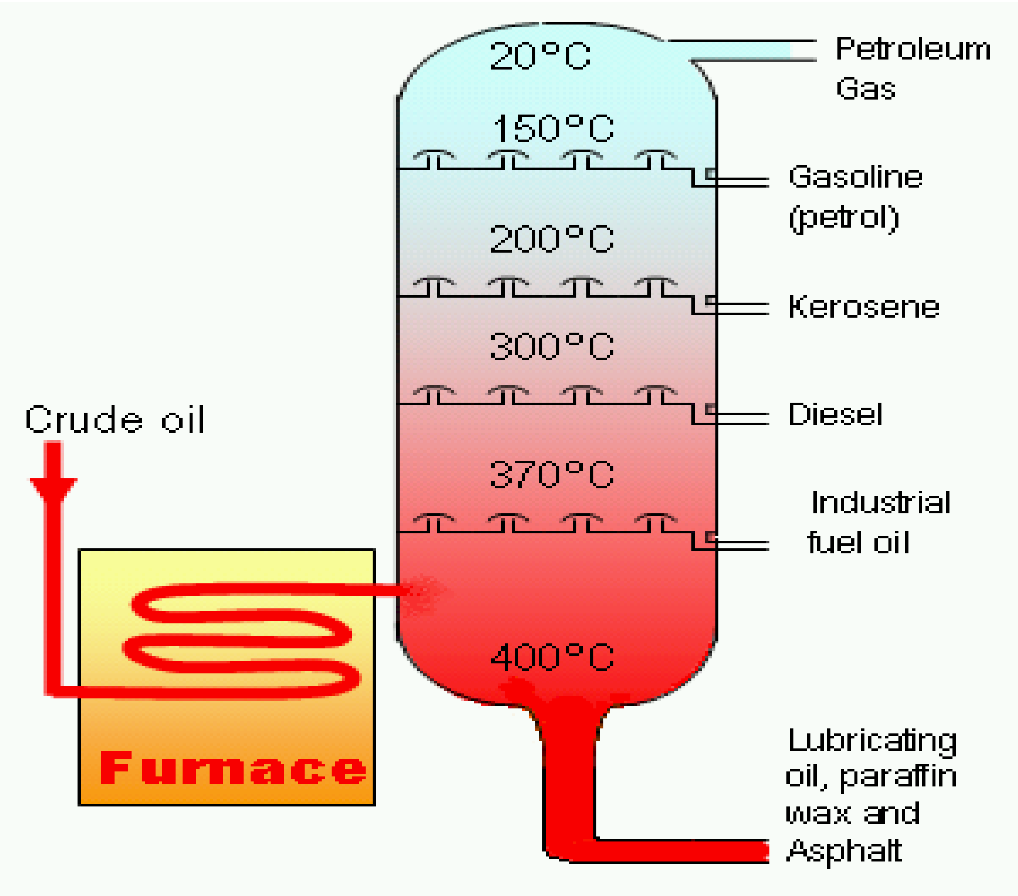

Figure 2.2 Simple Fractional Distillation (Pighadshy, 2008)

2.2.2 Configurations

Configurations differ from one refinery to the other (Speight, 2011; Ocic, 2005), and the four main configurations are: Topping, Hydroskimming, Cracking, and Coking refineries.

- **A topping Refinery**

The first and foremost refinery configuration is the topping refinery which is designed to separate the crude oil into its constituent petroleum products by atmospheric distillation process. Topping refinery (Figure 2.3) is made up of the necessary utility systems (steam, power, boiler, cooling tower, and water treatment plants), tankage, a crude distillation unit, and recovery facilities for gases and light hydrocarbons.

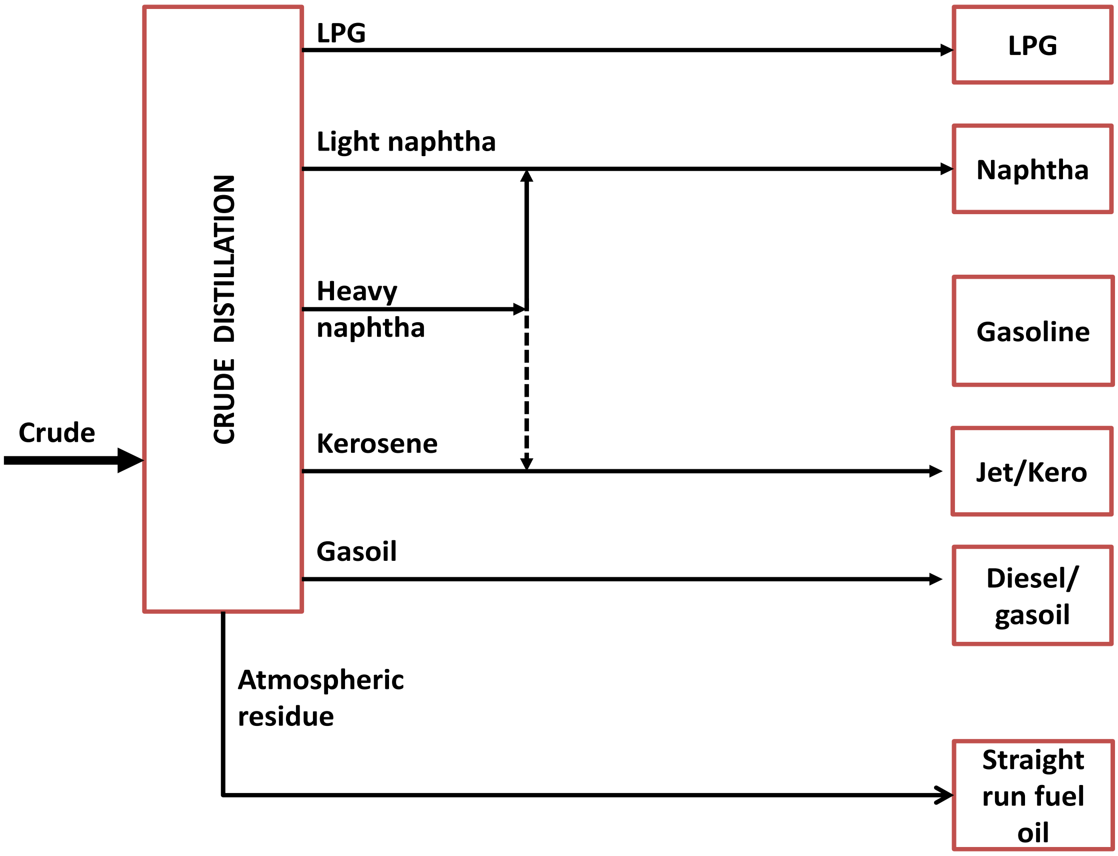

Figure 2.3 A Topping Refinery (Speight, 2011)

- **A Hydroskimming Refinery**

The addition of hydrotreating (hydrodesulfurization) and reforming units to the topping refinery results in a more flexible hydroskimming refinery. Hydroskimming refinery (Figure 2.4) produces desulfurized fuel and high octane gasoline (petrol). The inclusion of a catalytic reformer increases the gasoline octane and provides hydrogen for the hydrotreaters. Hydrotreatment units on the other hand increase the quality of the product from environmental viewpoint by removing sulphur and nitrogen impurities.

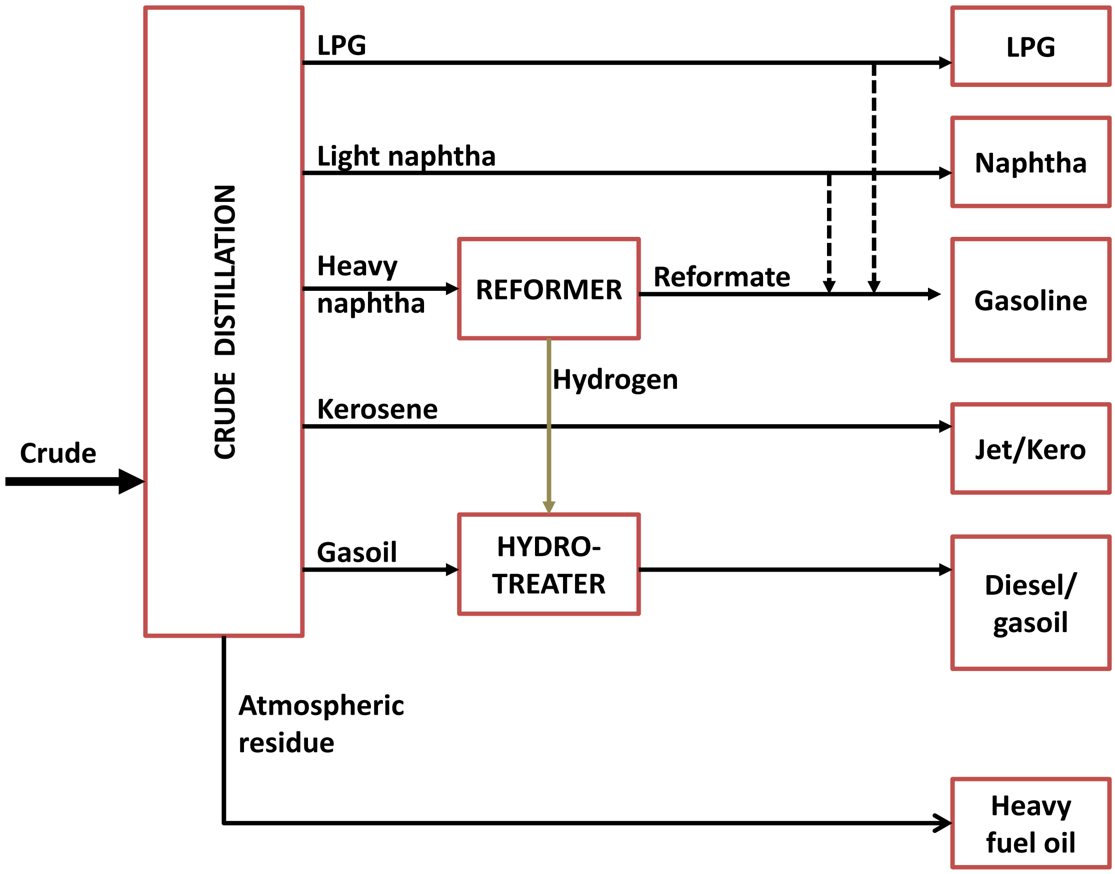

Figure 2.4 A Hydroskimming Refinery (Speight, 2011)

- **A Catalytic Cracking Refinery**

The addition of a vacuum distillation unit and catalytic cracking process to the hydroskimming refinery results in a more versatile catalytic cracking refinery (Figure 2.5). It incorporates all the basic units found in both topping and hydroskimming refineries. It also accommodates gas oil conversion plants, such as catalytic cracking and hydrocracking units. It produces large amount of gasoline (petrol) and other valuable petroleum products.

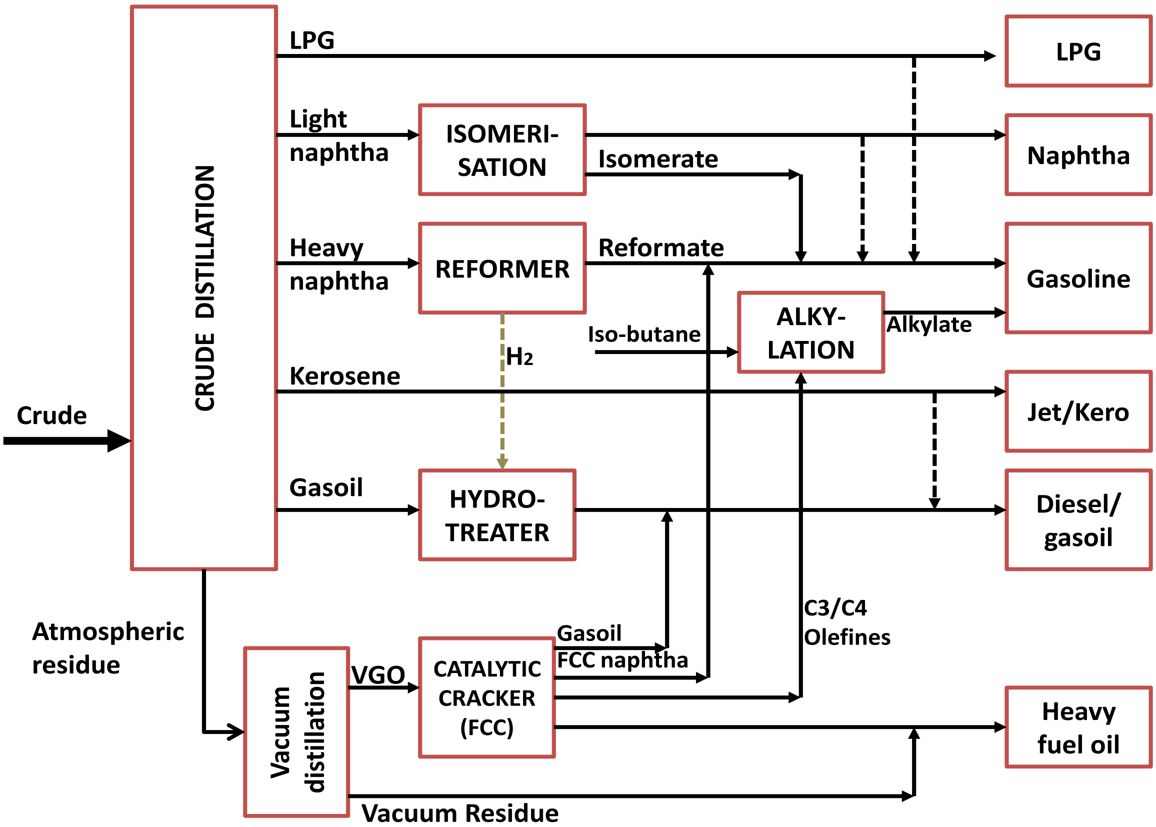

Figure 2.5 A Catalytic Cracking Refinery (Speight, 2011)

- **A Coking Refinery**

The addition of a coking process to the catalytic cracking refinery results in a deep conversion and complex coking refinery. The coking refinery (Figure 2.6) is equipped to process the vacuum residue into high valuable products using the delayed coking process. It adds further complexity to the catalytic cracking refinery by high conversion of fuel oil into distillates and petroleum coke. It also incorporates solvent extraction processes for lubricants production. Its petrochemical units recover propylene, benzene, and xylenes for further processing into polymers.

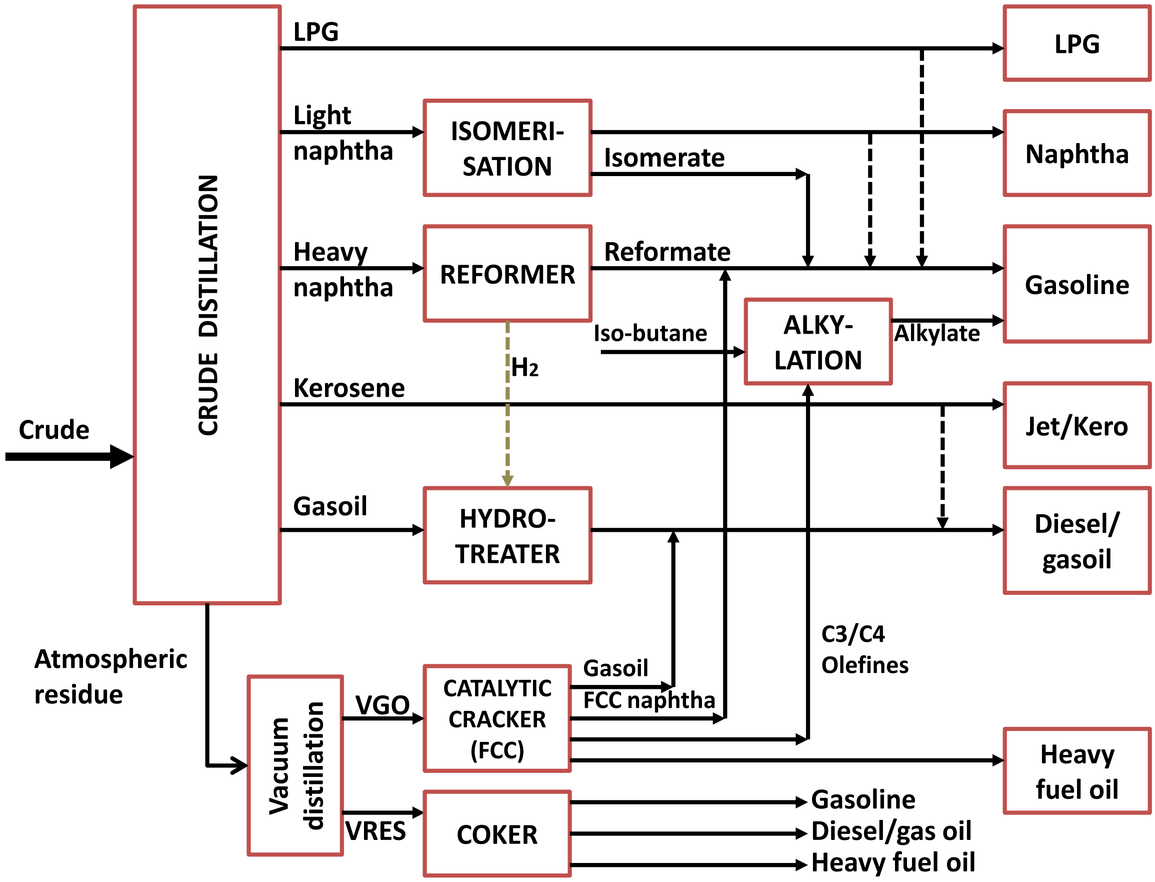

Figure 2.6 A Coking Refinery (Speight, 2011)

2.2.3 Refining Tools

Fragile demand and high stocks of refined products in several regions of the world have led to low refining margins, and depleted profit. Refiners must therefore pay more attention to cost effective projects that can deliver the anticipated rate of return on investment.

However, in some other regions of the world, such as Northern Alberta, Canada, the Middle East, parts of Asia, and Latin America, large investments in new refining assets are still ongoing (Independent Project Analysis, 2009). This is to enable these countries meet local anticipated growth in demand for certain petroleum products.

IPA (Independent Project Analysis) Approach to Petroleum Refining

IPA as a company is well known for its Best Practices in the execution of cost effective and predictable projects in the oil refining industry. In 2009 the company added 238 refining projects to its database, and these represent approximately $14 billion in capital investments. IPA's Refining Database includes refining and petrochemical projects of all types and sizes.

IPA's refining tools include large number of grassroots and collocated projects such as atmospheric and vacuum distillation to hydrogen compression and manufacturing. The percentages of the types of refining projects handled by IPA are illustrated in Figure 2.7.

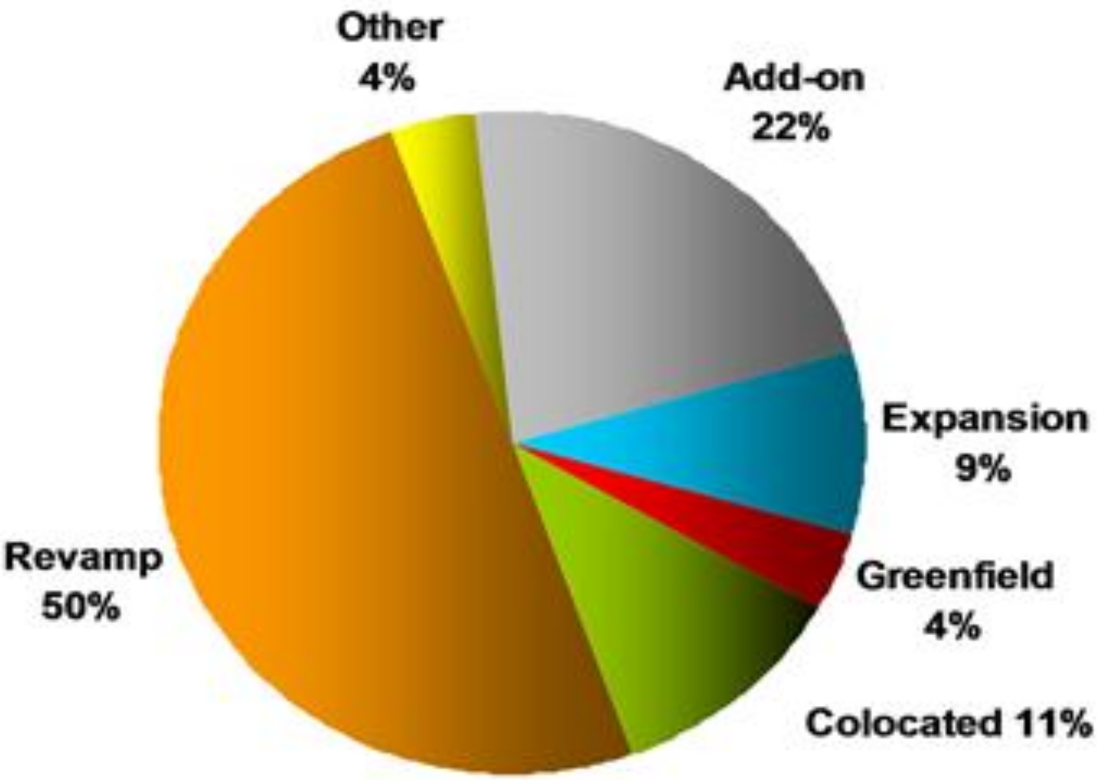

Figure 2.7 Refinery Project Type (Independent Project Analysis, 2009)

Types of Projects Represented in IPA's Refining Database
• Greenfield refineries
• Installation of new refinery units
• Large refinery revamps (multiple units)
• Revamp of individual refinery units
• Small refinery projects (replacement of pumps, piping, heat exchangers, etc.)
• IPA's small project database includes more than 6,000 small projects from more than 30 companies
• Heavy oil upgraders and other oil sands related facilities
• Gas plants
• DCS

From the above-mentioned data ***IPA was able to develop cost estimating relationships that serve as tools for benchmarking the cost and schedule of these projects.***

Figure 2.8 represents Independent Project Analysis (IPA) refining units for which it has developed cost estimating relationships that serve as tools for benchmarking the cost and schedule of refinery projects.

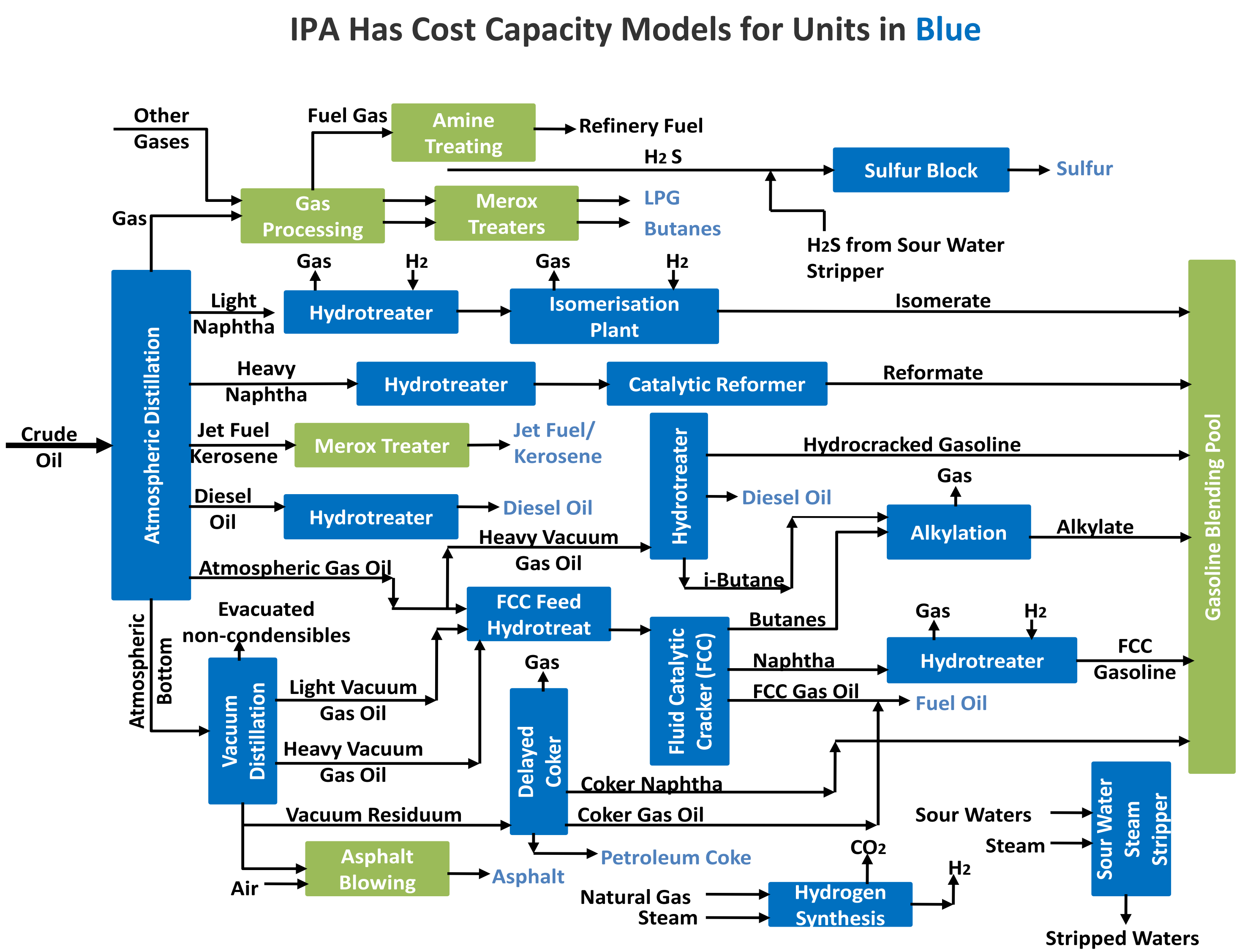

Figure 2.8 Refining Tools (Independent Project Analysis, 2009)

2.2.4 Current Challenges in Oil Refinery Technology (ORT)

The Oil and Gas Industry is confronted in recent times with several challenges in securing the much needed energy for the new generation (El-Banbi, 2010). El-Banbi opined that the increasing hydrocarbon demand has challenged the oil and gas industry to find and produce more hydrocarbons using new technologies.

Rosneft (2009) states that technical innovation efforts in oil refining are focused on the following areas: process optimization; expanding the product range; energy saving, sustainable use of resources and protection of the environment. Hence, to ensure compliance with Governments' requirements on fuel quality, the oil refinery modernization, and installation of units and facilities using new technologies for deeper oil processing must be encouraged. A representation of References on Current Challenges is presented in Table 2.1.

Table 2.1 References on Current Challenges

	References	Current Challenges	Current / Proposed Technologies
1	**Speight (2011)**	There are challenges of environmental regulations, and crude oil price volatility.	The construction of biofuel and renewable chemical production facilities to increase the efficiency of energy use are key to meeting some of these challenges.
2	**Branco, Gomes and Szklo (2010)**	The worldwide oil refining industry currently faces strong Challenges relating to uncertainties about i. future quality and quantity of raw materials (feedstock) and characteristics of final oil products. ii. These two factors will increase the use of fossil fuel and thus, the carbon dioxide (CO2) emissions of oil refineries.	Two main alternatives have been identified and adopted by several refiners worldwide to cope with aforementioned challenges. i. The first strategy is to increase refinery complexity and versatility with the flexibility to produce different highly specified oil derivatives including processing different raw materials, such as biomass, coal and heavy oil. ii. The second alternative is the integration of the refinery and petrochemical industries. This integration can increase the value of refining streams through the transformation of basic to final petro-chemical products. This is based on technological advances in fluid catalytic cracking (FCC) units.

3	**El-Banbi (2010)**	There are challenges to produce many of the available petroleum resources economically. i. Though some of the oil resources have already been converted to reserves but significant amount of the oils still remain in the resources category due to technological and economical reasons. ii. We need to find new ways to recover additional oil from existing reservoirs.	3D static and dynamic modelling has become a key differentiating technology in the management of petroleum reservoirs. i. The state-of-the-art software modelling programmes allow for better and more efficient decisions in developing and exploiting the field. ii. The reservoir modelling technology has added value to the oil and gas industry.
4	**Brown, M (2006)**	There are challenges of immediate feedstock valuation (assay) which is about being able to understand the qualities of a crude oil very quickly so that it can be valued appropriately.	BP has developed a portable micro technology-based device that can rapidly tell what the yield structure of a crude oil is, i.e. how much gasoline, diesel, and kerosene will be produced.
5	**Brown, M (2006)**	Given the world's reliance on fossil fuels to provide energy at a large scale for the foreseeable future, CO_2 emission from oil refineries were set to rise.	The use of carbon sequestration technology could help in mitigating this challenge. Carbon sequestration involves capturing CO_2 emitted from power plants and other industrial complexes and injecting it into geological structures deep below ground for long-term storage. The recovered CO_2 could be used for enhanced oil recovery (EOR) projects.
6	**Tashiro and Ogawa (2003)**	Asia-Pacific countries oil demand is predicted to reach about 20.6 million bpd(MMpd) by 2010 and exceed 29.7 MMbpd by 2020. These trends represents i. a growth rate of 3.9% per year; ii. expanded demand for electrical power that uses liquified petroleum gas (LPG) is predicted to exceed 4.5% per year.	The growing energy demand presents opportunities to build new refineries in the region. i. This led to the introduction of a bespoke facility called unitized smart- tailored (UST) refinery that is well-suited to achieve substantial reductions in CAPEX through a new technical approach. ii. Such designs can lower CAPEX by 30% for the refinery with similar functions and, thereby improve ROI by 5%.
7	**Pinto, Joly and Moro (2000)**	There are challenges of scheduling problems in oil refineries. i. The lack of computational technology for production scheduling is the main obstacle for the integration of production objectives and process operations. ii. The chemical processing industry had to go through severe restructuring in order to compete successfully in this new scenario.	A discrete time mixed integer optimization model is proposed for the generation of a plan for refinery crude oil management.

2.3 Cost Estimating Techniques

The previous section provided an overview of an oil refinery and its configurations. For the main requirements of this research to be properly addressed, it is necessary to discuss some generic issues associated with cost estimating. Life cycle costing being a prediction of the future must take cognisance of different cost estimating techniques that could be used during cost analysis. However, this depends on the availability of data, and the life cycle phase in which the calculations will be implemented. Society of Cost Estimating and Analysis (2007) defines cost estimating as "the art of approximating the probable cost or value of something, based on information available at the time". Dysert (1997) states that an estimate could be a combination of estimating techniques. The frequently used estimating techniques can be broadly classified as: Traditional, Bottom up (Engineering procedure), Activity based costing (ABC), Parametric (Top down), Design to cost (DTC), and Analogy.

2.3.1 Traditional Cost Estimating

Rush and Roy (2000) state that there are two main types of estimates used in traditional costing, namely: (a) an initial 'first sight' estimate done early in the project life cycle and it is based on expert opinion, (b) a detailed estimate done in order to calculate costs more precisely. The 'first sight' estimate is based around the expertise and experience of the estimator, and it is usually conducted using a past similar project. However, he suggests that 'first sight' cost estimates are useful for a rough order-of-magnitude estimate but are too qualitative for today's cost conscious environment, hence, the need for more quantitative estimates.

2.3.2 Bottom Up (Estimating by engineering procedures)

Bottom up cost estimating technique, otherwise known as 'estimating by engineering procedures' is associated with identifying and estimating all individual aspects (NASA, 2002), and these are later summed up to give a total estimate. Fabrycky and Blanchard (1991) suggest that this type of estimating procedure require detailed data and can be very time consuming because of hours of effort needed to perform the calculations. The rigorous data collection processes are thus not applicable within the early life cycle stages of the cost estimating. However, estimating by engineering procedures may result in an accurate estimate and can produce estimates with a low level of error.

2.3.3 Activity Based Costing (ABC)

Emblemsvag (2001) proposed the use of activity-based costing (ABC) in life cycle cost analysis. Activity based costing is a method for evaluating the cost and performance of activities by integrating each activity unit cost. "Comparing the traditional cost accounting methods that estimate overhead cost at a fixed rate of the product cost, ABC can estimate cost by considering activities to be taken" (Iwawaki *et al*, 2002). This procedure is akin to detailed estimating, and requires a detailed understanding of the product definition.

However, ABC is not appropriate for unique investments, since it requires extensive activity-cost databases (Korpi and Ala-Risku, 2008).

2.3.4 Parametric Estimating (Top down)

"A widely used method for estimating product cost at the early stages of development is known as parametric estimating" (Rush and Roy, 2000). The following example may highlight this concept. Generally, for a topping refinery design, capacity relates to the cost of plant's manufacture. Hence, as the charge (input) capacity of the refinery increases, so does the cost of manufacturing. This attribute (capacity) is commonly called a cost driver, which is related to cost by 'cost estimating relationships' (CERs). Alternatively, the concept of Refinery Complexity (cost driver) could be used to quantify the relative cost of a refinery but some methodological issues may limit the use of complexity factors in cost estimating. "Complexity factors do not account for the impact of capacity on cost, because the complexity factor is capacity invariant, and trends in complexity factors change slowly over time, making their application suspect" (Gary *et al*, 2007). Parametric estimating is based on the use of cost estimating relationships which are mathematical equations that relate costs to one or more variables of a product. It is therefore, paramount that accurate historical data from previous similar projects, in terms of attributes and technology are required.

2.3.5 Design To Cost (DTC)

Roy (2003) states that the goal of design to cost (DTC) is to make the design satisfy an acceptable cost, rather than letting the cost satisfy design parameters. Furthermore, design to cost activities during the conceptual and early stages, require establishing the trade-offs between cost and performance for each of the concept alternatives. It is opined that DTC can produce huge savings on product costs before the commencement of production. Durairaj, *et al* (2002) suggest that design to cost methodology has a process of selecting a system design. This process is divided into the following functions: Derivation of system performance; Evaluation of system costs; and Presentation of results and decision-making. Figure 2.9 illustrates an example of the types of input required for producing a DTC tool.

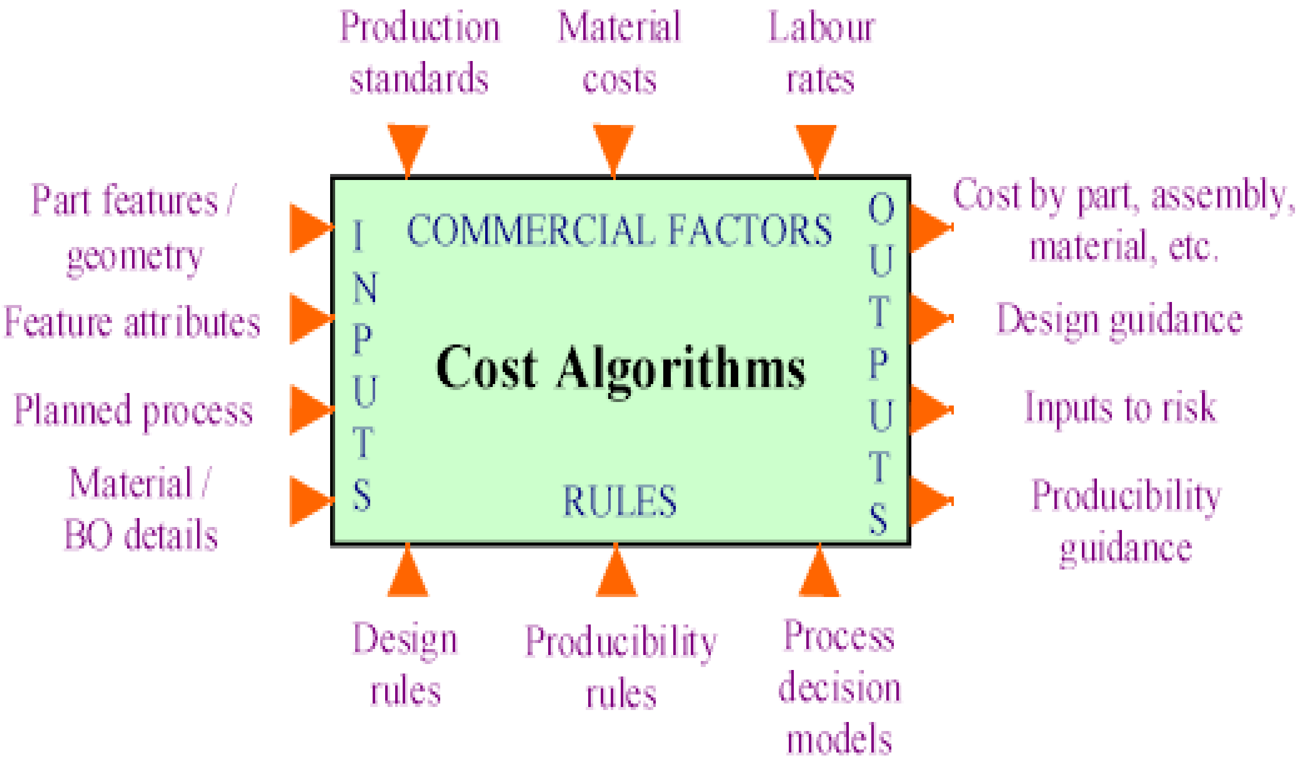

Figure 2.9 DTC model (Rush and Roy, 2000)

2.3.6 Estimating by Analogy

In estimating by analogy, as the name implies, the estimator draws comparison between different products or their attributes (Korpi and Ala-Risku, 2008). It could be implemented based on system level or on task level. Roy (2003) asserts that like products have similar costs. The technique requires the similarities and differences of items to be compared. The estimating process could be accomplished through the estimator's experience or via historical products databases. This estimating technique is appropriate for new products when there is paucity of data. The most prominent setback of estimating by analogy is the high degree of judgment required. Case-based reasoning is a technique which was developed from analogy based estimation. Table 2.2 indicates the types of estimating techniques used during the product life cycle.

Table 2.2 Cost Estimating Techniques and Product Life Cycle (Roy, 2003)

Matrix indicates which estimating technique is best used during the product life cycle					
TOOLS AND PROCESSES USED WHEN:	**PE**	**NN**	**CBR**	**ABC**	**Detailed Cost Estimation**
Concept design phase (innovation)	✓	✗	✓	✗	✗
Concept design (similar products)	✓	✓	✓	✗	✗
Feasibility studies	✓	✓	✓	✗	✗
Project definition	✓	✓	✓	✗	✗
Full scale development	✗	✗	✗	✓	✓
Production	✗	✗	✗	✓	✓
Key: PE – Parametric Estimating; NN – Neural Network; CBR – Case-Based Reasoning; ABC – Activity-Based Costing					

2.4 Life Cycle Costing

As a formal and applied discipline, life cycle costing was formally adopted as a tool for economic analysis by the US Department of Defense in the 1970s (Kawauchi and Rausand, 1999). Since then it has progressed into other industries (Figure 2.10) such as aerospace, power plants, oil and gas, railways, and building construction (Woodward, 1997; Kawauchi and Rausand, 1999; Carruba *et al*, 1992; Vega *et al*, 1998; Dougan and Reilly, 1993; Prescott, 1995). Along with this movement, the scope of LCC has evolved. Today, life cycle costing methods concentrating on one or a combination of life cycle stages can be seen (Sherif and Kolarik, 1981) where the life cycle could have two sequential users. Here, each user, whether manufacturer or user oriented, controls only a portion of the actual life cycle of the system.

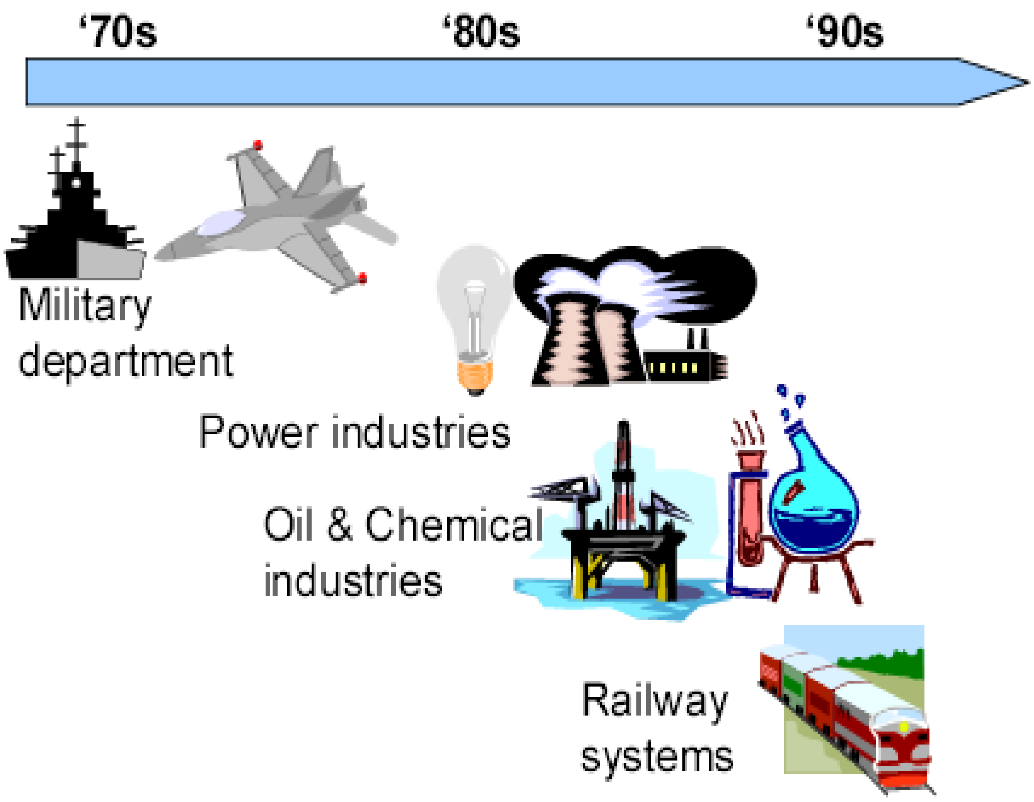

Figure 2.10 Development of LCC Applications (Kawauchi and Rausand, 1999)

2.4.1 Life Cycle Stages

The application of life cycle costing (LCC) needs the clarification of a basic concept, namely the "Life Cycle". Life cycle symbolises a lifetime and is an estimated variable, not a constant (Gluch and Baumann, 2004). Life cycle is the period over which all the life cycle costs of asset ownership are estimated (Thabit, 1984). Durairaj, *et al* (2002) defines life cycle stages as "the physical sequence of unit processes across the life cycle". According to the definition made by the US Department of Defense (2008) with respect to the conceptual framework of life cycle costing, the life cycle stages correspond to all the stages that went by, from the moment an item is first developed until the moment it is useless. International Electro-technical Commission (IEC 60300-3-3: Standards, 1996) defines "life cycle as a time interval between a product's conception and its disposal". Asset Management PAS 55-1 (2008) defines life cycle as "a time interval that commences with the identification of the need for an asset and terminates with the decommissioning of the asset or any associated liabilities".

2.4.1.1 Product life cycle

It is essential to note that different kinds of life cycle are considered in life cycle costing (Gluch and Bauman, 2004). Emblemsvag (2003) corroborated by stating three different life cycle perspectives often considered by decision-makers depending on their interpretation of the term 'life cycle'. He states that a marketing executive will think in terms of the *marketing perspective,* which consists of four stages:

- Introduction
- Growth
- Maturity
- Decline.

That a manufacturer will consider the *production perspective,* which consists of five main stages:

- Product conception
- Design
- Production and process development
- Production
- Logistics

When the product has reached the customer (user or consumer) a different *customer perspective* will be considered. This perspective includes five stages:

- Purchase
- Operating
- Support
- Maintenance
- Disposal

In view of the fact that the price the customer pays equals the cost to the manufacturer plus profit (add-on), the life cycle costs of the customer perspective will frequently be the most complete. Moreover, oftentimes it is true that the customer perspective incorporates the most costs in relation to infrastructure than in relation to any other type of service.

The product life cycle is all activities that the product undergoes without specific attention to which decision maker is involved (Emblemsvag, 2003). Fabrycky and Blanchard (1991) suggested a product life cycle (Figure 2.11) that establishes the need for the product in the first instance. It is believed that the recognition of a need for the product will definitely initiate a conceptual design activity that will satisfy that need.

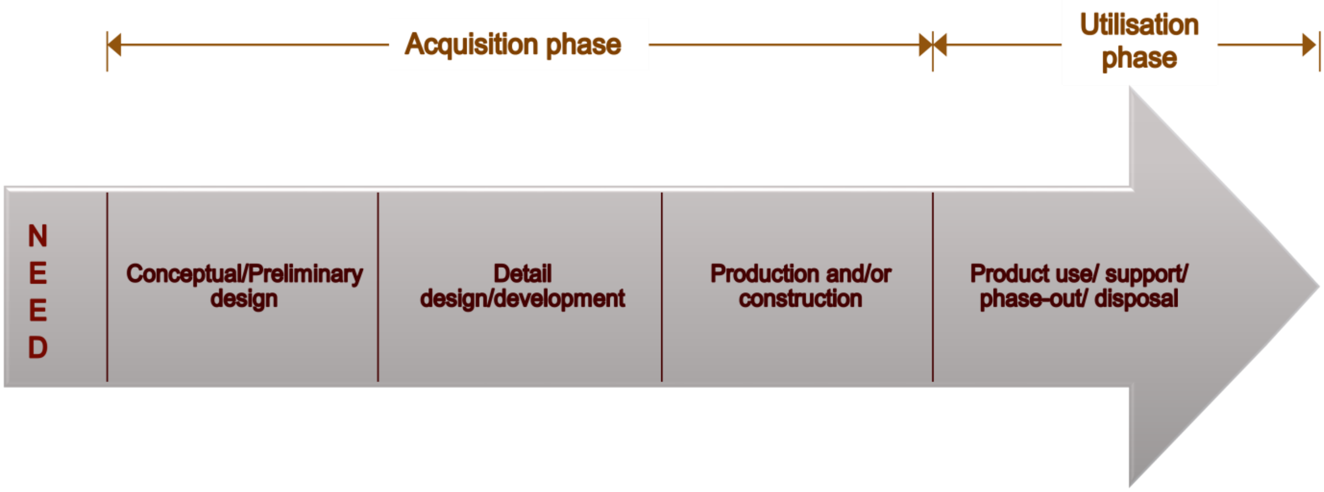

Figure 2.11 Product life cycle (Fabrycky and Blanchard, 1991)

Rosselot and Allen (2000) proposed a framework that incorporates both product and process life cycle stages. They state that a 'product life cycle' commences when raw materials are gotten and taken through the normal manufacturing steps until the product is delivered to the customer. The product will then be disposed of or recycled after use. The 'process life cycle' commences with planning, research and development, and thereafter the process is designed and constructed. It will have an active lifetime after which it will be decommissioned or if necessary restored or recycled. Figure 2.12 shows that the 'product life cycles' are represented along the horizontal axis, while the 'process life cycles' are shown along the vertical axis.

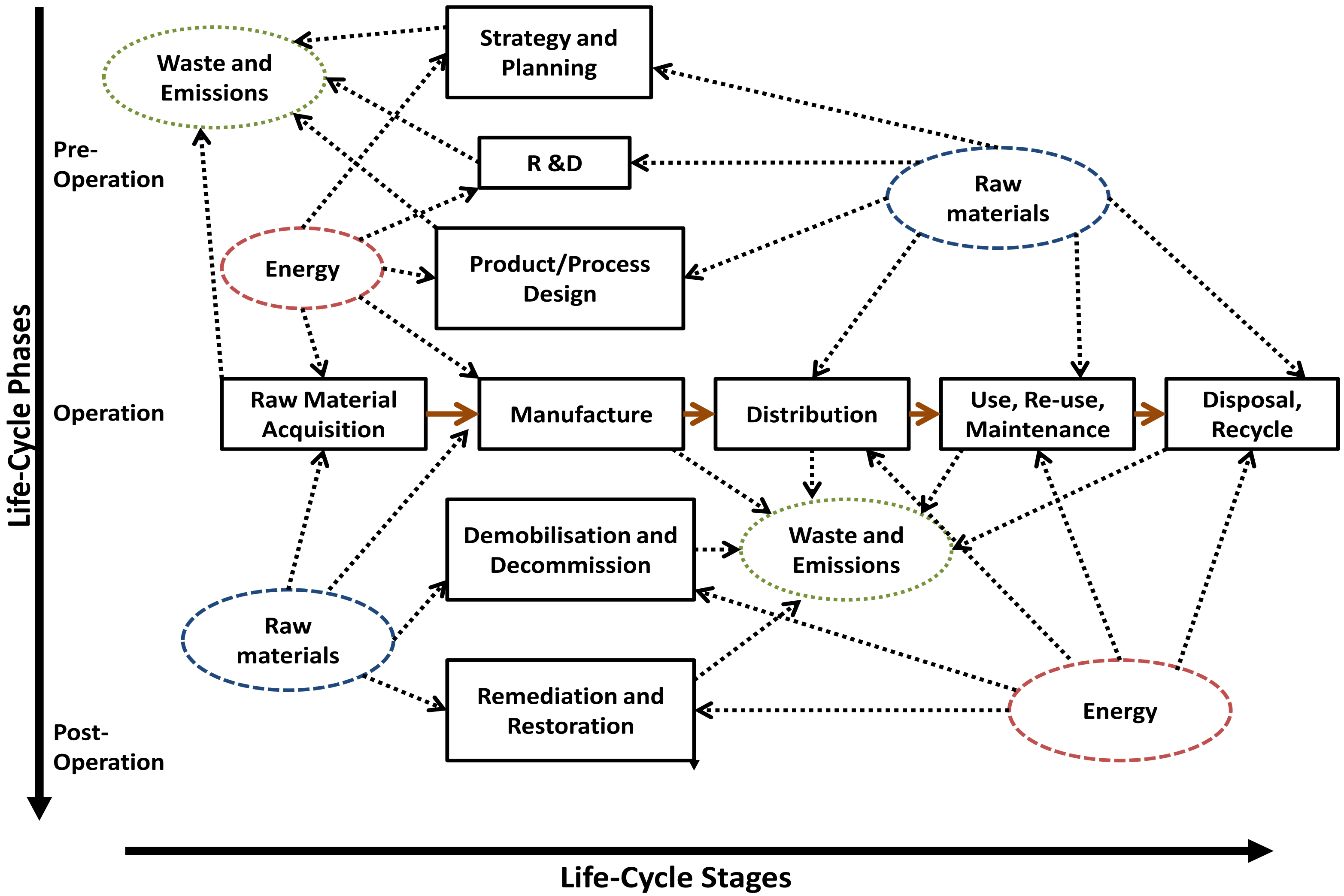

Figure 2.12 Product and Process Life Cycles (Rosselot and Allen, 2000)

A review of life cycle stages proposed by some authors will definitely give an insight into what is to be adopted or modified in order to develop a unique life cycle stages for an oil refinery. Moreover, life cycle stages can be customised to the need of a particular life cycle costing requirement.

The four models proposed for review are:

2.4.1.2 UK Ministry of Defence (MOD) Life Cycle Stages

The United Kingdom Ministry of Defence-MOD (Arnold, 2005) used the Concept, Assessment, Development, Manufacture, In-Service, and Disposal (CADMID) life cycle stages to optimise the delivery of equipment capability within agreed performance, time, and cost parameters. The CADMID life cycle includes:

Figure 2.13 UK MOD CADMID Life Cycle

- Concept: This stage includes a statement of the customer's requirement
- Assessment: The identification of risk at this stage will result in a balanced performance, time and cost.
- Development: This stage states the progressive reduction of risk and fixing of performance targets for manufacturing.
- Manufacture: This stage includes the delivery of solution that suits military requirement.
- In-Service: The in-service stage provides effective supports and delivery of agreed upgrades.
- Disposal: Disposal stage considers the safe disposal of the product or equipment.

CADMID was developed as part of the smart procurement initiative adopted by MOD to improve the way MOD acquires its defence capability. This type of life cycle involves one system user who controls the entire life cycle. The user maintains control of the system from its inception to its retirement.

2.4.1.3 Asset Management ‘PAS 55 – 1:2008’ Life Cycle Stages

The Asset Management life cycle includes:

Figure 2.14 Asset Management ‘PAS 55 – 1:2008’ Life Cycle

The Asset Management ‘PAS 55 – 1: 2008’ tends to cover the life cycle management of assets and in particular, the assets that are core to an organization’s objective, such as utility networks, railway and road systems, power stations, oil and gas installations, manufacturing and process plants, buildings and airports. ‘PAS 55 – 1: 2008’ states that delivering the best value for money in the management of physical assets is complex and entails careful consideration of the trade-offs between performance, cost and risk. Consequently, Asset management ‘PAS 55 – 1: 2008’ is a generic life cycle for the management of all physical assets. It is therefore, not tailored to any particular life cycle costing requirement.

2.4.1.4 System Engineering and NATO/RTO Life Cycle Stages

At a stage in NATO’s life cycle, a decision has to be made either to develop new systems or purchase commercial-off-the-shelf (COTS) systems in order to fill capability gaps (NATO/RTO, 2009). Consequently, NATO through the AAP – 48: Life Cycle Stages and Processes suggested ISO 15288 System Engineering – System Life Cycle Process for separating the life cycle into the following stages:

Figure 2.15 System Engineering and NATO/RTO Life Cycle

Each stage needs a different technique in conducting life cycle costing.

- Concept: This stage commences with a decision to fill a capability gap with military weapons solution and terminates with the statement of a need.
- Development: The development stage is conducted to develop a 'system of interest' that will accomplish the user requirements and can be manufactured, tested, appraised, operated, maintained and disposed.
- Production: This stage is conducted to manufacture the product, test and produce related enabling systems as required.
- Utilisation: This stage is conducted to operate the product at an agreed operational site. The product at this stage should be able to deliver the needed services with sustained operational and cost effectiveness.
- Support: This stage provides logistics, maintenance, and support services that will assist the product maintain operational and sustained service. The support stage terminates with the retirement of the product.
- Retirement: This stage commences with the removal of the product and related operational and support services.

  The purpose of the above-mentioned life cycle stages is to familiarise users on the application of life cycle costing of individual weapon systems, system of systems, and military business software (NATO/RTO, 2009).

2.4.1.5 Petroleum & Natural Gas Industries-Life Cycle Stages (EN ISO 15663-1&2: 2006)

Petroleum and Natural Gas Industries EN ISO 15663-1&2: 2006 separated the life cycle of offshore and upstream facilities into the following stages:

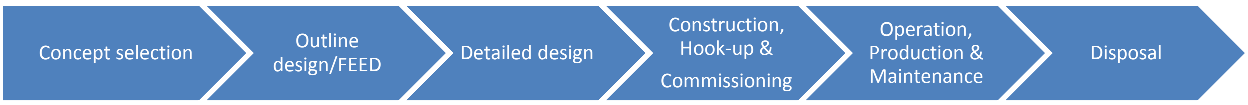

Figure 2.16 Petroleum & Natural Gas Industries (EN ISO 15663-1&2: 2006) Life Cycle

- Concept selection: This stage includes overall comparison of the main technical options. Processing, delivery, procurement options (lease or purchase) and the options for operation and maintenance are considered at this stage.
- Outline design/FEED: this stage includes the review of the technical options for facilities, processes and delivery resulting in the definition of a preferred technical

solution. Sizing and scoping the required utilities are considered at this stage. Overall layout, weight and dimensions are fixed on completion of outline design.

- Detailed design: The level of work at this stage includes system and equipment optimization with the limits defined during outline design.
- Construction and Commissioning: The level of work at this stage involves support to change control. The project managers should be able at this stage to assess the effect of concessions on the overall support costs.
- Operation and Maintenance: The level of work at this stage includes support for wide range of studies spanning all areas of oil well facility operation and maintenance. Where major modifications are considered, this will then be used as reference to the issues under concept, outline design, detailed design and construction/commissioning.
- Disposal: The work at this stage includes investigation of when and how all or part of the asset will be decommissioned and disposed.

The Petroleum and Natural Gas Industries life cycle focuses attention on acquisition and ownership of alternative options required to fulfil an oil and gas offshore/upstream asset need.

2.4.2 Life Cycle Costing Methodologies

Before a critical review of the various life cycle costing methodologies, it is essential to analyse some popular life cycle costing definitions as stated in Table 2.3 as this will create the background for a better understanding of the methodologies to be reviewed.

Table 2.3 Life Cycle Costing Definitions and References

	Reference	**Definition of Life Cycle Costing**
1.	Waghmode, *et al* (2010)	Life cycle costing (LCC) refers to “all the costs that will be incurred over the whole life cycle of a single product”.
2.	NATO/RTO Publication (2009)	Life cycle costing (LCC) is “the discipline or process of collecting, interpreting and analysing data and applying quantitative tools and techniques to predict the future resources that will be required in any life cycle stage of a system of interest”.

3.	Buildings and Constructed Asset Standards: ISO-15686-5 (2008)	Life cycle costing (LCC) is “a technique which enables comparative cost assessment to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial costs and future operational costs”.
4.	Petroleum and Natural Gas Industries-Life Cycle Costing EN ISO 15663 – 1&2 (2006)	Life cycle costing (LCC) is “the systematic consideration of the difference between costs and revenues associated with the acquisition and ownership of alternative options required to fulfil an asset need”.
5.	Singh and Tiong (2005)	Life cycle costing (LCC) is “a technique for determining the most effective capital investment option for achieving technical-economic optimization of a structure/system”.
6.	Vorarat and Al-Hajj (2004)	Life cycle costing (LCC) is “an evaluation technique for choosing between alternative options taking into consideration all costs from initial investment costs to subsequent maintenance and operating costs through to abandonment”.
7.	Rebitzer and Hunkeler (2003)	Life cycle costing (LCC) is “a cost management method with the goal of estimating the costs associated with the existence of a product”.
8.	Barringer (2003)	Life cycle costs (LCC) “are cradle to grave costs summarized as an economic model of evaluating alternatives for equipment and projects”.
9.	Durairaj, *et al* (2002)	Life cycle cost analysis (LCCA) may be defined as “a systematic analytical process for evaluating various designs or alternative courses of actions with the objective of choosing the best way to employ scarce resources”.
10.	Kirk and Dell’Isola (1995)	Life cycle costing (LCC) is “a type of investment calculus used to rank different investment alternatives”.
11.	Government Asset Management Committee, LCC Guideline (2001)	Life cycle costing (LCC) is “the total cost throughout an asset’s life, including planning, design, acquisition and support costs, and any other costs directly attributable to owing or using the asset”.
12.	Society of Automotive Engineers (SAE) (1999)	Life cycle costing (LCC) is “the total cost of ownership of machinery and equipment, including its cost of acquisition, operation, maintenance, conversion, and/or decommission”.

13.	Blanchard and Fabrycky (1998)	Life cycle cost (LCC) refers to "all costs associated with the product as applied to the defined life cycle".
14.	Woodward (1997)	Life cycle costing (LCC) is "concerned with optimising value for money in the ownership of physical assets by taking into consideration all the cost factors relating to the asset during its operational life".
15	IEC-60300-3-3: International Electro-technical Commission (1996)	Life cycle costing (LCC) is "the process of economic analysis to assess the life cycle cost of a product over its life cycle or a portion thereof".
16.	Dahlen and Bolmsjo (1996)	Life cycle costing (LCC) is "a method of analysis used when quantifying the costs related to a production system or a product during its life cycle".
17.	Spitzer and Elwood (1995); Henn (1993)	Life cycle costing (LCC) is "the summing up of total costs of a product, process or activity discounted over its lifetime".
18.	Executive Order 12873 "Federal Acquisition, Recycling and Waste Prevention" (1993)	Life cycle costing (LCC) is "the amortized annual cost of a product, including capital costs, installation costs, operating costs, maintenance costs, and disposal costs discounted over the lifetime of a product".

Considering the foregoing definitions of life cycle costing (LCC), the one that is as valuable as any and aptly defined than most is ***"Life cycle cost refers to all costs associated with the product as applied to the defined life cycle"*** (Blanchard and Fabrycky, 1998). The aforementioned definition of Blanchard and Fabrycky (1998) seems more pungent and may serve as a common denominator for all other definitions of life cycle costing.

Life cycle cost of a product being the total cost incurred over its life cycle means that acquisition cost is only a tip of the iceberg. Hence, a larger portion of the iceberg that relates to other costs (ownership cost) associated with the product is hidden beneath the waters (Barringer, 2003). Figure 2.17 is a representation of life cycle cost comprising of acquisition cost and ownership cost.

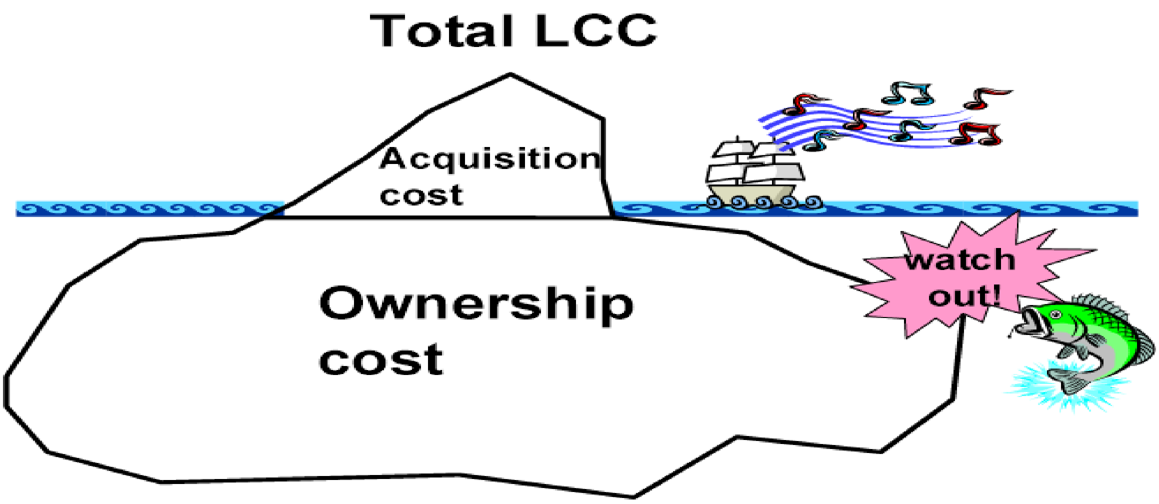

Figure 2.17 Life cycle costing consisting of acquisition cost and ownership cost (Kawauchi and Rausand 1999)

The goals of life cycle costing (LCC) as expressed by Woodward (1997) are:

- To enable investment options to be more effectively evaluated.
- To consider the impact of all costs rather than only initial capital costs.
- To assist in the effective management of completed projects.
- To facilitate choice between competing alternatives.

Life cycle costing follows a process and for the purpose of this research, the author will be reviewing seven (7) life cycle costing methodologies. The review will be conducted in two stages. The first stage will involve the analysis of the methodologies. Second stage will present a comparison of the elemental features of each methodology. This is essential because even if the methodologies follow the life cycle costing principle, they may differ in their approaches.

The methodologies to be reviewed are:

2.4.2.1 Life Cycle Costing Methodology of Fabrycky and Blanchard (1991)

Fabrycky and Blanchard (1991) suggested a holistic life cycle costing method to take care of detailed cost analysis of the costs associated with the entire life cycle of any product. Generally, they divided the total cost of a product or a system into four categories, namely:

- Research and development costs;

- Production and construction costs;
- Operation and maintenance costs; and
- Retirement and disposal costs.

The ten basic steps in their methodology are illustrated in Figure 2.18

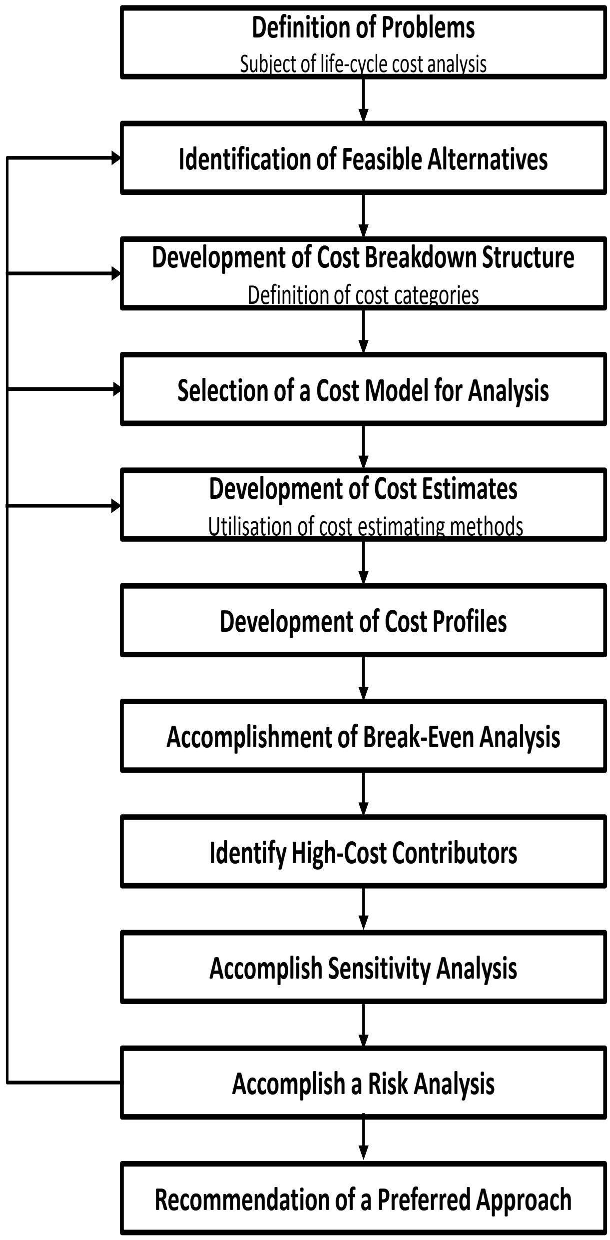

Figure 2.18 Life Cycle Costing Methodology (Fabrycky and Blanchard, 1991)

This methodology encompasses all basic features that can be used to analyse a life cycle as well as evaluate the total cost of any product. The methodology addresses a variety of issues at different stages of the system's life cycle. Its product life cycle in Figure 2.11

created a cost emphasis by the establishment of statement of need (design to requirement). The methodology can be properly applied to assess the capability of an existing system by the identification of cost drivers and expensive problem areas. Life cycle cost analysis is iterative, ongoing and should be customised to the specific application. For instance, with a little modification to this methodology's conceptual LCC model, an oil refinery upgrading may include the cost of additional units into its cost breakdown structure (CBS) because of the methodology's conformity with the usual steps to be followed irrespective of applications.

2.4.2.2 Life Cycle Costing Methodology of the Labour Factor by Dahlen and Bolmsjo (1996).

Life cycle costing can also be used to quantify the total costs of a production system from the point of view of the life cycle of investments in production equipment or product development. But the costs for labour under this circumstance are generally treated casually (Dahlen and Bolmsjo, 1996). Consequently, this methodology intends to expand the area of application to include analysis of investments done when increasing the production factor (labour). It includes the cost of an employee over the whole employment cycle, from recruitment to retirement. Estimating the costs of labour for an employee can be presented in a similar fashion as the costs over the life of production equipment. These personnel costs can be divided into three basic categories, namely:

1. **Employment costs:** The employment costs can be divided into three major sub-categories:
    - Recruitment costs
    - Additional (surplus) production costs
    - Education costs.
2. **Operation costs:** When an employee is acquainted with the work tasks, the costs tend to decrease towards a level comprising the following operation costs:
    - Wages
    - Overheads
3. **Work environment costs:** When the work becomes repetitive and is connected to static stress, the employee might be worn out just as the machine after sometime.

This situation can affect attendance and the number of work injuries, and there may be need for disability pensions that will increase the company's wage bill. The work environment costs include:

- Costs of absence
- Sickness benefits
- Rehabilitation costs
- Disability pension costs.

The aforementioned costs must be grouped according to the original cause of the cost in order to have control over their values. The allocation of all costs to their cost units on a proper allocation basis should be accomplished. Thereafter, an evaluation method where the costs are related to activities will be established to include some cost drivers. High cost contributors (cost drivers) for labour related costs may be labour hours, the number of employees, absenteeism, or the number of work injuries. The methodology's attention on the labour related costs for a production system may widen its field of application to include important industrial decisions.

2.4.2.3 Life Cycle Costing Methodology of Woodward (1997)

The objective of this methodology is to plan and monitor assets throughout their entire life cycle. This methodology concerns the optimisation of value for money in the ownership of physical assets. It considers all the cost factors relating to the assets during their operational life. Consideration of the trade-off between the cost factors will result in minimum life cycle cost of the asset. This procedure involves the evaluation of costs on a whole life basis before making a choice to procure an asset from the available alternatives (Woodward, 1997). A long-term outlook to the investment decision-making process is encouraged through this approach.

This methodology consists of eight (8) steps, namely:

1. **Establishment of operation profile (OP):** This describes the periodic cycle the equipment will undergo, and indicates when the equipment will and will not be working. It involves the start up, operating and shut down modes.

2. **Establishment of utilisation factors:** These factors show in what way the equipment will be functioning within each mode of the operating profile. Hence, even within the operating mode, the equipment might not be working continuously.
3. **Identification of all the cost elements:** This implies that every cost element must be identified through the development of a cost breakdown structure (CBS).
4. **Determine the critical cost parameters:** These are factors that control the degree of costs incurred during the life of the equipment e.g. MTBF, MTTR, energy use rate, etc.
5. **Calculation of all costs at current prices:** This implies that all costs should first be calculated at current rates.
6. **Escalation of current costs at assumed inflation rates:** All costs should be projected forward at appropriate inflation rates. The problem of projecting such costs should not be ignored, since lack of precision can lead to inaccurate calculations.
7. **Discounting of all costs to the base period:** In the recognition of the time value of money concept, all cash flows occurring at different time periods should be discounted back to the base period to ensure comparability.
8. **Summing up discounted costs to establish the net present value (NPV):** Adding up all the cash flows will allow the life cycle cost of the asset to be established.

The aim of this methodology is to enable investment options to be more effectively evaluated by the consideration of the impact of all costs rather than only the initial capital costs. It could assist in the effective management of completed projects, and would facilitate choice between competing options. This methodology aims to optimise the total costs of asset ownership, by identifying and estimating all the important net outlays that will arise during the ownership of an asset. The examination of trade-offs between different cost areas will ensure the best possible result in the selection, use and replacement of physical assets. Nevertheless, the applicability of the methodology depends upon accurate, relevant and timely information. However, the methodology is restricted in scope to the optimisation of value for money in asset ownership.

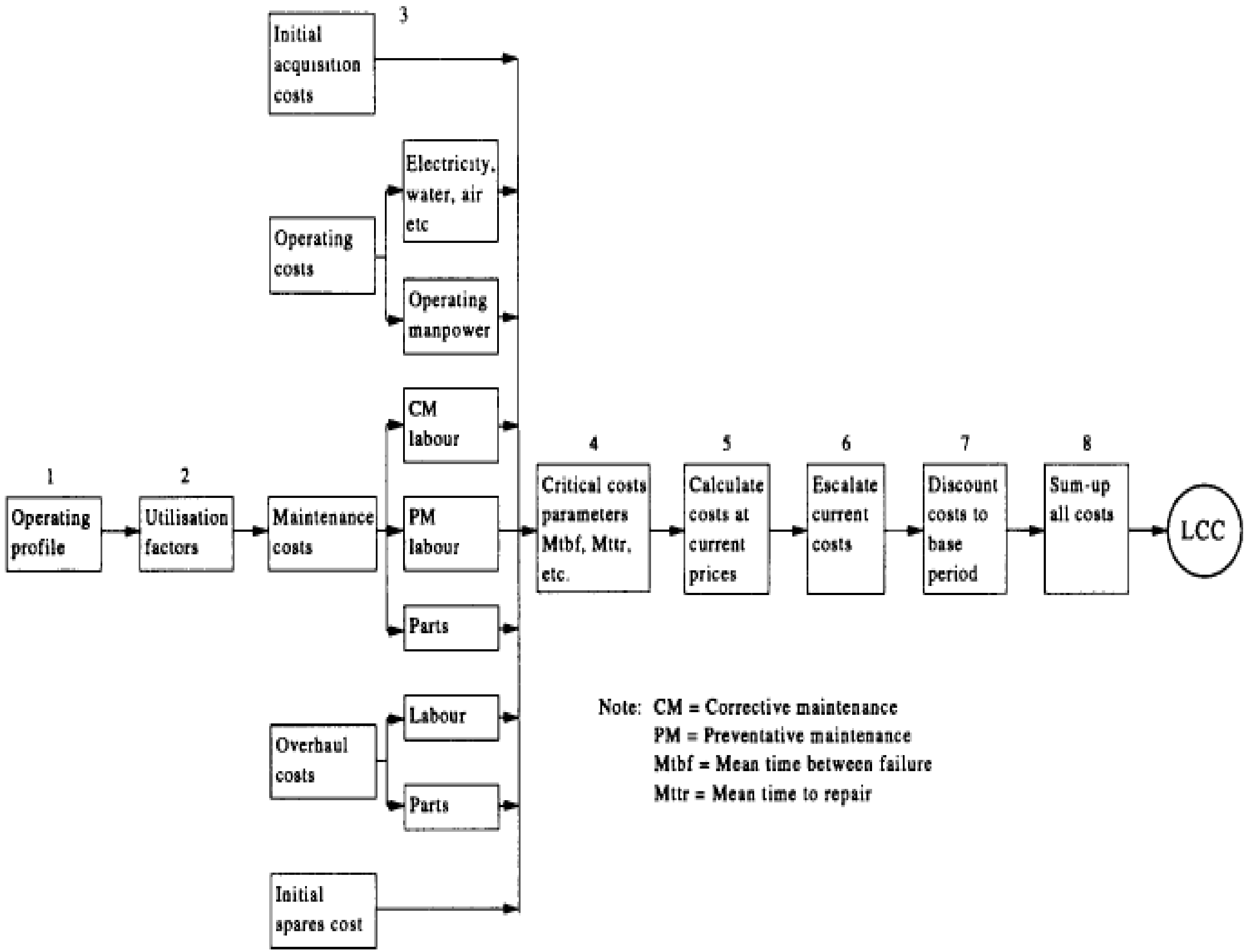

Figure 2.19 Life Cycle Costing Methodology (Woodward, 1997)

2.4.2.4 Life Cycle Costing Methodology of Kawauchi and Rausand (1999)

Kawauchi and Rausand (1999) suggested a sample of cost categories in their methodology that may be applicable in the evaluation of the costs associated with various systems including oil and chemical process assets. The cost category definition was proposed with reference to some cost breakdown structures. Generally, they divided the total cost of a system into three categories, namely:

- Life acquisition cost (LAC)
- Life ownership cost (LOC)
- Life loss cost (LLC).

The authors observed that all life cycle costing methodologies are not the same due to differences among the products or assets analysed. Consequently, they decided to review some common steps which seem to be vital in all the proposed methodologies they investigated (IEC 60300-3-3, 1996; ISO 15663-Draft, 1999; NORSOK:0-CR-001, 1996; NORSOK:0-CR-002, 1996; SAE ARP 4293,1992; Fabrycky and Blanchard, 1991; Greene and Shaw, 1990; Blanchard and Fabrycky, 1998; Clarke, 1990) and came up with six (6) basic steps of LCC methodology as stated below:

1. **Problems definition:** The initial step of any life cycle costing analysis is to clearly state the problems and the scope of the work.
2. **Cost elements definition:** It is essential to identify all cost elements that will influence the total life cycle cost of the system.
3. **System modelling:** There is a need to develop a model that can quantify the cost elements within a life cycle costing analysis. To develop a model means to discover appropriate relationship among input parameters and the cost elements.
4. **Data collection:** Input data accuracy is crucial in order to improve the certainty of any life cycle costing prediction. Data collection is required to identify the requirements and reliability of input data. Where actual data is not available, the cost elements relevant to the unavailable data could be estimated using expert opinions and judgments.

5. **Cost profile development:** The development of a cost profile is essential in any LCC analysis. A cost profile is achieved by running the developed cost models with input data. This could be done manually with a simple standardised spreadsheet or by the application of a net present value (NPV) formula that will take into account the time value of money.
6. **Evaluation:** This involves the selection of the most desirable system configuration among the alternatives evaluated.

The summarised basic steps are illustrated in Figure 2.20 as a concept map with each basic step further broken down into sub-activities that are incorporated into the life cycle costing analysis.

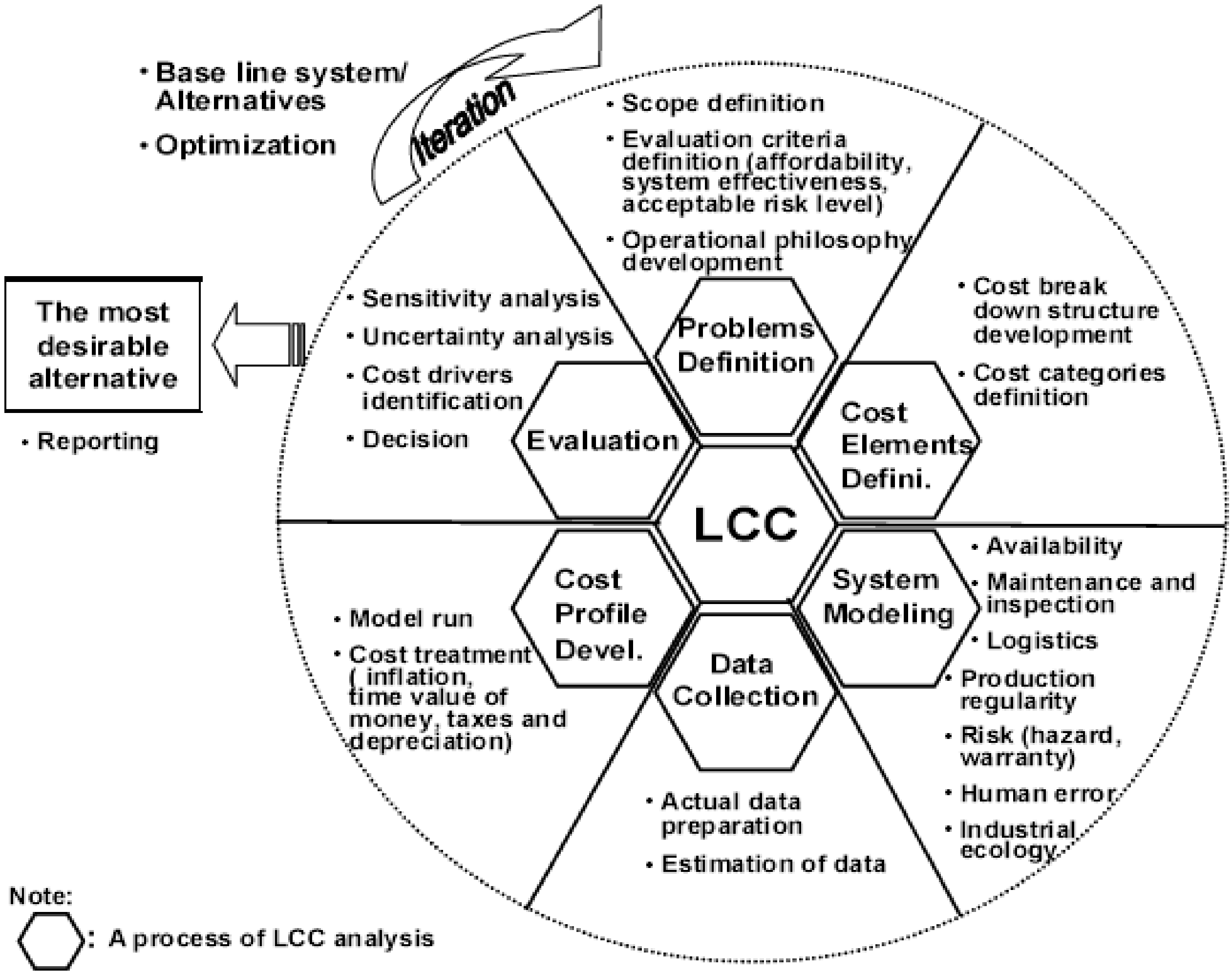

Figure 2.20 A LCC Concept Map (Kawauchi and Rausand, 1999)

These steps are iteratively carried out in a clockwise manner as long as the system has not satisfied the criteria defined in the first process. This methodology includes all the basic steps and features of a complete methodology that could be used to evaluate the life cycle and determine the total cost of any product or asset.

2.4.2.5 Life Cycle Costing Methodology of Iwawaki *et al* (2002)

This methodology addresses the applicability of Activity-Based Costing (ABC) approach for the determination of the life cycle cost of Reactor Effluent Air Coolers (REAC), a component of a hydroprocessing unit in a refinery. This component is usually affected by wet ammonium bisulphide (NH_4HS) which causes corrosion. The authors' life cycle costing methodology of REAC using an activity-based costing approach consists of five (5) steps, namely:

1. **Definition of the scope of assessment:** The scope describes a REAC with a lifespan of 20 years, and the cost evaluation includes the purchasing cost, operation and inspection costs to support the REAC, and the estimation of loss due to accidents.
2. **Definition of the activities:** The following seven (7) categories of activities were considered for the life cycle cost analysis using activity-based costing:
    - Purchasing and construction costs
    - Radioactive Testing (RT) for tube in REAC (biyearly)
    - Ultrasonic Testing (UT) for Header in REAC (biyearly)
    - Tube replacement
    - Header replacement
    - Water injection
    - Installation of on-line and real-time corrosion monitoring.
3. **Determination of cost for each activity:** The costs of all the activities were defined and recorded as activity costs. The risk of passive damages or accidents were defined and included in the LCC calculation. The costs of the risks were defined as the frequency of accidents or leakages.
4. **Construction of cost model based on activity data:** The activity model for REAC operation was constructed using IDEFO language. IDEFO means "Integrated

DEFinition Methodology" and was developed as a description support language for middle complexity systems.

5. **Calculation of costs:** By the application of the above-mentioned activity model, all activities generated in each year for the 20-year operation of the REAC were calculated. Thereafter, the total activity cost generated for the 20 years operation was converted to present value with a 7% discount rate.

   The aim of this methodology is to explore the applicability of Activity-Based Costing in the evaluation of the life cycle cost of a refinery component. This methodology could be used to support decision makers in optimising the life cycle costs associated with operation and maintenance activities affecting some refinery components.

2.4.2.6 Activity-Based Life Cycle Costing Methodology of Emblemsvag (2003)

This methodology could be used to supply an efficient and effective decision support in life cycle design. Moreover, life cycle costing methods should have the ability to handle uncertainty. The methodology has the best potential for effective cost evaluation in the context of life cycle design. In circumstances where there is lack of data and the presence of unexpected activities, uncertainty conditions have to be used in this methodology. Furthermore, when handling environmental issues, uncertainty must be considered due to paucity of hard data.

The methodology is based on a 10-step programme that can be applied whenever the activities are described in detail. The steps are represented in Figure 2.21.

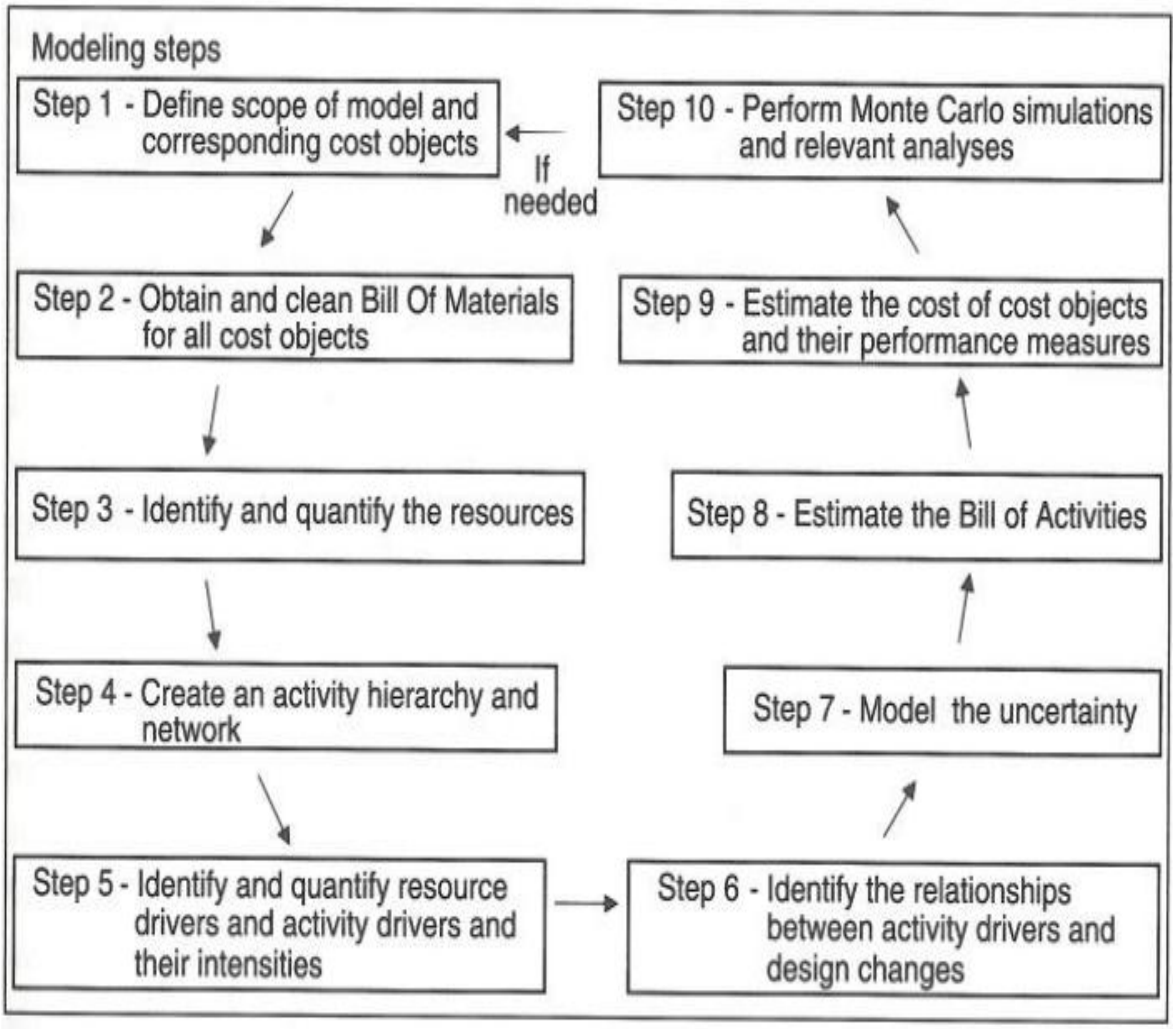

Figure 2.21 Activity-Based Life Cycle Costing Methodology (Emblemsvag, 2003)

The consideration of uncertainty and the application of the Monte Carlo simulation in conjunction with the steps provide the ability to identify the process and product design aspects that contribute most to the cost. Since this methodology can only be used whenever the activities are described in detail, it therefore means that it may not be easily adopted in conjunction with unique investments (e.g. an oil refinery) that require extensive activity-cost databases (Korpi and Ala-Risku, 2008). Emblemsvag (2003), the proponent of the methodology corroborated the aforementioned assertion by stating that "as a rule of thumb, it is therefore wise to avoid too many activities and drivers in the LCC model because the number of activities and drivers is the primary origin of data needs".

2.4.2.7 Life Cycle Costing Methodology for Petroleum and Natural Gas Industries (EN ISO 15663-1&2: 2006)

The aim of this International Standard is to provide guidance on the application of a life cycle costing methodology to be used in the evaluation of oil and gas offshore/upstream facilities. These include development and operation facilities for oil well drilling, oil production and offshore pipeline transportation. The methodology divides the total cost of an oil facility/system into three major categories, namely:

- CAPEX (capital expenditure)
- OPEX (operating expenditure)
- Revenue Impact: This involves the application of offshore reliability database (OREDA) to determine inventory data; operating data for calculating failure rates; failure event data; and maintenance data.

There are four basic steps in this methodology, and the steps with their sub-units are illustrated in Figure 2.22

The steps represent a number of tasks to assist the analyst in assessing the scope and scale of work to be undertaking. The methodology's process is iterative and could be repeated a number of times in any project. The repetition, however, is dependent on the outcome of the previous iteration.

The scope of this methodology is limited to life cycle costing applied to the estimating of cost difference between competing options. It is of value when decisions are to be taken in relation to new offshore investments in the oil and gas industry. The methodology is not concerned with determining the life cycle cost of individual equipment, since it will be vital to determine all costs associated with such equipment independently (EN ISO 15663-1&2: 2006).

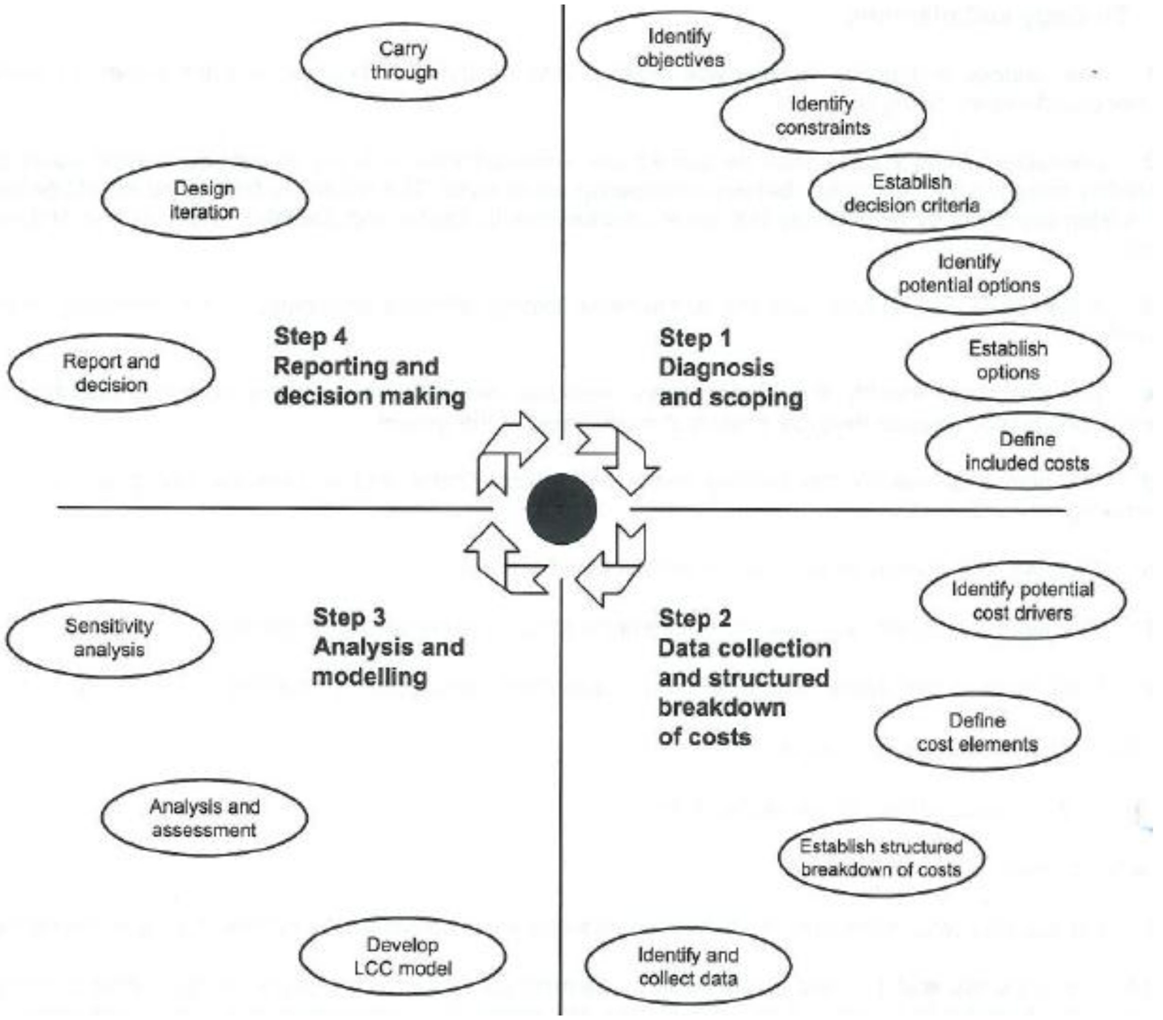

Figure 2.22 LCC Methodology for Petroleum & Natural Gas Industries (ISO 15663)

Having completed the first stage of the review (analysis of methodologies), the second stage which is the comparison of elemental features of each methodology is represented in Table 2.4. The choice of the elemental features is based on their relevance in the development of a complete life cycle costing methodology. Furthermore, the grades awarded in this comparison are defined on the basis of availability of the same feature in other methodologies. Grade “A” denotes availability and Grade “NA” denotes non-availability of any feature. The allocation of grades reflects the author’s own judgment on the basis of their assessment.

Table 2.4 Comparison of life cycle costing methodologies

No.	Features	LCC Method (Fab. & Blanchard.)	LCC Method (Dahl. & Bolms.)	LCC Method (Woodwd.)	LCC Method (Kawa. & Rausand)	LCC Method (Iwawaki *et al*)	Activity-Based LCC Method (Emblvg.)	LCC Method (EN ISO 15663)
1	Objective	Cost alternatives	LCC of labour	LCC of assets	Cost alternatives	Cost reduction	Cost reduction	Cost alternatives
2	Identification of alternatives	A	A	A	A	NA	A	A
3	Development of CBS	A	A	A	A	A	A	A
4	Generation of cost estimates	A	A	A	A	A	A	A
5	Development of cost profiles	A	A	A	A	A	A	A
6	Identification of cost drivers	A	NA	NA	A	NA	A	A
7	Determination of total cost	A	A	A	A	A	A	A
8	System effectiveness factors	NA	NA	A	A	NA	NA	A
9	Sensitivity analysis	A	A	A	A	NA	A	A
10	Risk analysis	A	A	A	A	A	A	A
11	Any special feature	Holistic method	Human factor	Asset method	Holistic method	Plant component	Uncertainty	Oil offshore facilities

Notes: A – Available; NA – Not Available.

2.4.3 Other Life Cycle Costing Tools

2.4.3.1 System Effectiveness

System effectiveness relates to the capability of a system to fulfil a defined requirement (Fabrycky and Blanchard, 1991). It is a function of availability, reliability, performance, maintainability, supportability, dependability, adaptability, readiness, flexibility, capacity, etc.

Engineering analyses may attract attention because systems fail, and they seldom fail on schedule (Emblemsvag, 2003). Consequently, life cycle cost analysis that ignores such issues (effectiveness attributes) will omit relevant costs and risks and thus present an erroneous reality. The life cycle cost of a product or system is closely associated to the effectiveness and efficiency of the product or system. This assertion is true for open complex systems that have long life span. In engineering-related life cycle costing, design engineers specifically focus on system effectiveness because they are the most important link in determining cost effective plants. However, they cannot conduct an effectiveness analysis unless they have reasonable failure data from plant operations (Barringer, 2003), thus the need for plant and industry databases of failure features. Moreover, accessibility of a good failure data requires the identification of both failure and success data.

Though, cost is a measure of resource, system effectiveness in an engineering sense is a measure of the value obtained (Emblemsvag, 2003).

2.4.3.2 Cost Trade-offs

Trade-off is the substitution of one cost element for another (Woodward, 1997; Taylor, 1981). The importance of optimising life cycle costs by substituting one cost element for another cannot be over-emphasised.

It is essential to note that the choice of option following an evaluation is not just a financial decision. Decision should be made after a comparison between several parameters viewed from different perspectives, e.g. financial (initial costs, future revenue, etc), engineering (reliability, maintainability, etc), and marketing (production capacity, flexibility, etc). Trade-offs could be introduced between the aforementioned considerations. For example, allocation of more money to design could reduce future operating and maintenance costs. The design stage is the most critical time in the determination of life cycle costs because making a wrong decision at this stage will be extremely expensive as 70-80% (Figure 2.23) of the total life cycle cost of a system is committed at this stage (Rush and Roy, 2000; Asiedu and Gu, 1998; Dowlatshahi, 1992; Park et al, 2002).

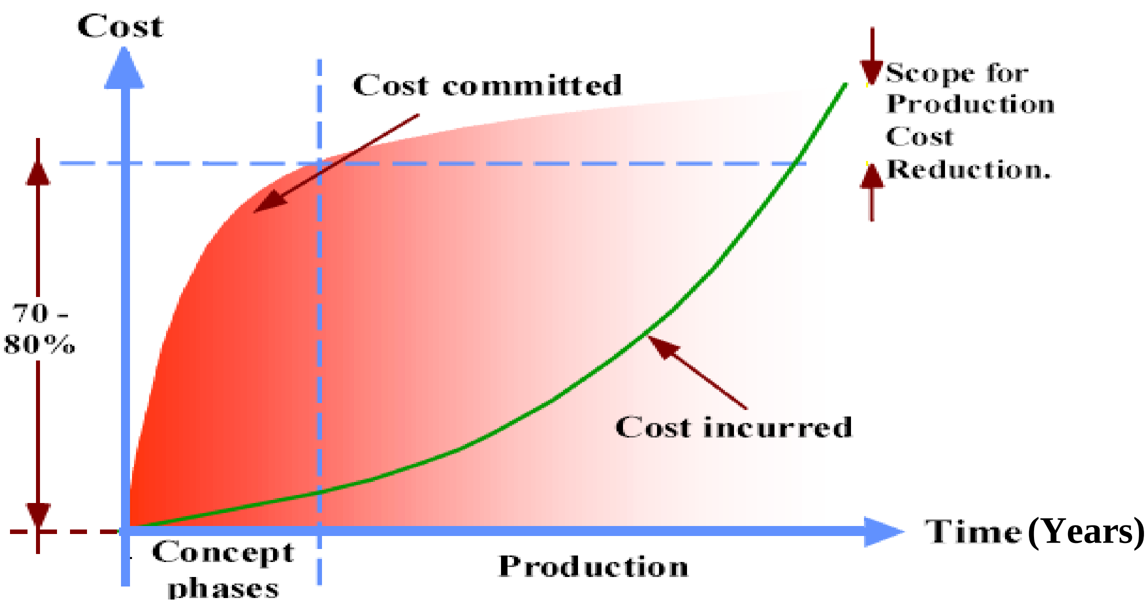

Figure 2.23 Cost commitment curve (Rush and Roy, 2000)

The following examples of trade-offs (Woodward, 1997) may be considered:

- Devote more resources to Research and Development stage to increase reliability and maintainability thereby reducing maintenance cost.
- Increase machine efficiency to reduce scrap.
- Spend more on automation (higher initial costs) leading to lower manning costs.

In spite of significant changes in design, past plant records of cost and performance (Figure 2.24) could also be used to obtain predictions for newly-acquired plants and to estimate trade-offs between the cost parameters. Hence, accurate records of the following variables become essential:

- Causes of downtimes;
- Reasons for damages;
- Maintenance periods and cost;
- Downtime and value of lost production;
- Production hours;
- Running hours;
- Spare usage and cost; etc.

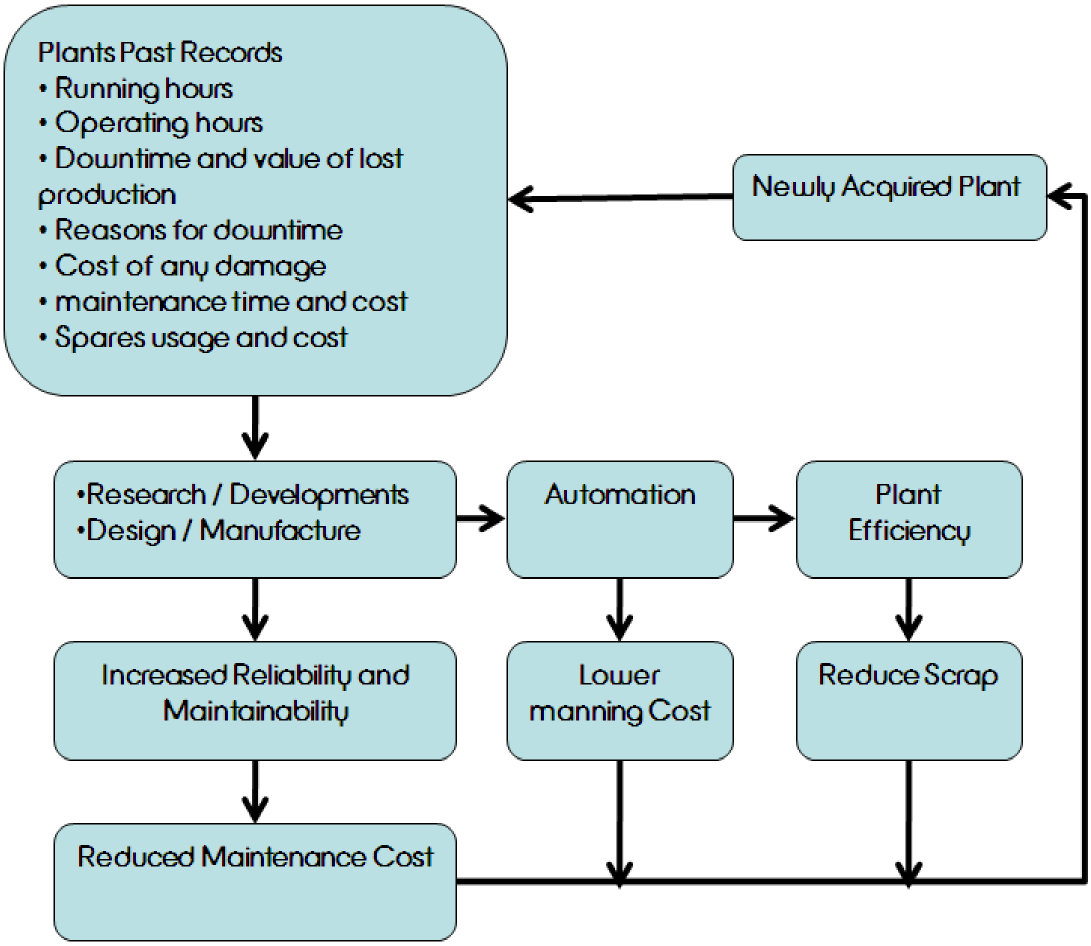

Figure 2.24 Proposed Framework for Cost Trade-offs

2.4.3.3 Discount Rates

"Discounting is a process for calculating the amount today that a sum of money in the future is worth using a specified discounting rate"(Boussabaine and Kirkham, 2004). Discounting translates asset life cycle costs into present value. In as much as the discount rate reflects the time value of money concept, it could be a real discount rate adjusted to remove the effects of inflation or a nominal discount rate adjusted to show expected inflation. Consequently, the choice of the correct discount rate depends on whether the costs and benefits are estimated in real or nominal terms. Hence, a real discount rate that has been adjusted to remove the impact of expected inflation should be used to discount constant life cycle costs. Deducting expected inflation from a nominal interest rate could equal a real discount rate. A nominal discount rate that shows anticipated inflation could be utilised to discount nominal life cycle costs.

Ellingham and Fawcett (2006) state that the notion of applying a discount rate is commendable and mathematically straightforward but like all mathematical methods, the answer you receive is a reflection of the assumptions you make. Hence, the critical assumption for life cycle costing is the value of the discount rate.

Woodward (1997) suggested some methodologies in arriving at an appropriate discount rate. This could be a discount rate:

- At the current or expected rate the organisation must pay for the use of borrowed funds;
- At the rate of return that could be anticipated from loaning of money, but which is denied to the organisation by the need to fund its own projects (sometimes referred to as the opportunity cost);
- At the lowest rate of industrial borrowing for a financially sound and well established company;
- At a test discount rate based on the assumption that when inflation rates are reasonably low there is a stable relationship between inflation and base rate, implying a real discount rate;
- For investments in long-term treasury bonds that can be assumed to have no risk, and therefore could be taken as the treasury bond rate less an allowance for the expected rate of inflation.

2.4.3.4 Life of an asset

The predicted life of an asset has a major impact on its life cycle analysis. Woodward (1997) suggested five possible determinants of an asset's life as:

- **Physical life:** The period over which an asset is expected to last physically, to when replacement or rehabilitation is required;
- **Functional life:** The period over which the need for an asset is expected;

- **Technological life:** The period until technical obsolescence determines replacement as a result of technological superior alternatives;
- **Economic life:** The period until economic obsolescence determines replacement with a lower cost alternative;
- **Social and legal life:** The period until human desire or legal requirement determines replacement.

Gluch and Baumann (2004) state that life cycle represents a lifetime and is a calculated variable, not a constant. They agreed with the aforementioned lifetimes of Woodward (1997) but suggested the inclusion of a 'utility life' which is the estimated time an asset can satisfy established performance standards.

2.4.3.5 Cost Breakdown Structure (CBS)

In accomplishing a life cycle cost analysis it is essential to develop a structural breakdown of cost showing the various categories that are considered to provide the total cost. There is no set rule for breaking down cost in as much as the method applied can be customised to a specific application (Vorarat and Al-Hajj, 2004). The level of breakdown and the cost categories included will depend on the life cycle stage, the nature of data to be extracted, data availability, and the product being designed/purchased (Asiedu and Gu, 1997).

Fabrycky and Blanchard (1991) argued that the CBS should be able to link objectives and activities with resources, and should include a logical subdivision of cost by functional activity area. They inferred that a good CBS should be able to display the following attributes:

- All life cycle costs should be considered and recognised in the CBS;
- Cost categories in the CBS must be well stated so that everyone concerned can have the same understanding of what is considered and what is not;
- Costs must be decomposed to a level necessary to give management the visibility needed in evaluating various aspects of the system;

- The cost breakdown structure (CBS) and the stated categories should be coded in a way to facilitate the analysis of specific areas of interest while ignoring other areas.

2.4.3.6 Reliability and Maintainability

Reliability and maintainability are system effectiveness attributes that are considered at the design stage. "Reliability is the probability that an item can perform a required function under given conditions for a given time interval" (Kawauchi and Rausand, 1999; Sheikh *et al*, 1990). "Maintainability is the probability that a failed item will be restored to its satisfactory operational state within a specified total downtime when maintenance action is started according to stated conditions" (Dhillon, 1989).

Mean-time-between-failure (MTBF) is the random variable in reliability just as mean-time-to-repair (MTTR) is the random variable in maintainability. It is essential to note that the choice of option following an evaluation is not just a financial decision. Decision is made after a comparison between several parameters viewed from different perspectives, e.g. engineering (reliability and maintainability), marketing (production capacity and flexibility), etc.

> ***"Reliability factors*** are used in the determination of maintenance frequencies. These are derived from plant's reliability prediction data. ***Maintainability factors*** are employed to determine personnel costs. These are derived from plant's maintainability prediction data"(Fabrycky and Blanchard, 1991). The motivation for improving reliability has been driven by a desire to reduce maintenance costs.
>
> **'HSB Solomon Associates LLC'** as a company offers a holistic approach to reliability and maintenance improvement. The company provides benchmarking and performance improvement services to the energy industry. It helps clients identify and close their performance gap in order to actualise the full margin potential of their assets.
>
> **Solomon's Performance Improvement Process (RAM)** could assist industrial plant owners to:

1. Decrease the probability of a catastrophic event that can be caused by a maintenance related shutdown or start-up;
2. Reduce maintenance downtime by focusing on the elimination of repetitive failures;
3. Minimise maintenance labour, material and overhead costs with a resultant increase in profits;
4. Increase production capacity without costly capital investment;
5. Achieve sustainable operational excellence through reliability and maintenance optimisation.

2.5 Research Gap Analysis

An extensive literature review shows that there are few life cycle costing applications in the oil and gas industry.

Petroleum and Natural Gas Industries – Life Cycle Costing Standard (EN ISO 15663 – 1&2: 2006) developed an exclusive methodology for the economic evaluation of oil and gas offshore facilities while Iwawaki *et al* (2002) presented a methodology for the evaluation of a generic refinery component (Reactor Effluent Air Coolers) using activity-based costing approach. But the development of a high level life cycle costing framework for the holistic evaluation of new, revamped, and maintenance of existing refinery complexes is yet to be established.

Furthermore, the comparison of the main features of the methodologies in Chapter 2, Table 2.4 shows that only a few of them incorporated some system effectiveness factors that could only be derived when the asset performance data is available. Researchers and authors (Kawauchi and Rausand, 1999; Vorarat and Al-Hajj, 2004; Singh and Tiong, 2005; Iwawaki *et al*, 2002) have emphasised the need for a life cycle costing framework that will not only consider total cost but also system effectiveness.

The main research gaps can therefore be summarised as:

- There is a lack of a high level life cycle costing framework for the holistic evaluation of new, revamped, and maintenance of the existing refineries.

- There is a lack of structured framework to determine the system effectiveness of new oil refineries in the absence of performance data.

Based on the current research gaps, it therefore, becomes apparent that there is a need to develop a comprehensive life cycle costing framework for the evaluation of not only the total cost and system effectiveness of new refineries, but also the revamping and maintenance of the existing refineries.

2.6 Summary

This chapter presented a detailed review of several concepts relating to life cycle costing and its applicability. Several areas were explored including oil refinery configurations, refining tools, current challenges in oil refinery technology, cost estimating techniques that could be used in life cycle costing analysis, product life cycle stages, life cycle costing methodologies, and several life cycle costing tools required for the successful accomplishment of any life cycle costing analysis.

However, it was identified that there is a lack of formal and comprehensive life cycle costing framework that could be utilised for the evaluation of new, revamped, and maintenance of existing refinery complexes. Furthermore, it was identified that there is a need for a life cycle costing framework that could evaluate system effectiveness when there is no performance data. The author will be addressing these key issues in the following chapters.

The next chapter will define the research objectives and methodology based on the research gaps identified from the literature review.

CHAPTER 3 RESEARCH AIM, OBJECTIVES AND METHODOLOGY

3.1 Introduction

The intention of this chapter is to give an account of how the research gaps identified in Chapter 2 led to the aim and objectives of the research as well as the reason for choosing a suitable research approach. Selecting an appropriate approach is vital in achieving accurate and reliable results. Furthermore, this chapter presents the procedure the author will adopt to ensure the validity of the study.

3.2 Research aim and objectives

The aim of this research is:

To develop a comprehensive life cycle cost estimating framework for the evaluation of not only the total cost and system effectiveness of new refineries but also the revamping, and maintenance of the existing refineries.

A number of objectives were defined with the purpose of fulfilling the above-mentioned aim of the study. These objectives are:

- To identify oil refinery configurations and technological challenges;
- To identify various life cycle costing methodologies;
- To define a conceptual life cycle costing model and cost breakdown structure for oil refineries;
- To identify high level cost drivers for oil refinery;
- To develop a life cycle cost estimating framework for oil refineries;
- To validate the framework with industry and academic experts.

The following section provides the research strategy leading to the formation of the research methodology of this study.

3.3 Research approaches

There are two main approaches to any research design: ‘quantitative’ and ‘qualitative’ (Gummesson, 1991). These approaches are also described as ‘fixed’ and ‘flexible’ design in some literature (Robson, 2002).

A quantitative approach is selected when the events of attraction are quantified (Robson, 2002). This means that the majority of the data upon which the analysis is based is in a numerical format. In quantitative approach the researcher is 'detached' to avoid influencing the research findings (Robson, 2002).

Conversely, Creswell (1998) defines qualitative research as: "an inquiry process of understanding based on distinct methodological traditions of inquiry that explores a social or human problem. The researcher builds a complex, holistic picture, analyses words, reports detailed views of informants, and conducts the study in a natural setting". The exploratory features of a qualitative research led to the evolution of research questions and ideas, and as the research develops the researcher tends to learn more about the research problem and the environment.

A major difference between quantitative and qualitative research is that quantitative researchers deal with fewer variables and plenty of cases, while qualitative researchers depend on a lot variables and few cases (Creswell, 1998).

3.4 Research Methodology

The purpose of reviewing the research approaches is to decide on a suitable strategy. Consequently, an exploratory study based on the qualitative research approach was adopted due to the nature of the objectives. Moreover, the research tradition for qualitative type of inquiry supported by a comprehensive literature review and industrial survey presented an appropriate approach to carry out the study. In consonance with the adopted approach, a research methodology was formulated as illustrated in Figure 3.1.

The methodology that will give a brief background to the ongoing efforts and plan of work consists of six (6) main phases, namely:

Phase 1: Literature Review

The purpose of this phase is to collect and critically review published works and data on current studies associated with life cycle costing issues in relation to oil refineries. It establishes the extent of existing knowledge in order to provide the background to the topic and to support the logic of the research. On completion of this phase, the scope of current theory and practice would have been identified. This, then, will be used as the basis for the definition of the research gap that requires further investigation and creation of new ideas.

Phase 2: Data Collection

Before going into specific details on the main output of the data received through the questionnaire and semi-structured interview, it is essential to summarise the approach taken in relation to this phase of the work. The intention of this phase is to select suitable setting in order to identify research issues and gaps. This would form the basis for developing new ideas on how to improve these areas. This stage also concerns the preparation of questionnaires and the conduct of semi-structured interviews with industry experts and professionals in the fields of cost engineering and oil refining technology. The information collected from the questionnaire and associated interviews should represent a vital aspect of this research. If this procedure is meticulously followed, the information obtained will enhance the development and the modification of the initial conceptual LCC model and its cost breakdown structure that will be integrated into the overall LCC framework for oil refineries.

The purpose of the questionnaire is to collect information needed to meet the goal of this research by taking into account the current life cycle costing practice in the oil refining industry. A comprehensive questionnaire was designed to define the main points to be addressed. Respondents were asked questions that are very much incidental to the proper understanding of life cycle costing issues and practice in their organisations. The data collected were examined in their field forms to ensure that they were complete, consistent and that the instructions issued were carefully followed. This examination of the collected data was aimed at getting rid of responses found to be inadequate for analysis.

The semi-structured interview was used in combination with the industry-based questionnaire because of the qualitative and exploratory nature of the study. The purpose of the semi-structured interview was to get feedbacks on the relevance of the cost categories in the LCC model, and to ascertain whether the cost items in the CBS are true representative of costs associated with the life cycle costing of oil refineries.

Phase 3: Data Analysis

This phase is concerned with analysing, comparing and evaluating the data gathered based on the questionnaire, conducted interviews and literature review. The information extracted from the aforementioned procedure will assist the author in the development of a life cycle cost estimating framework.

This phase presents the results of problems under investigation. To increase the accuracy of the results, the unwieldy data are meticulously edited, analysed and later categorised to bring out specific results. The analysis is mostly based on the computation of various percentages using pie charts. Pie charts were used to facilitate and highlight specific response comparisons. The questionnaire commenced with 'open ended' questions on a series of general information to determine the respondents' broad experience and their level of involvement in the oil and gas industry. The questions asked and responses from respondents are presented in Chapter 4, Section 4.3.

Phase 4: Framework Development

In this phase, the proposed life cycle cost estimating framework will be developed. A combination of the literature review findings, industrial survey and semi-structured interview with industrial experts will support the selection of appropriate factors and parameters for the framework development. Thereafter, the result of data analysis will assist in the modification and fine-tuning of the proposed framework.

Phase 5: Detailed Case Study

The purpose of this phase is to explore the application of the proposed framework on a case study. The framework will be used to predict the operating costs associated with the most effective refinery scheme selected through a screening process (Multi-Criteria Decision Making approach using the AHP) in the framework.

Phase 6: Validation

In this phase, validation of the framework will be conducted simultaneously in two ways. First, the suitability of the framework will be investigated through its application on a case study. Thereafter, a validation questionnaire will be used to extract experts' opinions regarding the framework's applicability. Second, the experts will have the opportunity to assess the reasonableness of the assumptions used, and the effectiveness of the cost estimates.

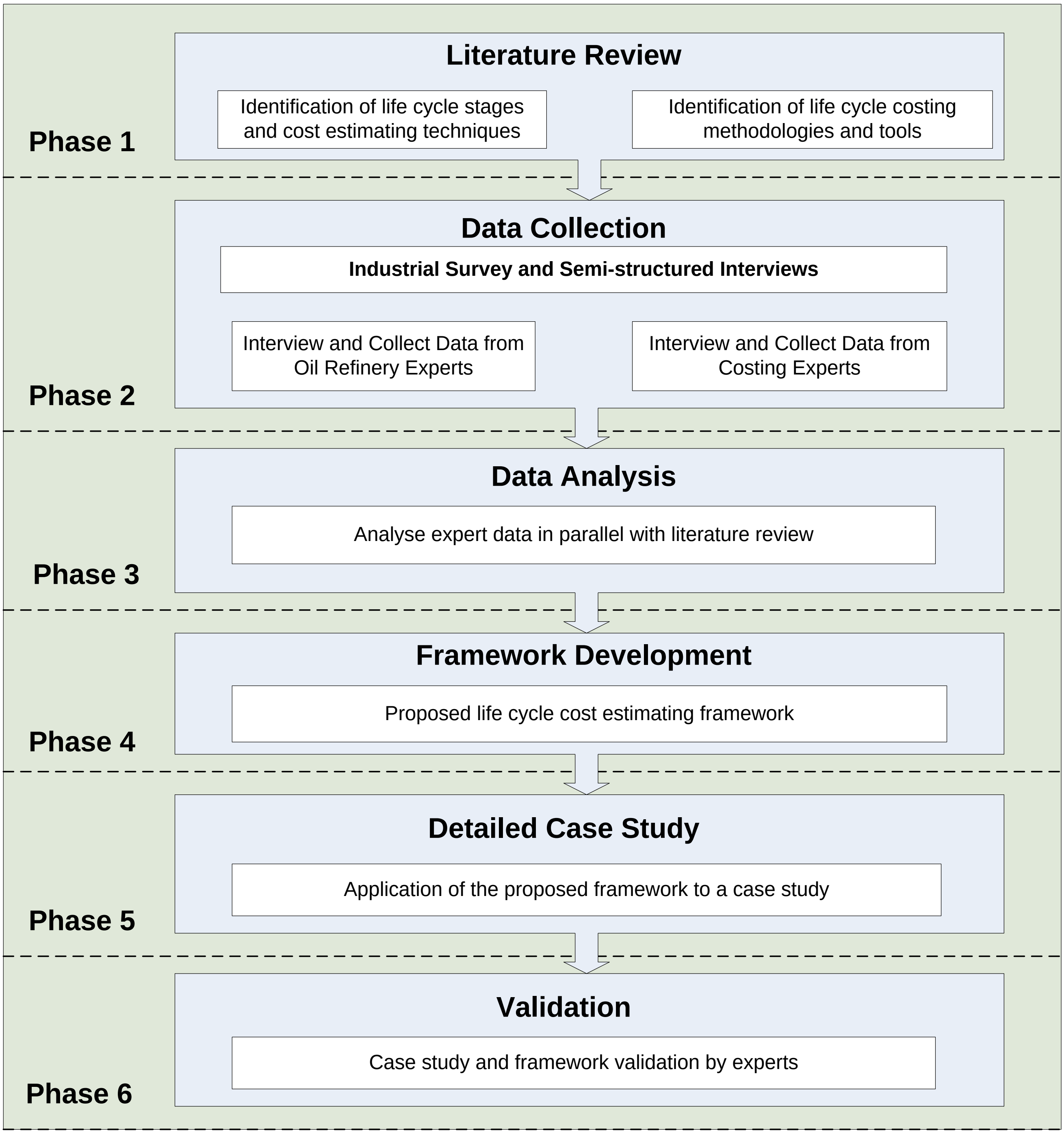

Figure 3.1 Research Methodology

In the next Chapter, the author provides an outline of the knowledge and issues surrounding the development of a life cycle cost estimating framework for oil refineries.

CHAPTER 4 FRAMEWORK DEVELOPMENT

4.1 Introduction

The literature review highlighted a lack of a comprehensive life cycle costing framework for oil refineries. This section, therefore, covers the actual process followed in the framework development. A vital requirement for the development of a life cycle cost estimating framework is the identification of a structured conceptual life cycle costing model and a cost breakdown structure that will depict major cost categories and cost elements in the overall life cycle cost estimating framework.

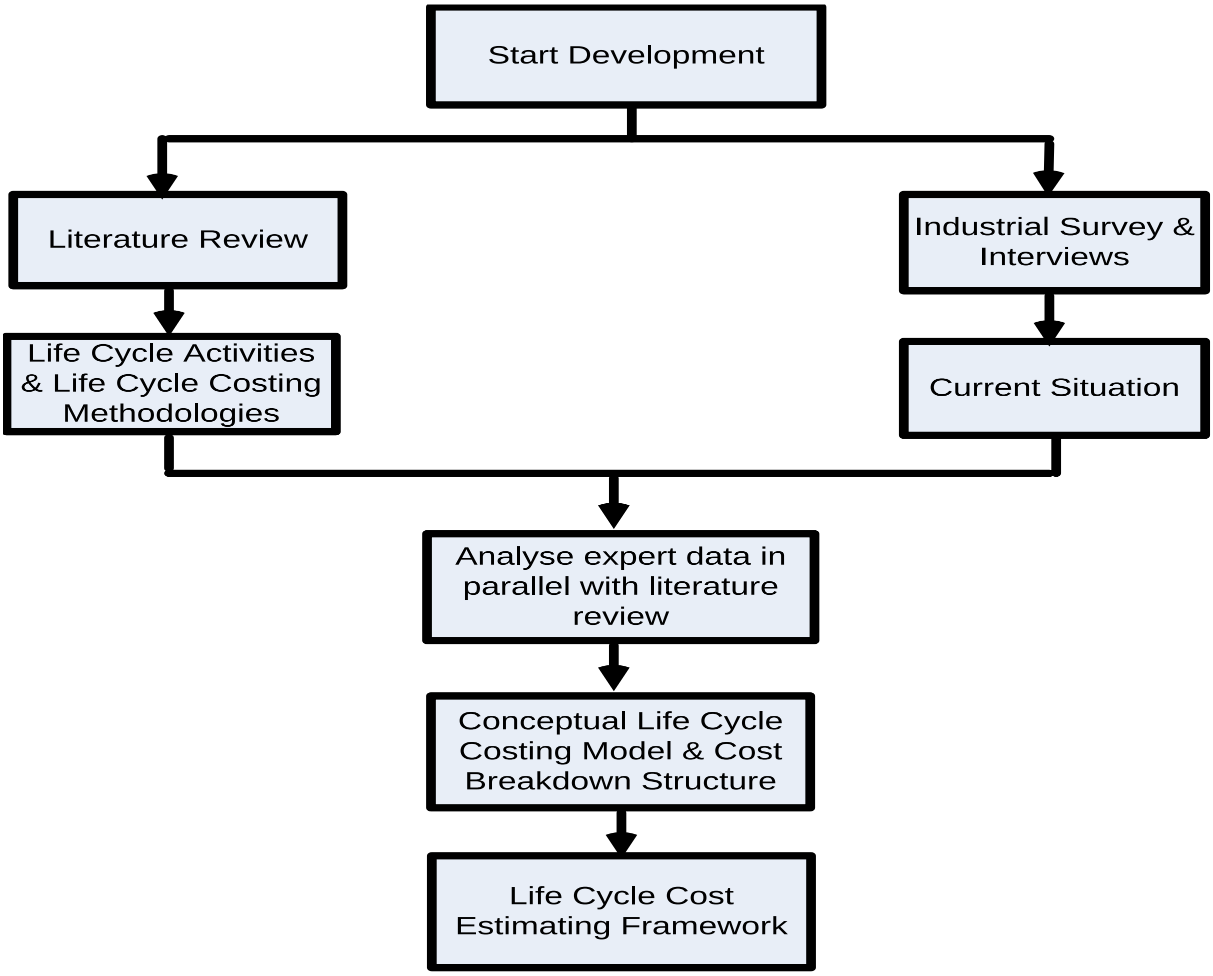

Figure 4.1 Flow Chart of Framework Development

The development of the proposed conceptual life cycle costing model that shows cost categories in the LCC framework went through several steps. Figure 4.1 presents a flow chart of conceptual LCC model and LCC framework development. First, available relevant literature was reviewed to identify the main activities and cost categories to be depicted in an oil refinery conceptual LCC model. Second, a questionnaire was prepared and used to gather relevant data on current practice from oil refiners and cost experts in the fields of oil refining, design and cost engineering of refineries. Finally, semi-structured interviews were conducted to solicit expert opinions in confirming the relevance of the cost categories, and the identification of areas of improvement in the content of the conceptual model and its cost breakdown structure. Moreover, questionnaire and semi-structured interview were used to minimise subjectivity on specific details necessary for the development, improvement and fine-tuning of the conceptual model.

4.2 Data Collection

4.2.1 Literature Sources

The collection of data commenced with exploring related literature to identify life cycle stages and cost categories to be depicted in an oil refinery conceptual LCC model. Technology in the oil refining industry tends to be more of upgrading existing facilities and the construction of new refineries using already established technologies than the introduction of completely new product (Lucas, 2000; Gary *et al*, 2007; Speight, 2011). They opined that researchers and specialist contractors (plant manufacturers) provide these technologies at very high costs but rarely come up with completely new products. Hence, the proposals to be made in this research should respond to the logic and peculiarity of the oil refining industry.

Furthermore, El-Banbi (2010) and Lucas (2000) affirm that though the oil industry spends large amount of money on technology development through its specialist consultants/contractors, but that it spends less than 3% of its sales revenue on R&D compared to micro-electronics and pharmaceutical companies 12% and 20% respectively. Consequent upon the aforementioned assertions (Lucas, 2000; Gary et al, 2007; El-Banbi, 2010; Speight, 2011), it therefore implies that the design of a conceptual model for oil refineries must consider the peculiarity of the oil refining industry product life cycle stages where each actor, whether the manufacturer (specialist consultant/contractor) or user (oil refinery company) controls only a portion of the actual life cycle of the product/system. Whilst, the life cycle cost is the aggregate of all costs incurred in a product's life, it must be pointed out that there are differences between the cost issues that will be of interest to the manufacturer of the product and the user of the product. This situation must have consequences for the necessary level of details applicable in the development of a conceptual LCC model for oil refineries.

Since conceptual LCC models are constructed at a macro level with minimum of details and limited ability to quantify cost features of a system (Waghmode et al, 2010), the cost breakdown structure (CBS) thus becomes essential in explaining the cost details in each cost category of the model. For a successful accomplishment of any life cycle cost analysis, a cost breakdown structure must be developed to show the various cost elements that are integrated to provide the total cost. Moreover, there is no set rule for breaking down cost as long as the method applied can be customised to a specific application (Vorarat and Al-Hajj, 2004).

Having gotten a clear idea of what should constitute a conceptual LCC model for oil refineries from literature sources; it is now pertinent to conduct an industrial survey using a questionnaire to acquire the information needed on current life cycle costing practice in the oil refining industry and its related sectors.

4.2.2 Industrial Survey (Questionnaire)

- **Questionnaire purpose**

  The purpose of the questionnaire is to collect information needed to meet the goal of this research by taking into account the current life cycle costing practice in the oil refining industry. The information gathered will assist in the development of a conceptual life cycle costing model and its cost breakdown structure. The questionnaire will also be used in identifying various life cycle costing tools and features required for the development of an overall life cycle costing framework for oil refineries.

- **Questionnaire design**

The survey was carried out in five consecutive stages. Most of the questions were 'open-ended' as this will give the respondents the flexibility to respond without being restricted by the context of the questions.

Questions 1-7 were used to identify the role of the companies in the oil and gas industry, the kind of petroleum products they deliver, and the configurations and complexities of their units.

Questions 8-20 were used to gather information on current life cycle costing practice in the industry.

Questions 21-24 were used to solicit information on current operation and maintenance challenges being experienced in industry.

Questions 25-27 cover environmental impact issues and challenges.

Questions 28-30 were used to collect information on current risks and uncertainties associated with oil refinery life cycle costing.

It must be emphasised that the choice of respondents was done on purposive basis because of the high level of specialisation and professionalism required in this sector of the oil and gas industry (Robson, 2002). Most of the respondents have spent between 10-35years of working experience in their various domains. These professionals are therefore competent to give useful information on the area of study. The questionnaire was sent to a sample of 32 individuals and companies, all of which have been known to be experienced oil refiners, oil/chemical plant cost engineers, chemical engineers, design engineers, and independent consultants with interest in the life cycle costing of industrial plants. An introductory letter was written to solicit their participation in the study, as well as stating the overall goal of the survey. Following an information process check, 20 completed questionnaires were received but subsequent preliminary examination of the answers showed that usable responses found to be adequate for analysis amounted to 15. This corresponds to 47% of the total sample. In line with the commitment given to the respondents, individuals and companies are not identified by name. A copy of the questionnaire used for the industrial survey is presented in Appendix A.

4.3 Data Analysis

The result and analysis of every question will be presented in this section. It is important to state that not all respondents answered all the questions, and some answers are synonymous, hence are reworded to convey the same meaning. To increase the accuracy of the descriptive analysis of the results, the number of answers conveying the same meaning were categorised and put in parenthesis in a number of instances.

Question 1: What sector of the oil and gas industry do your company operate?

Comments:

- Oil refining industry (7 respondents)
- Offshore/Upstream sector of the oil and gas industry (2 respondents)
- Industrial plants cost engineering (3 respondents)
- Design and project management (2 respondents)
- Power generation and chemical plant installation (1 respondent)

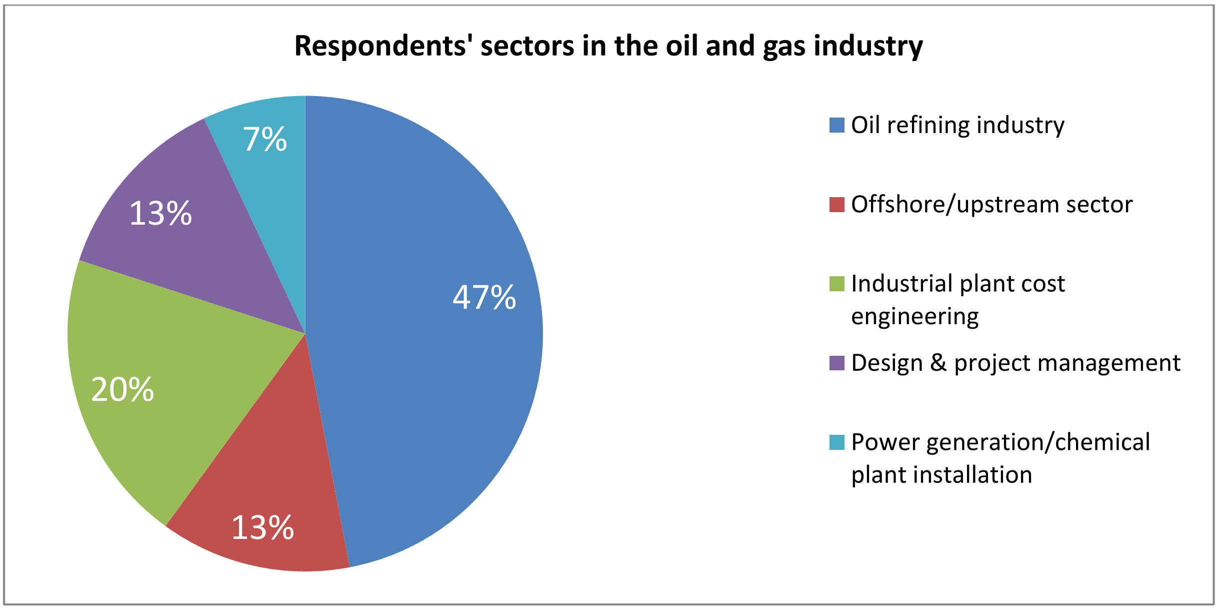

Figure 4.2 Respondents' sectors in the oil and gas industry

Figure 4.2 shows that 47% of the respondents are from the oil refining industry, while the remaining 53% are from oil and gas related sectors.

Question 2: What kind of products and services do you deliver?

Comments: Responses received include:

- Major petroleum products (6 respondents)
- Refinery decontamination chemicals and services (2 respondents)
- Consultancy related services (5 respondents)
- Offshore oil production and facilities maintenance (2 respondents)

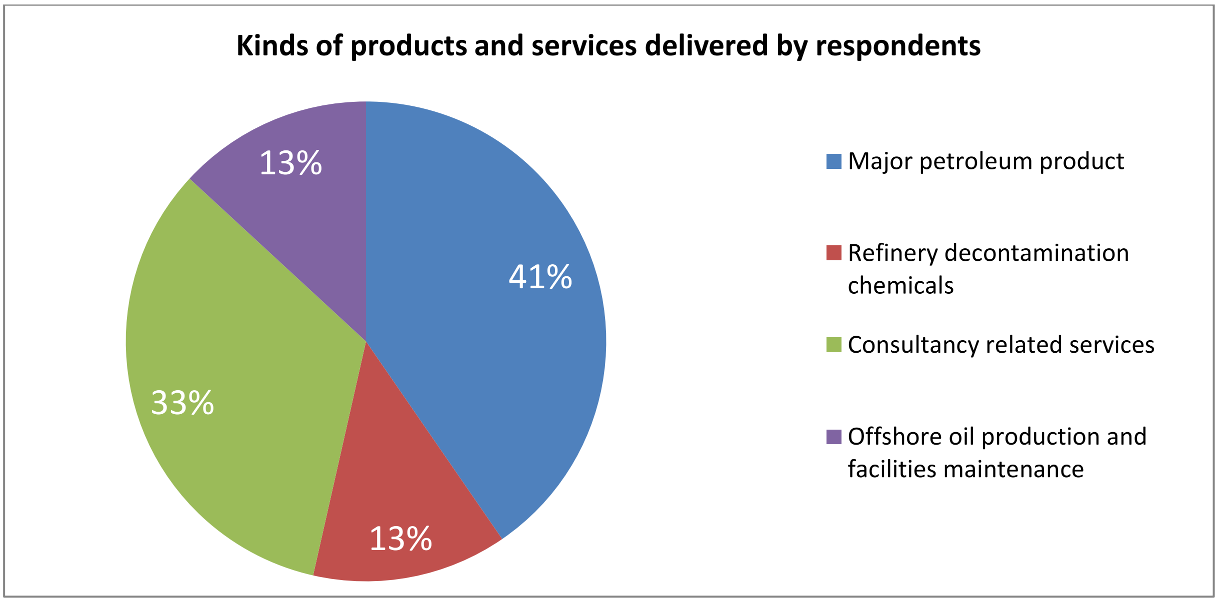

Figure 4.3 Kinds of products and services delivered by respondents

Figure 4.3 shows that majority of the respondents deliver main petroleum products (AGO, PMS, LPG) and consultancy services.

Question 3: What are the main functions of your business?

Comments: This question is similar to Question 1, so almost all the respondents repeated the answers they gave in Question 1.

Question 4: what is the number of employees in your business unit?

Comments: Responses to this question varied according to the size of the organisations and consultancy outfits. The average number of employees for consultancy firms is 20 while the average number of employees in companies is 200.

Question 5: What is the average life expectancy of your plant?

Comments: Respondents from consultancy firms did not answer this question while almost all respondents involved in crude oil processing chose over 20 years as the lifespan of their plants or equipment. This means that the physical life of an oil refinery is above 20 years.

Question 6: What is the installed capacity of your refinery?

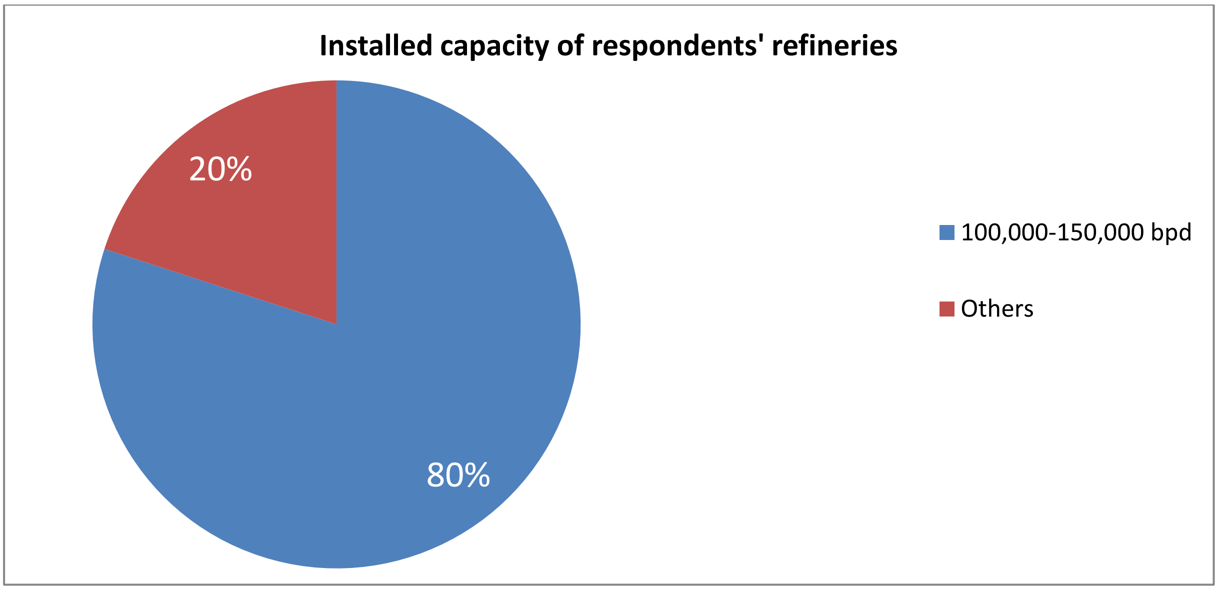

Figure 4.4 Installed capacity of respondents' refineries

Comments: Figure 4.4 shows that 80% of respondents involved in oil refining chose 100,000 – 150,000bpd (barrels per day) as the installed capacity of their main unit. Refineries of this charge capacity are therefore common in UK and Nigeria.

Question 7: What is the level of complexity of your refinery?

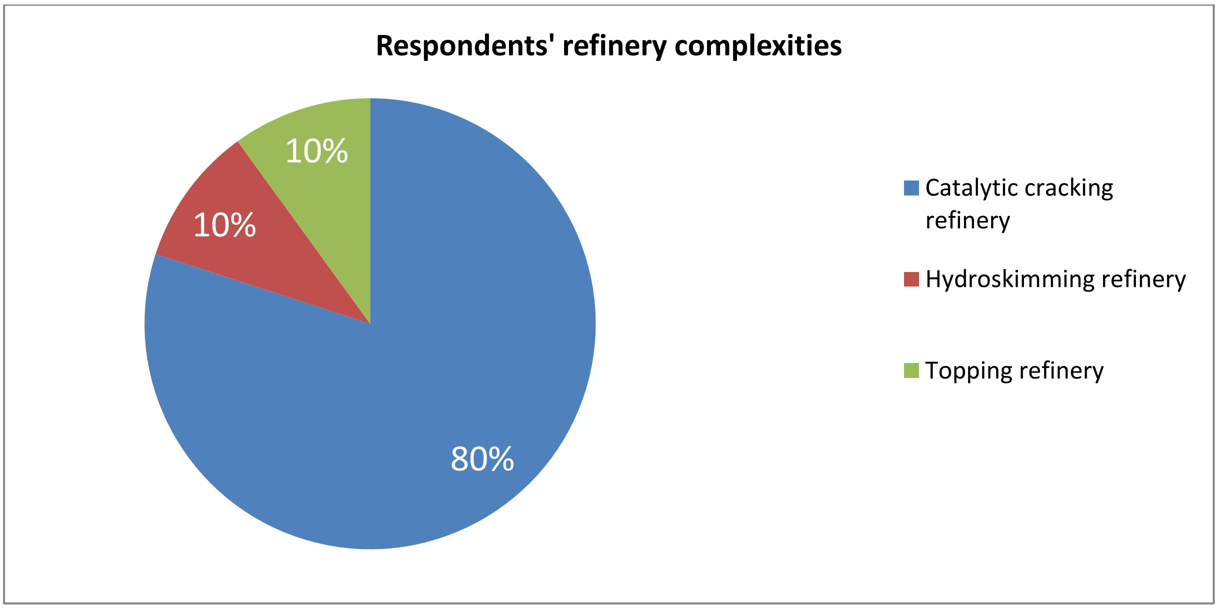

Figure 4.5 Respondents' refinery complexities

Comments: Figure 4.5 shows that 80% of the respondents involved in oil refining chose catalytic cracking refinery, 10% of the respondents chose hydroskimming, 10% chose topping while no respondent opted for Coking refinery.

Question 8: What is your role in cost engineering in the oil and gas sector?

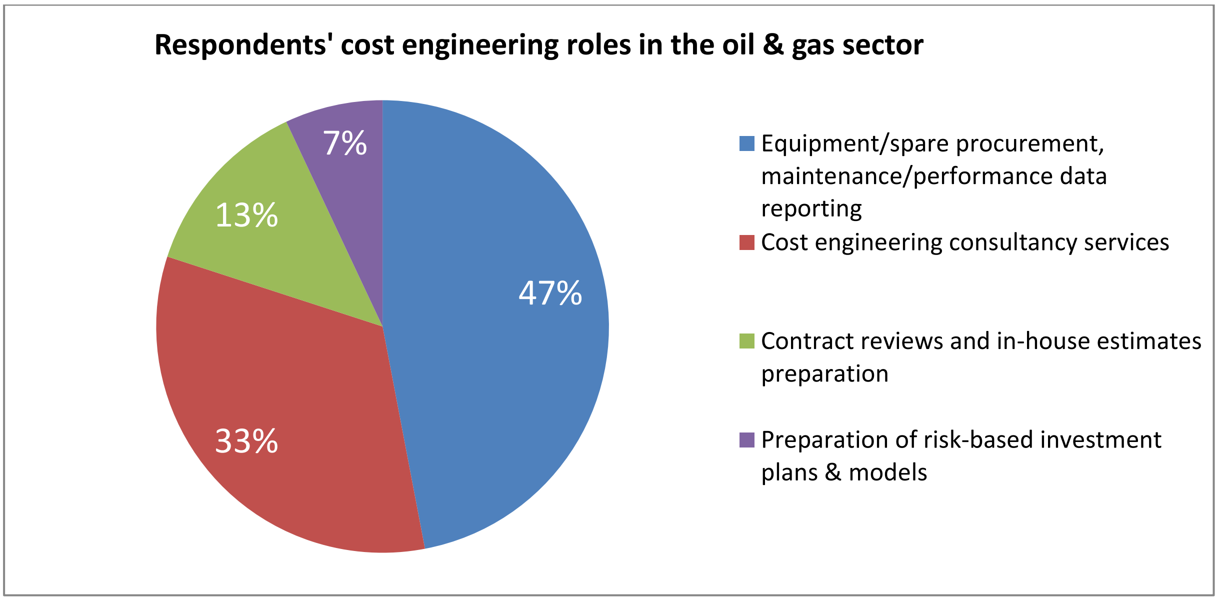

Figure 4.6 Respondents' cost engineering roles in the oil and gas sector

Comments: The percentage numbers of respondents and their roles as shown in Figure 4.6 are: equipment/spares procurement, maintenance costs & performance data reporting (47%); cost engineering consultancy services (33%); contract reviews & preparation of in-house estimates for new and existing facilities (13%); preparation of risk-based investment plans & models (7%).

Question 9: What do you consider to be the current challenges in oil refining and oil and gas industry?

Comments: The percentage numbers of responses according to the challenges are:

- Low capacity utilisation and rising cost of ownership (33%)
- Plant complexity and turnaround maintenance (20%)
- Non-availability of trained and experienced personnel to replace an aging work force (7%)
- Competition and dwindling profit (20%)
- Scope definition (7%)
- No response (13%).

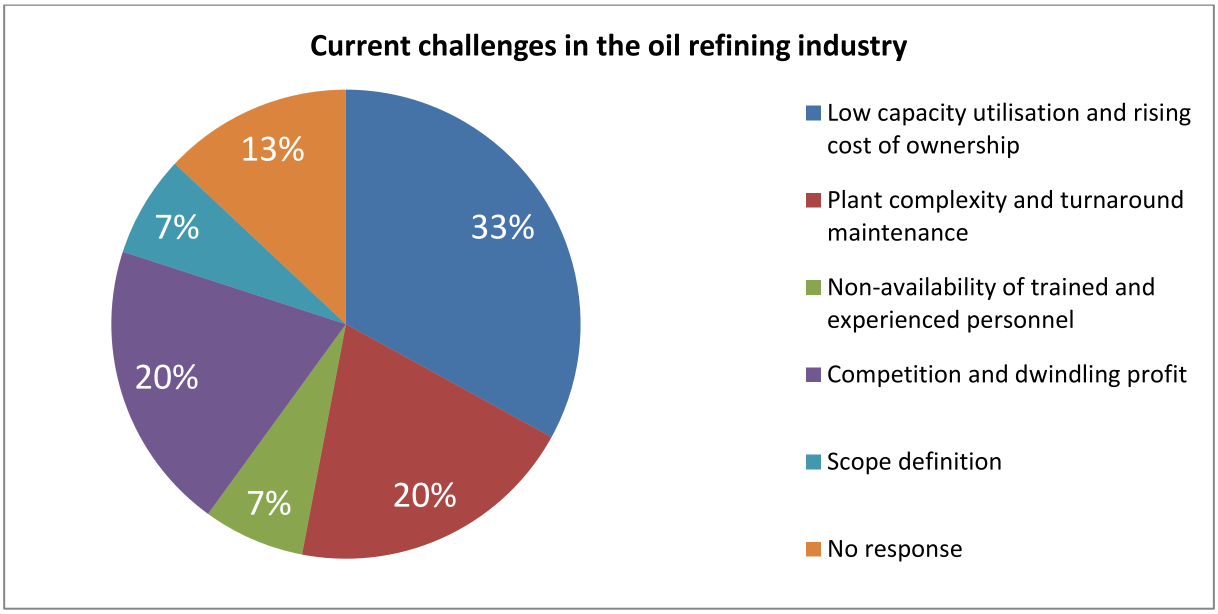

Figure 4.7 Current challenges in the oil refining industry

Figure 4.7 shows that low capacity utilisation, rising cost of ownership, turnaround maintenance, competition, and dwindling profit are the major challenges facing the industry.

Question 10: What do you understand to be life cycle costing?

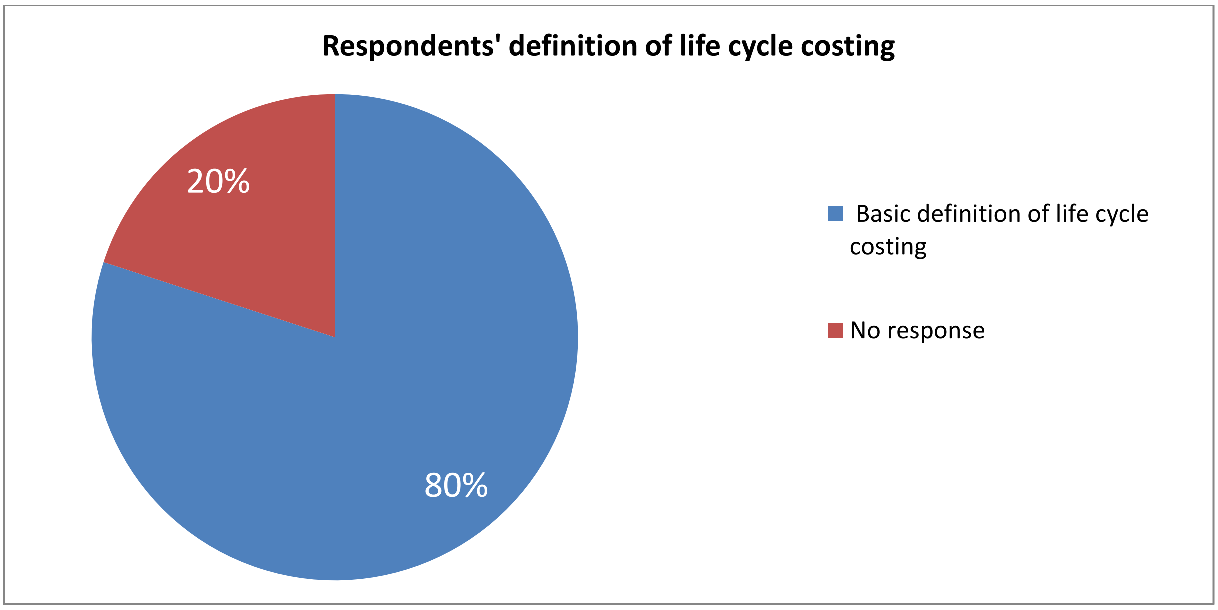

Figure 4.8 Respondents' definition of life cycle costing

Comments: The responses presented in Figure 4.8 shows that 80% of the respondents have basic knowledge of what life cycle costing means. The aggregation of their definitions implies that life cycle costing is the total cost of a product from conception to disposal.

Question 11: What methods do you use in life cycle costing?

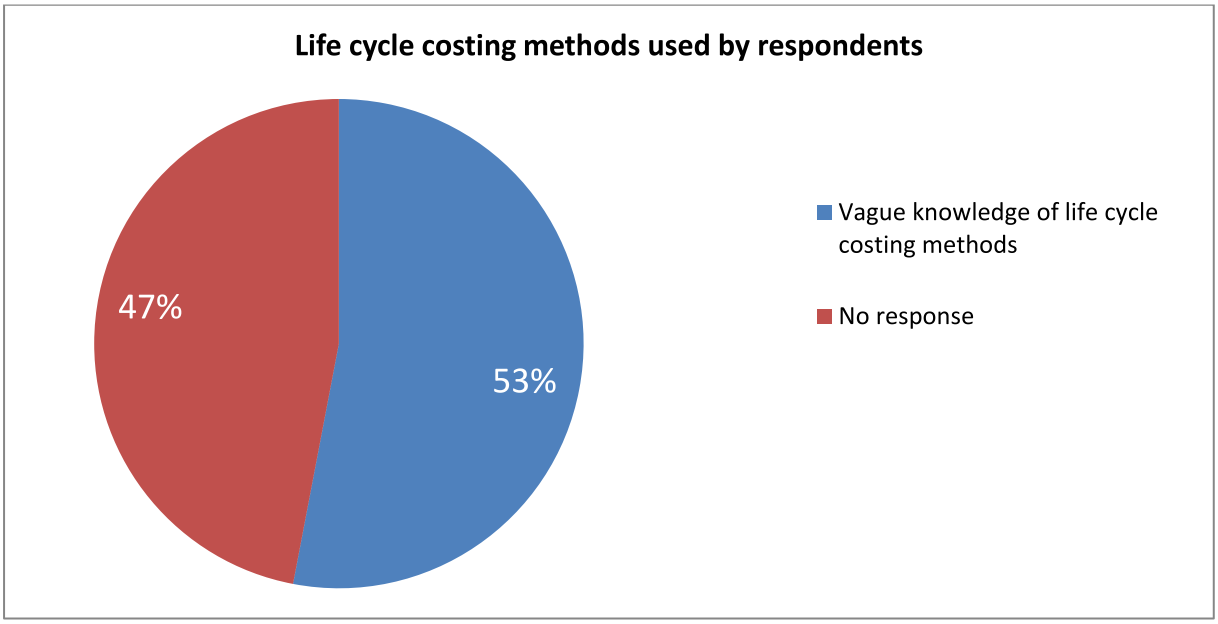

Figure 4.9 Life cycle costing methods used by respondents

Comments: Figure 4.9 shows that 53% of the respondents acknowledged the existence of various investment appraisal methods that could be used by decision makers. The methods they presented ranged from net present value to cost benefit analysis. But net present value (NPV) is an economic evaluation method which is just a step among several steps to be undertaken in the life cycle costing analysis of a product, while cost benefit analysis is an evaluation method undertaken during the feasibility studies of new investments. The respondents from their answers do not have in-depth understanding of the life cycle costing methods. This implies that there is a lack of standardised and normalised procedure that could be applied in the life cycle costing analysis of oil refineries. Hence, the standardisation of procedure is the main deficiency to be tackled.

Question 12: What data and information (sources) are used in life cycle costing?

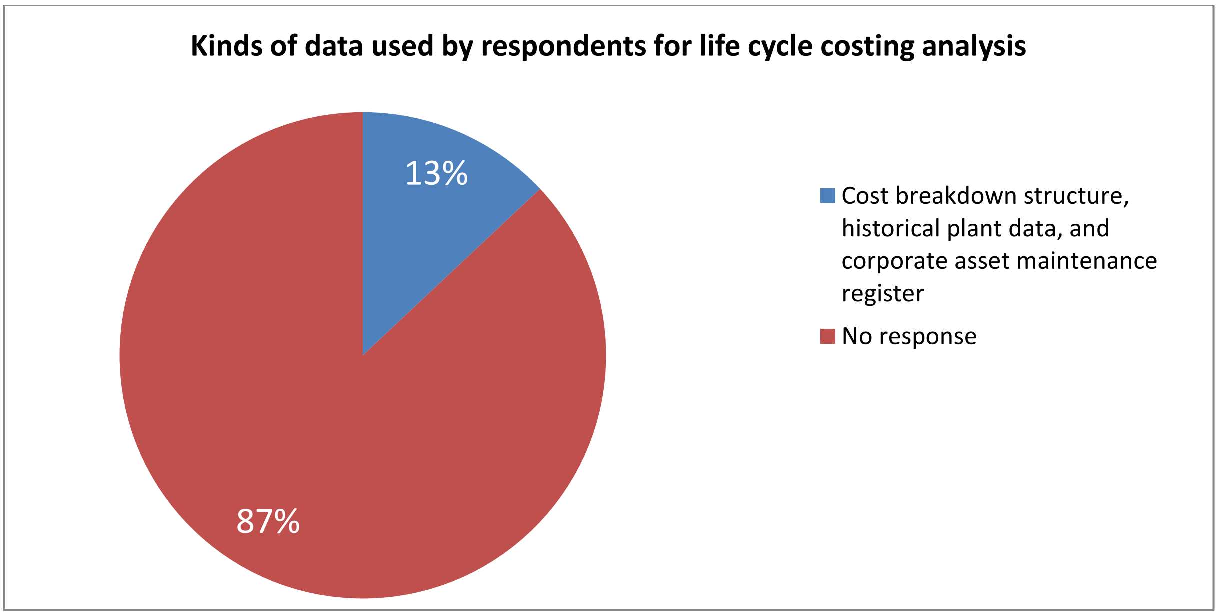

Figure 4.10 Kinds of data used by respondents for life cycle costing analysis

Comments: Figure 4-10 shows that only 13% of the respondents answered this question. They said that the cost breakdown structure, historical plant data, and corporate asset maintenance registers could be used as sources of data. The number of responses shows that the entrenchment of LCC technique in the industry still appears to be insufficient.

Question 13: What are the challenges in life cycle costing?

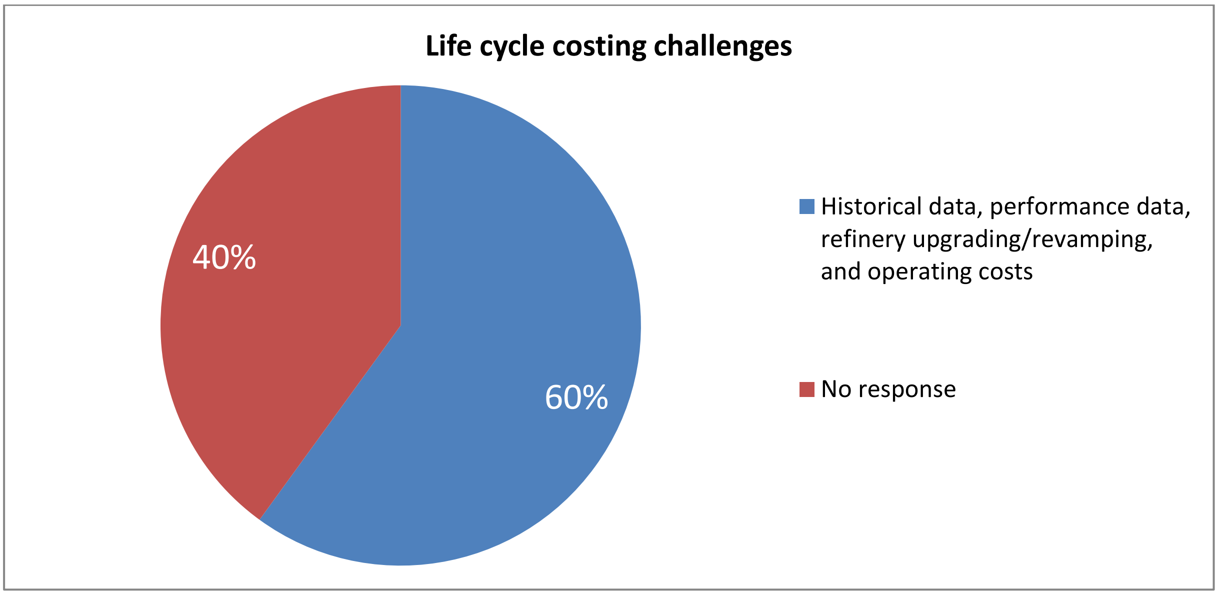

Figure 4.11 Life cycle costing challenges

Comments: The responses as presented in Figure 4.11 shows that 60% of the respondents answered this question. The answers are: poor asset historical data, uncertainty in performance, high cost of plant replacement, cost of revamping, and increased operation and maintenance cost. This implies that lack of historical plant data, uncertainties in plant performance (reliability and maintainability), cost of replacement or upgrading, revamping cost, and increased operation and maintenance costs are the challenges facing the industry and the successful implementation of life cycle costing.

Question 14: What is your understanding of the technological options in oil refining?

Comments: This question was completely misunderstood by the respondents. The author could have reframed it to convey its real meaning. However, the author meant 'their understanding of refinery configurations'. I presume that Question 7 must have taken care of this question.

Question 15: Could you please describe the life cycle costing process? For instance, what are the steps? Do you have an example?

Comments: Most of the respondents repeated the answers they gave in Question 11. This question refers to the detailed steps to be undertaken in arriving at the life cycle cost of a product, which is more elaborate than just mentioning the conceptual life cycle costing model that shows cost categories in the life cycle costing process or framework. Notwithstanding the mix up, it was identified that no respondent made mention of a cost breakdown structure (CBS) which is the engine room of any life cycle costing analysis. The responses show that there is no standardised cost breakdown structure with the features needed for life cycle costing to be progressively executed. This implies that staff and departments responsible for evaluating investments in the oil refining industry lack a long-term perspective of asset management. The lack of a standardised CBS could make it impossible to conduct comparative analysis between different projects or to conduct single project analysis for budgetary purposes. A standardised CBS is therefore recommended for the industry.

Question 16: Please indicate the cost drivers you consider relevant for the life cycle costing of an oil refinery/oil and gas industrial assets?

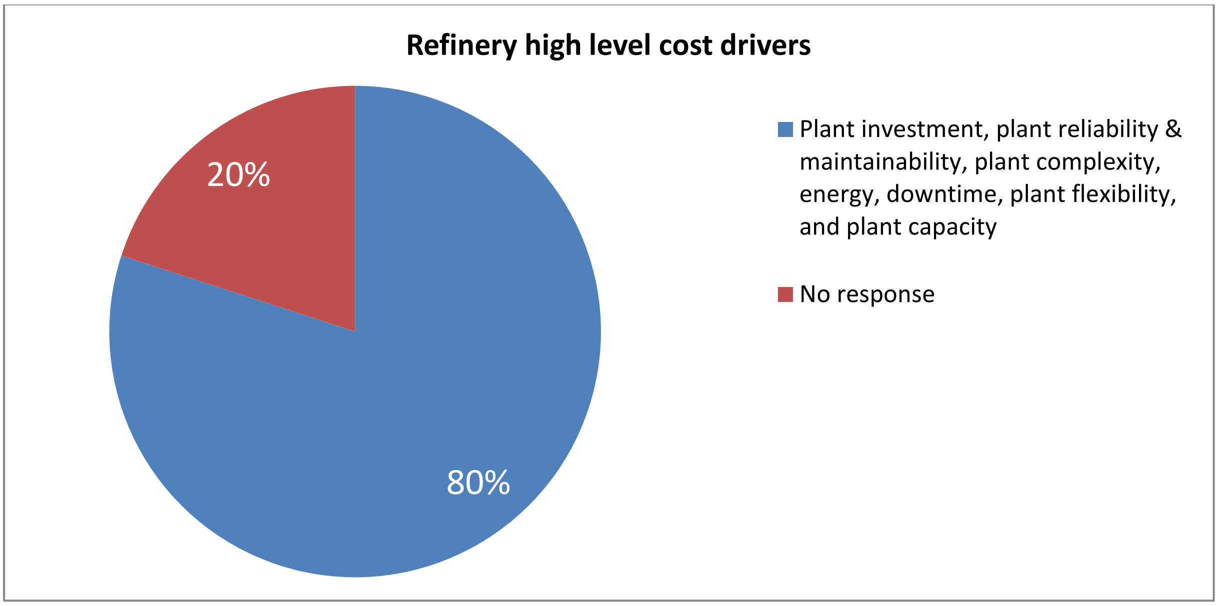

Figure 4.12 Refinery high level cost drivers

Comments: Figure 4.12 shows that 80% of the respondents answered this question. The responses include: plant investment; plant reliability and maintainability; plant complexity; energy; downtime; plant flexibility; and plant capacity. Hence, the aforementioned refinery cost contributors could be taken as the high level cost drivers.

Question 17: What are the relationships between the more significant ones?

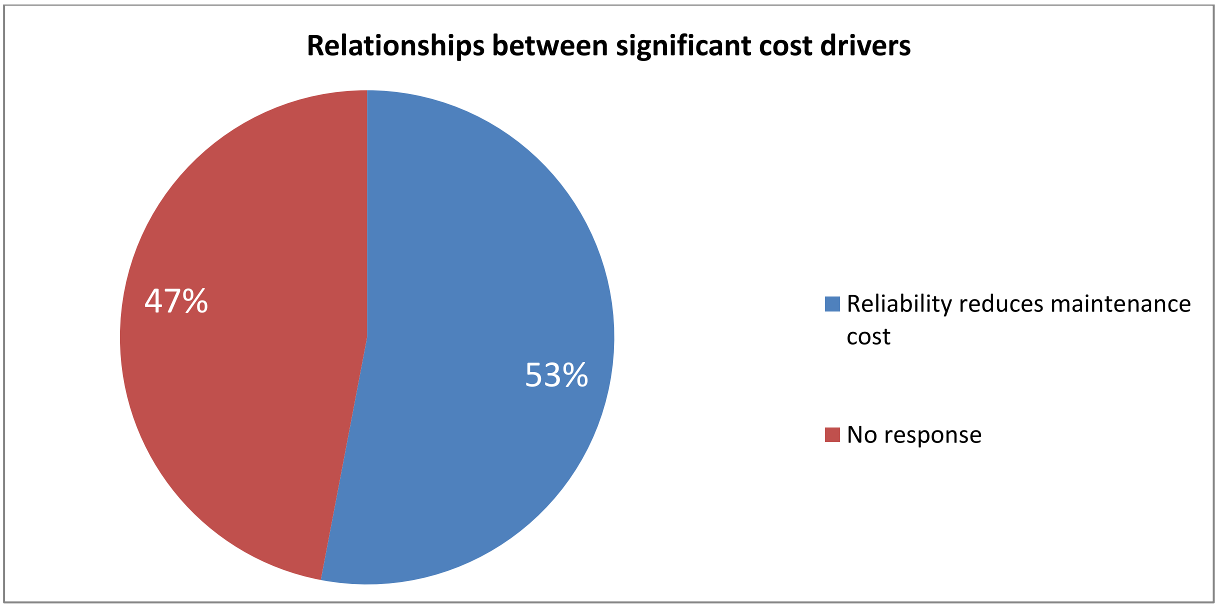

Figure 4.13 Relationship between significant cost drivers

Comments: 53% of the respondents said that reliability could drive down maintenance cost as presented in Figure 4.13. However, 47% of the respondents did not answer this question. Reliability as a matter of fact can reduce maintenance cost because if a plant is reliable the frequency of failure will be reduced thereby reducing maintenance cost.

Question 18: What are the life cycle stages of an oil refinery?

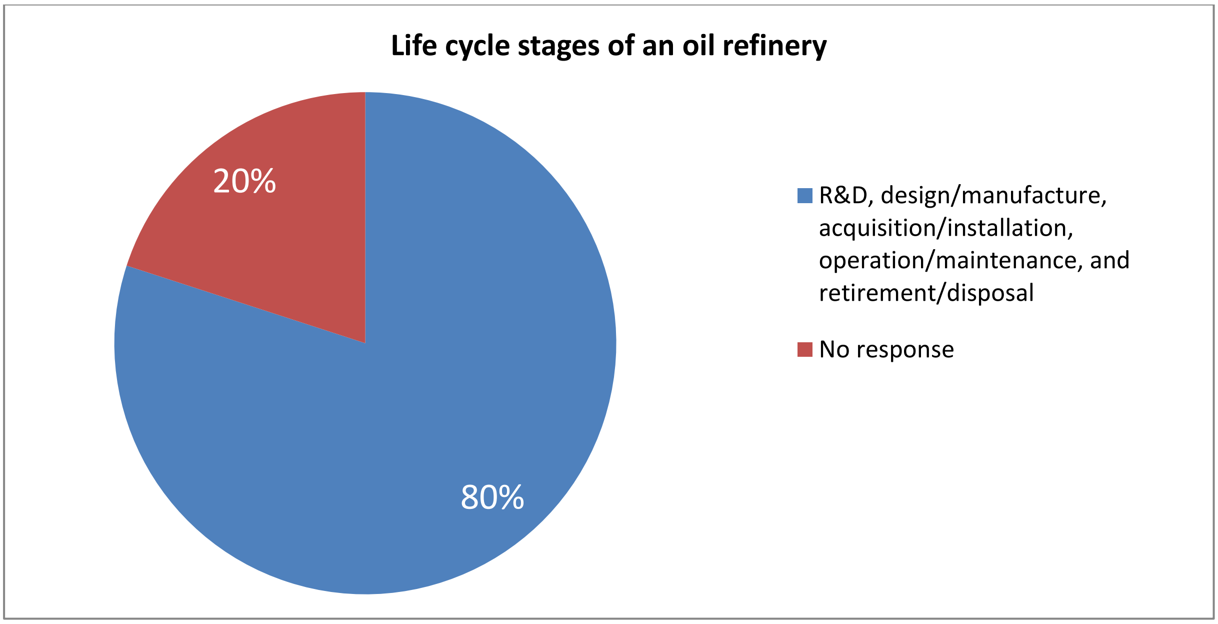

Figure 4.14 Life cycle stages of an oil refinery

Comments: Figure 4.14 shows that 80% of the respondents mentioned various life cycle stages with terminologies that could be categorised to portray the same meaning and provide a standard life cycle stages for oil refinery. For example, R&D, concept, and definition stages could be taken as Research/Development Stage. Design/development, development, design, assessment, production, and manufacturing stages could be taken as Design/Manufacturing Stage. Investment, installation, acquisition, construction, and commissioning could be taken as Acquisition/Installation Stage. While in-service, facility usage, operation, maintenance, utilisation, and operation/support could be taken as Operation/Maintenance Stage. For the disposal stage, some respondents used retirement, end of life, recycle, remanufacture, decommissioning, etc. These stages could be categorised to mean Retirement/Disposal Stage.

Question 19: How many codes and standards of which the title includes the term “Life Cycle Costing” do you know?

Comments: Only 2 respondents answered this question. They mentioned PAS 55, ISO 15663, HM Treasury ‘Green Book’, and NATO/RTO Code of Practice for Life Cycle Costing. This means that most respondents are not aware of International Standards for Life Cycle Costing.

Question 20: How many of the codes and standards are specifically meant for the oil and gas industry?

Comments: There is no response to this question except one that mentioned ISO 15663 – Petroleum and Natural Gas Industries: Life Cycle Costing Standard.

Question 21: What are the challenges in operation and maintenance?

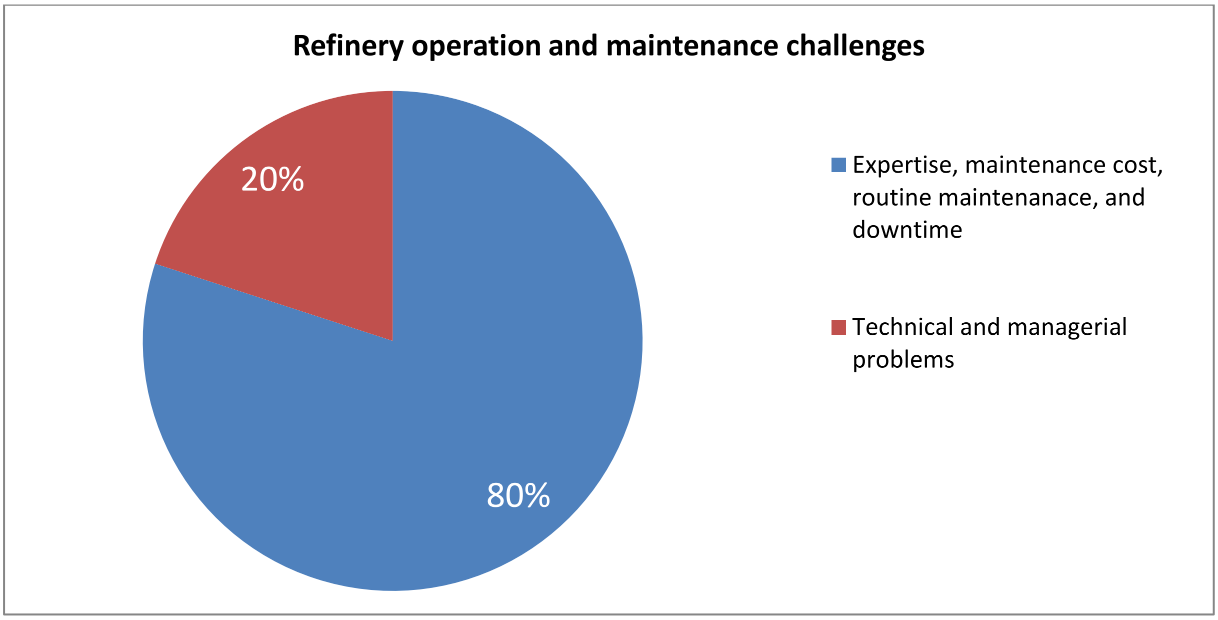

Figure 4.15 Refinery operation and maintenance challenges

Comments: Figure 4.15 shows that 80% of the respondents gave the challenges as: lack of experienced staff, making value-based decisions on maintenance intervals, cost of maintenance, turnaround maintenance scheduling, and downtimes, while 20% of the respondents gave their challenges as technical and managerial problems. This implies that major operation and maintenance challenges in the industry are: expertise, mean-time-to-repair (Maintainability), reliability, routine maintenance planning, cost of lost production, and management policies.

Question 22: What are the issues in operation and maintenance related to life cycle cost?

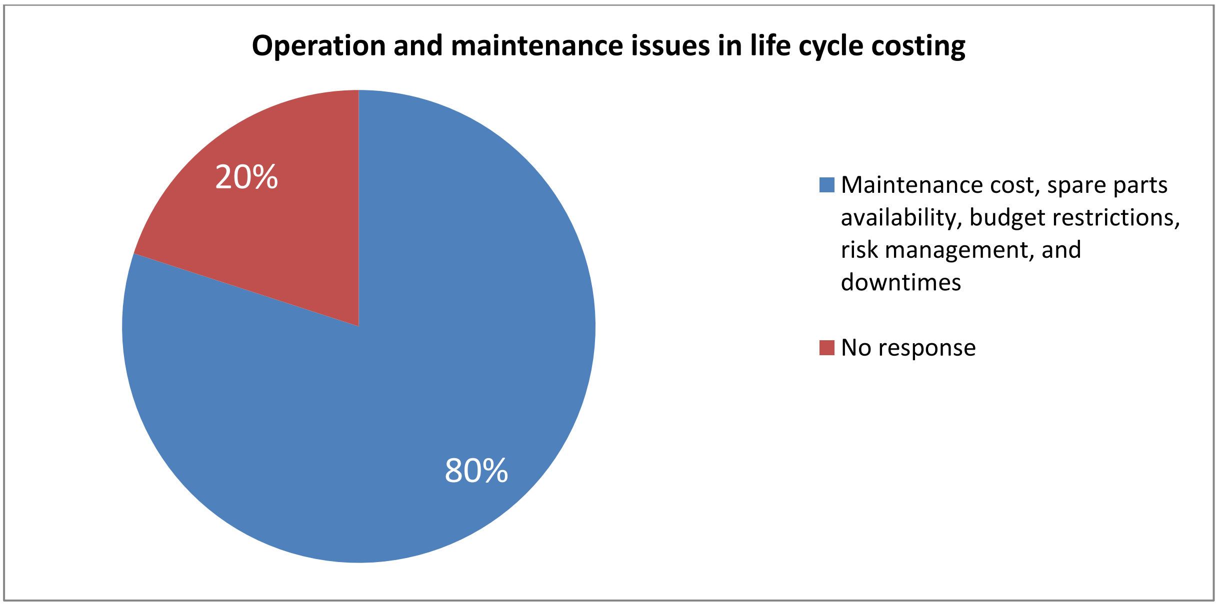

Figure 4.16 Operation and maintenance issues in life cycle costing

Comments: This question is similar to the last question but with emphasis on life cycle costing. The answer given by 80% of the respondents as shown in Figure 4.16 includes: maintenance cost, spare parts availability, budget restrictions, increasing risk with declining condition, long lead items, downtimes (cost of lost production).

Question 23: What bottlenecks are there in operation and maintenance?

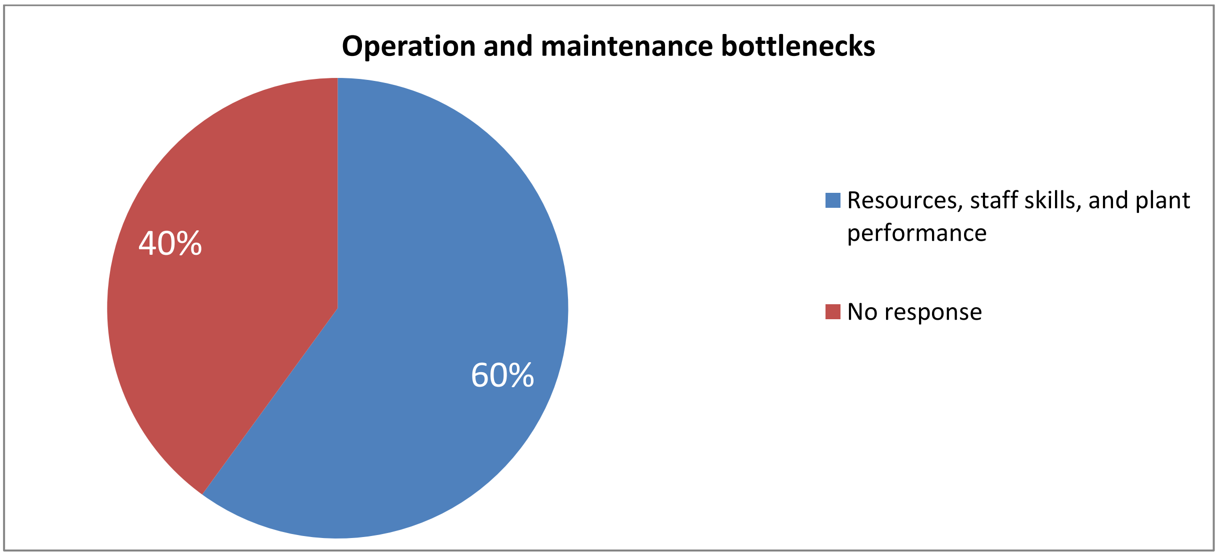

Figure 4.17 Operation and maintenance bottlenecks

Comments: Figure 4.17 shows that 60% of the respondents answered this question and gave the logjams as: resources, staff skills, and plant's performance.

Question 24: What operations and maintenance models do you use? For example mathematical models, decision making models, scheduling models, etc.?

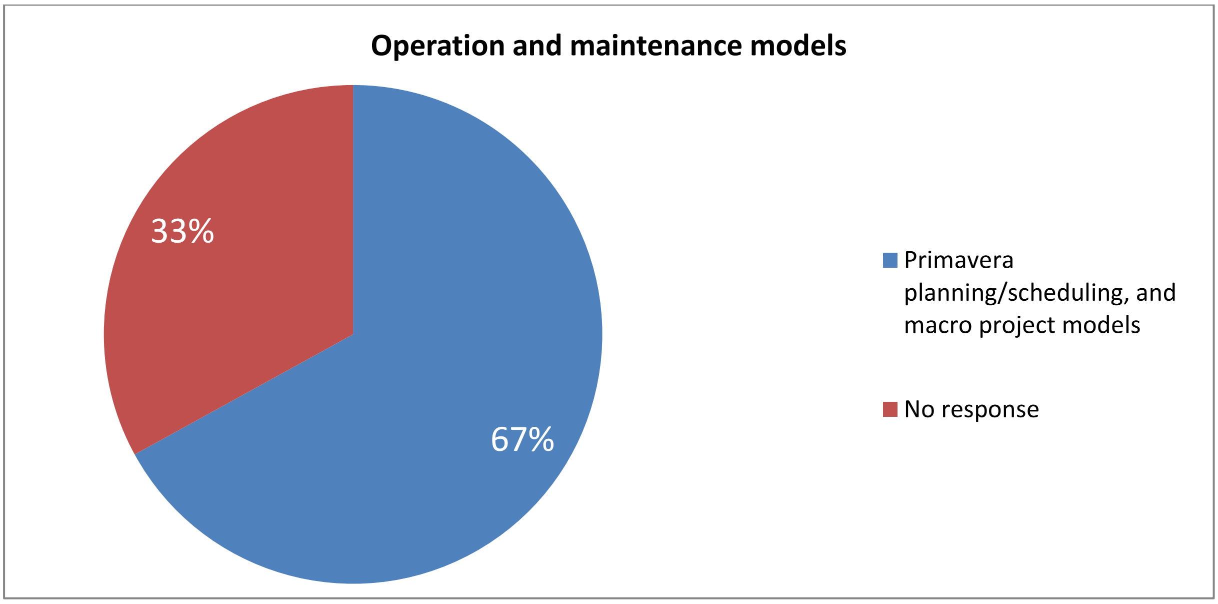

Figure 4.18 Operation and maintenance models

Comments: Figure 4.18 shows that 67% of the respondents answered this question. The responses include: Primavera planning/scheduling, and macro project models.

Question 25: What are the environmental impact challenges of CO_2 emission and its cost related issues?

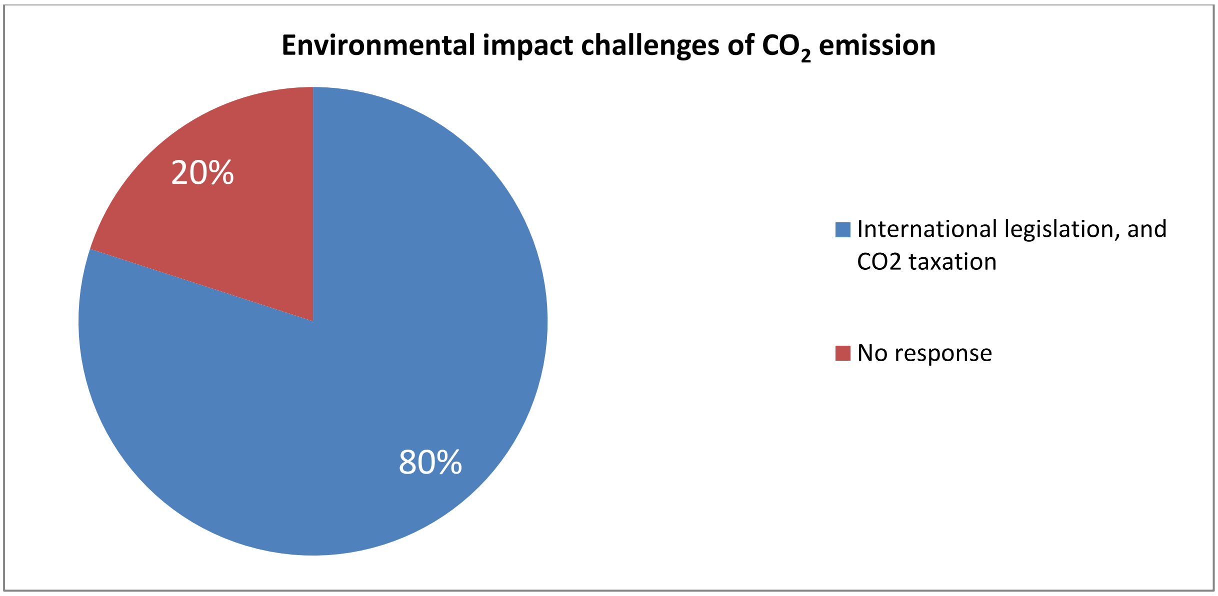

Figure 4.19 Environmental impact challenges of CO_2 emission

Comments: Figure 4.19 shows that 80% of the respondents answered this question. The responses centred on the topical issue of international legislation on the impact and cost of CO_2 emission (CO_2 taxes). From the responses it seems some companies are contemplating the inclusion of CO_2 cost into the design of new plants and cost models because of the international regulations on CO_2 emission.

Question 26: What are the technologies to curb environmental impact for now and in the future?

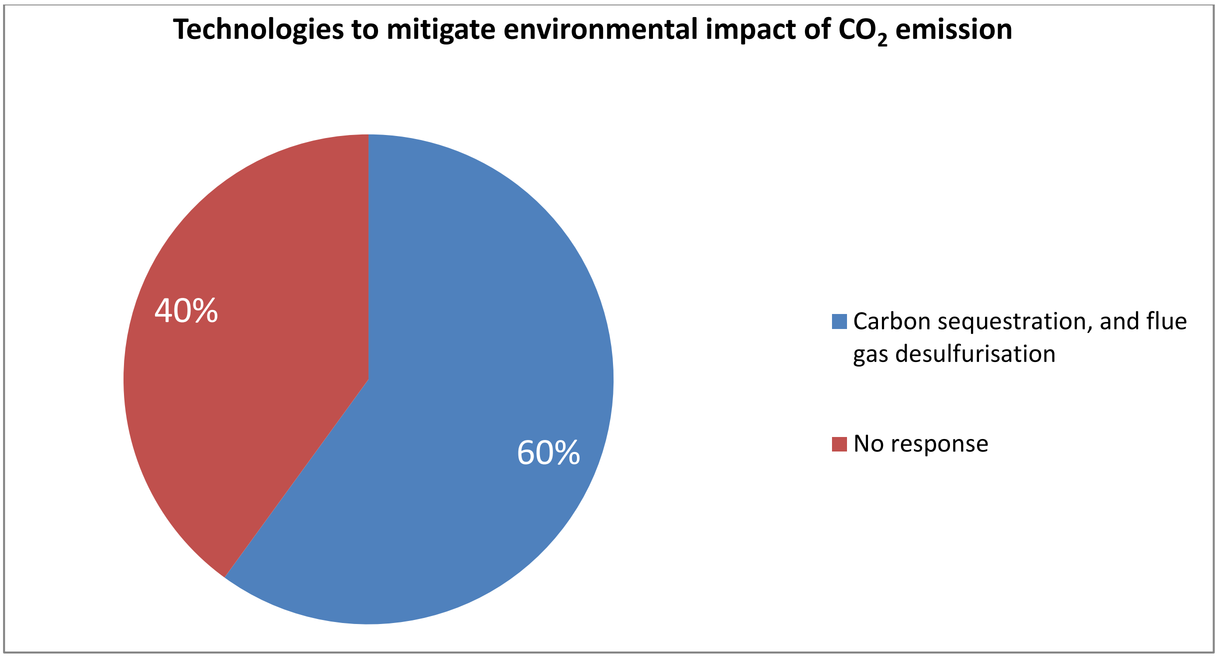

Figure 4.20 Technologies to mitigate environmental impact of CO_2 emission

Comments: Figure 4.20 shows that 60% of the respondents answered this question and gave the technologies as: carbon sequestration technology, flue gas desulphurisation. Carbon sequestration technology involves capturing CO_2 emitted from power plants and other industrial complexes and injecting it into geological structures deep below ground for long-term storage. The recovered CO_2 could be used for enhanced oil recovery (EOR) projects.

Question 27: What are the environmental impacts cost drivers and cost models?

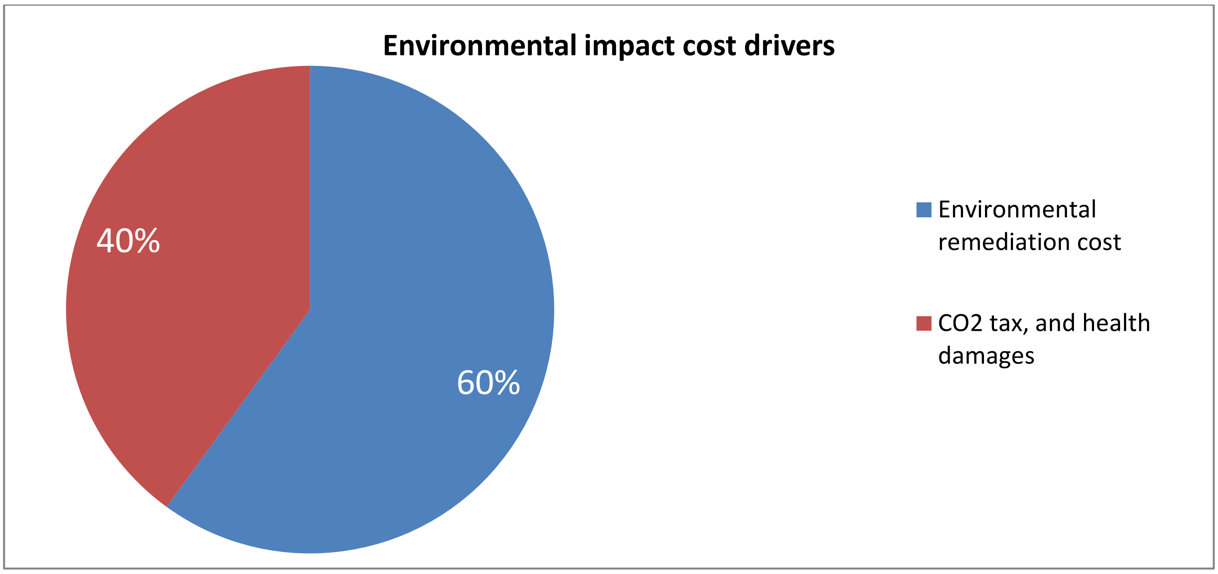

Figure 4.21 Environmental impact cost drivers

Comments: Figure 4.21 shows that 60% of the respondents mentioned environmental remediation cost while 40% gave CO_2 tax and health damages as cost drivers. However, they did not mention any cost model currently in use for the evaluation of environmental impacts.

Question 28: What are the significant risks associated with an oil refinery and appearing in the life cycle costing?

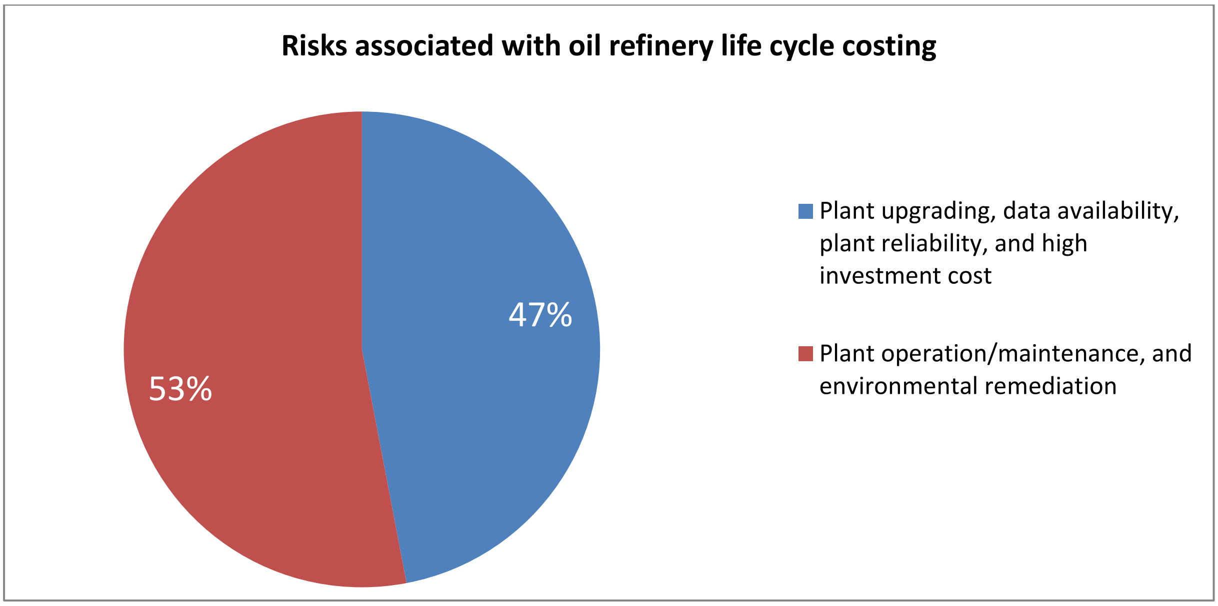

Figure 4.22 Risks associated with oil refinery life cycle costing

Comments: Figure 4.22 shows that 47% of the respondents gave the associated risks as: plant upgrading and revamping, data availability, plant reliability, high investment cost while 53% of the respondents mentioned plant operation, maintenance, and environmental remediation cost as risks.

Question 29: What are the uncertainties in life cycle costing in refineries?

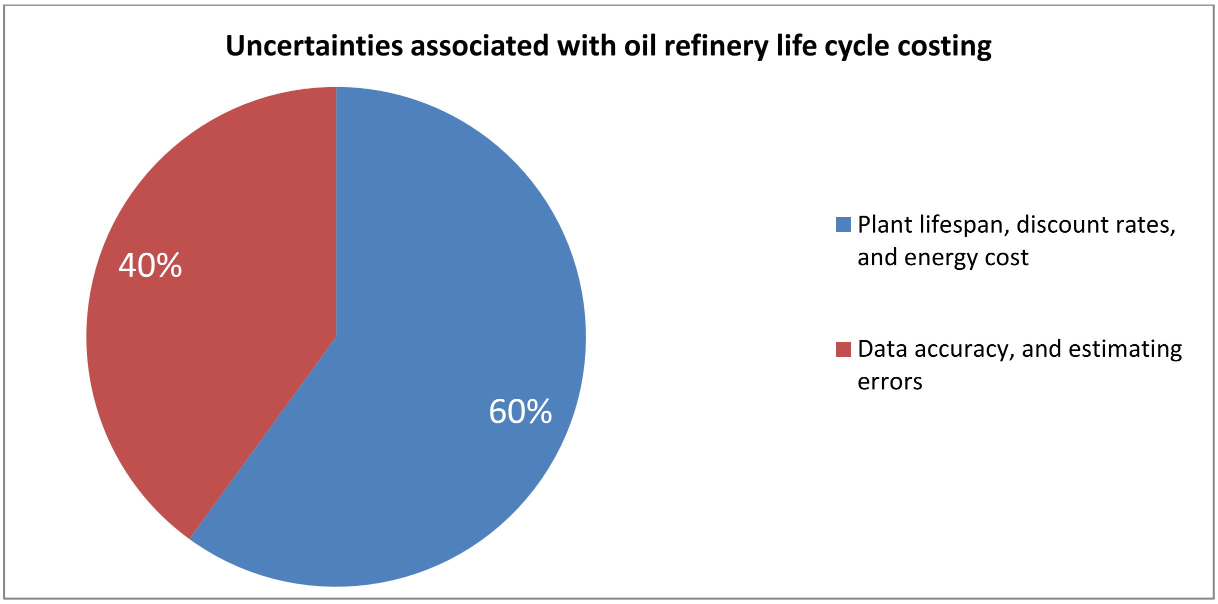

Figure 4.23 Uncertainties associated with oil refinery life cycle costing

Comments: Figure 4.23 shows that 47% of the respondents gave the uncertainties as plant lifespan, discount rates, energy cost while 40% mentioned data accuracy and estimating errors.

Question 30: What are the methods used to model risk and uncertainty?

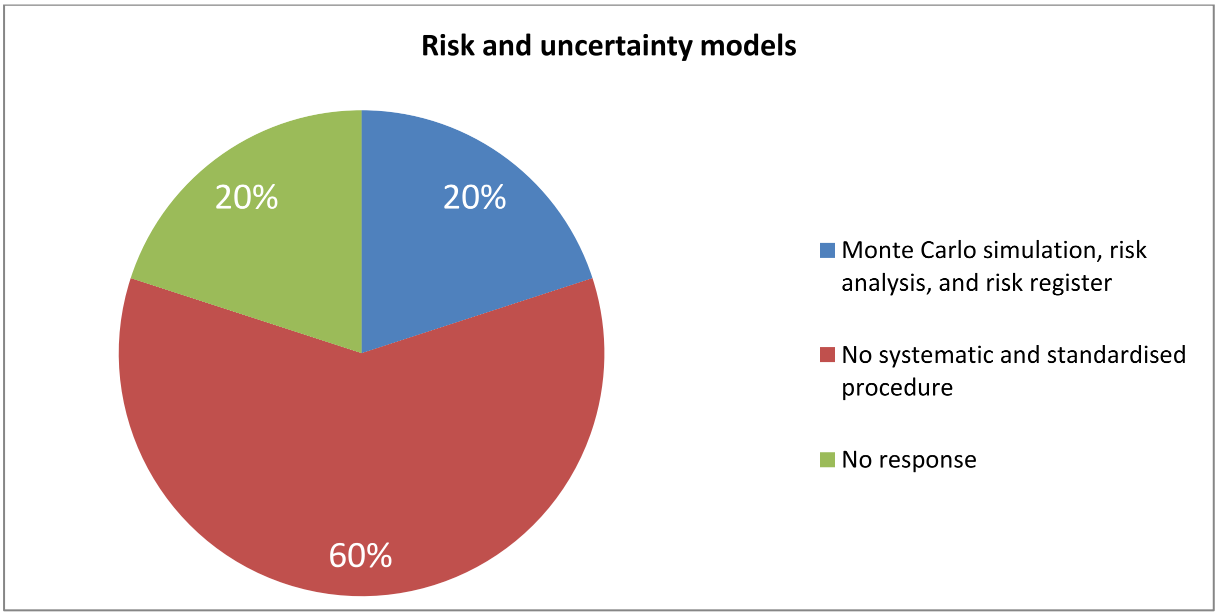

Figure 4.24 Risk and uncertainty models

Comments: Figure 4.24 shows that very few companies and firms (20%) possess standardised procedure for evaluating risk analysis and uncertainty and this ranged from risk analysis based on individual task measurement, Monte Carlo simulation, and provision of a defined risk register. 60% lack a systematic procedure for this purpose. The responses to this question show that minimal use is made of risk and uncertainty estimation, and this could impinge on the full advantage that could be derived from LCC technique.

4.3.1 Summary

The results of the data analysis raised a vital issue of standardised procedure for the determination of a comprehensive life cycle cost analysis for oil refineries. The implications of the findings suggest that indeed there is a lack of standard conceptual life cycle costing model with major cost categories and cost breakdown structure specifically designed for oil refineries. The standardised model and its cost breakdown structure when developed will be integrated into the overall LCC framework within the study.

4.4 Conceptual Life Cycle Costing Model

Based on current information gathered from the literature review and industrial survey a conceptual LCC model was developed. The proposed conceptual model as presented in

Figure 4.25 could be used to address major cost categories that are vital in the implementation of cost analysis across the entire life cycle of a refinery. The conceptual model stages, however, are demarcated in such a pattern that life cycle costing can be conducted at any specific stage in the life of a refinery. Cost emphasis (design to requirements) has already been created to meet three main categories of need: operational requirement, technical requirement, and performance requirement. The consideration of an identified need for a product is bound to initiate conceptual activities to meet that need.

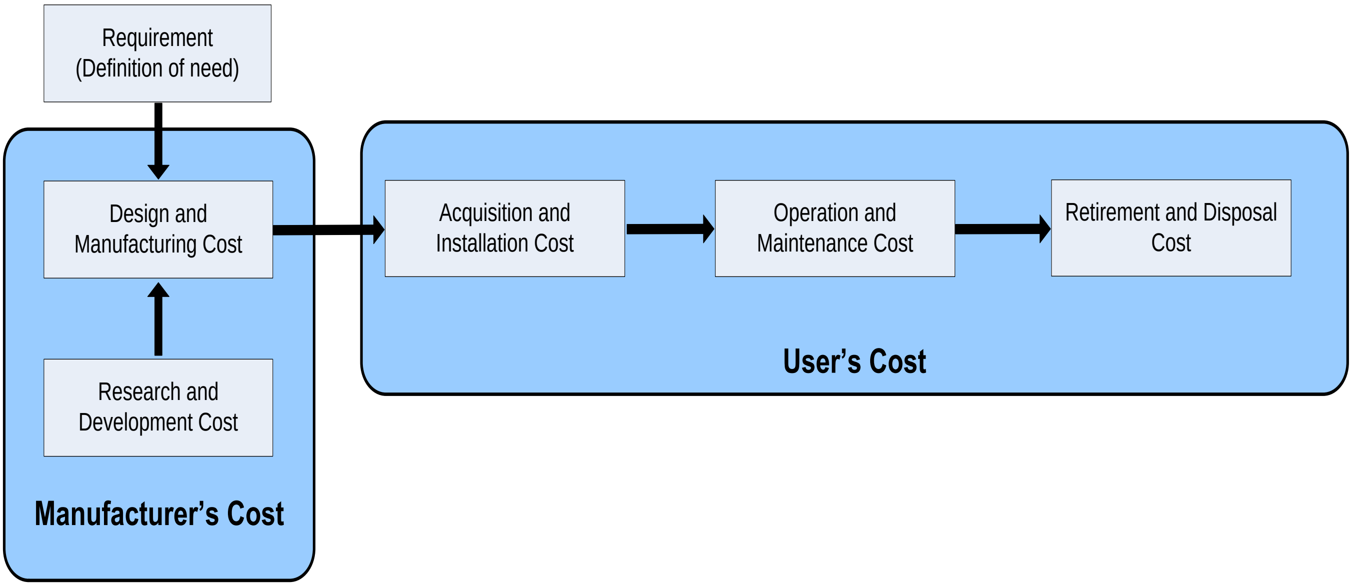

Figure 4.25 Proposed Conceptual Life Cycle Costing Model for Oil Refineries

NATO/RTO (2009) defines a requirement as "a singular documented need of what a particular product or service should be or do". Life cycle cost analysis could be iterative, ongoing and must be tailored to a specific application. For example, a refinery upgrading could extend this model to include the cost of additional facilities into its cost breakdown structure.

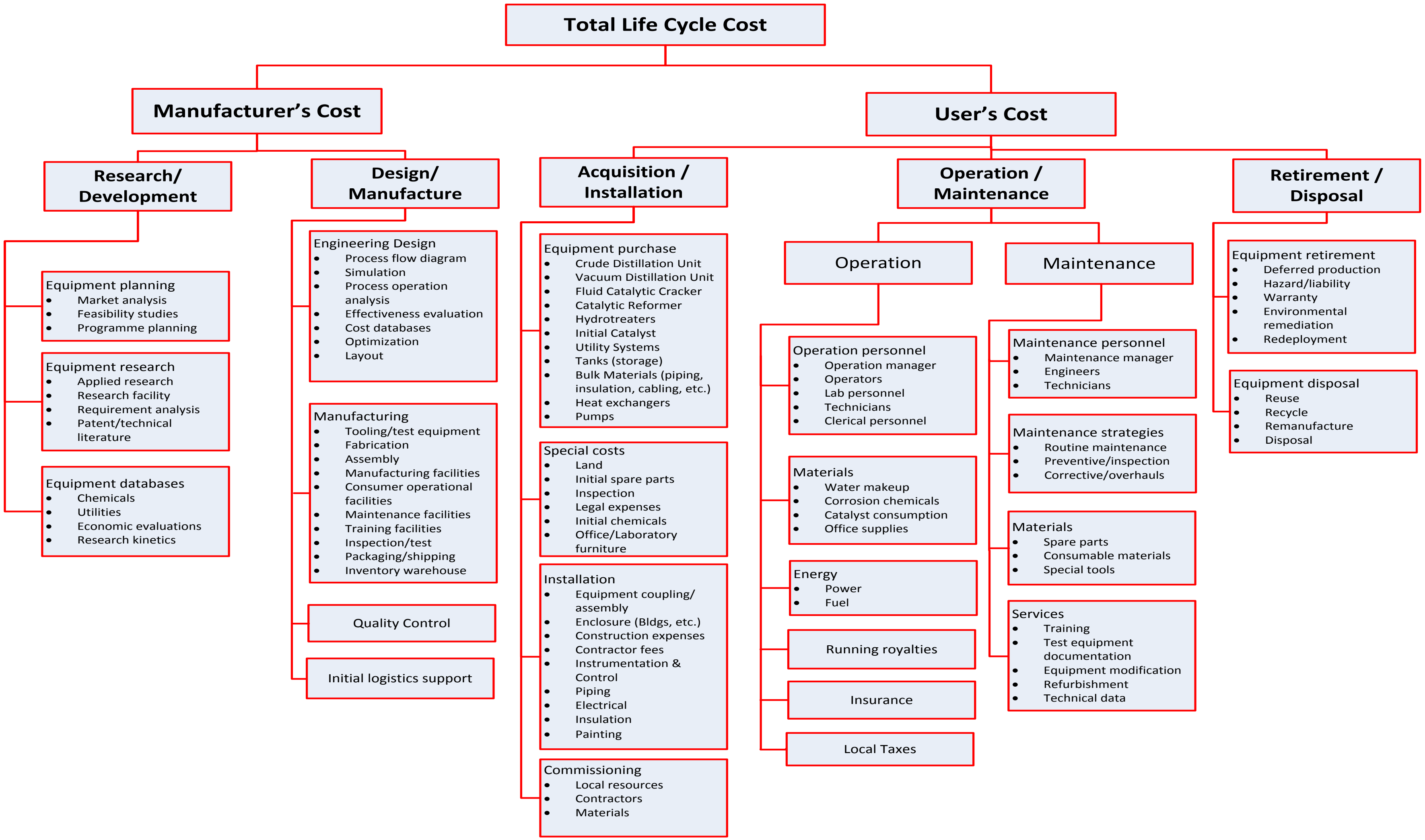

Figure 4.26 Proposed Life Cycle Cost Breakdown Structure for Oil Refineries

4.4.1 Life Cycle Cost Breakdown Structure for Oil Refineries

Since conceptual life cycle costing models are constructed at a macro level with minimum of details and limited ability to quantify cost features of a system (Waghmode *et al*, 2010), the life cycle cost breakdown structure (CBS) in Figure 4.26 thus becomes essential in explaining the cost details in each cost category of the model. For a successful accomplishment of any life cycle cost analysis, a cost breakdown structure must be developed to show the various cost elements that are integrated to provide the total cost in the overall life cycle costing framework. Consequently, the structural breakdown of cost was tailored to a specific application, e.g. oil refineries. The superiority of the conceptual LCC model in Figure 4.25 lies in its detailed life cycle cost breakdown structure as presented in Figure 4.26. The level of cost breakdown and the number of cost categories will depend on the life cycle stage, the nature of data to be extracted, and the product being designed/purchased (Asiedu and Gu, 1997).

Fabrycky and Blanchard (1991) argued that the CBS should include a logical subdivision of cost by functional activity area. They inferred that a good CBS should be able to display the following attributes:

- All life cycle costs should be considered and recognised in the CBS;
- Cost categories in the CBS must be well stated so that everyone concerned can have the same understanding of what is considered and what is not;
- Costs must be decomposed to a level necessary to give management the visibility needed in evaluating various aspects of the system;
- The cost breakdown structure (CBS) and the stated categories should be presented in a way to facilitate the analysis of specific areas of interest while ignoring other areas

4.5 Validation of Conceptual Model

The selection of experts for this validation was based on a combination of factors, such as their knowledge and experience in oil refining processes, life cycle cost estimating, cost engineering and related areas. The proposed conceptual model as presented in Table 4.1 was presented to six experts for validation. Semi-structure interviews were conducted to get their feedbacks on the relevance of the cost categories in the model. The experts were also asked to comment on whether the cost items in the CBS (Figure 4.26) are true representative of costs associated with the life cycle of an oil refinery. The author, however, explained to them that the cost categories are high level representative of costs in the life of a refinery, and their feedbacks should take that into consideration. Two of the interviewees are life cycle cost experts from the academia, while four are a mixture of a refinery maintenance manager and independent consultants with vast experience and expertise in oil and chemical industry's life cycle costing. None of them has less than twenty years experience in his domain.

The interviews were conducted in person, where the expert sat face-to-face with the researcher during the session. The interview sessions lasted between 1 – 2 hours. However, to maximise the benefit of the sessions, a semi-structured approach was adopted where the experts were allowed to comment freely on all issues relating to oil refinery and its cost engineering. The experts expressed satisfaction with the cost elements hierarchical representation as they could relate all cost elements to their parent categories within the life cycle stages of the model. However, they commented on various areas of improvement as represented in Table 4.1. The interviewees agreed that the cost breakdown structure when fine-tuned could represent a generic breakdown of cost that will be quite useful in the life cycle cost analysis of oil refineries.

Table 4.1 Outcome of Validation Sessions for the proposed LCC Model and its CBS

Validation sessions	Respondent	Outcome
Semi-structured interview	A lecturer in Engineering Project Management, University of Manchester, UK. He has about 20 years experience in life cycle costing issues. He has also co-authored a book on life cycle costing and has publications on life cycle costing.	• Clarification of the views on the life cycle cost model from the user's perspective, and how it differs from the manufacturer's perspective. • Identification and explanation of further input into the design cost components of the cost breakdown structure (CBS). • Expansion of the retirement/disposal cost activities of the model's cost breakdown structure (CBS) to include disposal strategies.
Semi-structured interview	A principal consultant with EA Technology Consulting Limited. An expert in power engineering asset management with interest in oil and chemical industry asset management and life cycle costing. He has 25 years experience on the above-mentioned areas.	• Understanding the cost elements and activities at the disposal stage of the life cycle costing of a refinery. • Refinement of the CBS to include the cost implications of environmental remediation in the disposal and retirement of an oil refinery.
Semi-structured interview	An independent consultant with over 30years experience in nuclear fuel cycle, and chemical plants cost engineering. He is currently an NVQ assessor with the Association of Cost Engineers (ACostE), UK	• Clarification on the design cost elements of the cost breakdown structure (CBS) of the LCC model. • Refinement of the life cycle stages of an oil refinery for incorporation into the LCC model as an integral part of the framework. • Expansion of design/manufacture cost within the CBS to include plant cost databases and layout.
Semi-structured interview	An academic in the School of Applied Sciences, Cranfield University, with publications and interest in life cycle costing of building and engineering systems.	• Improvement of the model by incorporating user's need and requirements into the design/manufacture phase of the LCC model. • Inclusion of some cost elements and activities specific to the CBS of oil refinery, e.g. maintenance materials and services.

Semi-structured interview	A refinery maintenance manager with over 20years experience in the oil refining industry in UK.	• Identification and explanation of further input into the operation cost of a refinery. • Understanding the need for reliable and maintainable plant by the consideration of component and equipment failure rates and data, e.g. reliability and maintainability factors.
Semi-structured interview	An emeritus professor of life cycle costing with over 35years experience in the defence systems acquisitions in UK	• Consideration of additional output of a particular petroleum product, and/or economic objective to increase output as plant user's identified requirements into the design process. • To be careful with assumptions of discount rates. Need for identification and consideration of various methodologies in the selection of discount rates to be used in the framework, e.g. discount rate at the current or expected rate the organization must pay for the use of its borrowed funds, etc.

Consequently, the author has incorporated the experts' recommendations into the conceptual model and its cost breakdown structure (CBS) as illustrated in Figures 4.25 and 4.26.

4.6 Refinery High Level Cost Drivers

Kawauchi and Rausand (1999) define a cost driver in relation to life cycle costing as “life cycle cost element which has a major impact on the life cycle costing”. Roy *et al* (2001) define it as “any factor that significantly affects cost”.

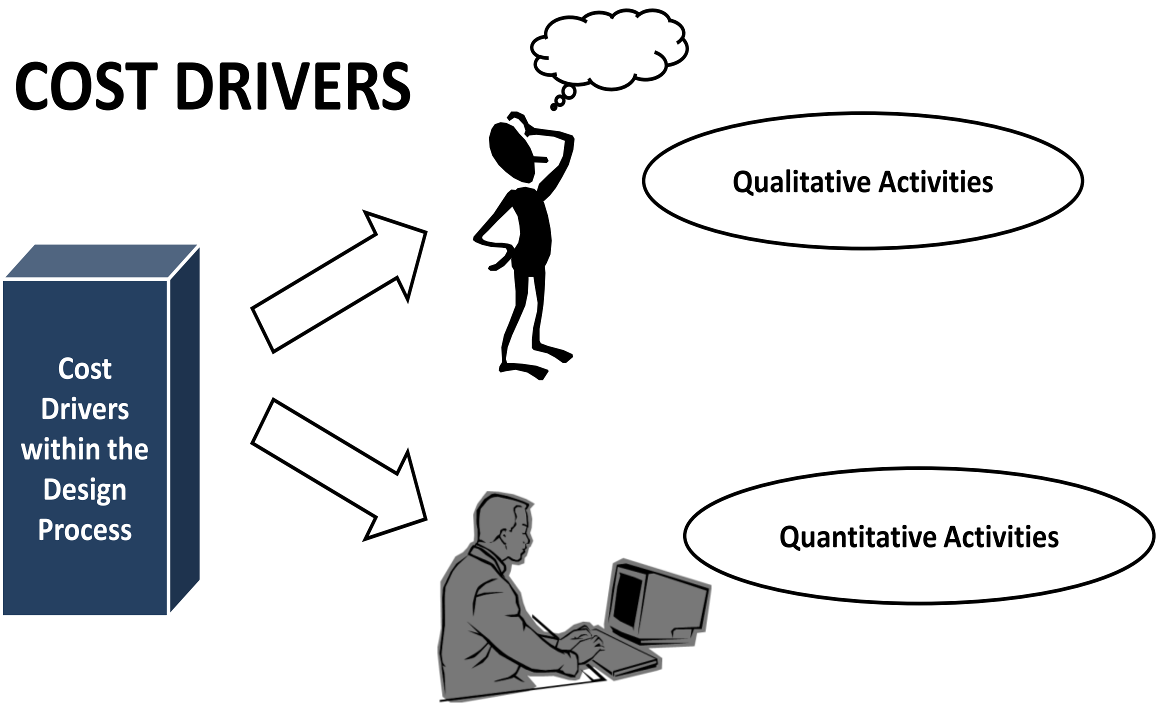

Figure 4.27 Qualitative and Quantitative Cost Drivers (Roy *et al*, 2001)

Quantitative cost driver is one that has a value attached to it and whose primary data is in form of a number, e.g. energy. *Qualitative cost driver* is one which cannot be assigned a value, and whose primary data is in the form of expert opinion or judgment, e.g. flexibility. Figure 4.27 represents qualitative and quantitative cost drivers within the design process.

With the identification of the main cost drivers of a refinery from the literature and the industrial survey, the author was able to list eight key cost areas as high level cost drivers in the life of an oil refinery. They are represented in Figure 4.28.

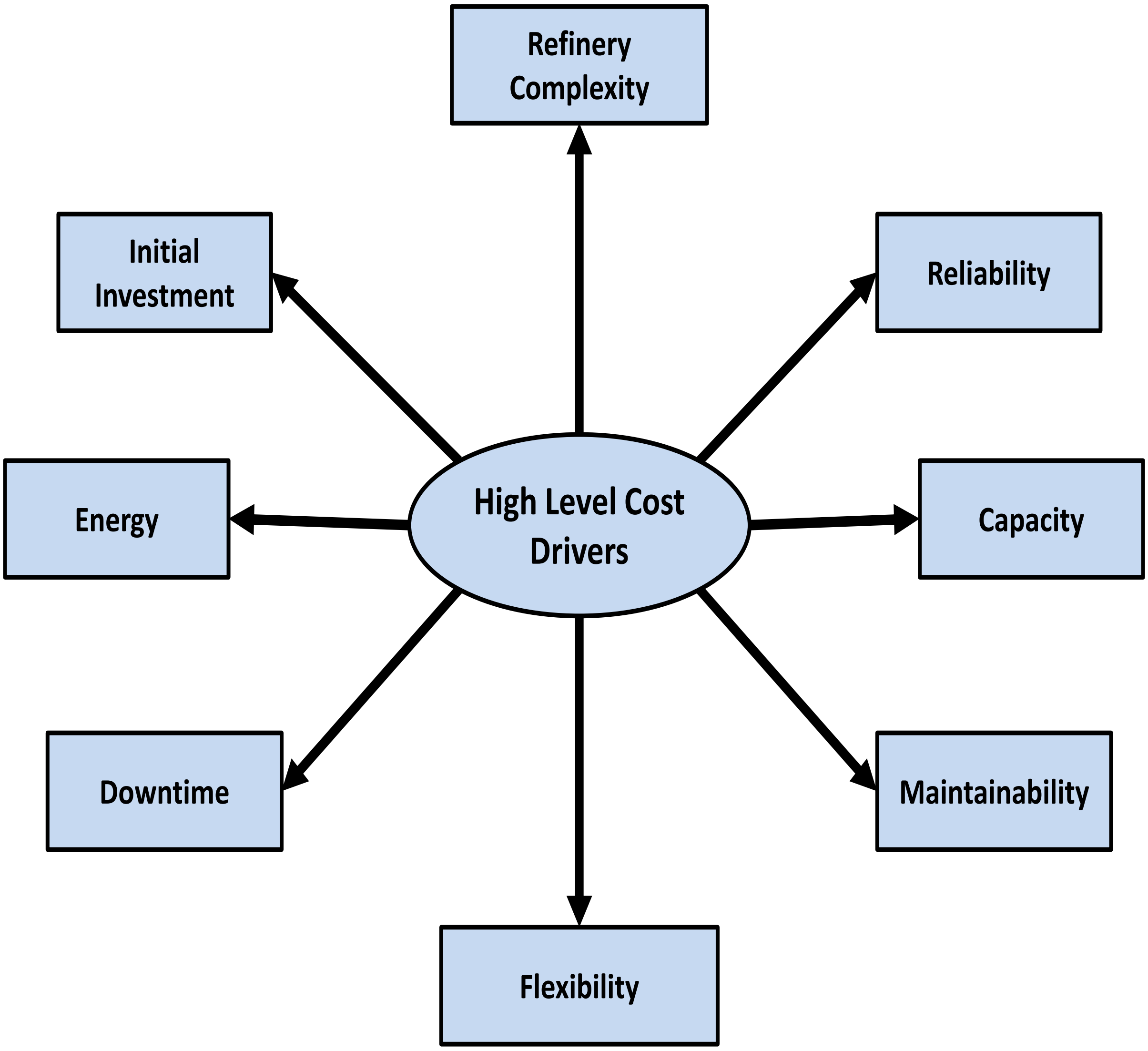

Figure 4.28 Refinery High Level Cost Drivers

- **Refinery Complexity:** Refinery complexity is a design attribute and a significant cost driver that indicates how complex a refinery is in relation to the topping refinery. The complexity index of refinery 'R' is determined by the complexity of each individual unit weighted by the percentage distillation capacity of a topping refinery (Gary *et al*, 2007). The higher the index, the higher is the complexity and greater is the cost of the refinery. USA refineries rank highest in complexity index, averaging 9.5 compared with Europe's 6.5 (Maples, 2000).
- **Reliability:** Reliability as a design parameter and a major cost driver can reduce maintenance cost when optimised. "Reliability is the probability that an item can perform a required function under given conditions for a given time interval

(Kawauchi and Rausand, 1999; Sheikh *et al*, 1990). Reliability's random variable is mean-time-between-failure (MTBF).

- **Capacity:** Charge capacity represents the input capacity of the refinery unit while production capacity represents the maximum amount of refined streams that can be produced (output). One of the factors that have a major effect on a refiner's profit is the charge and production capacities of the refinery. In refinery design, capacity relates to the cost of plant's manufacture. Hence, as the capacity of the refinery increases, so does its cost (Gary et al, 2007).
- **Maintainability:** Maintainability is a design attribute while maintenance is a consequence of design (Wu *et al*, 2006). Maintainability factors are employed to determine personnel costs (Fabrycky and Blanchard, 1991). "Maintainability is the probability that a failed item will be restored to its satisfactory operational state within a specified total downtime when maintenance action is started according to stated conditions" (Dhillon, 1989). Maintainability is a key business objective and cost driver that impact on plant's availability. In maintainability, the random variable is mean-time-to-repair (MTTR).
- **Flexibility:** Flexibility is the ability to adapt to changes in requirement. It can be achieved through the ability to expand the production facility (Ishizaka and Labib, 2011). When a system user is confronted by evenly-matched options, a flexible solution that works for both options is attractive (Ellingham and Fawcett, 2006). Flexibility and capacity are major cost drivers that have direct impact on the refiner's business sustainability and shareholders return on investment (ROI).
- **Downtime:** Downtime is a major cost driver that is associated with plant's idle times during maintenance or breakdown. It could be referred to as the cost of lost production. The cost of lost production could be estimated based on unavailability services of the production system, and it could have some serious impact on the life cycle costing assuming the idle times are high (Kawauchi and Rausand, 1999).
- **Initial Investment:** Initial investment includes purchase cost, cost of finance, installation, commissioning and training costs. Purchase cost may involve the cost evaluation of items like land, buildings/enclosures, fees, furniture and equipment (Woodward, 1997). Most of these items could be estimated by acknowledging

contract quotations from manufacturers, suppliers and agents. Finance cost may include the cost implications of various sources of funds, while other costs will be for plant installation and the training of staff to man it.

- **Energy:** Energy is associated with the refinery operation. The energy consumption and cost in the oil refining industry are quite high (Ocic, 2005). O'Brien and Jensen (2005) state that the atmospheric and vacuum distillation consumes 35 to 40% of the total process energy in a refinery. These distillation processes are not necessarily the most energy consuming but because each barrel of crude oil must go through an initial separation process by distillation (North, 2000). In the same vein, because many refinery distillates must be hydrotreated before going into downstream refining units, another 20% of energy in a refinery is dissipated by hydrotreating units (Gary et al, 2007). Table 4.2 shows cost categories where the high level cost drivers are determined in Figure 4.26.

Table 4.2 Cost categories where the high level cost drivers are determined in the CBS

Manufacturer's Cost	User's Cost
Refinery complexity	Initial investment
Reliability	Energy
Capacity	Downtime
Maintainability	
Flexibility	

4.7 Refinery Revamp and Maintenance

4.7.1 Refinery Revamp

With few new refineries being built, oil refinery unit revamps are now common in the oil refining industry. Revamping refinery units for minimum capital investment entails a holistic view of the integrated system and an understanding of which process flow scheme modifications are practicable.

By definition, revamps commence with an existing plant, and most of the existing equipment performance is critical (Barletta *et al*, 2000). Complete use of existing equipment minimizes the capital cost of a refinery unit revamp (Golden, 1997). The first step in any revamp is to accurately determine the units' capabilities and limitations. If rightly executed, the test run keeps apart the successful revamp from the unsuccessful one. A vital step in controlling revamp costs is an effective conceptual process design (CPD). Conceptual design requires a good knowledge of the integrated plant because the CPD is the most important revamp cost factor (Martin and Cheatham, 1999).

During the conceptual process design (CPD), all associated revamp modifications must be identified so that a cost estimate can be prepared. It is only when the scope of work is well defined that costs can be accurately estimated. Barletta *et al* (2002) state that "a poorly defined scope is the number one cause of revamp cost escalation". Conceptual process design (CPD) defines the process flow scheme and, therefore, the revamp scope.

Golden, *et al* (2003) defined a best practices methodology to a refinery revamp. This methodology adopts a logic-based approach for process design, equipment specification and preliminary estimating, all integrated into a unified whole. Refinery revamp work is often hindered by existing limits of the process, plot area, piping and offsites. Therefore, without a precise knowledge of these constraints, it will be impossible to define an accurate work scope. The logic-based approach as shown in Figure 4.29 can be applied by revamp engineers once the project constraints are known.

The feedback loop allows course correction when required. The feedback between blocks 6 and 5 takes into account that the existing equipment may currently be under-utilized. Practical alternatives may exist, or major logjams may prevent the original business objectives from being realized without large investment or a long shutdown. A comprehensive test run is a significant part of logic-based approach. In the absence of a test run, it could be impossible to determine the true causes that hinder existing operations and equipment reliability.

Refinery revamps are considered successful if throughput, yield and reliability objectives are achieved, and if revamps are on schedule and under budget. Budget overruns can destroy revamp economics. Cost estimating, cost control, project management, and scheduling are important activities that must be well executed but if the conceptual process design (CPD) is insufficient in detail, no amount of the aforementioned cost management activities can prevent scope growth.

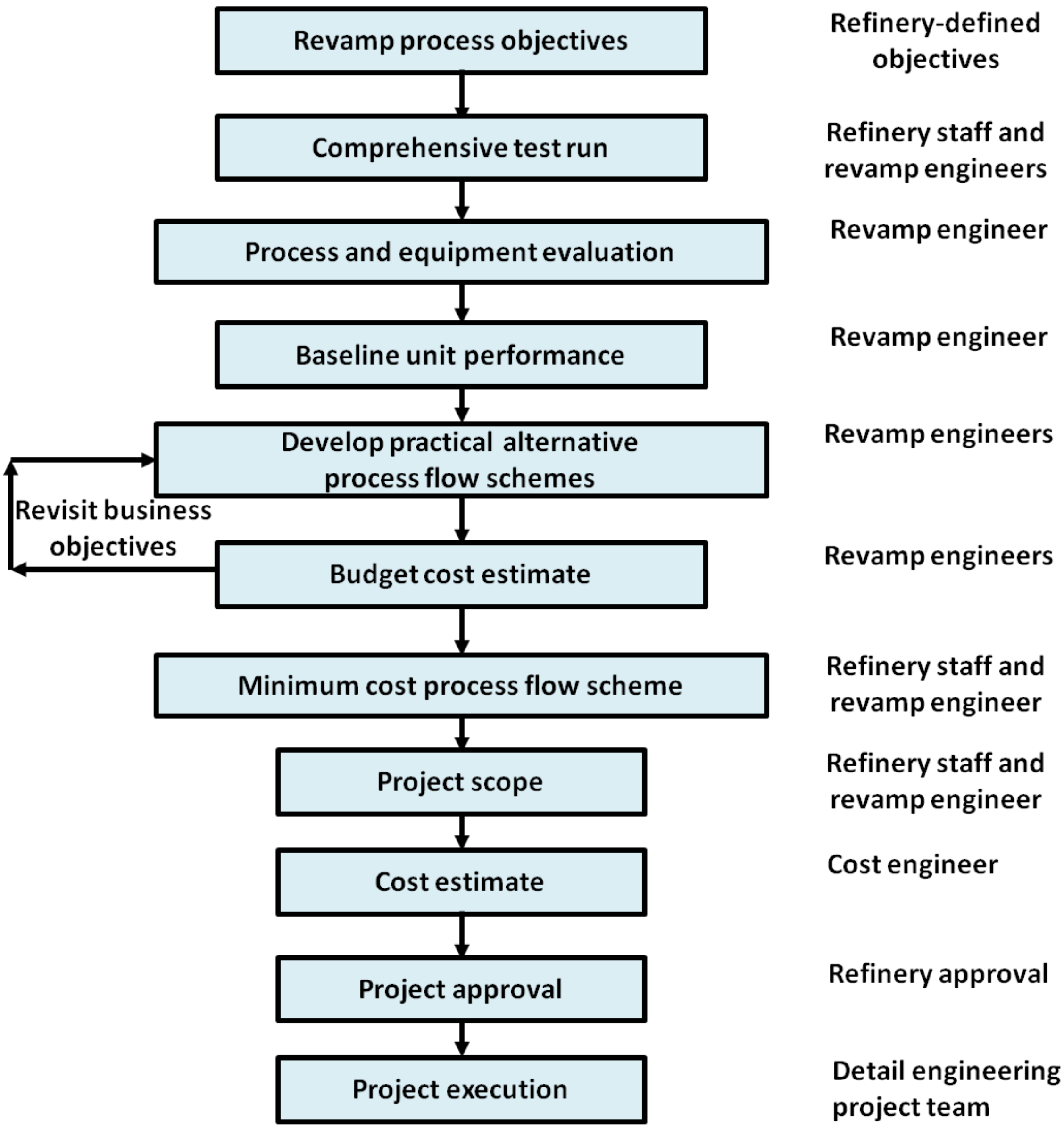

Figure 4.29 Revamp execution - logic-based approach (Golden, 2003)

4.7.2 Refinery Maintenance

Lingham (2010) defines maintenance as "the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to a state in which it can perform the required function".

Henni (2009) states that oil refineries maintenance is about avoiding emergency critical situations, and identifying problems before they become cause for concern. It involves getting difficult tasks promptly completed so that shutdowns and downtimes can be reduced. One of the major cost drivers in a refinery operation is the cost of maintenance. This varies between 3% and 8% (includes materials and labour) of the plant investment per year (Gary et al., 2007). As a result, maintenance and its strategies are of special importance in the oil and gas industry.

Refinery Maintenance Strategies

- **Corrective (Reactive) Maintenance**
  Corrective maintenance is basically the "run it till it breaks" maintenance mode. Actions are not taken to maintain the equipment as the original intention of the designer is to ensure that the design life is reached. When corrective maintenance strategy is applied, maintenance is not implemented until failure occurs. It is considered the best strategy where profit margins are huge. However, increasing global competition and dwindling profit margins have compelled refiners to adopt a more reliable and effective maintenance strategies.
- **Preventive (regular, periodic and planned) Maintenance**
  This strategy is based on component reliability and it could be used for stabilising the reliability of a refinery. Information on reliability makes it possible to analyze the component in question and a periodic maintenance programme for the plant could be developed. This strategy tries to ascertain a series of checks and replacements with a frequency related to the failure rate. Furthermore, preventive maintenance is effective in overcoming the challenges associated with components' wear and tear. It essential to use it for those items of equipment that incur high downtime costs whereas items of equipment incurring low downtime costs can be attended to or replaced as they wear out.
- **Condition-based Maintenance**

  Maintenance decision is made depending on the measured data from a set of sensors. Monitoring techniques such as remote plant monitoring, vibration monitoring, lubricating analysis could be employed. The monitored data of equipment parameters could tell engineers whether the situation is normal, allowing the maintenance staff to apply necessary measures before failure occurs. This maintenance strategy is often designed for rotating and reciprocating machines, e.g. turbines, centrifugal pumps, heat exchangers and compressors (Alnaijar and Alsyouf, 2003).

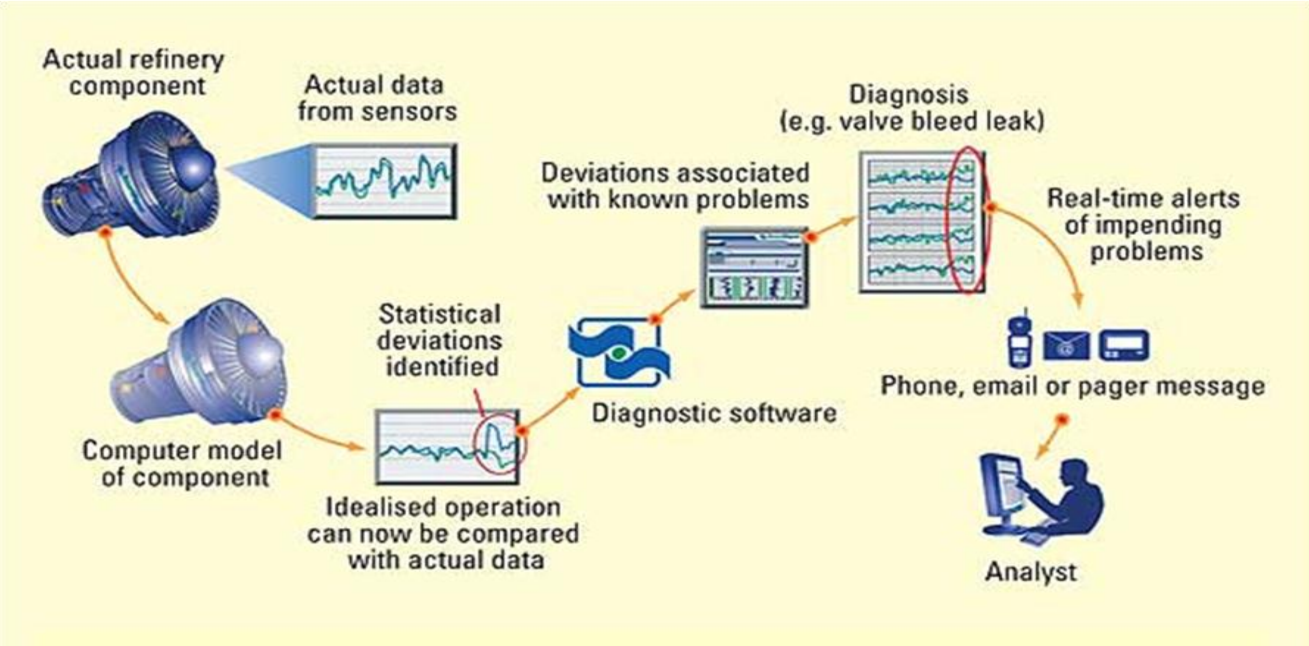

Figure 4.30 Remote plant monitoring (Brown, 2006)

Remote plant monitoring in Figure 4.30 shows new ways of collecting and using refinery data to maximum advantage. Remote plant diagnostic software automatically alerts an analyst to potential problems with refinery operations before they develop into larger problems (Brown, 2006).

- **Predictive Maintenance**

  Predictive maintenance makes it possible to predict when the controlled quantity value will reach or exceed the threshold value. Basically, predictive maintenance differs from preventive maintenance by basing maintenance need on the actual condition of the plant rather than on some preset schedule. This strategy helps to ascertain the condition of equipment in order to forecast when maintenance should be conducted. This technique is more cost-efficient than the preventive maintenance because tasks are carried out only when they are necessary.

- **Reliability Centred Maintenance**

  This strategy is used to determine the maintenance requirements of any physical asset in its operating state. It recognizes that all equipment in a facility is not of equal importance to either the process or facility safety. It recognizes that equipment design and operation differs and that different equipment will have a higher probability to undergo failures from different degradation mechanisms than others. RCM appreciates the fact that maintenance activities on equipment that is inexpensive and unimportant to facility reliability may best be left to a corrective (reactive) maintenance approach

Maintenance Strategy Selection Criteria

Selection of maintenance strategy in the refining industry depends on some criteria. Pariazar et al (2008) states the key criteria for selection of maintenance strategy as:

- Equipment's wear and tear
- Customer satisfaction
- Skilful human resources
- Risk
- Personnel training
- Environmental effects
- Equipment and personnel efficiency
- Products quality
- Reliability
- Hardware cost
- Equipment safety.

4.8 Framework development overview

The validation sessions and informal discussions with key industry practitioners revealed that there is no high level LCC framework for oil refineries. These observations were subsequently confirmed by the results of the industrial survey as presented in Section 4.3.

The development of the proposed framework was anchored on a number of features identified to be essential towards the accomplishment of life cycle costing analysis for oil refineries. The features were defined based on findings from the literature (Table 2.4) and the industrial survey. The proposed framework is a simple tool that can be used by decision makers to achieve three main objectives, namely:

- Evaluation of different alternative schemes on the basis of system effectiveness and total life cycle cost of the effective option.
- Evaluation of the life cycle cost of a refinery for revamping and maintenance purposes.
- Evaluation of the life cycle cost of a refinery at any stage of its life cycle for budgetary purposes.

4.9 Life Cycle Cost Estimating Framework

The main characteristic of the life cycle cost estimating framework is its principal role as a tool to estimate not only the cost of a refinery's entire lifecycle but also its system effectiveness. The framework's ability to evaluate the system effectiveness of alternative schemes in the absence of performance data makes it unique. The LCC framework is shown in Figure 4.31. It consists of nine main components. Hence, discussion will centre on these main components.

4.9.1 Problem definition

- **Objective:** The first step of any life cycle costing analysis is to vividly state the problems and the scope of work to be undertaken. This step is vital to the successful application of life cycle costing in any project. The purpose is to develop an understanding of the issues, assumptions and the need for the analysis. For example, there may be a need for a life cycle cost analysis in evaluating alternative refinery configurations, or alternative refinery operational methods.
- **Evaluation criteria:** The evaluation criteria to select an effective refinery with predicted life cycle cost should include not only the total cost but also the system effectiveness. Decisions on ***cost*** should not be made in isolation of ***effectiveness*** of the system. Researchers and authors (Kawauchi and Rausand, 1999; Vorarat and Al-Hajj, 2004; Singh and Tiong, 2005; Iwawaki *et al*, 2002) have emphasised the need for a life cycle costing framework that will not only consider total cost but also system effectiveness. Evaluation will be carried out in distinct phases within the

framework. First, evaluation will be carried out on a qualitative basis in the absence of performance data using a multi-criteria decision making technique to select the most effective refinery scheme from the alternatives presented. Second, the selected alternative will be further evaluated to ascertain its life cycle cost. It is important to emphasize that the evaluation of effectiveness is separated from the evaluation of cost.

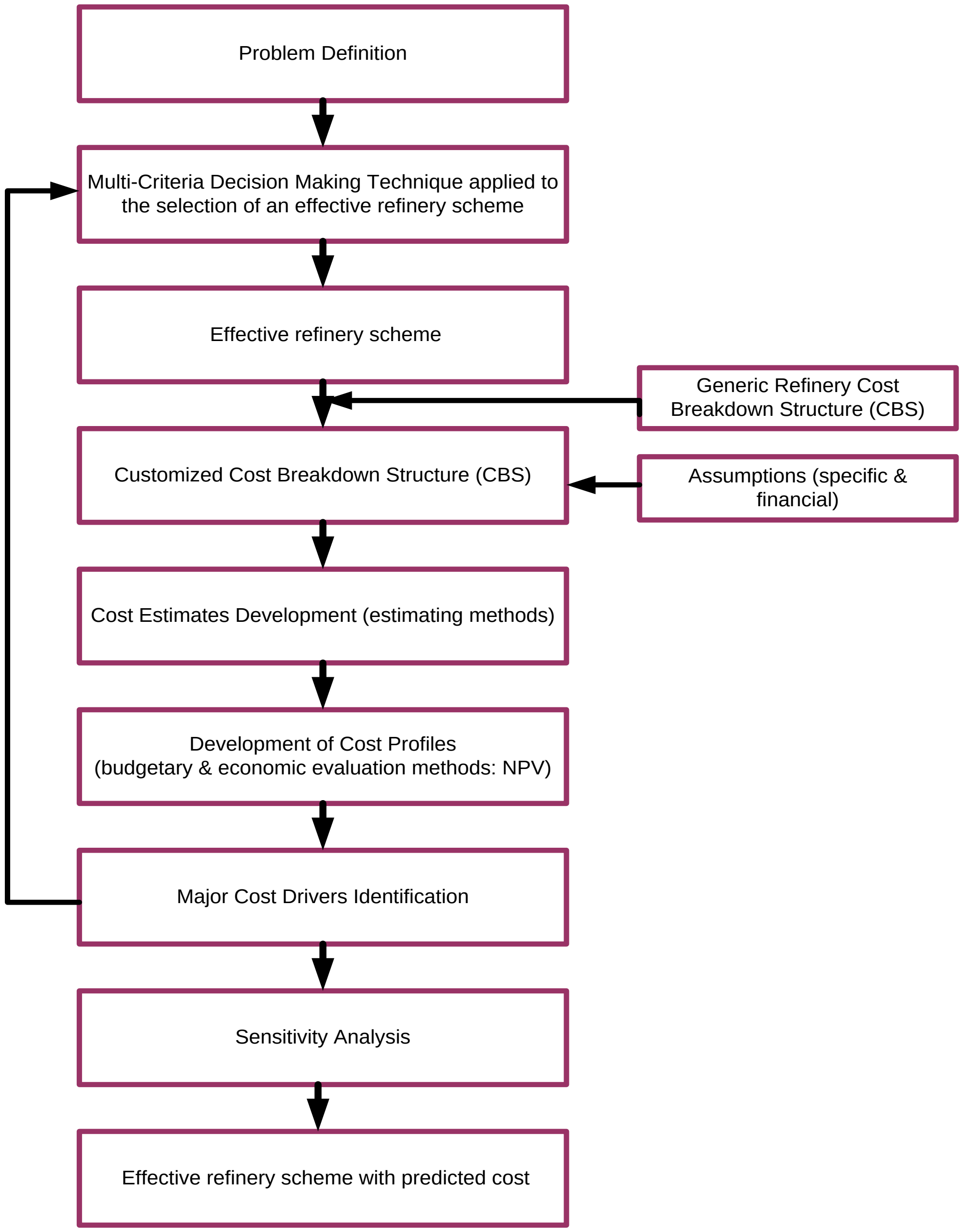

Figure 4.31 Proposed Life Cycle Cost Estimating Framework for Oil Refineries

4.9.2 Multi-criteria decision making technique applied to the selection of an effective refinery scheme.

As stated in Chapter 2, Section 2.4.3, system effectiveness relates to the capability of a system to fulfil a defined requirement. It is a function of some effectiveness attributes associated with the design of an oil refinery, e.g. reliability, maintainability, capacity, and flexibility. Consequently, life cycle cost analysis that ignores such issues will omit relevant costs and risks and thus present an erroneous reality (Emblemsvag, 2003). This assertion is true for an open complex system like the oil refinery that has long lifespan. However, some of these attributes are quite intangible in nature and even the tangible ones can only be modelled from past data of similar plants working under similar conditions. Unfortunately, this data is not readily available. Moreover, the research timeframe may not permit the modelling of these attributes or encourage a cost intensive data collection from a competitive oil refining industry that is commercially sensitive. As a result, the evaluation of options for system effectiveness will be carried out on a qualitative basis using a multi-criteria decision making technique to select an effective refinery scheme from several alternatives. The technique uses expert opinion and judgment in complex decision making scenario in the absence of data.

Quite unlike models and methodologies that use quantitative measurements, measurements in MCDM (multi-criteria decision making) are presented qualitatively as indicators of the strength of various preferences (Saaty, 2005). Some of the models and methodologies for MCDM that are currently in use are: Goal programming (GP), Grey relational analysis (GRA), Dominance-based rough set approach (DRSA), Multi-attribute global inference of quantity (MAGIQ), Analytic hierarchy process (AHP), Outranking methods, and Multi-criteria utility theory (MAUT).

4.9.3 Effective refinery scheme

The effective refinery scheme will be the selected option based on the result of the multi-criteria decision making technique used in the evaluation.

4.9.4 Customised cost breakdown structure

Given the selection of an effective refinery scheme, the next procedure will be to develop a customised cost breakdown structure for the selected option. However, there will be some level of cost elements input from the generic cost breakdown structure developed in this chapter. Furthermore, some specific assumptions that will flow into the cost estimates development will be considered here. Discussion on cost breakdown structure is covered in Chapter 2, Section 2.4.3.

4.9.5 Cost estimates development

With the acknowledgement of life cycle cost analysis objective, the identified life cycle activities associated with the selected refinery option being analysed, and the cost structure within the customised CBS, the cost estimating function could be conducted. Cost estimates can be developed using different estimating methods; estimating by engineering procedures, parametric estimating methods, etc. Cost estimating techniques are discussed in Chapter 2, Section 2.3.

4.9.6 Development of cost profile

Cost profile should be developed for projecting costs into the future. When considering costs that will be incurred in the future, it is essential to discount all expenditures to a specific decision point. Thus, discounted cash flow (time value of money) technique such as PV (present value) should be used to discount all future costs to the present day value. The formula is:

$$PV = \frac{FV}{(1+i)^n}$$

Where *PV* is present value

FV is future value

i is discount rate

n is number of years.

PV is a compounding process that shows the value of life cycle cost at a specified date in the future that is equivalent in value to a specified sum today (Boussabaine and Kirkham, 2004).

4.9.7 Major cost drivers identification

An important goal of life cycle cost analysis is the identification of major cost drivers, which may have significant impact on the total life cycle cost. If a cost driver is identified, it is important to establish the causes of the high cost. Assuming there are opportunities for cost effectiveness improvement in the design, the analyst could recommend the consideration of those high cost items as input into a new plant design (see a proposed framework for cost trade-offs in Chapter 2). Furthermore, the modification of design in line with cost drivers could effectively reduce the life cycle cost of a plant.

4.9.8 Sensitivity analysis

The sensitivity of the major cost drivers should be tested by changing their values to see if the overall result will be altered significantly. The less the final outcome is altered by these changes, the more reliable the result will be. The results of sensitivity analysis are usually presented in a set of three values, e.g. low, medium and high. In the implementation of life cycle cost analysis, the result is a distribution of possible values and not just a figure. These values range between low limit (optimistic value) and the upper limit (pessimistic value), while the most feasible life cycle cost value will be the baseline (Navarro-Galera *et al*, 2010).

4.9.9 Effective refinery scheme with predicted cost

The evaluation result shall be the total predicted life cycle cost for an effective refinery scheme.

The next chapter provides discussion on the application of the proposed framework on a case study.

CHAPTER 5 DETAILED CASE STUDY

5.1 Introduction

The aim of this section is to explore the application of the proposed framework on a case study. The framework will be used to predict the operating costs associated with the most effective refinery scheme selected through a screening process (Multi-Criteria Decision Making approach using the AHP) in the framework. The proposed life cycle cost estimating framework is represented in Figure 4.31.

5.2 Framework application on a case study

A step by step application of the framework to the case study is as stated below:

5.2.1 Problem definition

- **Objective**

There is a need for an effective refinery that can successfully meet the user's overall operational demand in terms of operating costs reduction. The motivation for considering operating costs stems from the fact that operation and support costs (in-service costs) are the most significant portion of the life cycle cost of any system (Kawauchi and Rausand, 1999; Waghmode *et al*, 2010). US government records have shown that the cost of operating and supporting any system may exceed the initial cost of that system as much as ten times (Asiedu and Gu, 1998).

- **Evaluation criteria**

The evaluation criteria to select an effective refinery with predicted operating cost should include not only the total cost but also the system effectiveness. Evaluation will be carried out in distinct phases within the framework. The evaluation will normally be in two stages: (a) Initial evaluation will be carried out on a qualitative basis using a multi-criteria decision making technique (AHP) to select the most effective refinery scheme from three options of topping refineries. (b) The selected option will be further evaluated to predict its life cycle operating cost. It is important that option generation and evaluation are carried out in distinct phases to ensure that evaluation does not stifle option generation process.

5.2.2 Multi-Criteria Decision Making Technique applied to the selection of an effective refinery scheme

"Multi-criteria decision making (MCDM) refers to making decisions in the presence of multiple, usually conflicting criteria" (Xu and Yang, 2001). It is a decision making process that supports decision makers confronted with numerous and conflicting evaluations to arrive at the best solution from among several alternatives. Detailed discussion on multi-criteria decision making techniques is presented in Chapter 4.

The author defines analytic hierarchy process (AHP) as the best suited technique for this case study. The AHP developed by Thomas Saaty (Saaty, 1980; 1982; 1990) is a robust and flexible multi-criteria decision making (MCDM) technique for complex problems where both qualitative and quantitative aspects are considered.

The choice of AHP amongst other multi-criteria decision making technique is because it provides a convenient way to quantify the qualitative attributes of the options presented, hence removing subjectivity in the result (Tiwari, 2006). Its matrix system of pairwise comparisons can be utilized to subjectively establish the relative weight between criteria, and alternatives. Though, AHP is based on subjective judgments from experts, it has an indispensable characteristic that other subjective methods lack; an internal logical consistency check (Emblemsvag, 2003) because as human beings our judgments with respect to qualitative issues are seldom consistent. Hence, AHP is capable of producing logical consistent results. In the next Section, the author will explore its application in the selection of an effective topping refinery.

5.2.2.1 Analytic hierarchy process (AHP) applied to the selection of the most effective refinery scheme

- **Introduction**

  This analysis describes the use of the AHP in the selection of the most effective topping refinery. AHP takes into consideration the decision makers' personal inconsistencies as their judgments as human beings with respect to qualitative issues are seldom consistent. The AHP accommodates and quantifies these inconsistencies in the analysis. An inconsistency ratio of less than 0.1 (10 percent) shows that the result is sufficiently accurate but if greater than 0.10, the result may be less predictable and may require re-evaluation. Lee and Kim (2001) opined that decision makers feel comfortable with AHP because it is simple and easy to understand.

- **The Analytic Hierarchy Process**

  The AHP assists the analyst to organize the essential aspects of a problem into a hierarchical pattern. Moreover, by reducing complex decisions to a series of simple comparison and rankings, and later synthesizing the results, the AHP not only assists the analyst to arrive at the best decision but provides clarity in the manner the choices are made (Bevilacqua and Braglia, 2000). The AHP has particular application in group decision making (brainstorming).

The overall procedure of the AHP is as follows:

a. Definition of decision criteria in the form of a hierarchy of objectives. The hierarchy is structured at different levels from the top (the goal) through intermediate levels (criteria) to the lowest level (the alternatives).
b. The criteria are weighted as a function of their importance for the corresponding element of the higher level. For this purpose, AHP uses simple pairwise comparisons to determine weights and ratings so that the analyst can concentrate on just two elements at a time.
c. After the development of a judgment matrix, a priority vector to weight the elements of the matrix is calculated. This is the normalized eigenvector of the matrix.

Eigenvector and Eigenvalue

The normalized eigenvector and the principal eigenvalue of the comparison matrix give the relative importance of various criteria being compared (Bhushan and Rai, 2004). The normalized eigenvector is called priority vector. Since it is normalized, the sum of all elements in priority vector is 1. The priority vector therefore shows relative weights among the things compared.

Apart from the relative weight, the consistency ratio could also be checked. To accomplish this, we need what is called principal eigenvalue. The principal eigenvalue is derived from the summation of products between each element of eigenvector and the sum of columns of the reciprocal matrix. The AHP takes into consideration our personal inconsistencies in decision making because our judgment with respect to qualitative issues are hardly consistent. The AHP accommodates and quantifies these inconsistencies in the analysis. If the consistency index fails to get to a required level then results derived from the comparisons may be re-examined. The Consistency Index, CI, is calculated as:

$$CI = (\lambda_{max} - n)/(n - 1)$$

Where λ_{max} is the maximum eigenvalue of the judgment matrix, while n is the number of elements to be compared. The CI can be compared with that of a random matrix, RI. The ratio of CI/RI is called the consistency ratio, CR. Saaty (1980) suggests that the value of CR should be less than 0.1.

Saaty (1986), Harker and Vargas (1987) state the axioms of AHP as follows:

i. Homogeneity: This axiom states that comparisons are meaningful if elements are comparable. Hence, we cannot compare refineries with aircrafts.
ii. Dependence: This axiom allows comparisons among a set of elements with respect to another element at the higher level. Consequently, comparisons at the lower level depend on the element at the higher level.
iii. Expectations: This axiom simply states that any change in the structure of the hierarchy will require new evaluations of preferences for the new hierarchy.
iv. Reciprocal condition axiom: This axiom is derived from the intuitive idea that if an alternative or criterion A is n times preferred to B, then B is 1/n times as preferred as A.
v. Inconsistency ratio: An inconsistency ratio (IR) of 0.10 (i.e. 10 percent) or less is a positive evidence of an informed judgment.

- **Decision Scenario**

The AHP hierarchy developed in this study is a three level process in which the top level represents the main goal of effective refinery selection and the lowest level comprises the alternative topping refineries.

The criteria that influence the primary goal are included at the second level and are related to different system effectiveness requirements.

The development of the system effectiveness criteria and the selection of topping refinery options were carried out by a panel of experts (decision makers) in consonance with the author.

A panel of experts (decision makers) was put together to encourage communication and meetings where expert opinions and knowledge could contribute to the process. The panel was made up of three (3) PhD researchers in the School of Engineering, Cranfield University, whose research studies are mainly focused on oil refinery scheduling, operations, planning, and design parameters.

The chairperson of the three-man panel of experts is a chemical engineer with a total of 17years experience in petrochemical process plant design in Nigeria and UK. She has worked in various capacities as a trainee manager, assistant maintenance manager, and refinery operations manager. The second panellist is a petrochemical engineer with a total of 10years working experience in oil refinery scheduling and planning. He is the project manager of an oil and gas servicing company in Nigeria. His company handles the turnaround maintenance of some oil refineries in Nigeria. He has benefitted from various overseas training programmes in the past. The third panellist is a chemical engineer with 9years working experience as an independent consultant saddled with the responsibility of conducting training programmes on refinery operations and economics for oil refinery companies in Nigeria and South Africa.

The establishment of this panel proves to be appropriate for this type of study because it allows expert opinions and knowledge to be obtained on a subject matter. The panel (decision makers) worked for a period of two weeks, and each session lasted for two hours.

The search for criteria was first conducted by the panel (decision makers), where ten (10) system effectiveness criteria were identified, namely: availability, reliability, maintainability, flexibility, capacity, supportability, dependability, readiness, adaptability, and producibility. To limit the complexity of the analysis to be undertaken, the number of evaluation criteria was reduced to four (4) by categorising similar attributes and discarding the less important ones. The four system effectiveness criteria chosen by the panel (decision makers) are reliability, maintainability, capacity, and flexibility. These criteria were selected because of their impact on refinery operation, maintenance, production, and adaptation. The panel argued that a plant which is reliable and maintainable leads to optimum availability and user satisfaction, while flexibility and capacity may have direct impact on the refiner's revenue (return on investment) and business sustainability. Furthermore, three alternatives of topping refinery (Preflash Drum Scheme, Prefractionator Scheme, and Dual Drum Scheme) were identified for the study.

Bevilacqua and Braglia (2000) state that "an increase in the number of parameters does not imply a higher degree of analysis accuracy". With a large number of attributes, the quantitative evaluation of the factors becomes more complex and subject to the risk of inaccurate results. Moreover, most of the above-mentioned system effectiveness criteria are not easy to evaluate because of their complex and intangible nature. In addition, the nature of the weights of importance that the panel of experts (decision makers) must allocate to these factors during the selection process will be highly subjective as the refineries (Figures 5.1, 5.2, and 5.3) are still in the design/manufacture phase. Mean-time-between-failure (MTBF) and mean-time-to-repair (MTTR) which are random variables in reliability and maintainability respectively are some tangible aspects that can only be estimated from failure data in existing plants (oil refineries), working under similar conditions. But unfortunately these data may not be readily available (Gluch and Baumann, 2004). For the resolution of this problem, a multi-criteria decision making approach using the AHP was proposed, where both qualitative and quantitative aspects could be considered.

- **Topping Refinery**

The first and foremost refinery configuration is the topping refinery which is designed to separate the crude oil into its constituent petroleum products by atmospheric distillation process (Speight, 2011). Topping refinery consists of tankage, an atmospheric tower, side strippers, desalter, crude furnace, heat exchangers, pumps, recovery facilities for gases and light hydrocarbons, and the necessary utility systems.

The topping refineries in Figures 5.1, 5.2, and 5.3 were chosen for this study because the topping refinery is the first and essential building block in any refinery complex. Moreover, it is the main unit upon which other units derive their complexities. Thus, refinery complexity indicates how complex a refinery is in relation to the topping refinery. The complexity index of refinery R is determined by the complexity of each individual unit weighted by its percentage of topping refinery (Gary et al, 2007).

The three alternatives of topping refinery are:

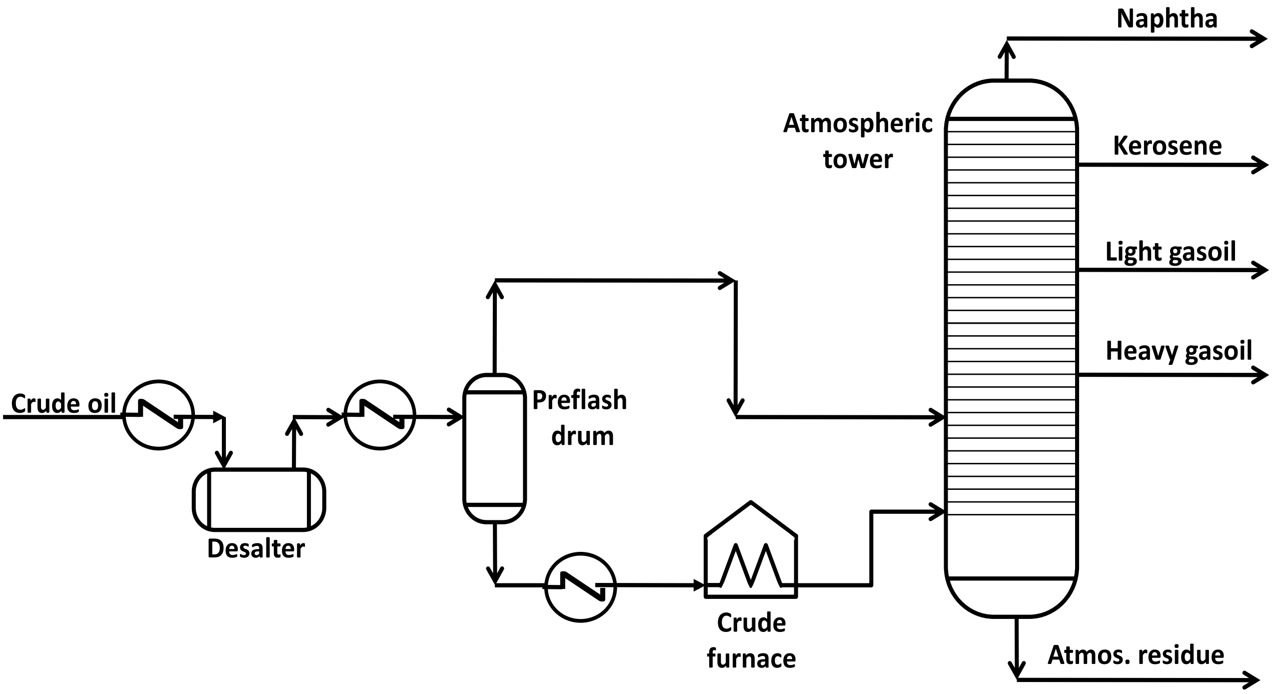

Figure 5.1 Preflash Drum Scheme (Hori, 2000)

The desalted crude oil is heated, and then introduced to a preflash drum where flashed water and light hydrocarbons are separated. The flashed vapour is sent directly to the atmospheric tower. The flashed liquid is further heated by heat exchangers and a crude oil furnace. This system reduces pressure drop through the crude oil furnace, and prevents mal-distribution of crude oil to the furnace tube passes.

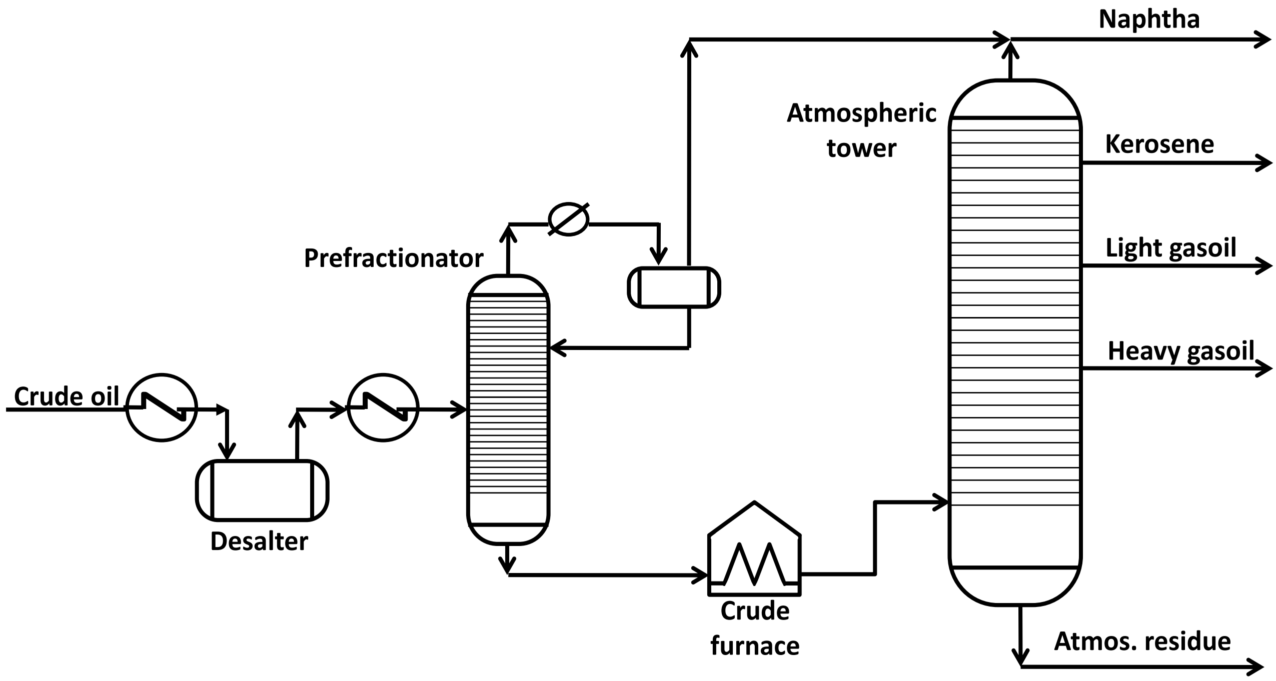

Figure 5.2 Prefractionator Scheme (Hori, 2000)

A prefractionator is installed to remove gas and part of naphtha from the crude oil. Since gas and part of the naphtha are removed in the prefractionator, the diameter of the atmospheric tower can be reduced. The pressure drop through the feed furnace may also be reduced. This system is often applied when processing crude oils that are rich in gas and naphtha fractions. It is also applied as a means of increasing the capacity of an existing unit.

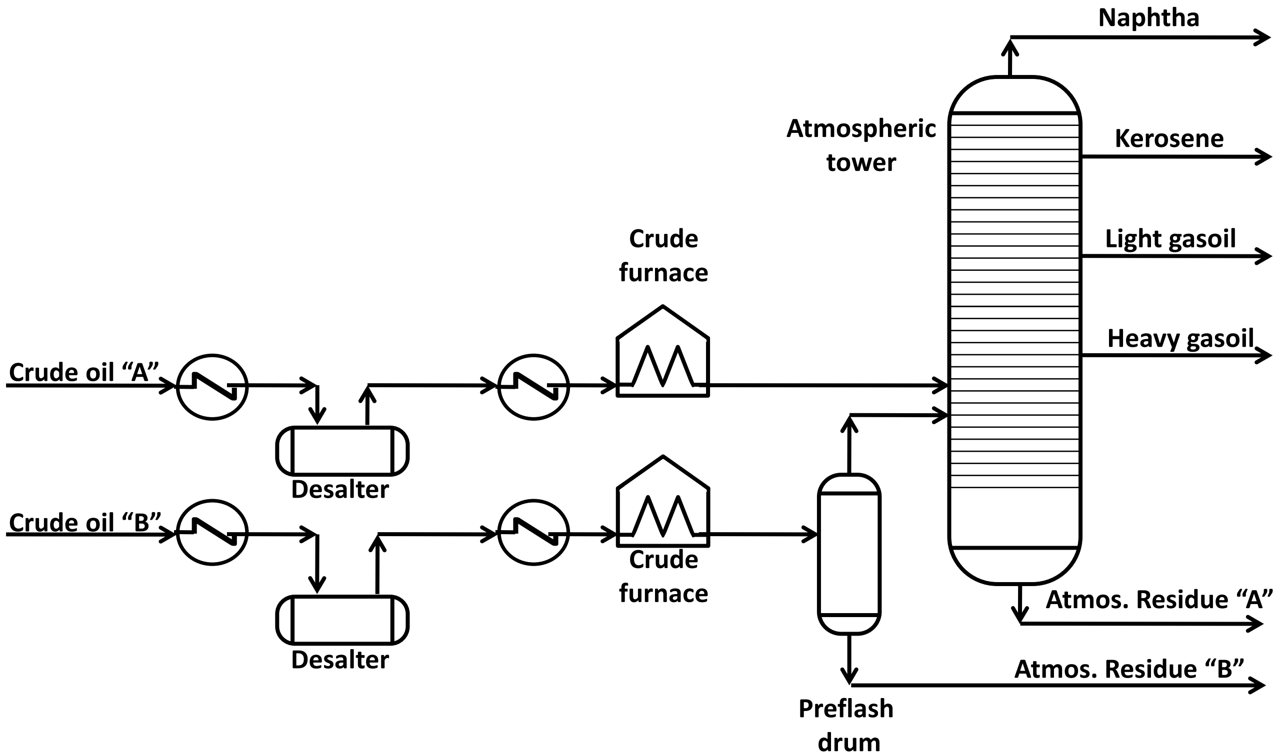

Figure 5.3 Dual Drum Scheme (Hori, 2000)

This system is applied to process two or more kinds of crude oil whose properties, e.g. sulphur content are very different. An additional crude feed train provided with flash drum is installed to yield separately the residue from each crude oil.

- **System effectiveness**

Fabrycky and Blanchard (1991) defined system effectiveness as "the probability that a system or product can successfully meet an overall operational demand within a given time when operated under specified conditions". Thus, system effectiveness relating to the ability of a topping refinery to fulfil the user's overall operating requirement is a function of the following attributes: reliability, maintainability, capacity and flexibility. The above-mentioned attributes are useful to the Decision Makers in subjectively assessing the level to which each alternative satisfies the system effectiveness criteria.

a) Flexibility

Flexibility is the ability to adapt to changes in requirement. It can be achieved through the ability to expand the production facility and sharing of resources (Ishizaka and Labib, 2011). When a system user is confronted by evenly-matched options, a flexible solution that works for both options is attractive. Ellingham and Fawcett (2006) state that it is reasonably easy to estimate the cost of providing an option to switch use, but valuing the option is a bigger task because years after the decision had been made, it may not be clear whether flexibility would have justified its huge cost.

b) Reliability

"Reliability is the probability that an item can perform a required function under given conditions for a given time interval" (Kawauchi and Rausand, 1999; Sheikh *et al*, 1990). Operational reliability plays an active role in the process of decision making. Reliability, which is expressed in terms of mean-time-between-failure (MTBF), is a major parameter in determining operation and maintenance costs in life cycle cost analysis.

c) Capacity

Charge capacity represents the input capacity of the refinery unit while production capacity represents the maximum amount of refined streams that can be produced. One of the factors that has a major effect on a refiner's profit is the charge and production capacities of a plant. Topping, hydroskimming, cracking and coking refineries are described in terms of their charge capacity, which describes the input feed capacity of the plant. Refineries generally have an on-stream (full capacity) factor of about 92% to 96% (Gary *et al*, 2007).

d) Maintainability

"Maintainability is the probability that an item will be retained in or restored to a specified condition within a given period of time when maintenance is performed in accordance with prescribed procedures and resources" (Fabrycky and Blanchard, 1991). It therefore measures the ease and speed with which a system can be restored to operational condition after a failure. Maintainability is a design parameter which impacts on life cycle cost, especially operation and maintenance costs. In maintainability, the random variable is mean-time-to-repair (MTTR) just as mean-time-between-failure (MTBF) is the random variable in reliability. An important objective must be to provide a system that is highly reliable and maintainable as these two factors have direct impact on a system's operation and maintenance cost. These are commonly referred to as life cycle cost of ownership.

- **Decision Hierarchy**

The AHP hierarchy for this decision is shown below:

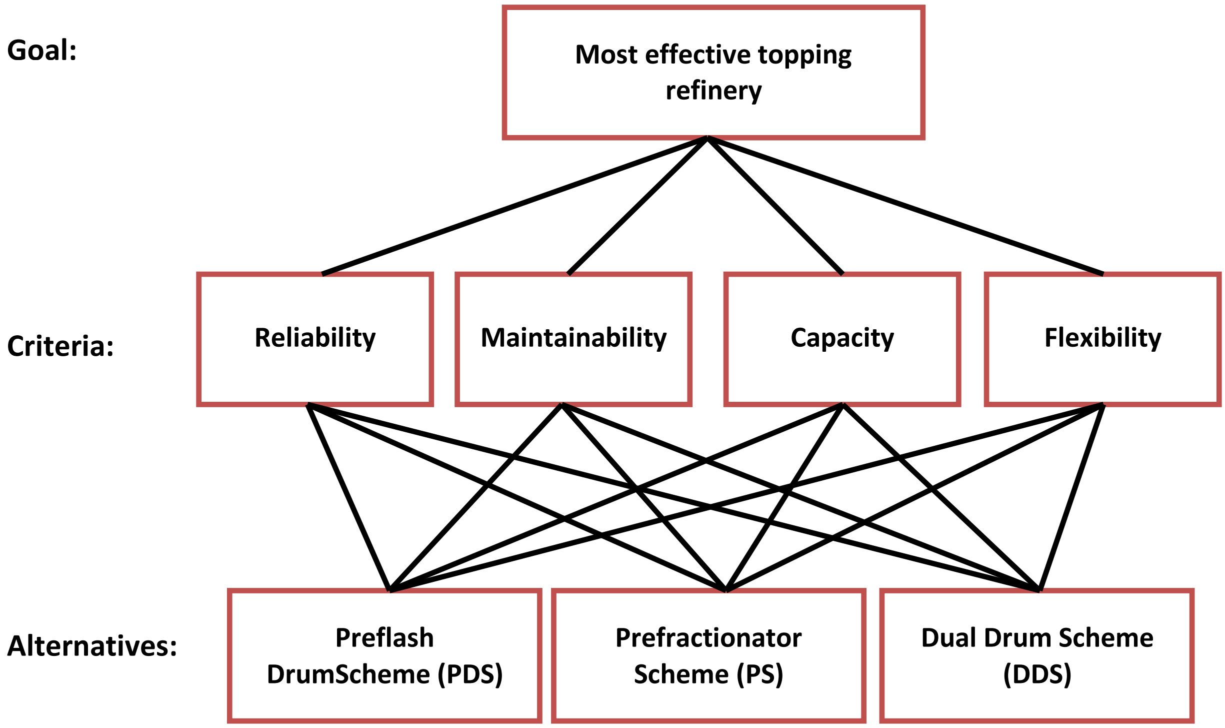

Figure 5.4 Decision hierarchy for the selection of an effective refinery

- **Pairwise Comparison**

As the AHP analysis progresses, the priorities for the alternatives will be determined with respect to each of the decision criteria, and priorities for each of the criteria with respect to their importance in reaching the goal.

The priorities will be derived from a series of measurements: pairwise comparisons involving all the elements.

The elements at each level will be compared, two by two, with respect to their contribution to the element above them. The comparisons will begin by comparing the alternatives with respect to their strengths in meeting each of the criteria. The next step will be to compare the criteria with respect to their importance to reaching the goal. Since we have three alternatives and we need to compare each one to each of the others, we will make three pairwise comparisons with respect to each criterion: PS vs. DDS, PS vs. PDS, and DDS vs. PDS.

The AHP Fundamental Scale in assigning the weights is stated below in Table 5.1

Table 5.1 The Fundamental Scale for Pairwise Comparisons (Saaty, 1980)

Intensity of Importance	Definition (Judgement)	Explanation
1	Equal Importance	Two elements contribute equally to the upper level criteria.
3	Moderate importance	Experience and judgement moderately favour one element over another.
5	Strong importance	Experience and judgement strongly favour one element over another.
7	Very strong importance	One element is favoured very strongly over another; its dominance is demonstrated in practice.
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation.

Note: Intensities of 2, 4, 6, and 8 can be used to express intermediate values.

- **Alternative versus Criteria**

a) Reliability

The next step will be to compare pairs of alternatives with respect to Reliability. The Decision Makers will decide for each comparison which alternative is the weaker with respect to Reliability, giving its reliability a weight of 1. Using the AHP Fundamental Scale (Figure 5.1), the Decision Makers will assign a weight to the reliability of the other alternative. The comparisons are summarized below in Table 5.2

Table 5.2 Alternatives compared with respect to RELIABILITY

PS	1	DDS	3	DDS reliability is moderately preferred to that of PS. Weight: 3
PS	3	PDS	1	PS reliability is moderately preferred to that of PDS. Weight: 3
DDS	5	PDS	1	DDS reliability is strongly preferred to that of PDS. Weight: 5

Key: PDS is Preflash Drum Scheme, PS is Prefractionator Scheme, and DDS is Dual Drum Scheme.

The next step is to transfer the weights to a matrix, using a method unique to the AHP.

Reliability	PS	DDS	PDS	Priority
PS	1	1/3	3	0.258
DDS	3	1	5	0.637
PDS	1/3	1/5	1	0.105

Sum of Priorities 1.00

Inconsistency 0.04

By processing this matrix mathematically, the AHP derives priorities for the alternatives with respect to reliability. Priorities are measurements of their relative strengths, derived from the judgment of the decision makers as entered into the matrix. These can be calculated by hand, or with a spreadsheet programme, or by using specialized AHP software (Expert Choice 11).

They are shown above to the right of the matrix, along with an Inconsistency Factor (Saaty, 2006). ***However, in this study, Expert Choice 11 (AHP software) was used to compute the priorities and inconsistency ratios.***

b) Maintainability

Table 5.3 Alternatives compared with respect to MAINTAINABILITY

PS	3	DDS	1	PS maintainability is moderately preferred to that of DDS. Weight: 3
PS	1	PDS	4	PDS maintainability is more than moderately preferred to that of PS. Weight: 4
DDS	1	PDS	5	PDS maintainability is strongly preferred to that of DDS. Weight: 5

Key: PDS is Preflash Drum Scheme, PS is Prefractionator Scheme, and DDS is Dual Drum Scheme.

Maintainability	PS	DDS	PDS	Priority
PS	1	3	1/4	0.226
DDS	1/3	1	1/5	0.101
PDS	4	5	1	0.674

Sum of Priorities 1.00

Inconsistency 0.08

c) Capacity

Table 5.4 Alternatives compared with respect to CAPACITY

PS	1	DDS	5	DDS capacity is strongly preferred to PS capacity. Weight: 5
PS	3	PDS	1	PS capacity is moderately preferred to PDS capacity. Weight: 3
DDS	7	PDS	1	DDS capacity is very strongly preferred to PDS capacity. Weight: 7

Key: PDS is Preflash Drum Scheme, PS is Prefractionator Scheme, and DDS is Dual Drum Scheme.

Capacity	PS	DDS	PDS	Priority
PS	1	1/5	3	0.188
DDS	5	1	7	0.731
PDS	1/3	1/7	1	0.081

Sum of Priorities 1.00

Inconsistency 0.06

d) Flexibility

Table 5.5 Alternatives compared with respect to FLEXIBILITY

PS	1	DDS	4	DDS flexibility is more than moderately preferred to that of PS. Weight: 4
PS	3	PDS	1	PS flexibility is moderately preferred to that of PDS. Weight: 3
DDS	7	PDS	1	DDS flexibility is very strongly preferred to that of PDS. Weight: 7

Key: PDS is Preflash Drum Scheme, PS is Prefractionator Scheme, and DDS is Dual Drum Scheme.

Flexibility	PS	DDS	PDS	Priority
PS	1	1/4	3	0.211
DDS	4	1	7	0.705
PDS	1/3	1/7	1	0.084

Sum of Priorities 1.00

Inconsistency 0.03

- **Criteria versus the Goal**

As the decision makers have evaluated the alternatives with respect to their strength in meeting the criteria, they will now evaluate the criteria with respect to their importance in reaching the goal. In this case, the decision makers have agreed on the following relative weights for the various pairs of Criteria.

Table 5.6 CRITERIA compared with respect to reaching the GOAL

Reliability	2	Maintainability	1	Reliability (absence of failure) is adjudged more important than Maintainability because if there is no plant failure there will be no need for corrective maintenance except for the usual routine and preventive maintenance. Reliability increases asset availability thereby reducing maintenance costs. Reliability is somewhat moderately more important than Maintainability. Weight: 2.
Reliability	4	Capacity	1	Capacity is needed in optimising the refiner's revenue. But it is not enough because if the plant is unreliable there may be frequent plant failure and downtimes that may lead to loss of production which may eventually affect revenue. Reliability is somewhat strongly more important than capacity. Weight: 4.
Reliability	5	Flexibility	1	Flexibility is important because the plant will have the ability to adapt to changes in requirement. But operational reliability on the other hand is a vitally important requirement for plant's availability to perform its function. Reliability is strongly more important than flexibility. Weight: 5.
Maintainability	2	Capacity	1	Capacity is needed to optimise the refiner's revenue. Maintainability also means the ease and speed with which a plant can be restored after failure. But for the repairs not to affect revenue, the user can choose from the various maintenance strategies, a more cost effective procedure that can reduce downtime with less impact on revenue. Maintainability is somewhat moderately more important than Capacity. Weight: 2.

Maintainability	3	Flexibility	1	The importance of Flexibility has been described above. Maintainability requires a plant that is serviceable (easily repaired) and supportable. It is therefore, a key business objective and cost driver that impact on plant's availability, operation and maintenance costs. Maintainability is moderately more important than Flexibility. Weight: 3
Flexibility	1	Capacity	2	Flexibility is the ability to adapt to changes in requirement. Capacity is needed for the refiner's business sustainability and has direct impact on shareholders' return on investment (ROI). Consequently, adaptation to suit new conditions and situations may not always be enough. Capacity is therefore, somewhat moderately more important than Flexibility. Weight: 2.

Pairwise comparison of four elements requires six separate comparisons, while that of three elements require three.

The number of comparisons can be calculated using the following formula: $\frac{n(n-1)}{2}$

Where n is the number of elements. The above-mentioned pairwise comparisons of the four elements require a larger matrix.

Table 5.7 Priorities of all Criteria in reaching the Goal

Criteria	Reliability	Maintainability	Capacity	Flexibility	Priority
Reliability	1	2	4	5	0.507
Maintainability	1/2	1	2	3	0.264
Capacity	1/4	1/2	1	2	0.143
Flexibility	1/5	1/3	1/2	1	0.086

Sum of Priorities 1.00

Inconsistency 0.01

From this decision, Reliability, the highest ranked Criterion in reaching the Goal, is about twice as important in reaching the goal as the second highest ranked Criterion, Maintainability. Similarly, Maintainability is about twice as important as Capacity, which in turn is about twice as important as Flexibility.

- **Final Priorities Synthesis**

As we have known the priorities of the Criteria with respect to the Goal, and the priorities of the Alternatives with respect to the Criteria, we can conveniently calculate the priorities of the Alternatives with respect to the Goal.

Table 5.8 Calculations for the Alternatives with respect to the Criteria

Priority (Criterion versus Goal)		Alternative	X		Y		Z
Reliability	0.51	Prefractionator Scheme	0.258	x	0.51	=	0.13
		Dual Drum Scheme	0.637	x	0.51	=	0.32
		Preflash Drum Scheme	0.105	x	0.51	=	0.05
			1.00				0.51
Maintainability	0.26	Prefractionator Scheme	0.226	x	0.26	=	0.06
		Dual Drum Scheme	0.101	x	0.26	=	0.03
		Preflash Drum Scheme	0.674	x	0.26	=	0.18
			1.00				0.26
Capacity	0.14	Prefractionator Scheme	0.188	x	0.14	=	0.03
		Dual Drum Scheme	0.731	x	0.14	=	0.10
		Preflash Drum Scheme	0.081	x	0.14	=	0.01
			1.00				0.14
Flexibility	0.09	Prefractionator Scheme	0.211	x	0.09	=	0.02
		Dual Drum Scheme	0.705	x	0.09	=	0.06
		Preflash Drum Scheme	0.084	x	0.09	=	0.01
			1.00				0.09

Key: Column X shows the priority of this alternative with respect to this Criterion.

Column Y shows the priority of this criterion with respect to the goal.

Column Z shows the product of the two, which is the global priority of this alternative with respect to the goal.

PDS is Preflash Drum Scheme; PS is Prefractionator Scheme; DDS is Dual Drum Scheme.

Taking a look at the Prefractionator Scheme (PS) one can notice that its priority with respect to the Goal is 0.24, calculated as follows:

PS priority with respect to reliability 0.258 x 0.51 = 0.13, plus

PS priority with respect to maintainability 0.226 x 0.26 = 0.06, plus

PS priority with respect to capacity 0.188 x 0.14 = 0.03, plus

PS priority with respect to flexibility 0.211 x 0.09 = 0.02.

Total priority of 0.13 + 0.06 + 0.03 + 0.02 = 0.24

Table 5.9 Overall priorities for all the Alternatives

Alternative	Global Priority with Respect to				
	Reliability	Maintainability	Capacity	Flexibility	Goal
PS	0.13	0.06	0.03	0.02	0.24
DDS	0.32	0.03	0.10	0.06	0.51
PDS	0.05	0.18	0.01	0.01	0.25
Total:	0.51	0.26	0.14	0.09	1.00

Key: PDS is Preflash Drum Scheme, PS is Prefractionator Scheme, and DDS is Dual Drum scheme.

- **Decision/Result**

Consequent upon the AHP result, the Dual Drum Scheme with a priority of 0.51 is the most effective alternative. Preflash Drum Scheme with a priority of 0.25 is second, and Prefractionator Scheme at 0.24 is third.

5.2.3 The most effective refinery scheme

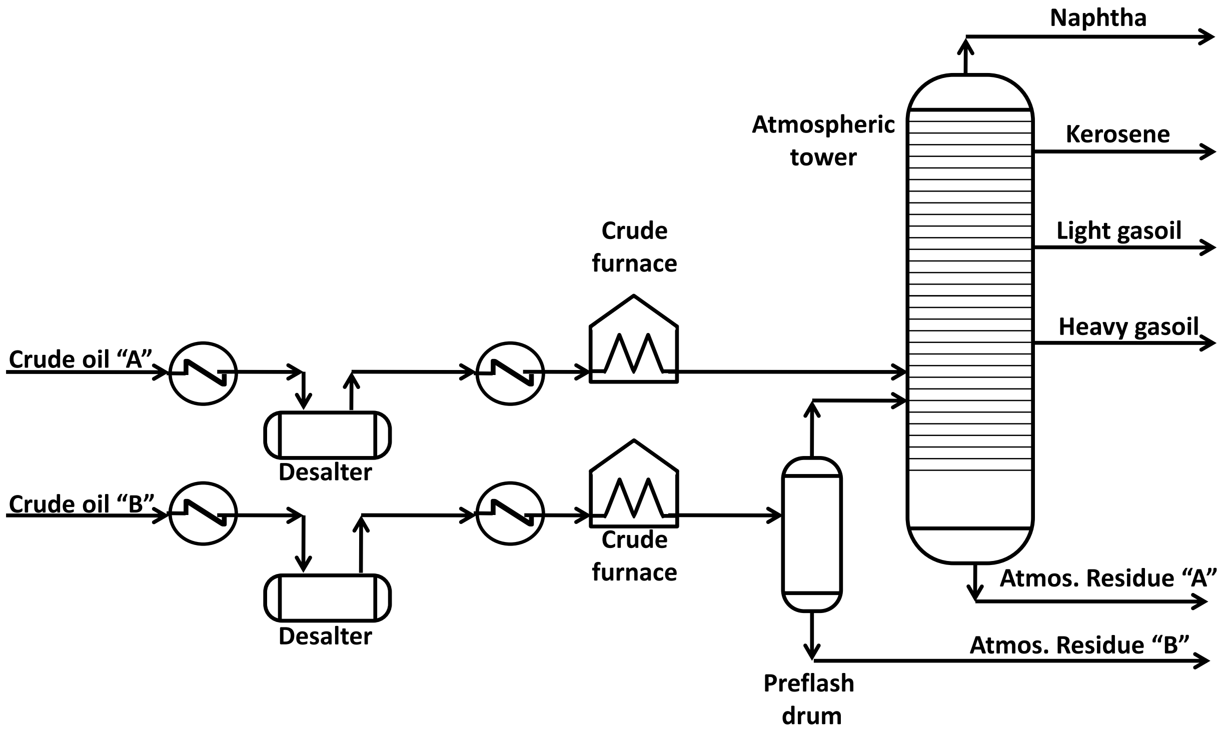

Figure 5.5 Most effective refinery scheme (Dual Drum Scheme: Hori, 2000)

Based on the AHP result, the 'Dual Drum Scheme' (Hori, 2000) with a priority of 0.51 was chosen by the Decision Makers as the most effective topping refinery.

5.2.4 Customized Cost Breakdown Structure (CBS) for the most effective refinery scheme

As a result of AHP result, the 'Dual Drum Scheme' with a priority of 0.51 was selected as the most effective topping refinery (Figure 5.5). Consequently, a customised cost breakdown structure as presented in Figure 5.6 was developed to show the cost elements to be considered in predicting the total life cycle cost of the selected refinery. However, the application of the proposed LCC framework on the case study will only consider the effective refinery operating cost. The motivation for considering operating cost was discussed in Section 5.2.1. There will also be some level of cost elements input from a generic cost breakdown structure (Figure 4.26) developed in Chapter 4. In addition, some specific assumptions that will flow into the cost estimates development will be considered at this level. See Figure 4.31 for the evaluation steps in the LCC framework.

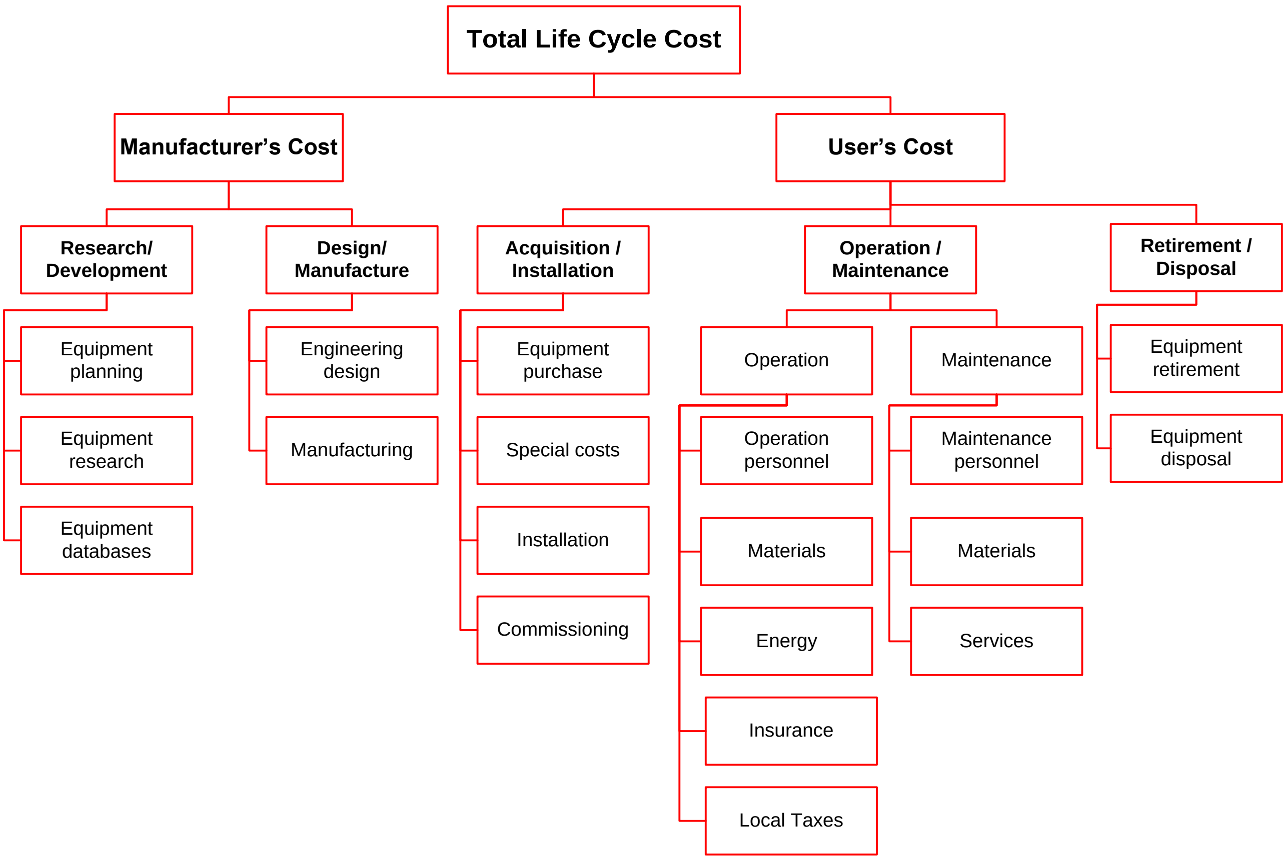

Figure 5.6 Customized cost breakdown structure (CBS) for the 'Dual Drum Scheme'

- **Research/Development Cost of 'Dual Drum Scheme'**

  The cost estimates development at this stage includes all such costs incidental to the development of the most effective refinery. The main cost components are equipment planning, equipment research and equipment databases as presented in Figure 5.7.

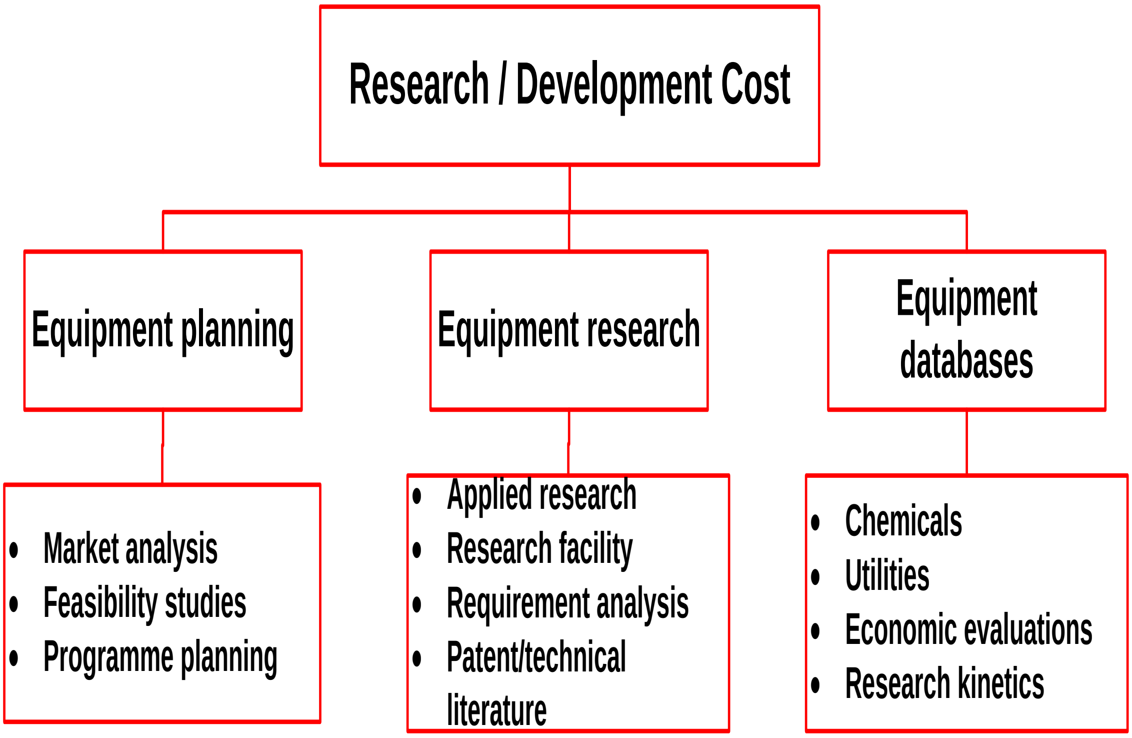

Figure 5.7 'Dual Drum Scheme' customized CBS for Research/Development Cost

- **Design/Manufacture Cost of 'Dual Drum Scheme'**

  The cost estimates development includes the cost of accomplishing an effective refinery design criteria and manufacture. The activities at this stage should be capable of transforming the user's overall operational demand (operation, technical, and performance requirements) into an effective refinery. The main cost components at this stage are engineering design and manufacturing as presented in Figure 5.8.

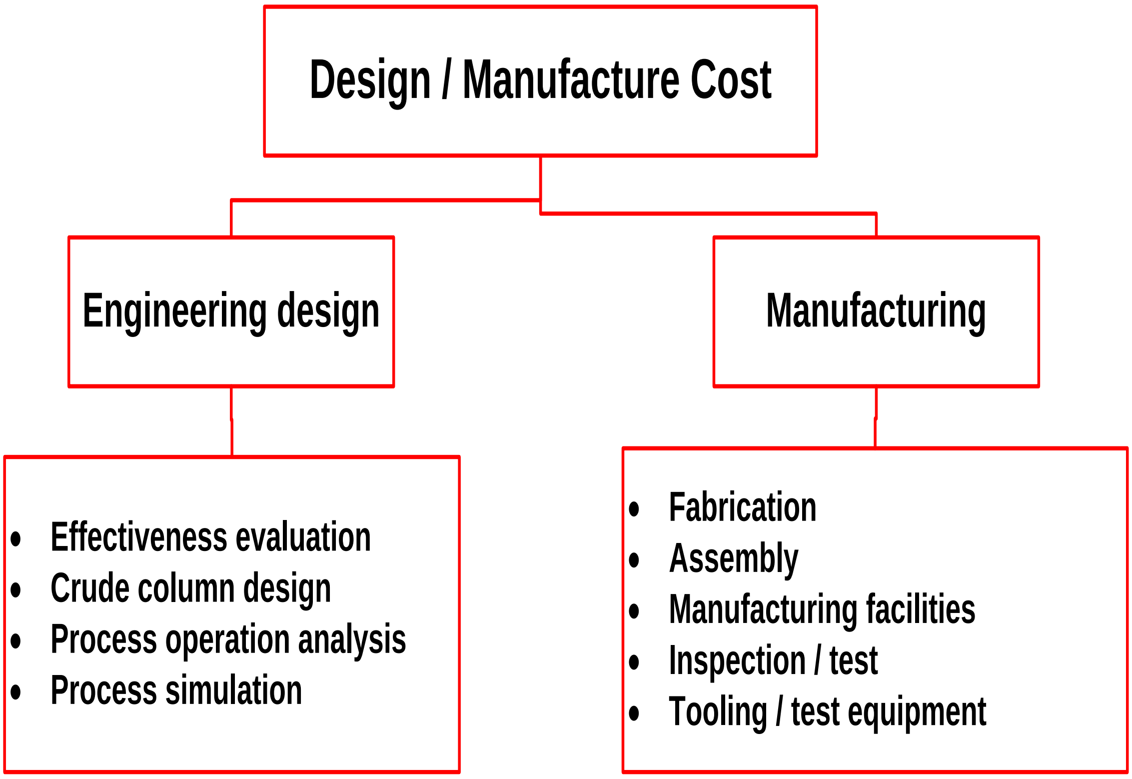

Figure 5.8 'Dual Drum Scheme' customized CBS for Design/Manufacturing Cost

- **Acquisition/Installation Cost of 'Dual Drum Scheme'**

  The cost estimates development at this stage will incorporate cost elements under purchase cost, special costs, installation cost and the cost of commissioning the effective refinery. Most of these items could be estimated by acknowledging contract quotations from manufacturers, suppliers and agents. Figure 5.9 represents the aforementioned costs.

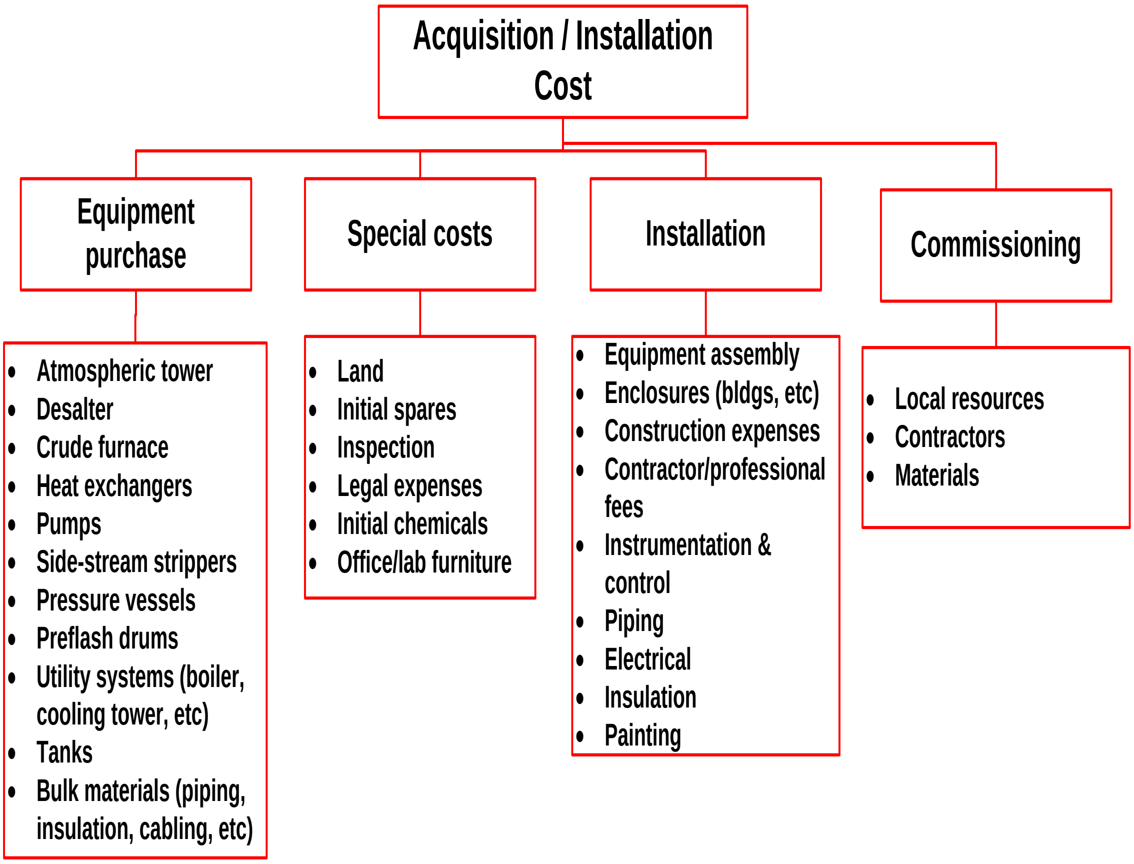

Figure 5.9 'Dual Drum Scheme' customized CBS for Acquisition/Installation Cost

- **Operation Cost of 'Dual Drum Scheme'**

  The cost estimates development at this stage incorporates the regular, and customary recurring costs of operating the effective refinery at the planned operational site in order to deliver the expected services. The main cost components are operation personnel cost, materials cost, energy cost, cost of insurance, and local taxes as presented in Figure 5.10.

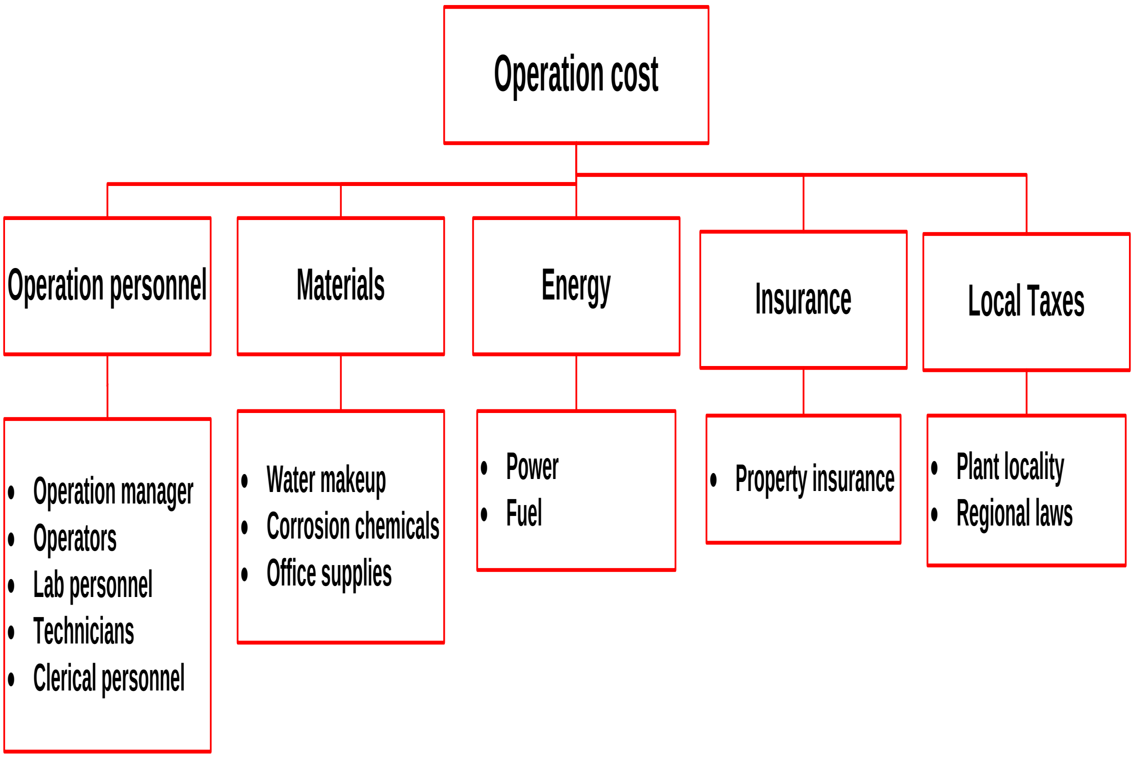

Figure 5.10 'Dual Drum Scheme' customized CBS for Operation Cost

- **Maintenance Cost of 'Dual Drum Scheme'**

  The cost estimates development at this stage includes all costs that will assist the effective refinery maintain operational and sustained service. This stage terminates with the retirement of the effective refinery. The main cost components are maintenance personnel cost, materials cost, and the cost of services as presented in Figure 5.11.

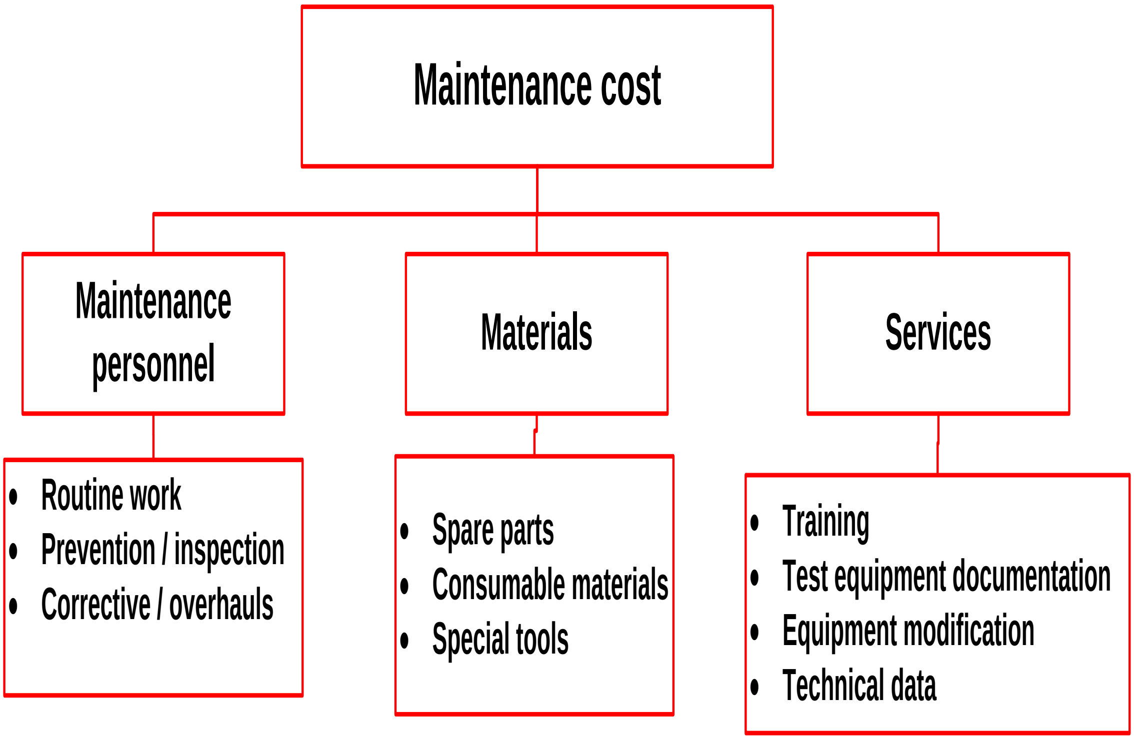

Figure 5.11 'Dual Drum Scheme' customized CBS for Maintenance Cost

- **Retirement/Disposal Cost of 'Dual Drum Scheme'**

  The cost estimates development at this stage includes the cost of all work carried out for the investigation of when and how all or part of the effective refinery will be retired, decommissioned or disposed of. The main cost components are the cost of equipment retirement, and equipment disposal cost as presented in Figure 5.12.

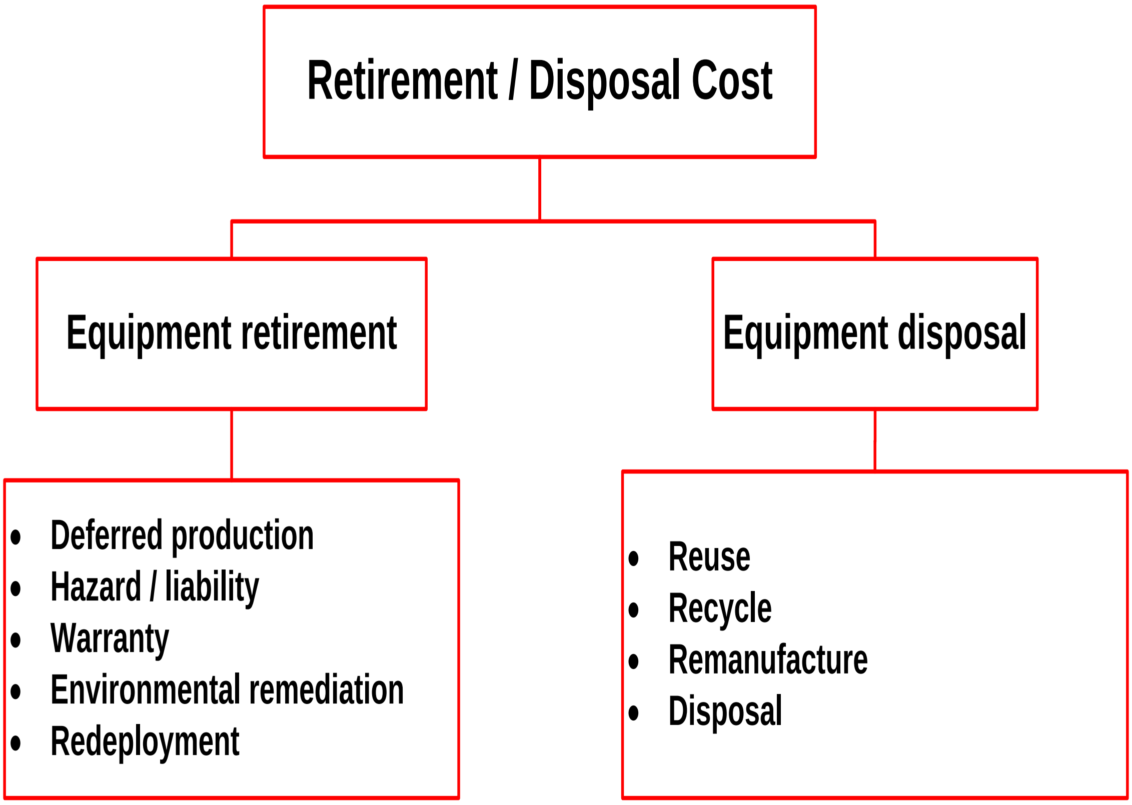

Figure 5.12 'Dual Drum Scheme' customized CBS for Retirement/Disposal Cost

5.2.5 Cost Estimates Development

Cost estimating methods that could be employed at the operation stage of the life cycle of a system include parametric estimating, estimating by analogy, activity-based costing, and estimating by engineering procedures (Fabrycky and Blanchard, 1991; NATO/RTO, 2009). The use of different estimating methods depends on the availability of data and the stage of the life cycle in which the calculations are been implemented (Korpi and Ala-Risku, 2008).

In order to capture actual costs, the author used estimating by engineering procedures for the calculation of the operating cost for the 'dual drum scheme'. Estimating by engineering procedure involves the assignment of cost to each element at a low level of detail. Thereafter, the costs are summed up into a total for the system.

The cost data used for calculating the operating cost of the dual drum scheme was sourced from industry historical cost data, literature (Gary *et al*, 2007; Peters *et al*, 2003; Ocic, 2005; Navarrete and Cole, 2001).

Assumptions

- **Refinery charge capacity:** 150,000 BPSD (barrels per stream day)
- **Refinery on-stream time:** Refineries generally have an on-stream (full capacity) factor of about 92% to 96% (Gary *et al*, 2007). But for this study, a factor of 94% will be used. Furthermore, the refinery is assumed to function for 345 days in a year after deducting downtimes for maintenance activities, etc.
- **Life expectancy of the dual drum scheme:** A functional life of 20 years (the period over which the need for the plant is anticipated).
- **Discount rate:** A discount rate of 5% for industrial borrowing for a financially sound, and well established company.
- **Percentage of water makeup to cooling tower:** 3% (1% evaporation, 1% windage loss, and 1% blowdown to control solids concentration)
- **Percentage of water makeup to boiler:** 3% (blowdown to control solids concentration).
- **Industrial power cost:** $0.08/KWh.
- **Corrosion chemicals & supplies:** 0.15% of plant investment per year.

- **Maintenance including materials and labour:** 5% of plant investment per year.
- **Insurance:** 0.5% of plant investment per year.
- **Local taxes:** 1% of plant investment per year.
- **Cost of water makeup:** $0.05/1000gallon.
- **Total steam produced:** 120,000 lb/hr
- **Process water:** 200 gpm (gallon per minute)
- **Daily industrial power for the unit:** 1,500 KWh
- **Fuel gas cost:** $8.00/MMBtu (Million Metric British thermal unit)
- **Cooling tower capacity:** 10,000 gpm (gallon per minute)
- **Fuel requirement for full load operation:** 120 MMBtu/hr
- **Annual plant investment:** $150,000,000
- **Number of operation personnel:** 22
- **Annual salary plus payroll responsibilities:** $100,000 per person

Exclusions

- Corporate overhead cost
- Research and development cost
- Sales expenses (distribution and marketing)
- Royalties (topping refinery is not a proprietary process)
- Catalyst consumption.

Table 5.10 Estimation of Direct Annual Operating Cost

Operation Cost Category	Quantitative Expression	Cost/year
Water Makeup	i. Cooling tower (makeup=3%) Makeup=(0.03)(10,000gpm)=300gpm (gallon per minute) ii. To boiler (boiler makeup =3%; Total steam produced=120,000 Ib/hr) Water makeup=(120,000)(0.03)=3,600 Ib/hr. Where 500 lb/hr = 1 gpm. Therefore, 3,600 lb/hr = 7.2gpm iii. Process water=200gpm Total makeup water (300+7.2+200) = 507.2gpm Cost of makeup water = $0.05/1000 gal Annual water makeup cost : (507.2gpm/1000)(1440min/day)(345days/yr)(0.05) =	$12,668
Energy • Power • Fuel	Industrial power costs range from $0.08/KWh Annual Power cost= (1,500KWh) (24hrs)(345days)($0.08) = $993,600 Fuel requirements= 120 MMBtu/hr Fuel gas cost = $8.00/MMBtu(Million Metric British thermal unit) Fuel gas purchased =(120MMBtu/hr)($8.00/MMBtu)=$960/hr. Annual Fuel Cost=($960)(24hrs)(345days) = $7,948,800 Total Annual Energy Cost=$993,600/yr+$7,948,800/yr = $8,942,400/yr.	$8,942,400
Corrosion Chemical & Miscellaneous Supplies	Corrosion control, office supplies and other miscellaneous supplies is 0.15% of the plant investment per year Annual cost = ($150,000,000)(0.0015) =	$225,000

Insurance	The cost is usually about 0.5% of the plant investment per year ($150,000,000)(0.005) =	$750,000
Local taxes	Local taxes usually account for 1% of the plant investment per year ($150,000,000)(0.01) =	$1,500,000
Maintenance	The cost is usually about 5% of plant investment per year, including materials and labour: ($150,000,000)(0.05) = $7,500,000	$7,500,000
Operation personnel	The number of personnel depends on the complexity and location of the plant. For a typical topping refinery, the following may be considered. No. Per shift Total payroll Refinery manager 1 1 Operations manager 1 1 Maintenance manager 1 1 Engineers 1 2 Operators 3 12 Clerical personnel 1 1 Technician 1 2 Lab personnel 1 2 Total 22 Annual salary plus payroll responsibilities = $100,000 per person. Annual cost = ($100,000)(22) = $2,200,000 Subtotal =	$2,200,000 $21,130,068
	Contingency: 10% of $21,130,068 =	$2,113,007
	Total Annual Operating Cost	**$23,243,075/yr**

5.2.6 Development of cost profile

Cost profile should be developed for projecting costs into the future. When considering costs that will be incurred in the future, it is essential to discount all expenditures to a specific decision point. Thus, discounted cash flow (time value of money) technique such as PV (present value) should be used to discount all future operating costs to the present day value. The formula is:

$$PV = \frac{FV}{(1+i)^n}$$

Where *PV* is present value

FV is future value

i is discount rate

n is number of years

The total direct annual operating cost for the 'dual drum scheme' at the end of twenty years will be $464,861,500 ($23,243,075 x 20). This is the amount that will accrue in twenty years from now, assuming the annual operating cost is constant. In projecting costs into the future, this evaluation method could be used either to compare two or more alternatives on an equal basis or as a budgetary profile using constant dollars to allow for the evaluation of a single plant in terms of today's dollars.

Using the formula:

$$PV = \frac{464{,}861{,}500}{(1+0.05)^{20}} = 175{,}201{,}410$$

Hence, the present value (PV) of the total direct operating costs for the 'Dual Drum Scheme' is $175,201,410

Alternatively, a customized spreadsheet model can be developed to take care of the calculations when annual operating cost varies over time as a result of plant's age, price escalations, and other factors. Nevertheless, this depends on the availability of operating cost data.

The following formula could also be used for the same purpose.

$$NPV = \sum_{n=0}^{T} Cn(1+ i)^{-n}$$

Where NPV is the net present value of future cash flows;

Cn is the nominal cash flow in the n^{-th} year;

n is the specific year in the life cycle costing period;

i is the discount rate;

T is the length of the time period under consideration, in years.

The key is to keep life cycle costing as uncomplicated as possible.

5.2.7 Major cost drivers identification

Table 5.11 Identification of major cost drivers for the annual operating cost of the 'DDS'

Summary of Direct Annual Operating Costs		**$/year**
Makeup water	**(1%)**	**12,668**
Energy	**(38%)**	**8,942,400**
Corrosion chemicals/Miscellaneous supplies	**(1%)**	**225,000**
Insurance	**(3%)**	**750,000**
Maintenance	**(32%)**	**7,500,000**
Local taxes	**(6%)**	**1,500,000**
Operation personnel	**(10%)**	**2,200,000**
Contingency	**(9%)**	**2,113,007**
Total Annual Operating Cost		**$23,243,075**

Given the operating cost presented above, the analyst may wish to identify those items of cost that are major cost drivers. A review of the cost items indicates that there are three major cost drivers, namely: 'energy' which constitutes 38% of the total, 'maintenance' which represents 32% of the total, and 'operation personnel' with 10% of the total.

An important goal of life cycle cost analysis is the identification of cost drivers, which may have significant impact on the total life cycle cost. If a cost driver is identified, it is important to establish the causes of the high cost. Assuming there are opportunities for cost effectiveness improvement in the design, the analyst could recommend the consideration of those high cost items as input into a new plant design. Furthermore, the modification of design in line with cost drivers may effectively reduce the life cycle cost of a plant.

5.2.8 Sensitivity analysis

NATO/RTO (2009) states that risk and uncertainty analysis at the operation stage of a system usually take the form of a sensitivity analysis around the major cost drivers. The sensitivity of the major cost drivers should be tested by changing their values to see if the overall result will be altered significantly. The less the final outcome is altered by these changes, the more reliable the result will be.

Different methods of sensitivity analysis have been developed, and these are suited for specific situations (Marseguerra *et al*, 1998). Generally, there are two main approaches to sensitivity analysis (Bertini *et al*, 1998). These are deterministic and stochastic approaches. The deterministic approach applies only to a simple system with few parameters, while stochastic approach may handle complex systems with many parameters, and it could be performed by Monte Carlo simulation.

5.2.9 Effective refinery scheme with predicted cost

The evaluation result is an effective topping refinery (dual drum scheme) with a predicted life cycle operating cost of $175,201,410.

The next chapter includes discussion on the validation of the framework and cost estimates development in the case study.

CHAPTER 6 VALIDATION

6.1 Introduction

Validation of the framework was carried out after its application to a case study. The validation exercises were conducted by experts from two companies and academia, namely: a refinery process design/cost engineering company, oil refining company, and an academic expert involved in oil refinery design parameters. The author at each interactive session presented his work to the expert. Thereafter, they both went through the framework's steps and relevance, including the completeness of the cost elements, and assumptions used in the development of the cost estimates. A list of the questions used to elicit the opinions of the experts is presented in Appendix B.

6.2 Validation by Refinery Process Design Company

The first validation was with refinery process designers and cost engineers. On this occasion the author presented his work to the managing director, and two senior members of staff of the company. The MD has a total of 35 years experience in oil refinery process design, petrochemical and upstream project management. The validation exercise lasted for two hours. The author upon completion of his presentation handed over his work to the experts for analysis. The summary of the assessment is as follows: they thought that the development of a life cycle cost estimating framework for oil refineries is timely. The MD said that though plant components' life cycle costing are done to some extent in the industry but not to the level we have developed it.

The following paragraphs present the questions asked, as well as the responses from the experts.

Question 1: How rigorous is the framework?

Response: The MD said that the quantitative approach of the framework in assessing refinery life cycle costs is a good indication of the rigorous nature of the framework.

Question 2: Was the framework easy to use?

Response: They said that the framework seems a simple tool to use because the steps for total cost and system effectiveness evaluation are clearly defined. The MD was particularly impressed about the author's choice of topping refinery configurations in the AHP analysis. He said that topping refinery as an essential building block in any refinery complex is sufficient to illustrate the principle and applicability of the framework.

Question 3: Do you think the framework has helped to prepare a good life cycle cost estimate?

Response: They answered in the affirmative but were quick to state that some of the assumptions used in the development of the cost estimates are no more realistic. It was at this point that they offered to provide the author with some current cost data, especially on refinery maintenance, material and manpower. This aspect was initially quantified using estimating by analogy because of paucity of data.

Question 4: Could the framework be used in practice to evaluate the life cycle cost of new and existing refineries?

Response: They particularly identified the framework's potential in being part of current practice since the industry does not have any high level standardised procedure for now. However, the MD said he was not too comfortable with the author's selection criteria in his AHP analysis that excluded crude quality. The MD was actually making reference to plant's ability to adapt to changes in requirement. But the author reminded him that flexibility which is one of the selection criteria could actually take care of crude quality. He then recommended the inclusion of a refinery option that could take care of heavy crude oil in the AHP analysis. The author and his panel of experts had since implemented this recommendation by re-evaluating the whole AHP process with the inclusion of the 'Dual Drum Scheme' that can simultaneously refine two types of crude.

Question 5: Do you think the cost elements in the customised cost breakdown structure (CBS) are adequate?

Response: They felt that the customised CBS hierarchical display of cost items is satisfactory but recommended the inclusion of the missing cost items e.g. side-stream strippers, and pressure vessels into the acquisition/installation cost category.

Question 6: Do you think the estimated operation cost considered all the necessary cost items?

Response: They expressed satisfaction with the level of coverage but recommended the inclusion of the number of shifts for the plant operators under the operation personnel cost. The industrial power cost range under the energy cost was also said to be low and needs readjustment to reflect current unit rate.

Question 7: How logical are the steps in the framework?

Response: We found the two main stages of evaluation in the framework very logical. These include the initial evaluation using the AHP approach to select an effective refinery scheme, and the second evaluation process implemented to ascertain the total life cycle cost of the selected option.

Question 8: Is there novelty in the framework?

Response: They stated that the use of an analytical method (AHP) to solve the problem of lack of performance data is actually a novel idea on its own. However, they said that pragmatic novelty can only be confirmed in the field of practice when the framework is subjected to rigorous evaluation processes involving all stages of a plant’s life cycle. Moreover, they opined that because the AHP technique uses expert opinion and judgment to arrive at results could raise some fundamental questions on judgment consistency, experience and expertise of the decision makers (panel of experts).

Overall, the experts believed that the improvement of the framework based on their recommendation and suggestions could make it adequate for the evaluation of the total life cycle cost and system effectiveness of oil refineries.

6.3 Validation by Oil Refining Company

The second validation was with oil refining company. As usual, the author on this occasion presented his work to the Head of projects, and six other unit heads. The head of projects at the company has a total of 32 years experience in oil refining across UK. The validation exercise lasted for two and half hours. The author upon completion of his presentation solicited for the experts' views on his work. The summary of the feedback is as follows: the head of projects said they were impressed with the way the framework was adapted to make a quantitative assessment of refinery life cycle operating cost, and not just qualitative assessment. Other unit heads corroborated by saying that the idea of developing a high level life cycle costing framework at this time when the industry is experiencing low capacity utilisation and rising cost of ownership is a welcome development but inquired whether the framework has the capability of handling refinery revamping.

The following paragraphs present the experts' responses to the questions asked.

The experts responded to the first three questions by stating that the evaluation steps in the framework are quite logical and straightforward. They were content with some of the assumptions used but recommended updating of a few, e.g. total steam produced, and volume of process water.

Regarding the question on whether the framework could be used in practice to evaluate the life cycle cost of new and existing refineries, they said that it seems the framework is primarily developed for new refineries. One of the experts commented that he would like to see a life cycle costing framework that could provide detailed cost estimates for refinery revamping and upgrading which is the current practice in Europe. The author responded by saying that the framework was developed to serve three main purposes, namely: evaluation of different alternative refinery scheme on the basis of system effectiveness and total life cycle cost of the effective option; evaluation of the life cycle cost of revamping and upgrading of oil refineries; and evaluation of the life cycle cost of a refinery at any stage of its life cycle for budgetary purposes. In as much as no new refineries are currently being constructed in Europe, several other new refinery projects are still ongoing in other parts of the world (Independent Project Analysis, 2009). Detailed discussion on IPA's approach to petroleum refining is covered in Chapter 2.

The experts' response to the last four questions includes their mixed views on whether the cost items in the customised cost breakdown structure are adequate or not. Some of the experts while commending the hierarchical display of cost items in the customised CBS, others needed explanation for the exclusion of reliability and maintainability from the customised CBS, and the operating cost estimates. They mentioned 'HSB Solomon Associates LLC' as a company that offers reliability and maintainability (RAM) improvement to the industry. Discussion on Solomon Associate's RAM modelling is covered in Chapter 2. The author tried to explain that reliability and maintainability are design attributes that could only be estimated or modelled with input from past records of similar plants. Unfortunately, these records and data are not readily available, and the research timeframe may not permit the modelling of these attributes. As a result, the evaluation of options for system effectiveness was carried out on a qualitative basis using the AHP approach to select an effective refinery scheme. Furthermore, the experts were meant to understand that these attributes cannot have monetary values attached to them because they are already covered under the engineering design cost code category of the CBS. Similarly, they cannot also be displayed as cost items in the operating cost estimates because their cost impacts are deemed to be included in the maintenance and operation personnel costs.

The question on framework's novelty was however parried by the experts who stated that novelty could be ascertained in the field when the framework is subjected to rigorous evaluation processes. They, however, commended the AHP's value-adding potential in solving the problem of performance data during the option selection process. They asked questions on the AHP technique and the reliability of its result since it is based on expert opinion and judgment. The author within the limited time tried to explain its main procedure in complex decision making scenario because its complete modus operandi is not a process the author can conclude in few hours.

The experts concluded by commending the effort of the author and his supervisor in bringing to the fore a framework that if when refined and tested could assist the industry in maintaining a standardised procedure for the evaluation of total life cycle cost of oil refineries. They, however, stressed the importance of incorporating all necessary instruments that could make the framework handle revamping and upgrading of oil refineries effectively.

6.4 Validation by academic expert

The last validation exercise was with a final year PhD student in the School of Engineering, Cranfield University, whose research study is focused on oil refinery scheduling, planning and design parameters. The academic expert was the chair person of a three-man panel of experts that assisted the author with communication and meetings where expert opinions and knowledge contributed to the selection of an effective refinery scheme using the AHP approach. Details of the panel's contribution to the AHP analysis are presented in Chapter 5. The expert has a total of 17 years experience in petrochemical process plant design in Nigeria and UK.

This last validation lasted for two hours. The author after his presentation handed over his work to the expert who already is familiar with some aspects of the work. The summary of the feedback is as follows: She expressed satisfaction with the framework's ability to handle both qualitative and quantitative evaluations. The following paragraphs present the expert's responses to the questions asked.

The expert responded to the first four questions by stating that she thinks the framework is rigorous and easy to use but asked why the author did not consider a comprehensive evaluation of the total cost of all the life cycle stages of the selected option of the topping refinery. She said this could have given a true picture of the rigorous nature of the framework and its applicability. In responding, the author retrospectively reminded her that aside from the research timeframe, the choice of AHP technique in evaluating system effectiveness was made because of lack of relevant performance data. Similarly, scarcity of industry cost data is a major problem in the evaluation of the life cycle cost of industrial plants.

The author explained that the oil refining industry is highly competitive and commercially sensitive. The companies under this umbrella are always reluctant to release cost information because of the fierce competition in the industry. Survivability, in the face of dwindling global economy is quite critical to them. Consequently, only privileged researchers sponsored by them may be able to reduce the impact of data unavailability in LCC research works. Moreover, besides the granted privilege, the researchers' institutions may be under some obligation to sign confidentiality agreements with the sponsoring companies for data protection.

The expert responded to the question of cost items adequacy in the customised CBS by suggesting the inclusion of initial spare parts and corrosion chemical into the special costs sub-unit of the acquisition/installation cost category. She equally recommended the expansion of enclosure cost item under the installation sub-unit of acquisition/installation cost category to include all buildings and shelters that will house the plant units and equipment because according to her the word 'enclosure' may look vague to non-industry practitioners. The expert also said that she was not comfortable with the author's lumping of spare parts and consumables materials as a cost item under maintenance materials. She said that there are two types of spare parts; initial spare parts that will come with the newly acquired plant and the spare parts that will be used during maintenance to replace failed ones after the initial spares must have been exhausted. In the same vein she spoke about the two types of consumable materials; contractor's consumable materials if the maintenance activity is to be contracted to an external firm, and plant owner's consumable materials if the maintenance is to be conducted in-house. The author had since incorporated the expert's recommendations into the final work.

When asked to comment on the relevance of the AHP process and the novelty it added to the framework in helping to solve the problem of performance data, she said that it will be unfair for her to comment on this aspect of the work because she was part of the process. She advised the author to leave that aspect for other experts to assess.

The expert concluded by thanking the author for giving her the opportunity to further explore a vital aspect of her research work and to contribute her wealth of knowledge in an area she is passionately attached to in the last one and half decades.

6.5 Summary

The validation of the framework was successfully carried out in two ways. First, the experts validated the overall content of the framework and its applicability in the evaluation of total life cycle cost and system effectiveness (qualitative approach). Second, the experts validated the cost estimates development and the reasonableness of the assumptions used in the development of the cost estimates (quantitative approach). On completion of this process, a series of questions was used to elicit the experts' opinions regarding the framework's applicability and effectiveness. Finally, the recommendations and suggestions made by the experts towards the improvement of the framework have been implemented.

The next chapter includes the development of discussion on the results of the preceding chapters, research contribution, research limitations, future work, and conclusions.

CHAPTER 7 DISCUSSION, FUTURE WORK, AND CONCLUSIONS

7.1 Introduction

This chapter summarises the findings of the research, and their implications to the development of a life cycle costing framework for oil refineries. The author will in this chapter collate all the pieces of work with the aim of providing the reader with a comprehensive perception of the research findings.

Section 7.2 discusses the findings of this research in accordance with the research steps taken. Section 7.3 highlights the research contributions, and the research limitations are discussed in Section 7.4. In Section 7.5 the author will be discussing future work in relation to the subject area, and finally, Section 7.6 presents the research conclusions.

7.2 Discussion of Research Findings

This section analyses the key research findings. The order of discussion of the findings will reflect the sequence of the study within the body of the thesis.

7.2.1 Literature review

The review of literature revealed that life cycle costing is a data intensive process, with paucity of cost and performance data inhibiting the successful accomplishment of any life cycle cost analysis. In spite of this, there is a lack of a specific methodology that could be used for a holistic evaluation of not only the total cost of new refineries but also the system effectiveness when there is no performance data. Several fields and concepts were explored in the literature. This is to enable the author to develop a good understanding of life cycle costing methodologies and tools, and their implications and interactions with the relevant issues relating to the development of a life cycle costing framework for oil refineries.

Several approaches and conceptual models for life cycle stages were reviewed and advantages and issues relating to their attachment to specific activities assessed. Refinery life cycle stages and their cost categories were defined to establish the technical background of this research. This investigation is vital in understanding the implications of the physical sequence of unit processes across the industry because the greatest advantage is realised when life cycle costing is integrated across the entire life cycle.

Furthermore, the review of literature identified available life cycle costing methodologies from other domains that could not be directly applied in the context of this research. The reasons being that though, the methodologies follow the life cycle costing principle, they differ in their approaches and choice of elemental features that are relevant in the development of a comprehensive LCC framework for oil refineries. Nonetheless, the author was able to identify some vital features from such methodologies which when integrated with available refining technical processes would assist in the development of a preferred life cycle costing framework for the oil refining industry.

Finally, the process of acquiring performance data for system effectiveness evaluation is currently cumbersome and cost intensive for the reasons presented in Chapter 6. The comparison of the main features of the methodologies in Chapter 2, Table 2.4 shows that only a few of the methodologies integrated some system effectiveness factors that could be derived when there is performance data. Consequently, there is a lack of a practical guide to compare two or more options of refinery schemes for system effectiveness when there is no performance data.

The literature review offered the author the opportunity to compare specific LCC methodologies and practices, and to develop the research aim on life cycle cost estimating framework for oil refineries.

7.2.2 Industry Survey

A vital requirement for the development of LCC framework is the identification of a conceptual life cycle costing model and a cost breakdown structure that show major cost categories and cost elements that are to be integrated to provide the total cost. A clear idea of the concepts necessary for the development of the conceptual life cycle costing model and its cost breakdown structure has been established from literature sources. It is therefore pertinent to conduct an industrial survey using a questionnaire to elicit the opinions of experts on current practice in the industry.

The survey which was carried out in five consecutive stages revealed that there is a lack of a comprehensive LCC framework for oil refineries. Furthermore, it was identified that low capacity utilisation, rising ownership cost, competition, and dwindling profit are major challenges facing the oil refining industry. The author therefore believes that the formalisation of life cycle costing practice in the industry using the proposed LCC framework would assist in mitigating some of these challenges.

The results of the data analysis also raised a vital issue of standard conceptual life cycle costing model with major cost categories and cost breakdown structure specifically designed for oil refineries. Hence, lack of standardised procedures for a comprehensive LCC framework, a conceptual LCC model, and cost breakdown structure are the main deficiencies to be tackled.

7.2.3 Framework development

The framework development was anchored on a number of features and findings from Chapters 2 and 4. The conceptual LCC model and its cost breakdown structure were integrated into an overall LCC framework. The use of the framework will assist decision makers in achieving three main objectives, namely: a) evaluation of different alternative schemes on the basis of system effectiveness and total life cycle cost of the effective option; b) evaluation of the life cycle cost of a refinery for revamping and maintenance purposes; c) evaluation of the life cycle cost of a refinery at any stage of its life cycle for budgetary purposes. The framework's ability to evaluate the system effectiveness of alternative refinery schemes in the absence of performance data makes it unique.

7.2.4 Framework application and validation

The proposed framework was used to forecast the operating costs associated with the most effective refinery schemes selected on a qualitative basis using a multi-criteria decision making technique. A step by step application of the framework on a case study was carried out in Chapter 5. Finally, the framework and the case study were validated by refinery process designers/cost engineers (PIPDEV), oil refining company (Petroplus), and an academic expert. First, the experts validated the overall content of the framework and its applicability using a qualitative approach. Second, they validated the cost estimates development and the reasonableness of the assumptions using a quantitative approach. On completion of the exercise, the experts believed that the improvement of the framework based on their recommendations and suggestions could make it adequate for the evaluation of the total life cycle cost and system effectiveness of oil refineries.

7.3 Research Contribution

The impact of this research was an increased understanding of the concepts and issues associated with oil refinery life cycle costing and its tools. Furthermore, the research contributed to better knowledge of the basic life cycle costing features to be captured for the development of a structured LCC framework for oil refineries. Based on these findings, the main research contributions of this study are summed up into the following key areas:

The research findings identified the need for a specific conceptual life cycle costing model with major cost categories and cost breakdown structure for oil refineries. Consequently, a conceptual model was developed and used to define the major cost categories that are vital in the implementation of cost analysis across the entire life cycle of a refinery. The superiority of the model lies in its detailed life cycle cost breakdown structure. Cost emphasis (design to requirement) was also created as input into the design/manufacture stage of the model to take care of the requirements (operation, technical, and performance requirements) that could contribute to long-term cost reduction. The conceptual model and its cost breakdown structure were subsequently integrated into the overall LCC framework for oil refineries.

The information gained during the literature search indicates the lack of a life cycle costing framework that will not only consider total cost but also system effectiveness. As a result of these findings, a novel life cycle cost estimating framework was proposed. The main characteristics of the framework is its principal role in estimating not only the total cost but also the system effectiveness of a new refinery using a multi-criteria decision making technique in its selection among other options when there is no performance data.

The result of the research findings led to the development of a framework for life cycle cost trade-offs (Figure 2.24) when plants' past records on cost and performance could be used to obtain predictions for newly-acquired plants which will in turn produce predictions that could be used in the design of new plants. The frameworks process is iterative and could be utilised in the estimation of trade-offs between the cost parameters.

Finally, the research has also resulted in the identification of high level qualitative and quantitative cost drivers for oil refineries. The identified cost drivers are refinery complexity, reliability, maintainability, capacity, flexibility, downtime, energy, and initial investment. Detailed discussion on refinery high level cost drivers is presented in Chapter 4, Section 4.6.

7.4 Research limitations

The framework has several limitations. The following paragraphs will discuss these limitations.

The capturing of cost and performance data from the industry is deemed commercially confidential and the author's interactions with industry practitioners confirmed this fact. Hence, the framework could not be used for the complete evaluation of the total cost of all the life cycle stages of the selected option of refinery because of lack of cost and performance data.

Few oil refining companies participated in the survey and not all the respondents that participated in the survey had an in depth understanding of life cycle costing concepts and the major issues relating to its applicability and long-term benefits.

The framework cannot be used for the evaluation of system effectiveness by an individual who has not gone through the learning curve of intricate decision making procedure using the multi-criteria decision making technique.

Only three experts (decision makers) were used for the AHP analysis. It would have been better to have as many as six experts in order to avoid bias.

7.5 Future work

The anticipated future work could focus on the following topics:

With governments and oil refining companies grappling with the problem of CO_2 emission and environmental degradation, further research may need to be carried out in order to test the framework's applicability in evaluating the life cycle cost of environmental consequences and remediation by assigning monetary values to these consequences.

The framework could be further developed into a complete functional software tool that may have the capability of storing all life cycle cost estimates assessments for quick alternatives comparisons by the decision makers. Moreover, this will enable the cost engineer or decision maker keep track of the cost estimates development and progress throughout the life of a refinery. The anticipated consistency of the framework could improve the efficacy of historical data.

The framework was only applied to the evaluation of life cycle operating cost of a refinery. To further confirm the framework's applicability and robustness, more case studies involving the total cost of all the life cycle stages of a refinery could be conducted.

7.6 Conclusions

This section aims to address the aim and objectives of the study as defined in Chapter 3. This section develops how each objective was achieved within the study. This research has achieved the aim and objectives as stated below:

The first objective was to identify oil refinery configurations and technological challenges. This involves the identification of the current configurations used by the industry, and the current challenges associated with oil refinery technology (ORT). The key issues captured from the review of literature and industry survey are that:

- There are four major configurations of oil refinery, namely: topping, hydroskimming, catalytic cracking, and coking refineries.
- The first three levels of configuration are the most common.
- A number of challenges in oil refining technology (ORT) were identified with some current and proposed technologies defined towards the mitigation of the challenges.
- Other petroleum refining tools used by some companies to develop cost estimating relationships, and performance improvement were identified.

The second objective was to identify various life cycle costing methodologies. It was identified that:

- There are various basic elemental features in the methodologies that contribute towards the achievement of a life cycle cost analysis.
- The composition of some of these basic features was found to be linked to the cost estimates development process.
- The relative importance of each feature towards the accomplishment of a life cycle cost analysis varies as not all the methodologies incorporated all the features.

- Some of the various life cycle costing methodologies analysed could not be directly applied in the context of this research because though, they follow the life cycle costing principle, they differ in their approaches and choice of elemental features relevant in the development of a complete LCC framework for oil refineries.

The third objective was to define a conceptual life cycle costing model and cost breakdown structure for oil refineries. Available relevant literature was reviewed, and an industry survey was carried out to identify the main activities and cost categories to be depicted in an oil refinery conceptual LCC model. It was identified that:

- The design of a conceptual LCC model for oil refineries must consider the peculiarities of the oil refining industry as this must have consequences for the necessary level of details to be considered in the development of a conceptual LCC model.
- Conceptual models are constructed at a macro level with minimum of details and limited ability to quantify cost estimates of a system; hence a cost breakdown structure must be developed to define the cost details in each category of the model.
- There is a lack of standard conceptual life cycle costing model with major cost categories and cost breakdown structure specifically designed for oil refineries.

The fourth objective was to identify the high level cost drivers for an oil refinery. It was identified from the review of literature and industry survey that:

- There are eight high level qualitative and quantitative cost drivers in the life of a refinery

The fifth objective was to develop a life cycle cost estimating framework for oil refineries. To achieve this objective, the author:

- Incorporated the conceptual life cycle costing model and its cost breakdown structure into an overall life cycle cost estimating framework
- Identified a number of vital features from the analysed LCC methodologies that were integrated with the available refinery technical processes to develop the LCC framework for oil refineries.
- Identified the framework's ability to evaluate the system effectiveness of alternative refinery schemes when there is no performance data.
- Identified that the use of the framework would institute a standardised procedure for the comprehensive evaluation of not only the total cost and system effectiveness of new refineries but also the revamping, and maintenance of the existing refineries.
- Demonstrated the applicability and effectiveness of the framework through its application on a case study.

The sixth objective was to validate the framework with a detailed case study. To achieve this objective,

- The LCC framework and the cost estimates development in the case study were validated by experts from the industry and the academia.
- A questionnaire was designed to elicit the experts' opinions regarding the framework's applicability and effectiveness.
- The experts used for the validation exercises have confirmed the comprehensive nature of the LCC framework. Although, it was not possible to validate the framework with real life data, qualitative validation does show the applicability and effectiveness of the framework.

The implementation of the findings of this research within the industry would provide the much needed long-term benefit that comes with the formalisation of life cycle costing practice.

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APPENDIX A

INDUSTRY SURVEY QUESTIONNAIRE ON LIFE CYCLE COSTING FOR OIL REFINERIES

Introduction: The purpose of this questionnaire is to collect information on the current life cycle costing practice in the oil refining industry. This work is part of an M.Sc by Research study undertaken at Cranfield University.

Disclaimer: Your response will be treated in the strictest confidence. Respondents' names will not be disclosed nor identified in the research report. Please be assured that the information provided will only be used for academic and research purposes and will not be passed to a third party.

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Interviewee Details: (or attach your business card)

Name:

Job Title:

Area of Interest in Oil and Gas industry:

Organisation:

Address:

Tel:

Email:

Years of Experience:

About Your Company

Q.1 What sector of the oil and gas industry do your company operate?

Q.2 What kind of products do you deliver?

Q.3 What are the main functions of your business?

Q.4 What is the number of employees in your business unit?

About your Plant / Equipment

Q.5 What is the average life expectancy (time individual unit remain in use before being replaced or upgraded) of your refinery?

0-5 years 5-10 years 10-15 years 15-20 years over 20 years

Q.6 What is the installed capacity of your refinery?

10,000-50,000bpd 50,000-100,000bpd 100,000-150,000bpd

150,000-200,000bpd over 200,000bpd

Q.7 What is the level of complexity of your refinery?

Topping Hydro-skimming Cracking Coking

Other (please specify)?

Life Cycle Costing Section

Q.8 What is your role in cost engineering in the oil and gas sector?

Q.9 What do consider to be the current challenges in oil refining and/or the oil and gas industry?

Q.10 What do you understand to be life cycle costing?

Q.11 What methods do you use in life cycle costing

Q.12 What data and information (sources) are used in life cycle costing

Q.13 What are your problems in life cycle costing?

Q.14 What is your understanding of the technological options in oil refining?

Q.15 Could you please describe the life cycle costing process? For instance: What are the steps? Do you have an example?

Q.16 Please indicate the cost drivers you consider relevant at each stage of the life cycle costing of an oil refinery/oil and gas industrial asset.

Q.17 What are the relationships between the more significant ones?

Q.18 What are the life cycle stages of an oil refinery?

Q.19 How many codes and standards of which the title includes the term "Life Cycle Costing" do you know?

Q.20 How many of the codes and standards are specifically meant for the Oil and Gas Industry?

Do you have any additional comments?:

Operations and Maintenance Section

Q.21 What are your challenges in operations and maintenance?

Q.22 What are the issues in operations and maintenance related to life cycle cost?

Q.23 What bottlenecks are there in operations and maintenance?

Q.24 What operations and maintenance models do you use? For example mathematical models, decision making models, scheduling models?

<u>Environmental Impact</u>

Q.25 What are the environmental impact challenges of CO_2 emission and its cost related issues? For example CO2 taxes.

Q.26 What are the technologies to curb environmental impact for now and the future

Q.27 What are the environmental impact cost drivers and cost models used?

<u>Uncertainty and Risks</u>

Risks are events which may or may not happen and should be included in risk registers for life cycle cost estimates. Uncertainty is the range of values in things that will always happen but it is not clear how much they will be. For example a puncture in your car tyre for your journey home is a risk with an associated time to fix. Whereas your time waiting at a know traffic light is an uncertainty, but you will always pass that traffic light.

Q.28 What are the significant risks associated with an oil refinery and appearing in life cycle costing?

Q.29 What are the uncertainties in life cycle costing in refineries?

Q.30 What are the methods used to model risk and uncertainty?

APPENDIX B

QUESTIONNAIRE FOR FRAMEWORK AND CASE STUDY VALIDATION

NAME:

POSITION:

COMPANY:

YEARS OF EXPERIENCE:

Please, could you help us by reviewing the framework and completing this questionnaire?

1.	How rigorous is the framework?
2.	Was the framework easy to use?
3.	Do you think the framework has helped to prepare a good life cycle cost estimates?
4.	Could the framework be used in practice to evaluate the life cycle cost of new and existing refineries?
5.	Do you think the cost items in the customised cost breakdown structure (CBS) are adequate?
6.	Do you think the estimated operation cost considered all the necessary cost items?
7.	How logical are the steps in the framework?
8.	Is there novelty in the framework?
9.	Do you have any suggestions for the improvement of the framework?
	Other comments or recommendations for the improvement of the framework.