ASSET MANAGEMENT LIFE CYCLE COSTING MODEL FOR STEEL MANUFACTURING INDUSTRY IN SAUDI ARABIA

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

Razak Faculty of Technology and Informatics
Universiti Teknologi Malaysia

SEPTEMBER 2021

DEDICATION

To all my family members, my wife Somia, my son Ahmed, daughter Maha and my new born son Anas

ACKNOWLEDGEMENT

Firstly, I would like to express my sincere gratitude to my supervisor Prof. Mohammed Salman Leong for the continuous support throughout my study. His knowledge, intellect and drive has equipped me with all the needed foundations to build up the skills required as a researcher to carry out this work. I would like to thank him for his patience, motivation, and immense knowledge shared. His guidance helped me in all the time of research and writing of this thesis.

I would also like to extend my sincere appreciation to my Co-Supervisor, Prof. Awaluddin bin Mohamed Shaharoun, not only for his insightful comments, guidance and encouragement, but also for the critical questioning and reviews along my research journey which derived me to widen my research from various perspectives.

I am extremely privileged for the opportunity I had working under the guidance of both gentlemen, and scholars. Their supervision has not only provided me with the desired academic skills, but also with moral qualities such as integrity, honesty and sense of fair play and justice that have provided the guidance to me, both morally and academically, throughout my postgraduate journey.

To my parents from whom I learned the true meaning of love, loyalty and endless commitment. They have taught me to face life challenges with a great courage and optimism, never to lose faith and be always positive while keeping the sky as a limit to my ambitions regardless of the situation.

To my beloved wife and kids, from whom I have got unlimited support without which I could have never managed to complete this study. They were my day to day motivation and cause to sustain the efforts and continue the journey. My wife who has completed her PhD last year, real fighter and unique example of strength and dedication, has been the light that always guided and encouraged me to continue the fight without fail.

Last but not the least, to my siblings, who have always provided me with their care and support and the unmatched sample of loyalty to the family. Throughout my research, they have always been there to offer words of encouragement.

ABSTRACT

Despite numerous studies have been conducted in the field of Life Cycle Costing (LCC), there are limited holistic and practical models have been introduced to the industry. When commencing a design and implementation project, Engineering Asset Management (EAM) must consider the overall life cycle of physical assets, including commissioning, operational and end-of-life phases. Life Cycle Costing was recently suggested by researchers to be utilized to optimize the selection and operation of engineering assets to achieve optimum asset selection and utilization. This research developed an LCC Decision Making Model to enable executives and business owners to make informed decisions for their new asset selection, current asset expansion or replacement options. The study reviews the literature on generic LCC frameworks and models, and utilizes the results of the review together with the professional inputs from the steel fabrication and manufacturing industry through a survey and semi structured interviews in Saudi Arabia in order to identify the problem and develop the conceptual framework. The review indicates the lack of a holistic Model, that considers the strategic and operational life cycle asset cost activities, and addresses the variables impacting those costs such as uncertainty and discounting that can aid organizations to achieve the optimum selection of their plants, and assist in managing their performance. Present models in literature mainly focus on the maintenance, but still dearth to address major components of the life cycle, neglect detailed uncertainty and discounting factors consideration, or do not consider sensitivity analysis. These factors resulted on models that lack practicality, accuracy and applicability in industry. Hence, a conceptual framework and its respective Cost Breakdown Structure (CBS) were developed. This conceptual framework and CBS provided the cost variables that are used for a case-study cost data collection from a plant in the steel fabrication industry. The conceptual framework and its CBS were validated by four industry experts. The historical costs were modelled, and the forecasted costs were derived using a model that includes Artificial Neural Network (ANN) methods and stochastic modelling. The developed mathematical model considered uncertainty and discounting factors, and simulated different weightages from probabilities derived from the industry. The prediction model derived high accuracy performance measures of operational and tactical dimensions such as annual revenues and income forecasted values, that aid in decision making for performance management. The model also regarded for performance measures including Return on Investment (ROI) and Pay Back Period (PB) for strategic dimensions that aid for comparisons for asset selection. The model provided a more accurate representation of long-term plant costs since it enables the quantification of risks anticipated during the plant's operations, and thus forecasts are based on a sounder approach than what was previously used in the industry. The developed model was then validated using industry data in a case study. Industry professionals confirmed that no solid forecasting tool is currently being utilized at the industry, which makes the proposed novel model ideal for aiding in the decision of selection of assets from existing options, and in the performance management of the assets for guiding decision makers on expansion and replacement decisions.

ABSTRAK

Walaupun banyak kajian dijalankan dalam bidang Kos Kitar Hayat (LCC), namun didapati tidak banyak model holistik dan praktikal telah diperkenalkan kepada industri. Semasa memulakan projek yang melibatkan reka bentuk dan perlaksanaan, Pengurus Aset Kejuruteraan (EAM) perlu mempertimbangkan kitar hayat menyeluruh aset fizikal, termasuk fasa pentauliahan, operasi dan akhir hayat. Kos Kitar Hayat disarankan oleh penyelidik untuk digunakan untuk mengoptimumkan pemilihan dan operasi aset kejuruteraan untuk mencapai pemilihan dan pengunaan aset yang optimum. Kajian ini membangunkan model Pembuatan Keputusan berdasarkan LCC bagi membolehkan eksekutif dan pemilik perniagaan membuat keputusan yang tepat bagi pemilihan aset baru mereka, membangunkan aset sedia ada atau pilihan sebagai gantian. Kajian ini mengkaji literatur mengenai kerangka kerja dan model LCC generik dan menggunakan hasil tinjauan bersama-sama dengan input dari profesional industri fabrikasi keluli dan industri perkilangan melalui kaji selidik dan wawancara separa berstruktur di Arab Saudi bagi mengenal pasti masalah dan membangunkan kerangka konsep. Permasalahan menunjukkan wujudnya kekurangan model holistik, yang boleh mengambil kira aspek strategik serta operasi aktiviti kos kitar hayat dan menangani pemboleh ubah yang mempengaruhi kos tersebut seperti ketidak tentuan dan pengurangan harga yang boleh membantu organisasi mencapai pemilihan loji secara optimum serta membantu dalam menguruskan prestasi mereka. Model terkini dalam literatur hanya tertumpu kepada aspek penyelengeraan, tidak berjaya untuk menangani komponen utama dalam kitar hayat, mengabaikan elemen ketidakpastian secara terperinci dan mempertimbangkan faktor pengurangan, atau tidak mengambil kira analisis kepekaan. Faktor tersebut menghasilkan model yang tidak praktikal, kurang tepat atau kurang sesuai dalam industri. Oleh itu kerangka konseptual dan Struktur Pemecahan Kos (CBS) dibangunkan. Kerangka Konseptual dan CBS ini memberikan pemboleh ubah kos yang digunakan untuk pengumpulan data kos kajian dari kilang di industri fabrikasi keluli. Kerangka konseptual serta CBS nya disahkan oleh empat pakar industri. Kos sejarah dimodelkan dan ramalan kos diperoleh menggunakan model yang merangkumi kaedah *Artificial Neural Network* (ANN) dan pemodelan stokastik. Model matematik yang dibangunkan mengambil kira faktor ketidaktentuan serta pengurangan dan memberi simulasi hasil pemberat yang berbeza dari kebarangkalian yang dihasilkan dari industri. Model ramalan memperoleh ukuran prestasi yang lebih tepat berkenaan dengan dimensi operasi dan taktikal seperti pendapatan tahunan dan nilai ramalan pendapatan, yang membantu dalam membuat keputusan untuk pengurusan prestasi. Model itu juga mengambil kira ukuran prestasi termasuk Pulangan Pelaburan (ROI) dan Tempoh Bayaran Balik Modal (PB) untuk dimensi strategik yang membantu perbandingan bagi pemilihan aset. Model ini memberikan gambaran yang lebih tepat berkenaan kos jangka panjang kerana ia mengambil kira pertimbangan risiko yang dijangkakan semasa loji beroperasi dan dengan itu ramalan adalah berdasarkan pendekatan yang lebih mantap dari apa yang pernah digunakan sebelum ini dalam industri. Model yang dibangunkan kemudian disahkan mengunakan data industri dalam sebuah kajian kes. Para profesional dalam industri mengesahkan bahawa tidak ada model ramalan yang standing pada masa ini yang digunakan dalam industri ini, yang menjadikan cadangan model baru ini amat sesuai bagi membantu dalam membuat keputusan pemilihan aset dari senarai cadangan yang sedia ada dan dalam pengurusan prestasi aset untuk membimbing pembuat keputusan mengenai pembangunan dan penggantian aset.

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AM	-	Asset Management
ANN	-	Artificial Neural Network
CBS	-	Cost Breakdown Structure
EAM	-	Engineering Asset Management
EPM	-	Economic Performance Measures
IRR	-	Internal Rate of Return
KPI	-	Key Performance Indicators
LCAM	-	Life Cycle Asset Management
LCC	-	Life Cycle Costs
PAM	-	Physical Asset Management
PB	-	Payback Period
PV	-	Present Value
RMC	-	Ratio of Maintenance to Capital Cost
ROC	-	Ratio of Operation to Capital Cost
ROI	-	Return on Investment

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CHAPTER 1

INTRODUCTION

1.1 Preamble

Businesses are facing considerable challenges in terms of sustainable growth in Return on Investment (ROI). The optimization of performance in engineering assets is crucial to achieve that sustainability. This growth can be achieved by implementing a holistic life-cycle costing methodology to define the efficient investment, and therefore contributing to a sustainable development and ROI (Sardar et. al. 2006, Kovacic and Zoller, 2015).

Productivity improvement has been suggested in the past two decades to address the following trends (Mitchell et al., 2002):

1) Ineffectiveness of previous cost cutting techniques
2) Downside of rapid growth.
3) Significant transformation of industry structure

Current expectations and challenges in production and operating companies are achieving sustainable growth in revenues, customer satisfaction and operational excellence while minimizing capital support and operating costs. (Mitchell et al., 2002). High levels of asset and equipment availability, reliability and maintainability are also required to achieve a sustainable management of physical assets and therefore reflects in an ever more optimized business profitability and ROI. Asset Management (AM) is a complex and multidisciplinary field of study as it entails a number of factors including a controlled and well-established processes, trained personnel, integration between technical and managerial areas, effective information management and highly committed leadership. (Duran and Afonso, 2019).

It was evident in the past decade that the literature had highlighted the significance of realizing asset management as part of a crucial part in the value chain and requiring a holistic approach to investigating challenges all over the traditional boundaries of the business, engineering and information technology disciplines (Amadi-Echendu, 2006; Kovacic and Zoller, 2015; Macchi et. al, 2018).

Asset management is typically considered as one of the last options to increase cost savings in the current competitive global economy and this is because of its complexity, particularly in many developing countries that normally lacks the resources and technology that enables the reduction of these complexities due to available data, software, research and infrastructure. It is believed that Asset Management (AM) need to consider the construction, utilization, operational as well as end-of-life stages of engineering physical assets whenever initiating a design and implementation project. Recent research suggested Life cycle costing in AM as a more effective methodology to view Assets from a holistic perspective rather than merely looking at narrower maintenance view. Due to its complexity, asset management has been represented through a model approach considering the Life Cycle Costing (LCC) of the assets. Nevertheless, existing AM models reflect inefficiencies in terms of comprehensively considering life cycle costs, in addition to aspects of sustainable development (Schuman and Brent, 2005; Macchi et al, 2018; Roda and Macchi, 2016).

Asset Lifecycle Costing includes the calculation of cost benefit analysis for the lifecycle of assets that includes the design of the asset, procurement and/or commissioning or installation, operation, maintenance and support, and lastly retirement and disposal costs of the asset. It also includes the evaluation of high-cost contributors, prospective areas of risk, cause and effect relationships; and realization of possible cost reduction areas. It requires a model-based approach to achieve asset performance excellence and optimization over asset lifecycle (Duran and Afonso, 2019).

It had been suggested that the role LCC plays in AM is mainly concerned on defining the life cycle management for a decision making standard for physical assets. This standard acts as a holistic and comprehensive approach in order to control the life

cycle activities of assets with a main objective of realizing the organization's goals (El-Akruti et al., 2015).

Figure 1.1 shows the tasks involved in LCC analysis of the life cycle process and costs associated with these tasks for each stage of the life of the asset. During the initial design stage, for example, the AM activities needs in LCC analysis may comprise of system definition, analysis, and alternative assessment. The main challenge in managing the life of the asset effectively falls in the integration of the different fragmented activities through the numerous stages of the life cycle. This shall then guide business owners and decision makers to the need-identification, alternative analysis, and project selection. The life of the asset from cradle to grave is covered in a LCC analysis, with justifiable assumptions made to neglect the least critical elements in the process and to look at all costs and aid manage the asset till its disposal. (Schuman and Brent, 2005, El-Akruti et al., 2015).

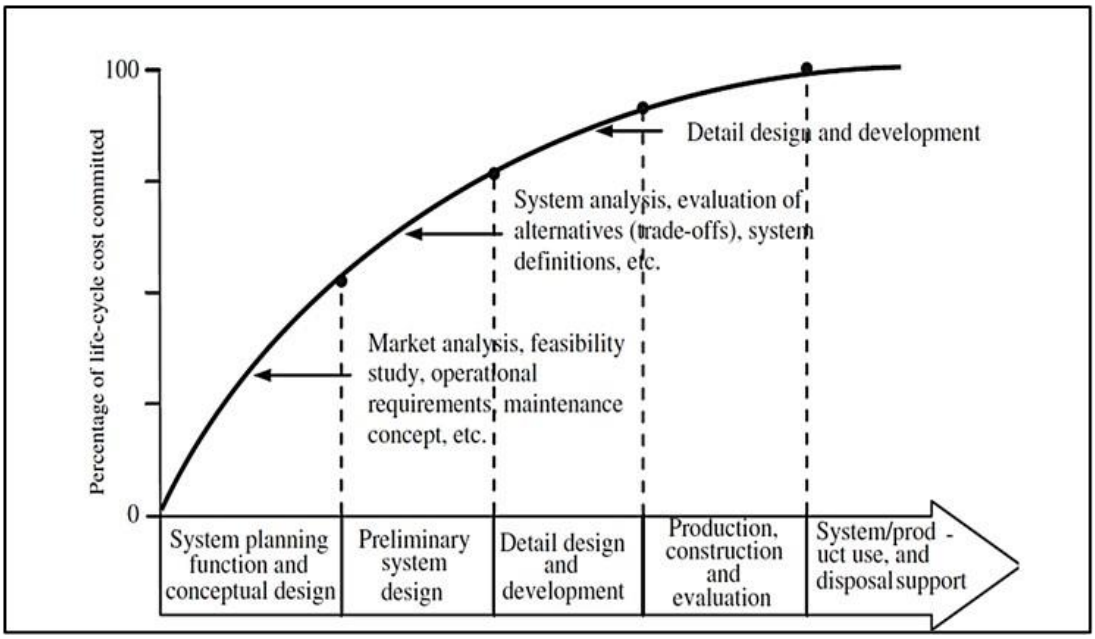

Figure 1.1 Life cycle processes and cost committed (Blanchard BS, Fabryky (2011)

It has also been noticed that the gaps realized on the level of integration of AM in organizations are not only contingent related reasons (industry, type of assets to manage etc.) but also to the gap in the necessary technologies / methodologies required

such as the availability of an LCC model to support the decision making process or the availability of performance indicators (Roda and Macchi, 2016). It is argued that an overall life-cycle costing model that is based on future options or alternative strategies is an appropriate way to identify efficient investment, thus contributing to sustainable development (Kovacic and Zoller., 2015).

1.2 Background of the Problem

Achieving the desired goals from physical assets depends fundamentally on the understanding of the nature of that asset. Manufacturing assets, as a focus of this research, are categorized as multi-unit asset system. Petchrompo and Parlikad, (2019), defines the term 'multi-unit system' as a system composed of multiple assets that share common characteristics or resources under the control of an organisation or a single-asset system composed of multiple components operating together (Petchrompo and Parlikad, 2019). Due to the complexity of this nature of assets, it is found very challenging to manage and requires a model approach in order to be able to achieve the desired productivity and financial objectives (Macchi et al, 2018; Roda and Macchi, 2016).

It was found from literature that research focused on Maintenance management models for physical or engineering AM in the industry, such as total productive maintenance (TPM) (Alsubaie and Yang, 2018; Modgil and Sharma, 2016; Campbell, 1995), reliability centered maintenance (RCM) (Piechnicki et al. 2017; Sifonte and Reyes-Picknell, 2017) and business centered maintenance (BCM) (Kelly, 1997). These models neglected the strategic view of asset management as they are applicable after the ownership of an asset thus does not look at potential costs for the investment at an early stage where most of the costs are committed. This makes the selection of physical asset system from a number of asset alternatives, particularly in multi assets such as production lines of a fleet of machines in manufacturing plants an industry challenge. It also covered a narrow view of the overall asset by focusing merely on maintenance not considering strategic and tactical factors related to asset life cycle including uncertainty, discounting, economic performance measures and cost elements

at the various life stages from an early stage of asset design (Alaswad and Xiang, 2017, Wang and Chenl, 2016, Fraser et al., 2015, Amadi-Echendu, 2004; Hoskins et al., 1998).

In addition, in order to attain optimum utilization of the assets over their lifecycle and to identify the optimum time and requirements for replacement and/or enhancement is not well covered in research. Researchers identified a more holistic approach to address multi asset objectives through Life Cycle Costing (LCC). LCC in AM decisions has been introduced as a holistic approach to address asset management from an organizations performance perspective and not merely focusing on cost elements as the traditional maintenance models. LCC covers all asset life stages from acquisition to disposal looking at all factors affecting costs during the life cycle and utilize those cost elements as a way to assess the feasibility of investments and/or requirements of existing and new assets. This aids to provide a decision tool for estimating the asset requirements or investment, identify cost drivers and highlight need for replacement or for asset selection.

Despite the research conducted in the field of LCC in AM, unfortunately, most of the LCC models reported were found to be far from ideal. The models had flaws in regard to either or all of the following factors, such as the uncertainty and risk modeling, discounting and the present value for predicted future money, covering uncertainty from a high level, not considering sensitivity analysis of the assumed discount rates or uncertainty factors, considering the strategic dimension for asset selection but not the operational performance management aspect at an early design stage considering only performance during operation, not considering the Economic Performance measures for performance evaluation, and many did not consider the corrective and preventive maintenance classification to view the tactical and operational cost implications (Eric Korpi Timo Ala-Risku, 2008; Roda and Macchi, 2016; Schmidt and Crawford, 2018).

In addition many of the case study applications compared to the methods suggested in the literature have encountered some deficiencies which included; covering fewer parts of the whole life cycle, estimating the costs on a lower level of

detail, using methods of cost estimation depending on expert opinion rather than statistical methods, and were based upon deterministic estimates of life cycle costs instead of using sensitivity analyses.

Furthermore, it's argued that to achieve optimum value from engineering assets over the asset's lifetime, operational reliability and systems engineering should be the means for that. Thus, cost activities that should be completed during each stage of the project life cycle need to be identified. In order to influence the decision making, the application of performance measurements for the operation and support stages need to be proposed. The identification of Asset Management (AM) model relative to the development of performance excellence and optimization in the industry is crucial.

The nature of the inter relationships of the different elements of asset management as an enterprise AM has recently been studied within the last few years and is not yet adequately defined either in the literature or in practice. The main focus has been on the specific asset life or specific issues like reliability or maintenance, whilst the concept of an enterprise AM has only been discussed in literature over the past decade, and it has not yet been fully developed or understood (Frolov et. al, 2009; El-Akruti et al., 2015, Roda and Macchi, 2016).

1.3 Problem Statement

The primary challenge faced by the industry is to have a systematic AM model for manufacturing assets based on a holistic Life cycle costing approach that aids in the optimum selection as well as the performance management of multi assets of a fleet of machines from a number of asset alternatives. Literature shows that there is no existence for an LCC Model, overseeing the strategic and operational life cycle asset cost activities, addressing the variables impacting those costs such as uncertainty and discounting that can aid organizations to achieve the optimum selection of their plants and assist in managing their performance. This fact is also stressed by the industry as the existence of such model that aids industry to choose multi asset systems from

several investment options as well as aid in the performance management of those assets is not present.

1.4 Aim of the Research

This study aims to develop and propose a Model for Life Cycle Costing Asset Management (LCAM) that utilizes Life Cycle Costing (LCC) to aid in the decision-making process for the selection of optimum multi-assets system from a few alternatives of multi assets in the initial investment stage as well as assisting the continuous monitoring and assessment of performance of multi assets at their utilization and/or replacement stages.

The model allows management to decide from a series of available alternatives of multi assets consisting of a fleet of machines in a manufacturing facility and uses prediction method to derive results that aids in what would be the best choice from a series of similar multi asset options. It may not be the mathematically optimum solution but one that is the best alternative to the company based on a series of decisions and constraints.

1.5 Research Questions

The research questions are :

1) What are the main critical life cycle cost variables for multi asset selection from a number of multi asset alternatives?
2) How are feasibility for new multi asset investments and asset utilization, and/or requirements of existing and new multi assets performed?
3) What circumstances exists in real-life operations and what impact significant or otherwise would such a model have in influencing management decision making?

1.6 Research Objectives

The research objectives are:

1) To derive Asset Life cycle cost variables that influence acquisition, operations and maintenance decisions.
2) To establish a decision-making model that aids in asset selection at the early Life cycle stages and asset performance management during the asset utilization and evaluate the model usability in a manufacturing capital intensive plant.

1.7 Research Scope

This research is focus on asset management, specifically in the capital-intensive industry, steel fabrication and manufacturing industry in Saudi Arabia which is an important component of the new and emerging economy towards reaching Saudi Arabia vision 2030. Being an asset-intensive industry, this represented a research opportunity of applying the LCC model for asset management. Data collection will be through primary data sources from the industry including questionnaire survey, interviews and historical cost data. Acquisition cost variables, and utilization cost variables including operation and maintenance variables that are not foreseen during the initial asset investment evaluation are considered in the scope of this study. Additional uncertainty factors that are associated to that utilization phase of the asset were considered. In the research the disposal cost was assumed to be negligible for the type of industry since no major impact cost or otherwise is believed to impact the course of study or the results. In summary, the boundaries of the research are defined to be focused on life cycle costing in the steel fabrication industry in Saudi Arabia with neglecting the disposal costs and using primary source of field data from existing industry for the purpose of model development through a case study.

1.8 Research Significance

The research outcome will aid asset managers and decision makers to deploy a LCC model that guides and aids in the selection of assets at the early stages of the decision making process and aids in the performance measurement and optimization of asset utilization throughout the asset life cycle. The model, unlike the maintenance models present covers a holistic view of the life cycle of the asset from acquisition to disposal covering the strategic, tactical and operational variables. It also considers factors that has not been covered thoroughly in present models such as uncertainty and discounting. The model provides a good level of accuracy in the results that makes it of considerable reliability through a novel mathematical model and utilizing an AI prediction model. In addition a sensitivity analysis has been considered that reflected the robustness of the model. The decision-making criteria will be based on LCC and will aid in the optimum selection from a few alternatives. This will be of great use to manufacturing plants in the capital-intensive industry to achieve higher ROI having considered the overall asset lifecycle.

1.9 Outline of the Thesis

Figure 1.2 shows an outline of the Thesis. In this Chapter 1, the first a background of the research was presented. The multi asset management concept and its complexity were reflected with the research and industry main challenges faced. This led to the articulation of the Problem Statement realized from the background and gaps in the field of multi asset management and the need for a LCC model was then reflected on the aim of the research. Researches Questions and Objectives were discussed, and the research significance was also outlined.

Chapter 2 covers the Literature Review, where two main types of review are discussed; first is the identification of assets life cycle stages and dimensions and cost estimating techniques, and the second is the identification of life cycle costing models and tools. Other AM concepts required for the purpose of the LCC model development was also reviewed such as risk and uncertainty, Multi asset concept, Discounting, and

performance management. The review resulted on a conclusion and the research gap is clearly described.

The overall research method and strategy is then presented. The system design and methodology of LCC model development and Analysis of Proposed LCC model will be discussed in Chapter 3. Chapter 4 presents the Conceptual Framework and Mathematical Model Development. This is followed by model construction and validation through a detailed case study in Chapter 5 and the results of the model is discussed in this chapter and the present research study is then concluded in Chapter 6.

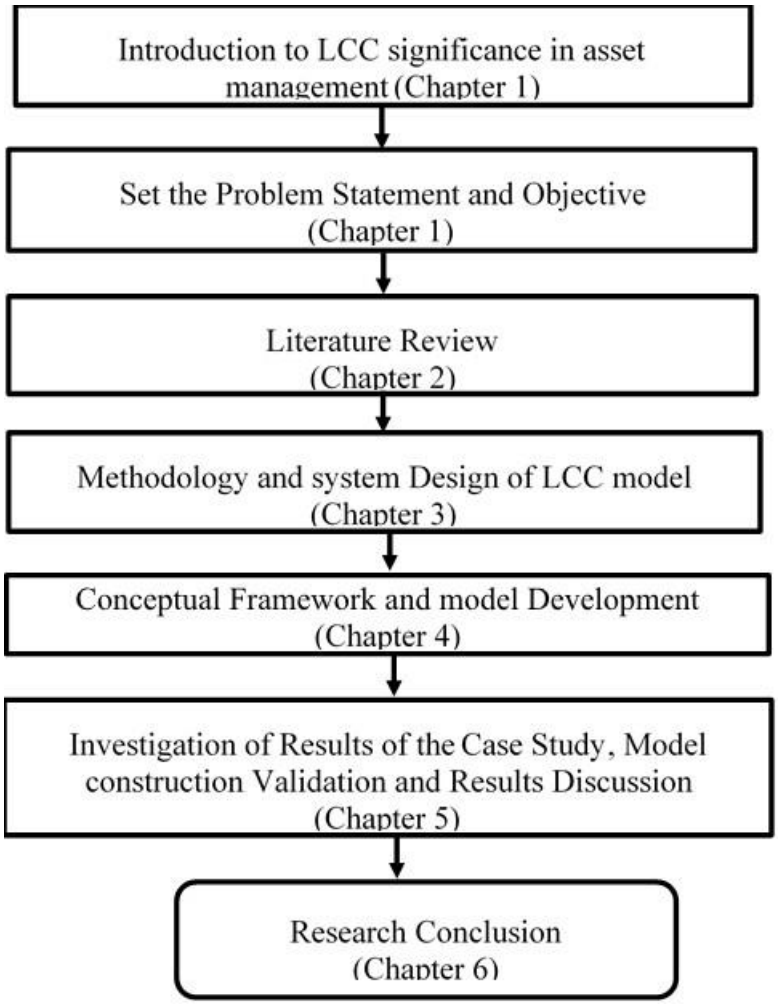

Figure 1.2 Outline of the thesis

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Appendix A Questionnaire

1) What sector of the Steel Fabrication and manufacturing industry does your company operate? Design and project Management/ Industrial Plants Cost Engineering/ Production/ Planning/ Other

2) What Kind of products and services do you deliver?

3) What is the number of employees in your business/plant?

4) What is the average life expectancy of your plant

5) What is the capacity of your industry?
   Please indicate in unit per day/month/year

6) What is the level of complexity of your plant?

7) What is your role in cost engineering in your plant/industry?
   Equipment/ Spare procurement/ Maintenance/ performance data reporting
   Cost engineering consultancy services
   Contract reviews and in-house estimates preparation
   Preparation of risk-based investments plans and models

8) What do you consider the current challenges in your industry/plant?
   a. Low capacity utilization and rising cost of ownership
   b. Plant complexity and turnaround maintenance
   c. Non-availability of trained and experienced personnel to replace the aging work force
   d. Competition and dwindling profits
   e. Scope definition

9) What do you understand to be life cycle costing?

10) What methods do you use in life cycle costing?

11) What data and information (sources) are used in life cycle costing?
   a. Cost break down structure
   b. Historical plant data
   c. Corporate asset maintenance register (Do not mention this)

12) What are the challenges in life cycle costing?
    a. Historical data
    b. Performance data
    c. Plant upgrading/revamping
    d. Operating costs

13) Could you please describe the life cycle costing process in your plant?

14) Please indicate the cost drivers you consider relevant for the life cycle costing in your industry?
    a. Plant investment/reliability/ maintainability/ plant complexity/ energy/ downtime/ plant flexibility/ plant capacity

15) What do you think is it the relationships of the more critical ones?
    a. Reliability reduces maintenance cost

16) What are the life cycle stages of your plant/Industry?
    a. R&D, Design
    b. Manufacture
    c. Acquisition
    d. Installation, operation
    e. Maintenance, retirement
    f. Disposal

17) How many codes and standards of which the title includes “life cycle costing” do you know of?

18) How many of the codes and standards are specifically meant for the Steel Fabrication industry?

19) What are the challenges in operation and maintenance?
    a. Expertise, maintenance cost, routine maintenance and downtime
    b. Technical and managerial problems

20) What are the issues in maintenance and operation related to LCC?
    a. Maintenance cost, spare parts availability, budget restrictions, risk management, and downtimes

21) What bottlenecks are there is operations and maintenance?
    a. Resources, staff skills, and plant performance

22) What operations and maintenance models do you use? For example, mathematical models, decision making models, scheduling models e.t.c.?

23) What are the related environmental impact challenges of CO2 emission and its cost related issues?
    a. International legislation, CO2 taxation

24) What are the technologies to curb environmental impact for now and in the future?
    a. Carbon sequestration, flue gas desulfurisation

25) What are the environmental impacts cost drivers and cost models?
    a. Environmental remediation cost
    b. CO2 tax and health damages

26) What are the significant risks associated to the plant and is reflected in the life cycle costing?
    a. Plant upgrading
    b. Data availability
    c. Plant reliability
    d. And high investment cost
    e. Plant operation/ maintenance, and environmental remediation

27) What are the uncertainties in life cycle costing in the industry?
    a. Plant life span
    b. Discount rates and
    c. Energy cost
    d. Data accuracy
    e. Cost estimation errors

28) What are the methods used to model risk and uncertainty
    a. Monte carlo simulation, risk analysis, and risk register
    b. No systematic and standerdised procedure

29) LCC model can be used to forecast the costs of all the life cycle phases for an asset and allows researchers to choose the most viable decision on the basis of total performance
    a. Strongly agree
    b. agree
    c. neutral
    d. disagree
    e. strongly disagree

30) Having an LCC Model is essential for guiding decision making in asset selection and/or enhancement
    a. Strongly agree
    b. agree
    c. neutral
    d. disagree
    e. strongly disagree

31) LCC acts as a maintenance guide
    a. Strongly agree
    b. agree
    c. neutral
    d. disagree
    e. strongly disagree

32) The presented Uncertainty Factors are covering the risks associated to operations and maintenance for the plant under study
    a. Strongly agree
    b. agree
    c. neutral
    d. disagree
    e. strongly disagree

33) Operating and maintenance factors presented in the CBS cover all the major LCC related to the plants under study
    a. Strongly agree
    b. agree
    c. neutral
    d. disagree
    e. strongly disagree

34) Uncertainty and Risk is critical to consider in the Forecasting process of LCC
    a. Strongly agree
    b. agree
    c. neutral
    d. disagree
    e. strongly disagree

35) The presented Uncertainty Factors are covering the risks associated to operations and maintenance for the plant under study
    a. Strongly agree
    b. agree
    c. neutral
    d. disagree
    e. strongly disagree

Appendix B Present values and Future predicted values with LCC

Table B.1 shows the future predicted values for twelve years extracted from NARX input simulations for case study.

Table B.1 The future predicted values for twelve years extracted from NARX input simulations for case study.

COST/YEAR	2018	2019	2020	2021	2022	2023	2024
Operations/Plant Manager	404699.992	406700	408700	404698.693	395058.858	395298.806	395338.03
Engineers	503600	502600	504170.956	1140700	1071273.47	1068219.58	1033632.21
Supervisors/Operators	417400	419400	275555.278	256800	384959.823	391027.292	380699.772
Lab Personnel	100241.143	130700	130600	130700	72084.0619	89133.6863	79853.8662
Technicians	353775.282	353899.976	317618.82	317600	303030.218	302720.076	302622.797
Clerical Personnel	43600	43600.0008	111600	111600	93952.3272	93601.6848	69888.3835
Power	44432.1696	48996.8317	48996.1799	40035.8347	38184.2973	38186.8649	38173.1309
Fuel/Gas	278615.685	372100	372100	374100	285743.743	277529.573	275751.405
Insurance	63500.0041	63500	81959.0775	136099.998	124197.564	106546.984	78230.1896
Local Taxes	3600	3600	13599.9992	13600	5936.5657	5113.2679	5209.2747
Spare parts for overhauls and unplanned maintenance	40800	40800	16304.4057	16300	37028.8981	32194.4007	22453.5335
Downtime cost	96199.9989	96200	96200	95581.9007	82753.9697	90136.7757	74631.7669
Maintenance Engineer	90700	90700	89335.813	43600	44480.7946	46626.8141	48190.3664
Engineers	10000.0009	10000	13362.4254	73500	37061.2329	63140.0073	66079.2755
Technicians	66610.967	49139.8879	51674.2776	95267.9363	62964.1868	85702.8546	85071.3338
QHSE Manager	178404.215	119214.994	73185.1643	252095.558	226180.874	220448.668	210345.168
Required maintenance equipment/ software	135196.016	127628.096	81700.024	81700	77874.8888	77926.6634	77813.4567
Inspection Cost	112500	113500	49900	48900	89623.7581	74594.7175	94933.1732
Scheduled maintenance cost	45400	45800	22800.0109	22700	38529.6208	40716.5705	34583.8756
Planned Downtime cost	59899.9999	59900	10444.3808	9100	55939.9198	55749.331	36415.2698
Spare Parts	88442.429	88899.8056	88850.1147	88881.4502	84572.6767	84653.4704	84358.3411
Consumable Materials	11800	11700.089	99799.947	99800	16403.3149	11760.9048	11396.6361

COST/YEAR	2025	2026	2027	2028	2029	2030
Operations/Plant Manager	395455.041	395489.691	3588755.42	3588706.1	3588724.76	3588799.3
Engineers	824058.433	810678.711	9580626.27	9663625.43	7973063.2	7898916.46
Supervisors/Operators	389819.049	324032.781	3430359.99	3318470.57	3526044.54	3012100.08
Lab Personnel	94760.0382	105157.306	788549.887	756579.035	769664.732	752809.286
Technicians	305424.219	306177.133	2746109.71	2746112.24	2746132.8	2764408.23
Clerical Personnel	65979.2417	66043.0463	662659.946	659542.483	606775.244	845514.978
Power	38296.2006	38396.839	346708.233	346798.688	347039.616	346405.47
Fuel/Gas	317932.676	328851.498	2572802.19	2551593.43	2732007.86	2931014.37
Insurance	89156.5357	77474.7931	742235.421	792569.133	744747.302	834854.574
Local Taxes	5151.5434	5422.1897	48537.6696	48770.6569	47552.5904	46509.3246
Spare parts for overhauls and unplanned maintenance	35051.034	29158.6189	223757.238	233723.708	273676.809	260007.507
Downtime cost	86078.1002	89580.218	722352.46	702458.574	718813.533	816250.086
Maintenance Engineer	44413.4351	57428.2854	466462.724	476075.081	412253.739	415026.922
Engineers	55690.6381	67575.7186	577808.226	551320.027	541428.724	602310.521
Technicians	76354.9115	83071.3614	772764.222	768480.453	762704.234	771075.225
QHSE Manager	197915.229	191324.331	1864751.27	1881916.9	1806552.06	1739363.07
Required maintenance equipment/ software	77815.7579	77891.5101	706156.988	706196.094	706149.973	706102.524
Inspection Cost	105858.452	103186.117	858629.41	873841.543	945603.827	891289.798
Scheduled maintenance cost	39568.8452	36860.2197	336142.807	330393.098	348588.86	369452.986
Planned Downtime cost	51562.1755	47827.0714	363023.602	357695.24	356321.635	505674.114
Spare Parts	84413.0364	83365.7875	768074.073	768049.824	767905.252	767946.793
Consumable Materials	11380.1285	11215.4459	101818.017	101864.221	101824.223	101804.39

Table B.2 shows the present values for twenty years the total LCC per year and LCC added with AC extracted from NARX input simulations for case study.

Table B.2 The present values for twenty years and the total LCC per year for case study

COST/YEAR	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Operations/Plant Manager	340300	254100	272200	344800	404700	262300	320300	363000	385500	385500	395500
Engineers	480900	435600	136100	130700	503600	882900	1140700	898400	479700	479700	480300
Supervisors/Operators	245000	225000	272200	381100	256800	354800	417400	344800	397600	397600	262500
Lab Personnel	49900	34500	36300	20900	20000	21800	130700	63500	95500	124500	114500
Technicians	208700	167900	181500	272200	344800	317600	353900	335800	337000	337100	302600
Clerical Personnel	11800	13600	8200	10000	43600	75300	111600	99800	41500	41500	106300
Power	11800	10900	23600	62600	39000	40800	49000	43600	42300	46700	46700
Fuel/Gas	340300	353900	407400	606200	278600	352100	344800	372100	265400	354500	354500
Insurance	72600	90700	82100	816700	63500	136100	75300	108900	60500	60500	78100
Local Taxes	0	1400	1800	7300	3600	6400	13600	9100	3400	3400	13000
Spare parts for overhauls and unplanned maintenance	0	0	4500	27200	16300	22700	40800	18100	38900	38900	15500
Downtime cost	45400	77100	54400	48100	45400	88000	96200	68100	91600	91600	91600
Maintenance Engineer	54400	63500	34500	54400	68100	43600	90700	77100	86400	86400	85100
Engineers	0	0	18100	10900	10000	10900	73500	45400	9500	9500	12700
Technicians	40800	63500	40800	51700	49000	73500	95300	81700	63500	46800	49200
QHSE Manager	149700	49900	179700	41700	66200	181500	257700	199600	169900	113600	69700
Required maintenance equipment/ software	77100	122500	90700	108900	81700	98900	135200	99800	128800	121600	77800
-Inspection Cost	72600	99800	81700	72600	90700	112500	55400	49900	107200	107200	47500
- Scheduled maintenance cost	18100	31800	36300	27200	22700	30900	45400	22700	43200	43200	21600
Planned Downtime cost	17200	22700	16300	18100	9100	16300	59900	36300	57100	57100	9900
Spare Parts	68100	22700	107100	16300	67200	88900	33600	49900	84300	84700	84600
Consumable Materials	45400	54400	72600	51700	11800	90700	99800	68100	11200	11200	95100
Total LCC per year	2350100	2195500	2158100	3181300	2496400	3308500	4040800	3455700	3000000	3042800	2814300
LCC+AC per year	12350100	12195500	12158100	13181300	12496400	13308500	14040800	13455700	13000000	13042800	12814300

COST/YEAR	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Operations/Plant Manager	375500	358490	358710	358750	358850	358880	325660	325660	325660	325660
Engineers	1086600	872120	869350	837960	747790	735650	869390	876920	723510	716780
Supervisors/Operators	244600	249330	254840	245460	253740	264040	211290	201130	219970	203330
Lab Personnel	124500	654100	808800	724600	859900	954200	715600	686600	698400	683100
Technicians	302500	274980	274700	274610	277160	277840	249190	249190	249200	250850
Clerical Personnel	106300	852600	849400	634200	598700	599300	601300	598500	550600	767300
Power	38100	34650	34650	33640	34750	34840	31460	31470	31490	31430
Fuel/Gas	364500	249300	251840	200230	288510	278410	233470	231540	247910	265970
Insurance	129600	102700	96690	70990	80900	70300	67350	71920	67580	75760
Local Taxes	13000	53900	46400	47300	46700	49200	44000	44300	43200	42200
Spare parts for overhauls and unplanned maintenance	15500	23600	25210	20380	21810	20460	20300	21210	24830	23590
Downtime cost	91100	75090	81790	67720	78110	81290	65550	63740	65230	74070
Maintenance Engineer	41500	40360	42310	43730	40300	52110	42330	43200	37410	37660
Engineers	70000	76300	73000	79600	75400	73200	74300	70300	71300	76600
Technicians	90800	57140	77770	77200	69290	75380	70120	69740	69210	69970
QHSE Manager	70100	75250	70040	70880	79600	73620	79220	70770	73930	77840
Required maintenance equipment/ software	77800	70670	70710	70610	70610	70680	64080	64080	64080	64070
-Inspection Cost	47500	61330	47690	66150	66060	63640	77920	79300	85810	80880
- Scheduled maintenance cost	21600	24960	26950	21380	25910	23450	20500	29980	21630	23530
Planned Downtime cost	8700	50760	50590	33040	46790	43400	32940	32460	32330	45890
Spare Parts	84700	76740	76820	76550	76600	75650	69700	69700	69680	69690
Consumable Materials	95100	88900	86700	83400	83300	81800	82400	82400	82400	82400
Total LCC per year	3499600	4423270	4574960	4138380	4280780	4357340	4048070	4014110	3855360	4088570
LCC+AC per year	13499600	14423270	14574960	14138380	14280780	14357340	14048070	14014110	13855360	14088570

Table B.3 shows the total LCC per costing attribute for twenty year extracted from NARX input simulations for case study

Table B.3 The total LCC per costing attribute for twenty years for case study

LCC Parameter	LCC Values
Operations/Plant Manager	7200020
Engineers	14384670
Supervisors/Operators	5902530
Lab Personnel	7621900
Technicians	5839320
Clerical Personnel	6721400
Power	753480
Fuel/Gas	6641480
Insurance	2478790
Local Taxes	493200
Spare parts for overhauls and unplanned maintenance	439790
Downtime cost	1541190
Maintenance Engineer	1165110
Engineers	940500
Technicians	1382420
QHSE Manager	2220450
Required maintenance equipment/ software	1830390
Inspection Cost	1573380
Scheduled maintenance cost	582990
Planned Downtime cost	696900
Spare Parts	1453230
Consumable Materials	1460800

Table B.4 shows the future predicted values for twelve years extracted from NARX input simulations for Scenario one.

Table B.4 The future predicted values for twelve years extracted from NARX input simulations for Scenario one

COST/YEAR	2018	2019	2020	2021	2022	2023	2024
Operations/Plant Manager	403700	405700	407700	403698.7	394058.9	394298.8	394338
Engineers	502600	501600	503171	1139700	1070273	1067220	1032632
Supervisors/Operators	416400	418400	274555.3	255800	383959.8	390027.3	379699.8
Lab Personnel	99241.14	129700	129600	129700	71084.06	88133.69	78853.87
Technicians	352775.3	352900	316618.8	316600	302030.2	301720.1	301622.8
Clerical Personnel	42600	42600	110600	110600	92952.33	92601.68	68888.38
Power	43432.17	47996.83	47996.18	39035.83	37184.3	37186.86	37173.13
Fuel/Gas	277615.7	371100	371100	373100	284743.7	276529.6	274751.4
Insurance	62500	62500	80959.08	135100	123197.6	105547	77230.19
Local Taxes	2600	2600	12600	12600	4936.566	4113.268	4209.275
Spare parts for overhauls and unplanned maintenance	39800	39800	15304.41	15300	36028.9	31194.4	21453.53
Downtime cost	95200	95200	95200	94581.9	81753.97	89136.78	73631.77
Maintenance Engineer	89700	89700	88335.81	42600	43480.79	45626.81	47190.37
Engineers	9000.001	9000	12362.43	72500	36061.23	62140.01	65079.28
Technicians	65610.97	48139.89	50674.28	94267.94	61964.19	84702.85	84071.33
QHSE Manager	177404.2	118215	72185.16	251095.6	225180.9	219448.7	209345.2
Required maintenance equipment/ software	134196	126628.1	80700.02	80700	76874.89	76926.66	76813.46
Inspection Cost	111500	112500	48900	47900	88623.76	73594.72	93933.17
Scheduled maintenance cost	44400	44800	21800.01	21700	37529.62	39716.57	33583.88
Planned Downtime cost	58900	58900	9444.381	8100	54939.92	54749.33	35415.27
Spare Parts	87442.43	87899.81	87850.11	87881.45	83572.68	83653.47	83358.34
Consumable Materials	10800	10700.09	98799.95	98800	15403.31	10760.9	10396.64

COST/YEAR	2025	2026	2027	2028	2029	2030
Operations/Plant Manager	394455	394489.7	3587755	3587706	3587725	3587799
Engineers	823058.4	809678.7	9579626	9662625	7972063	7897916
Supervisors/Operators	388819	323032.8	3429360	3317471	3525045	3011100
Lab Personnel	93760.04	104157.3	787549.9	755579	768664.7	751809.3
Technicians	304424.2	305177.1	2745110	2745112	2745133	2763408
Clerical Personnel	64979.24	65043.05	661659.9	658542.5	605775.2	844515
Power	37296.2	37396.84	345708.2	345798.7	346039.6	345405.5
Fuel/Gas	316932.7	327851.5	2571802	2550593	2731008	2930014
Insurance	88156.54	76474.79	741235.4	791569.1	743747.3	833854.6
Local Taxes	4151.543	4422.19	47537.67	47770.66	46552.59	45509.32
Spare parts for overhauls and unplanned maintenance	34051.03	28158.62	222757.2	232723.7	272676.8	259007.5
Downtime cost	85078.1	88580.22	721352.5	701458.6	717813.5	815250.1
Maintenance Engineer	43413.44	56428.29	465462.7	475075.1	411253.7	414026.9
Engineers	54690.64	66575.72	576808.2	550320	540428.7	601310.5
Technicians	75354.91	82071.36	771764.2	767480.5	761704.2	770075.2
QHSE Manager	196915.2	190324.3	1863751	1880917	1805552	1738363
Required maintenance equipment/ software	76815.76	76891.51	705157	705196.1	705150	705102.5
Inspection Cost	104858.5	102186.1	857629.4	872841.5	944603.8	890289.8
Scheduled maintenance cost	38568.85	35860.22	335142.8	329393.1	347588.9	368453
Planned Downtime cost	50562.18	46827.07	362023.6	356695.2	355321.6	504674.1
Spare Parts	83413.04	82365.79	767074.1	767049.8	766905.3	766946.8
Consumable Materials	10380.13	10215.45	100818	100864.2	100824.2	100804.4

Table B.5 shows the present values for twenty years the total LCC per year and LCC added with AC extracted from NARX input simulations for Scenario one.

Table B.5 The present values for twenty years and the total LCC per year for Scenario one

COST/YEAR	2010	2011	2012	2013	2014	2015	2016
Operations/Plant Manager	266700	199140	213360	270260	317200	205540	251050
Engineers	376940	341380	106680	102410	394720	692000	893980
Supervisors/Operators	192020	176380	213360	298710	201270	278080	327150
Lab Personnel	39120	27030	28450	16360	15650	17070	102410
Technicians	163580	131570	142240	213360	270260	248920	277370
Clerical Personnel	9250	10670	6400	7820	34140	59030	87480
Power	9250	8530	18490	49070	30580	32000	38400
Fuel/Gas	266700	277370	319330	475080	218340	275950	270260
Insurance	56900	71120	64360	640080	49780	106680	59030
Local Taxes	0	1070	1420	5690	2840	4980	10670
Spare parts for overhauls and unplanned maintenance	0	0	3560	21340	12800	17780	32000
Downtime cost	35560	60450	42670	37690	35560	68990	75390
Maintenance Engineer	42670	49780	27030	42670	53340	34140	71120
Engineers	0	0	14220	8530	7820	8530	57610
Technicians	32000	49780	32000	40540	38400	57610	74680
QHSE Manager	117350	39120	140820	32720	51920	142240	201980
Required maintenance equipment/ software	60450	96010	71120	85340	64010	77520	105970
-Inspection Cost	56900	78230	64010	56900	71120	88190	43380
- Scheduled maintenance cost	14220	24890	28450	21340	17780	24180	35560
Planned Downtime cost	13510	17780	12800	14220	7110	12800	46940
Spare Parts	53340	17780	83920	12800	52630	69700	26310
Consumable Materials	35560	42670	56900	40540	9250	71120	78230
Total LCC per year	1842020	1720750	1691590	2493470	1956520	2593050	3166970
LCC+AC per year	11842020	11720750	11691590	12493470	11956520	12593050	13166970

COST/YEAR	2017	2018	2019	2020	2021	2022	2023
Operations/Plant Manager	284480	385500	384500	394500	374500	358390	358610
Engineers	704090	479700	478700	479300	985600	972020	969250
Supervisors/Operators	270260	397600	396600	261500	243600	349230	354740
Lab Personnel	49780	95500	123500	113500	123500	653100	807800
Technicians	263150	337000	336100	301600	301500	274880	274600
Clerical Personnel	78230	41500	40500	105300	105300	851600	848400
Power	34140	42300	45700	45700	37100	34550	34550
Fuel/Gas	291590	265400	353500	353500	363500	259200	251740
Insurance	85340	80500	59500	77100	88600	72600	86590
Local Taxes	7110	5400	2400	12000	12000	52900	45400
Spare parts for overhauls and unplanned maintenance	14220	38900	37900	14500	14500	135000	191100
Downtime cost	53340	91600	90600	90600	90100	74990	81690
Maintenance Engineer	60450	86400	85400	84100	40500	40260	42210
Engineers	35560	8500	8500	11700	69000	85300	82000
Technicians	64010	63500	45800	48200	89800	80400	86700
QHSE Manager	156460	169900	112600	68700	89100	75150	79940
Required maintenance equipment/ software	78230	128800	120600	76800	76800	70570	70610
-Inspection Cost	39120	107200	106200	46500	46500	62300	65900
- Scheduled maintenance cost	17780	43200	42200	20600	20600	24860	26850
Planned Downtime cost	28450	57100	56100	8900	7700	50660	50490
Spare Parts	39120	84300	83700	83600	83700	76640	76720
Consumable Materials	53340	11200	10200	94100	94100	87900	85700
Total LCC per year	2708250	3021000	3020800	2792300	3357600	4742500	4971590
LCC+AC per year	12708250	13021000	13020800	12792300	13357600	14742500	14971590

COST/YEAR	2024	2025	2026	2027	2028	2029	2030
Operations/Plant Manager	358650	358700	358780	325560	325560	325560	325560
Engineers	937860	747690	735550	869290	876820	723410	716680
Supervisors/Operators	345360	353640	293940	311190	301030	319870	273230
Lab Personnel	723600	858900	953200	714600	685600	697400	682100
Technicians	274510	277060	277700	249090	249090	249100	250750
Clerical Personnel	633200	597700	598300	600300	597500	549600	766300
Power	34540	34650	34740	31360	31370	31390	31300
Fuel/Gas	250130	288410	298310	233370	231440	247810	265800
Insurance	70890	80800	70200	67250	71820	67480	75660
Local Taxes	46300	45700	48200	43000	43300	42200	41200
Spare parts for overhauls and unplanned maintenance	102800	117100	163600	102000	111100	147300	134900
Downtime cost	67620	78010	81190	65450	63640	65130	73970
Maintenance Engineer	43630	40200	52010	42230	43100	37310	37560
Engineers	88600	84400	82200	83300	89300	80300	85600
Technicians	81000	81900	82800	80200	86400	81100	88700
QHSE Manager	80780	89500	73520	79120	80670	63830	57740
Required maintenance equipment/ software	70510	70510	70580	63980	63980	63980	63970
-Inspection Cost	60500	59600	65400	68200	62000	67100	67800
- Scheduled maintenance cost	21280	25810	23350	20400	20880	21530	23430
Planned Downtime cost	32940	46690	43300	32840	32360	32230	45790
Spare Parts	76450	76500	75550	69600	69600	69580	69590
Consumable Materials	82400	82300	80800	61400	61400	61400	61400
Total LCC per year	4483550	4495770	4563220	4213730	4197960	4044610	4239030
LCC+AC per year	14483550	14495770	14563220	14213730	14197960	14044610	14239030

Table B.6 shows the total LCC per costing attribute for twenty year extracted from NARX input simulations for c Scenario one

Table B.6 The total LCC per costing attribute for twenty years for Scenario one

LCC Parameter	LCC Values
Operations/Plant Manager	6642100
Engineers	13584070
Supervisors/Operators	6158760
Lab Personnel	7528170
Technicians	5363430
Clerical Personnel	6628520
Power	689710
Fuel/Gas	6056730
Insurance	2102280
Local Taxes	473780
Spare parts for overhauls and unplanned maintenance	1412400
Downtime cost	1424240
Maintenance Engineer	1056110
Engineers	990970
Technicians	1385520
QHSE Manager	2003160
Required maintenance equipment/ software	1650340
Inspection Cost	1383050
Scheduled maintenance cost	519190
Planned Downtime cost	650710
Spare Parts	1351130
Consumable Materials	1261910

Table B.7 shows the future predicted values for twelve years extracted from NARX input simulations for Scenario two.

Table B.7 The future predicted values for twelve years extracted from NARX input simulations for Scenario two

COST/YEAR	2018	2019	2020	2021	2022	2023	2024
Operations/Plant Manager	402700	404700	406700	402698.7	393058.9	393298.8	393338
Engineers	501600	500600	502171	1138700	1069274	1066220	1031632
Supervisors/Operators	415400	417400	273555.3	254800	382959.8	389027.3	378699.8
Lab Personnel	98241.14	128700	128600	128700	70084.06	87133.69	77853.87
Technicians	351775.3	351900	315618.8	315600	301030.2	300720.1	300622.8
Clerical Personnel	41600	41600	109600	109600	91952.33	91601.69	67888.38
Power	42432.17	46996.83	46996.18	38035.84	36184.3	36186.87	36173.13
Fuel/Gas	276615.7	370100	370100	372100	283743.7	275529.6	273751.4
Insurance	61500	61500	79959.08	134100	122197.6	104547	76230.19
Local Taxes	1600	1600	11600	11600	3936.566	3113.268	3209.275
Spare parts for overhauls and unplanned maintenance	38800	38800	14304.41	14300	35028.9	30194.4	20453.53
Downtime cost	94200	94200	94200	93581.9	80753.97	88136.78	72631.77
Maintenance Engineer	88700	88700	87335.81	41600	42480.8	44626.81	46190.37
Engineers	8000.001	8000	11362.43	71500	35061.23	61140.01	64079.28
Technicians	64610.97	47139.89	49674.28	93267.94	60964.19	83702.86	83071.33
QHSE Manager	176404.2	117215	71185.16	250095.6	224180.9	218448.7	208345.2
Required maintenance equipment/ software	133196	125628.1	79700.02	79700	75874.89	75926.66	75813.46
Inspection Cost	110500	111500	47900	46900	87623.76	72594.72	92933.17
Scheduled maintenance cost	43400	43800	20800.01	20700	36529.62	38716.57	32583.88
Planned Downtime cost	57900	57900	8444.381	7100	53939.92	53749.33	34415.27
Spare Parts	86442.43	86899.81	86850.12	86881.45	82572.68	82653.47	82358.34
Consumable Materials	9800	9700.089	97799.95	97800	14403.32	9760.905	9396.636

COST/YEAR	2025	2026	2027	2028	2029	2030
Operations/Plant Manager	393455	393489.7	3586755	3586706	3586725	3586799
Engineers	822058.4	808678.7	9578626	9661625	7971063	7896917
Supervisors/Operators	387819.1	322032.8	3428360	3316471	3524045	3010100
Lab Personnel	92760.04	103157.3	786549.9	754579	767664.7	750809.3
Technicians	303424.2	304177.1	2744110	2744112	2744133	2762408
Clerical Personnel	63979.24	64043.05	660660	657542.5	604775.2	843515
Power	36296.2	36396.84	344708.2	344798.7	345039.6	344405.5
Fuel/Gas	315932.7	326851.5	2570802	2549593	2730008	2929014
Insurance	87156.54	75474.79	740235.4	790569.1	742747.3	832854.6
Local Taxes	3151.543	3422.19	46537.67	46770.66	45552.59	44509.33
Spare parts for overhauls and unplanned maintenance	33051.03	27158.62	221757.2	231723.7	271676.8	258007.5
Downtime cost	84078.1	87580.22	720352.5	700458.6	716813.5	814250.1
Maintenance Engineer	42413.44	55428.29	464462.7	474075.1	410253.7	413026.9
Engineers	53690.64	65575.72	575808.2	549320	539428.7	600310.5
Technicians	74354.91	81071.36	770764.2	766480.5	760704.2	769075.2
QHSE Manager	195915.2	189324.3	1862751	1879917	1804552	1737363
Required maintenance equipment/ software	75815.76	75891.51	704157	704196.1	704150	704102.5
Inspection Cost	103858.5	101186.1	856629.4	871841.5	943603.8	889289.8
Scheduled maintenance cost	37568.85	34860.22	334142.8	328393.1	346588.9	367453
Planned Downtime cost	49562.18	45827.07	361023.6	355695.2	354321.6	503674.1
Spare Parts	82413.04	81365.79	766074.1	766049.8	765905.3	765946.8
Consumable Materials	9380.129	9215.446	99818.02	99864.22	99824.22	99804.39

Table B.8 shows the present values for twenty years the total LCC per year and LCC added with AC extracted from NARX input simulations for Scenario two.

Table B.8 The present values for twenty years and the total LCC per year for Scenario two

COST/YEAR	2010	2011	2012	2013	2014	2015	2016
Operations/Plant Manager	225760	168560	180610	228770	268500	173980	212510
Engineers	319070	288970	90300	86690	334120	585760	756740
Supervisors/Operators	162540	149300	180610	252850	170370	235390	276930
Lab Personnel	33110	22880	24080	13850	13240	14450	86690
Technicians	138460	111370	120400	180610	228770	210710	234790
Clerical Personnel	7830	9030	5420	6620	28900	49970	74050
Power	7830	7220	15650	41540	25890	27090	32510
Fuel/Gas	225760	234790	270310	402150	184820	233580	228770
Insurance	48160	60200	54480	541820	42140	90300	49970
Local Taxes	0	900	1200	4820	2410	4210	9030
Spare parts for overhauls and unplanned maintenance	0	0	3010	18060	10840	15050	27090
Downtime cost	30100	51170	36120	31910	30100	58400	63810
Maintenance Engineer	36120	42140	22880	36120	45150	28900	60200
Engineers	0	0	12040	7220	6620	7220	48760
Technicians	27090	42140	27090	34310	32510	48760	63210
QHSE Manager	99330	33110	119200	27690	43950	120400	170970
Required maintenance equipment/ software	51170	81270	60200	72240	54180	65620	89700
-Inspection Cost	48160	66220	54180	48160	60200	74650	36720
- Scheduled maintenance cost	12040	21070	24080	18060	15050	20470	30100
Planned Downtime cost	11440	15050	10840	12040	6020	10840	39730
Spare Parts	45150	15050	71040	10840	44550	59000	22270
Consumable Materials	30100	36120	48160	34310	7830	60200	66220
Total LCC per year	1559220	1456560	1431900	2110680	1656160	2194950	2680770
LCC+AC per year	11559220	11456560	11431900	12110680	11656160	12194950	12680770

COST/YEAR	2017	2018	2019	2020	2021	2022	2023
Operations/Plant Manager	240810	375500	374500	384500	364500	357390	357610
Engineers	596000	469700	468700	469300	1075600	971020	968250
Supervisors/Operators	228770	387600	386600	251500	233600	348230	353740
Lab Personnel	42140	85500	113500	103500	113500	643100	797800
Technicians	222750	327000	326100	291600	291500	273880	273600
Clerical Personnel	66220	31500	30500	95300	95300	841600	838400
Power	28900	32300	35700	35700	27100	335500	335500
Fuel/Gas	246830	255400	343500	343500	353500	258200	250740
Insurance	72240	70500	49500	67100	88600	81600	85590
Local Taxes	6020	4600	7600	2000	2000	42900	35400
Spare parts for overhauls and unplanned maintenance	12040	28900	27900	4500	4500	32500	28110
Downtime cost	45150	81600	80600	80600	80100	73990	80690
Maintenance Engineer	51170	76400	75400	74100	30500	39260	41210
Engineers	30100	1500	1500	1700	5900	3253	5620
Technicians	54180	53500	35800	38200	79800	56040	76670
QHSE Manager	132440	159900	102600	58700	69100	64150	58940
Required maintenance equipment/ software	66220	118800	110600	66800	66800	69570	69610
-Inspection Cost	33110	97200	96200	36500	36500	80230	66590
- Scheduled maintenance cost	15050	33200	32200	10600	10600	13860	15850
Planned Downtime cost	24080	47100	46100	1100	2300	2966	2949
Spare Parts	33110	74300	73700	73600	73700	75640	75720
Consumable Materials	45150	1200	200	84100	84100	67900	65700
Total LCC per year	2292480	2813200	2819000	2574500	3189100	4732779	4884289
LCC+AC per year	12292480	12813200	12819000	12574500	13189100	14732779	14884289

COST/YEAR	2024	2025	2026	2027	2028	2029	2030
Operations/Plant Manager	357650	357750	357780	324560	324560	324560	324560
Engineers	936860	746690	734550	868290	875800	722410	715680
Supervisors/Operators	344360	352640	292940	310190	300030	318870	272230
Lab Personnel	713600	848900	943200	704600	675600	687400	672100
Technicians	273510	276060	276740	248090	248090	248100	249750
Clerical Personnel	623200	587700	588300	590300	587500	539600	756300
Power	335400	336500	337400	303600	303700	303900	303300
Fuel/Gas	249130	287410	297310	232370	230440	246810	264870
Insurance	69890	79800	69200	66250	70820	66480	74660
Local Taxes	36300	35700	38200	33000	33300	32200	31200
Spare parts for overhauls and unplanned maintenance	19280	30710	25360	19200	20110	23730	22490
Downtime cost	66620	77010	80190	64450	62640	64130	72970
Maintenance Engineer	42630	39200	51010	41230	42100	36310	36560
Engineers	5886	4944	6022	5133	4893	4803	5356
Technicians	76100	68190	74280	69020	68640	68110	68870
QHSE Manager	59780	58500	52520	58120	59670	52830	56740
Required maintenance equipment/ software	69510	69510	69580	62980	62980	62980	62970
-Inspection Cost	85050	94960	92540	76820	78200	84710	79780
- Scheduled maintenance cost	10280	14810	12350	10400	10880	10530	12430
Planned Downtime cost	2194	2569	2230	2184	2136	2123	2479
Spare Parts	75450	75500	74550	68600	68600	68580	68590
Consumable Materials	62400	62300	60800	61400	61400	61400	61400
Total LCC per year	4515080	4507353	4537052	4220787	4192089	4030566	4215285
LCC+AC per year	14515080	14507353	14537052	14220787	14192089	14030566	14215285

Table B.9 shows the total LCC per costing attribute for twenty year extracted from NARX input simulations for Scenario two

Table B.9 The total LCC per costing attribute for twenty years for Scenario two

LCC Parameter	**LCC Values**
Operations/Plant Manager	6284920
Engineers	13080500
Supervisors/Operators	5809290
Lab Personnel	7352740
Technicians	5051880
Clerical Personnel	6453540
Power	3212230
Fuel/Gas	5640190
Insurance	1899300
Local Taxes	362990
Spare parts for overhauls and unplanned maintenance	373380
Downtime cost	1312350
Maintenance Engineer	948590
Engineers	168470
Technicians	1162510
QHSE Manager	1658640
Required maintenance equipment/ software	1503290
Inspection Cost	1426680
Scheduled maintenance cost	353910
Planned Downtime cost	248470
Spare Parts	1247540
Consumable Materials	1062390

Table B.10 shows the future predicted values for twelve years extracted from NARX input simulations for Scenario three.

Table B.10 The future predicted values for twelve years extracted from NARX input simulations for Scenario three

COST/YEAR	2018	2019	2020	2021	2022	2023	2024
Operations/Plant Manager	161080	161880	162680	161079.5	157223.5	157319.5	157335.2
Engineers	200640	200240	200868.4	455480	427709.4	426487.8	412652.9
Supervisors/Operators	166160	166960	109422.1	101920	153183.9	155610.9	151479.9
Lab Personnel	39296.46	51480	51440	51480	28033.62	34853.47	31141.55
Technicians	140710.1	140760	126247.5	126240	120412.1	120288	120249.1
Clerical Personnel	16640	16640	43840	43840	36780.93	36640.67	27155.35
Power	16972.87	18798.73	18798.47	15214.33	14473.72	14474.75	14469.25
Fuel/Gas	110646.3	148040	148040	148840	113497.5	110211.8	109500.6
Insurance	24600	24600	31983.63	53640	48879.03	41818.79	30492.08
Local Taxes	640	640	4640	4640	1574.626	1245.307	1283.71
Spare parts for overhauls and unplanned maintenance	15520	15520	5721.762	5720	14011.56	12077.76	8181.413
Downtime cost	37680	37680	37680	37432.76	32301.59	35254.71	29052.71
Maintenance Engineer	35480	35480	34934.33	16640	16992.32	17850.73	18476.15
Engineers	3200	3200	4544.97	28600	14024.49	24456	25631.71
Technicians	25844.39	18855.96	19869.71	37307.17	24385.67	33481.14	33228.53
QHSE Manager	70561.69	46886	28474.07	100038.2	89672.35	87379.47	83338.07
Required maintenance equipment/ software	53278.41	50251.24	31880.01	31880	30349.96	30370.67	30325.38
Inspection Cost	44200	44600	19160	18760	35049.5	29037.89	37173.27
Scheduled maintenance cost	17360	17520	8320.004	8280	14611.85	15486.63	13033.55
Planned Downtime cost	23160	23160	3377.752	2840	21575.97	21499.73	13766.11
Spare Parts	34576.97	34759.92	34740.05	34752.58	33029.07	33061.39	32943.34
Consumable Materials	3920	3880.036	39119.98	39120	5761.326	3904.362	3758.654

COST/YEAR	2025	2026	2027	2028	2029	2030
Operations/Plant Manager	157382	157395.9	1434702	1434682	1434690	1434720
Engineers	328823.4	323471.5	3831451	3864650	3188425	3158767
Supervisors/Operators	155127.6	128813.1	1371344	1326588	1409618	1204040
Lab Personnel	37104.02	41262.92	314620	301831.6	307065.9	300323.7
Technicians	121369.7	121670.9	1097644	1097645	1097653	1104963
Clerical Personnel	25591.7	25617.22	264264	263017	241910.1	337406
Power	14518.48	14558.74	137883.3	137919.5	138015.8	137762.2
Fuel/Gas	126373.1	130740.6	1028321	1019837	1092003	1171606
Insurance	34862.61	30189.92	296094.2	316227.7	297098.9	333141.8
Local Taxes	1260.617	1368.876	18615.07	18708.26	18221.04	17803.73
Spare parts for overhauls and unplanned maintenance	13220.41	10863.45	88702.9	92689.48	108670.7	103203
Downtime cost	33631.24	35032.09	288141	280183.4	286725.4	325700
Maintenance Engineer	16965.37	22171.31	185785.1	189630	164101.5	165210.8
Engineers	21476.26	26230.29	230323.3	219728	215771.5	240124.2
Technicians	29741.96	32428.54	308305.7	306592.2	304281.7	307630.1
QHSE Manager	78366.09	75729.73	745100.5	751966.8	721820.8	694945.2
Required maintenance equipment/ software	30326.3	30356.6	281662.8	281678.4	281660	281641
Inspection Cost	41543.38	40474.45	342651.8	348736.6	377441.5	355715.9
Scheduled maintenance cost	15027.54	13944.09	133657.1	131357.2	138635.5	146981.2
Planned Downtime cost	19824.87	18330.83	144409.4	142278.1	141728.7	201469.6
Spare Parts	32965.21	32546.32	306429.6	306419.9	306362.1	306378.7
Consumable Materials	3752.051	3686.178	39927.21	39945.69	39929.69	39921.76

Table B.11 shows the present values for twenty years the total LCC per year and LCC added with AC extracted from NARX input simulations for Scenario three.

Table B.11 The present values for twenty years and the total LCC per year for Scenario three

COST/YEAR	2010	2011	2012	2013	2014	2015	2016
Operations/Plant Manager	168580	125870	134860	170820	200490	129920	158690
Engineers	238250	215780	67430	64730	249490	437400	565070
Supervisors/Operators	121370	111480	134860	188810	127220	175770	206790
Lab Personnel	24720	17080	17980	10340	9890	10790	64730
Technicians	103390	83160	89910	134860	170820	157340	175320
Clerical Personnel	5840	6740	4050	4940	21580	37310	55290
Power	5840	5390	11690	31020	19330	20230	24270
Fuel/Gas	168580	175320	201840	300290	138010	174420	170820
Insurance	35960	44950	40680	404580	31470	67430	37310
Local Taxes	0	670	900	3600	1800	3150	6740
Spare parts for overhauls and unplanned maintenance	0	0	2250	13490	8090	11240	20230
Downtime cost	22480	38210	26970	23830	22480	43610	47650
Maintenance Engineer	26970	31470	17080	26970	33720	21580	44950
Engineers	0	0	8990	5390	4940	5390	36410
Technicians	20230	31470	20230	25620	24270	36410	47200
QHSE Manager	74170	24720	89010	20680	32820	89910	127670
Required maintenance equipment/ software	38210	60690	44950	53940	40460	49000	66980
Inspection Cost	35960	49450	40460	35960	44950	55740	27420
Scheduled maintenance cost	8990	15730	17980	13490	11240	15280	22480
Planned Downtime cost	8540	11240	8090	8990	4500	8090	29670
Spare Parts	33720	11240	53050	8090	33270	44050	16630
Consumable Materials	22480	26970	35960	25620	5840	44950	49450
Total LCC per year	1164280	1087630	1069220	1576060	1236680	1639010	2001770
LCC+AC per year	11164280	11087630	11069220	11576060	11236680	11639010	12001770

COST/YEAR	2017	2018	2019	2020	2021	2022	2023
Operations/Plant Manager	179810	150200	149800	153800	145800	142956	143044
Engineers	445040	187880	187480	187720	430240	388408	387300
Supervisors/Operators	170820	155040	154640	100600	93440	92920	94960
Lab Personnel	31470	34200	45400	41400	45400	257240	319120
Technicians	166330	130800	130440	116640	116600	1095520	1094400
Clerical Personnel	49450	12600	12200	38120	38120	33640	33360
Power	21580	12920	14280	14280	10840	134200	134200
Fuel/Gas	184310	102160	137400	137400	141400	1032800	1002960
Insurance	53940	28200	19800	26840	47440	446400	382360
Local Taxes	4500	1840	3040	800	800	17160	14160
Spare parts for overhauls and unplanned maintenance	8990	11560	11160	1800	1800	130000	112440
Downtime cost	33720	32640	32240	32240	32040	295960	322760
Maintenance Engineer	38210	30560	30160	29640	12200	15700	16440
Engineers	22480	600	600	680	23600	130120	224800
Technicians	40460	21400	14320	15280	31920	22410	30680
QHSE Manager	98900	63960	41040	23480	91640	81660	79570
Required maintenance equipment/ software	49450	47520	44240	26720	26720	27820	27440
Inspection Cost	24720	38880	38480	14600	14600	32020	26360
Scheduled maintenance cost	11240	13280	12880	4240	4240	5440	3400
Planned Downtime cost	17980	18840	18440	440	920	98640	97960
Spare Parts	24720	29720	29480	29440	29480	30250	30280
Consumable Materials	33720	480	80	33640	33640	55160	38280
Total LCC per year	1711840	1125280	1127600	1029800	1372880	4566424	4616274
LCC+AC per year	11711840	11125280	11127600	11029800	11372880	14566424	14616274

COST/YEAR	2024	2025	2026	2027	2028	2029	2030
Operations/Plant Manager	143060	143100	143112	129820	129824	129820	129840
Engineers	374740	298660	293200	347360	350280	288640	286720
Supervisors/Operators	77440	80560	71760	40760	80120	75480	88920
Lab Personnel	285440	339560	377280	281840	270240	274960	268840
Technicians	1094040	1104240	1106960	992360	992360	992400	999000
Clerical Personnel	24280	23080	23320	23120	25000	21840	30520
Power	134160	134600	134960	121440	121480	121560	121320
Fuel/Gas	996520	1149640	1189240	929480	921760	987240	1059480
Insurance	279560	319200	276800	265000	283280	265920	298640
Local Taxes	14520	14280	15280	13200	13320	12880	12480
Spare parts for overhauls and unplanned maintenance	77120	122840	101440	76800	80440	94920	89960
Downtime cost	266480	308040	320760	257800	250560	256520	291880
Maintenance Engineer	17020	15800	20040	16920	18400	14240	14240
Engineers	235440	197760	240880	205320	195720	192120	214240
Technicians	30400	27760	27120	27080	27560	27440	27480
QHSE Manager	75120	71000	60080	62480	68680	61320	66960
Required maintenance equipment/ software	27040	27040	27320	25100	25140	25120	25180
Inspection Cost	30200	37840	30160	30280	31200	33840	31120
Scheduled maintenance cost	2120	3240	4400	5600	5520	2120	5720
Planned Downtime cost	7760	82760	69200	27360	25440	24920	79160
Spare Parts	30100	30000	29200	24400	24400	24320	27360
Consumable Materials	36960	36920	36320	32560	32560	32560	32560
Total LCC per year	4259520	4567920	4598832	3936080	3973284	3960180	4201620
LCC+AC per year	14259520	14567920	14598832	13936080	13973284	13960180	14201620

Table B.12 shows the total LCC per costing attribute for twenty year extracted from NARX input simulations for Scenario three

Table B.12 The total LCC per costing attribute for twenty years for Scenario three

LCC Parameter	LCC Values
Operations/Plant Manager	3103216
Engineers	6291818
Supervisors/Operators	2443760
Lab Personnel	3027920
Technicians	11046890
Clerical Personnel	524400
Power	1349590
Fuel/Gas	11301070
Insurance	3655760
Local Taxes	155120
Spare parts for overhauls and unplanned maintenance	976570
Downtime cost	2958870
Maintenance Engineer	492310
Engineers	1945480
Technicians	576740
QHSE Manager	1404870
Required maintenance equipment/ software	786080
Inspection Cost	704240
Scheduled maintenance cost	188630
Planned Downtime cost	648940
Spare Parts	593200
Consumable Materials	646710

Table B.13 shows the future predicted values for twelve years extracted from NARX input simulations for Scenario four.

Table B.13 The future predicted values for twelve years extracted from NARX input simulations for Scenario four

COST/YEAR	2018	2019	2020	2021	2022	2023	2024
Operations/Plant Manager	272429	243420	244620	242219.2	236435.3	236579.3	236602.8
Engineers	301560	300960	301902.6	683820	642164.1	640331.7	619579.3
Supervisors/Operators	249840	251040	164733.2	153480	230375.9	234016.4	227819.9
Lab Personnel	59544.69	77820	77760	77820	42650.44	52880.21	47312.32
Technicians	211665.2	211740	189971.3	189960	181218.1	181032	180973.7
Clerical Personnel	25560	25560	66360	66360	55771.4	55561.01	41333.03
Power	26059.3	28798.1	28797.71	23421.5	22310.58	22312.12	22303.88
Fuel/Gas	166569.4	222660	222660	223860	170846.2	165917.7	164850.8
Insurance	37500	37500	48575.45	81060	73918.54	63328.19	46338.11
Local Taxes	1560	1560	7560	7560	2961.939	2467.961	2525.565
Spare parts for overhauls and unplanned maintenance	23880	23880	9182.643	9180	21617.34	18716.64	12872.12
Downtime cost	57120	57120	57120	56749.14	49052.38	53482.07	44179.06
Maintenance Engineer	53820	53820	53001.49	25560	26088.48	27376.09	28314.22
Engineers	5400.001	5400	7417.455	43500	21636.74	37284	39047.57
Technicians	39366.58	28883.93	30404.57	56560.76	37178.51	50821.71	50442.8
QHSE Manager	106442.5	70929	43311.1	150657.3	135108.5	131669.2	125607.1
Required maintenance equipment/ software	80517.61	75976.86	48420.01	48420	46124.93	46156	46088.07
Inspection Cost	66900	67500	29340	28740	53174.25	44156.83	56359.9
Scheduled maintenance cost	26640	26880	13080.01	13020	22517.77	23829.94	20150.33
Planned Downtime cost	35340	35340	5666.628	4860	32963.95	32849.6	21249.16
Spare Parts	52465.46	52739.88	52710.07	52728.87	50143.61	50192.08	50015
Consumable Materials	6480	6420.053	59279.97	59280	9241.989	6456.543	6237.982

COST/YEAR	2025	2026	2027	2028	2029	2030
Operations/Plant Manager	236673	236693.8	2152653	2152624	2152635	2152680
Engineers	493835.1	485807.2	5747776	5797575	4783238	4738750
Supervisors/Operators	233291.4	193819.7	2057616	1990482	2115027	1806660
Lab Personnel	56256.02	62494.38	472529.9	453347.4	461198.8	451085.6
Technicians	182654.5	183106.3	1647066	1647067	1647080	1658045
Clerical Personnel	38987.55	39025.83	396996	395125.5	363465.1	506709
Power	22377.72	22438.1	207424.9	207479.2	207623.8	207243.3
Fuel/Gas	190159.6	196710.9	1543081	1530356	1638605	1758009
Insurance	52893.92	45884.88	444741.3	474941.5	446248.4	500312.7
Local Taxes	2490.926	2653.314	28522.6	28662.39	27931.55	27305.59
Spare parts for overhauls and unplanned maintenance	20430.62	16895.17	133654.3	139634.2	163606.1	155404.5
Downtime cost	51046.86	53148.13	432811.5	420875.1	430688.1	489150.1
Maintenance Engineer	26048.06	33856.97	279277.6	285045	246752.2	248416.2
Engineers	32814.38	39945.43	346084.9	330192	324257.2	360786.3
Technicians	45212.95	49242.82	463058.5	460488.3	457022.5	462045.1
QHSE Manager	118149.1	114194.6	1118251	1128550	1083331	1043018
Required maintenance equipment/ software	46089.45	46134.91	423094.2	423117.7	423090	423061.5
Inspection Cost	62915.07	61311.67	514577.6	523704.9	566762.3	534173.9
Scheduled maintenance cost	23141.31	21516.13	201085.7	197635.9	208553.3	221071.8
Planned Downtime cost	30337.31	28096.24	217214.2	214017.1	213193	302804.5
Spare Parts	50047.82	49419.47	460244.4	460229.9	460143.2	460168.1
Consumable Materials	6228.077	6129.268	60490.81	60518.53	60494.53	60482.63

Table B.14 shows the present values for twenty years the total LCC per year and LCC added with AC extracted from NARX input simulations for Scenario four.

Table B.14 The present values for twenty years and the total LCC per year for Scenario four

COST/YEAR	2010	2011	2012	2013	2014	2015	2016
Operations/Plant Manager	160020	119484	128016	162156	190320	123324	150630
Engineers	226164	204828	64008	61446	236832	415200	536388
Supervisors/Operators	115212	105828	128016	179226	120762	166848	196290
Lab Personnel	23472	16218	17070	9816	9390	10242	61446
Technicians	98148	78942	85344	128016	162156	149352	166422
Clerical Personnel	5550	6402	3840	4692	20484	35418	52488
Power	5550	5118	11094	29442	18348	19200	23040
Fuel/Gas	160020	166422	191598	285048	131004	165570	162156
Insurance	34140	42672	38616	384048	29868	64008	35418
Local Taxes	0	642	852	3414	1704	2988	6402
Spare parts for overhauls and unplanned maintenance	0	0	2136	12804	7680	10668	19200
Downtime cost	21336	36270	25602	22614	21336	41394	45234
Maintenance Engineer	25602	29868	16218	25602	32004	20484	42672
Engineers	0	0	8532	5118	4692	5118	34566
Technicians	19200	29868	19200	24324	23040	34566	44808
QHSE Manager	70410	23472	84492	19632	31152	85344	121188
Required maintenance equipment/ software	36270	57606	42672	51204	38406	46512	63582
-Inspection Cost	34140	46938	38406	34140	42672	52914	26028
- Scheduled maintenance cost	8532	14934	17070	12804	10668	14508	21336
Planned Downtime cost	8106	10668	7680	8532	4266	7680	28164
Spare Parts	32004	10668	50352	7680	31578	41820	15786
Consumable Materials	21336	25602	34140	24324	5550	42672	46938
Total LCC per year	1105212	1032450	1014954	1496082	1173912	1555830	1900182
LCC+AC per year	11105212	11032450	11014954	11496082	11173912	11555830	11900182

COST/YEAR	2017	2018	2019	2020	2021	2022	2023
Operations/Plant Manager	170688	231300	230700	236700	224700	215040	215660
Engineers	422454	287820	287220	287580	51360	83212	51550
Supervisors/Operators	162156	238560	237960	156900	146160	95380	128440
Lab Personnel	29868	57300	74100	68100	74100	391860	484680
Technicians	157890	202200	201660	180960	180900	164280	167600
Clerical Personnel	46938	24900	24300	63180	63180	510960	509040
Power	20484	25380	27420	27420	22260	207300	207300
Fuel/Gas	174954	159240	212100	212100	218100	55200	30440
Insurance	51204	48300	35700	46260	77160	675600	579540
Local Taxes	4266	3240	1440	7200	7200	31740	27240
Spare parts for overhauls and unplanned maintenance	8532	23340	22740	8700	8700	201000	174660
Downtime cost	32004	54960	54360	54360	54060	449940	490140
Maintenance Engineer	36270	51840	51240	50460	24300	241560	253260
Engineers	21336	5100	5100	7020	41400	201180	343200
Technicians	38406	38100	27480	28920	53880	34240	46020
QHSE Manager	93876	101940	67560	41220	143460	123000	119640
Required maintenance equipment/ software	46938	77280	72360	46080	46080	42320	42660
-Inspection Cost	23472	64320	63720	27900	27900	48780	40540
- Scheduled maintenance cost	10668	25920	25320	12360	12360	20910	22100
Planned Downtime cost	17070	34260	33660	5340	4620	30360	30940
Spare Parts	23472	50580	50220	50160	50220	45940	40320
Consumable Materials	32004	6720	6120	56460	56460	88740	63420
Total LCC per year	1624950	1812600	1812480	1675380	1588560	3958542	4068390
LCC+AC per year	11624950	11812600	11812480	11675380	11588560	13958542	14068390

COST/YEAR	2024	2025	2026	2027	2028	2029	2030
Operations/Plant Manager	211900	212500	212680	193360	195360	195360	195336
Engineers	62160	48140	41330	51540	56920	34060	40080
Supervisors/Operators	72160	121840	763640	867140	806180	919220	639380
Lab Personnel	434160	515340	571920	428760	411360	418440	409260
Technicians	164060	162360	166440	194540	144540	144600	154500
Clerical Personnel	379920	358620	358980	360180	358500	329760	459780
Power	207240	207900	208440	188160	188220	188340	187980
Fuel/Gas	30780	30460	59860	40220	68640	56860	55220
Insurance	425340	484800	421200	403500	430920	404880	453960
Local Taxes	27780	27420	28920	25800	25980	25320	24720
Spare parts for overhauls and unplanned maintenance	121680	190260	158160	121200	126660	148380	140940
Downtime cost	405720	468060	487140	392700	381840	390780	443820
Maintenance Engineer	261780	241200	312060	253380	258600	223860	225360
Engineers	359160	302640	367320	313980	299580	294180	327360
Technicians	46600	45140	41680	42120	41740	41460	41220
QHSE Manager	114680	107000	101120	101720	102020	92980	96440
Required maintenance equipment/ software	42060	42360	42380	38380	38380	38380	38320
-Inspection Cost	51600	55760	61240	46920	45200	51260	44680
- Scheduled maintenance cost	18680	21860	20100	18400	17980	18180	20080
Planned Downtime cost	19640	20140	25800	19040	14160	13380	27740
Spare Parts	45700	45000	43300	41600	41600	41480	41540
Consumable Materials	61440	61380	60480	54840	54840	54840	54840
Total LCC per year	3564240	3770180	4554190	4197480	4109220	4126000	4122556
LCC+AC per year	13564240	13770180	14554190	14197480	14109220	14126000	14122556

Table B.15 shows the total LCC per costing attribute for twenty year extracted from NARX input simulations for Scenario four.

Table B.15 The total LCC per costing attribute for twenty years for Scenario four

LCC Parameter	LCC Values
Operations/Plant Manager	3975234
Engineers	3550292
Supervisors/Operators	6367298
Lab Personnel	4516902
Technicians	3254910
Clerical Personnel	3977112
Power	2025636
Fuel/Gas	2665992
Insurance	5167134
Local Taxes	284268
Spare parts for overhauls and unplanned maintenance	1507440
Downtime cost	4373670
Maintenance Engineer	2677620
Engineers	2946582
Technicians	762012
QHSE Manager	1842346
Required maintenance equipment/ software	990230
Inspection Cost	928530
Scheduled maintenance cost	364770
Planned Downtime cost	371246
Spare Parts	801020
Consumable Materials	913146

Appendix C Conceptual Framework Validation Comments

Dr. Ahmed Elamin Haroun

Associate professor at Sudan University of Sc. and Tech

	Comments
1	There is no difference between Retirement and Disposal, it is better to just use Disposal.
2	In the Equipment Research section: one of the elements of design based could be market research. By applied research do you mean market research?
3	In the Equipment data bases section: Please add Input Raw Material Specification.
4	Before Quality control please add Process Performance (Effectiveness/Output quantity; efficiency "resources utilization").
5	Use just either the operational or tactical so as to make the framework simpler, and not many definitions.

Mr Khaja Jeelani

Procurement Manager

	Comments
1	Recommend the LCC conceptual Framework to be covering the Fabrication industry, and since fabrication includes several activities (Pressure vessels, Tanks, Structure steel and pipes), for case study the CBS should consider only one line of activities, as suggested the Pipe spool machine costs.
2	Reliability centred maintenance is not prominent in our industry. It is more relevant in 24/7 high critical operations such as Oil refinery, petrochemical industry and the likes
3	Depreciation costing need to be included in the framework
4	Warranty costing is a hidden cost that can be reflected in the framework
5	Environmental remediation is not a considerable factor for cost in our industry
6	Special costs to be defined as setup costs and remanufacture is better reflected by refurbishment cost

Prof Awaluddin Mohamed Shaharoun

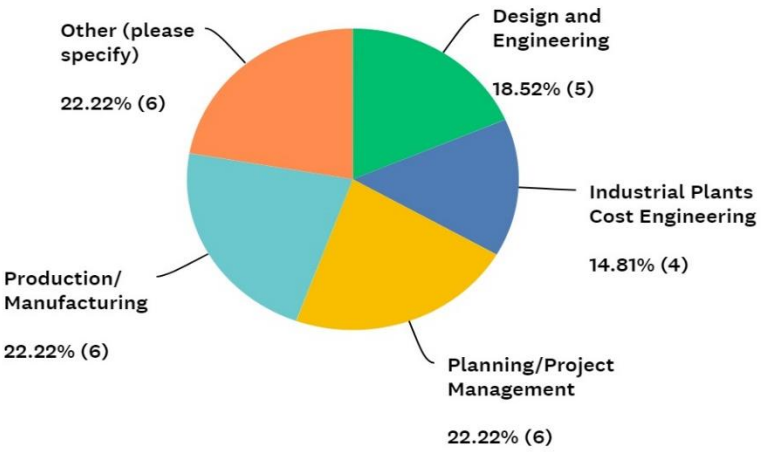
Islamic University of Madinah

	Comments
1)	A conceptual framework diagram should be very simple and self-explanatory and normally any other expert looking at it will see what he wants to check as existing and as well as quickly understand the logical flow and interconnections.
2)	I find some questions that remain unanswered after looking at your framework.
	2a) Why do you split your major phases into just two ie Acquisition and Utilisation? Normally we have Acquisition, Utilisation and Retirement/Disposal? The normal manner is into three phases because Utilisation is as distinct from Retirement as it is from Acquisition? You may need to argue why you decide to depart from normal practice here
2b)	You put something called Asset Support in which you put Technical Support, Procurement Human Resource, etc etc and you spread it over the two phases as if techical support and procurement costs only happen during acquisition phase but not during the Utilisation and Retirement phase. Is this what you mean? Are you implying the rest of the support functions will only occur during the implementation stage and not before? I would be very cautious to state that if i was you.
2c)	Are these Asset Support actually costs or just functions or just your way of explaining the components of the asset support? I cannot decipher them from the way you design the framework
3)	You have divided the costs into 3 levels -- Strategic, Tactical and Operational. I agree with the categories. What I find issue is the costs itself which you put into the categories. At strategic level we look at broader issues- cost benefit, IRR and ROI, process efficiency improvements and even non costs such as competitive advantage, technology acquisition and replacement costs etc. Sometimes the decision to choose which site/city or country to install can be a major cost consideration from the strategic viewpoint.
4)	At Tactical levels, where would you consider health and safety requirements costs, license to operate from safety regulators, compulsory upgrades due to technological and business considerations and annual safety inspections from licensing authorities?

Appendix D Descriptive Results from Survey

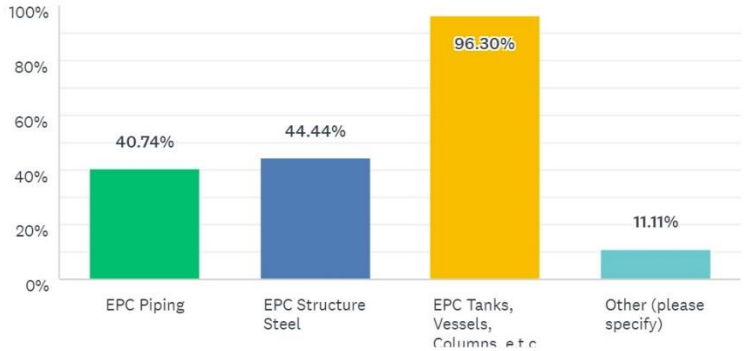
In what segment is your role in your company?

Answered: 27 Skipped: 0



What kind of products and services does your plant/business deliver

Answered: 27 Skipped: 0

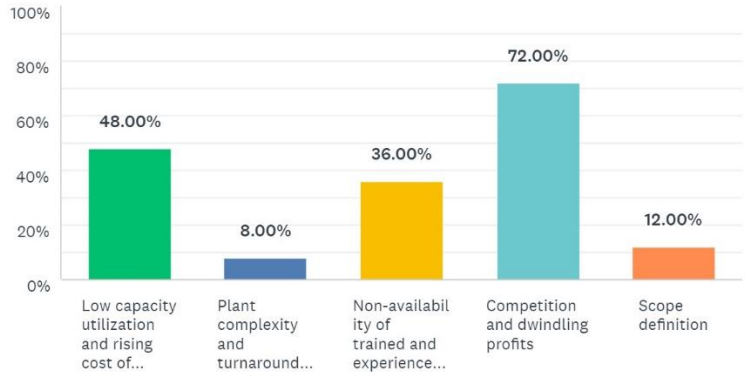


What data and information (sources) are used in life cycle costing?

Answered: 25 Skipped: 2

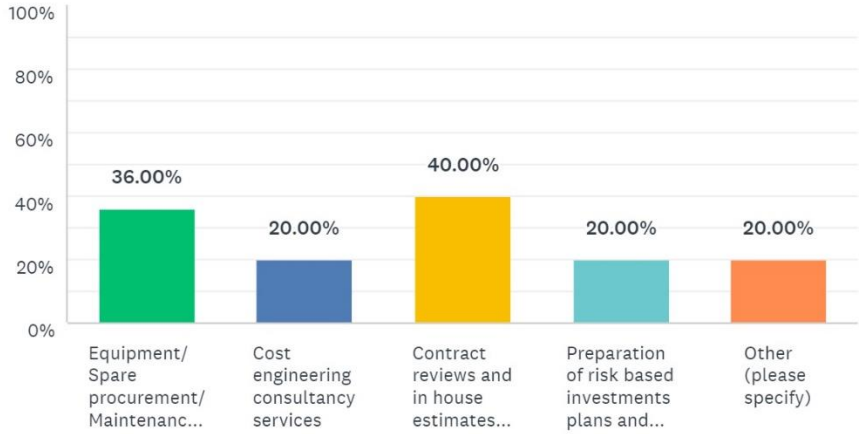
What do you consider the current challenges in your industry/plant?

Answered: 25 Skipped: 2



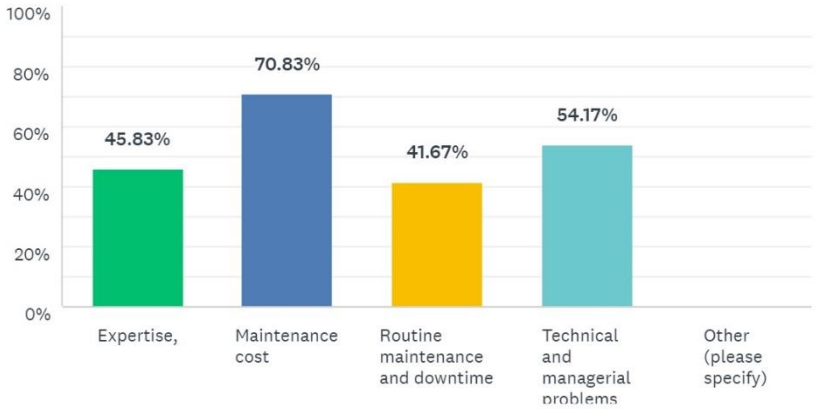
What is your role in cost engineering in your plant/industry?

Answered: 25 Skipped: 2



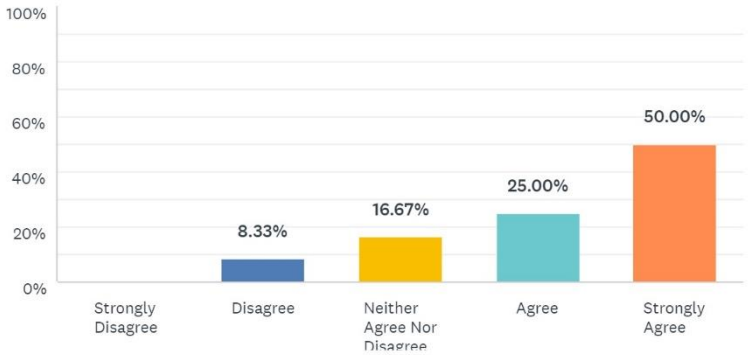
What are the challenges faced in operation and maintenance?

Answered: 24 Skipped: 3



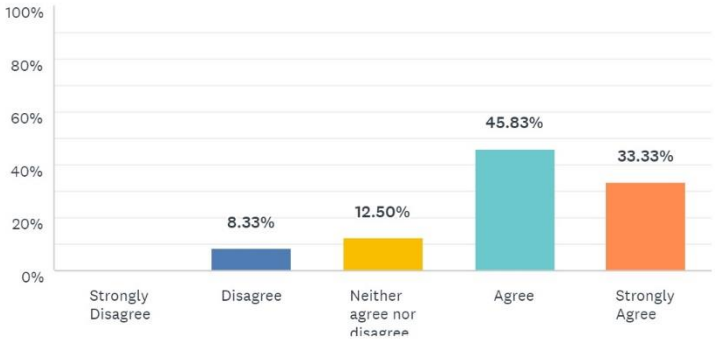
A LCC Conceptual Framework is essential for guiding the decision making in Asset Selection and/or enhancement

Answered: 24 Skipped: 3



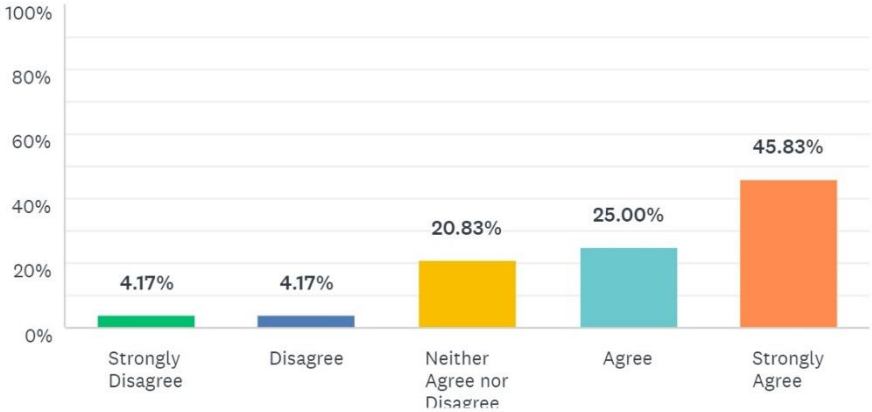
LCC model can be used to forecast the costs of all the life cycle phases for an asset and allows researchers to choose the most viable decision on the basis of total performance

Answered: 24 Skipped: 3



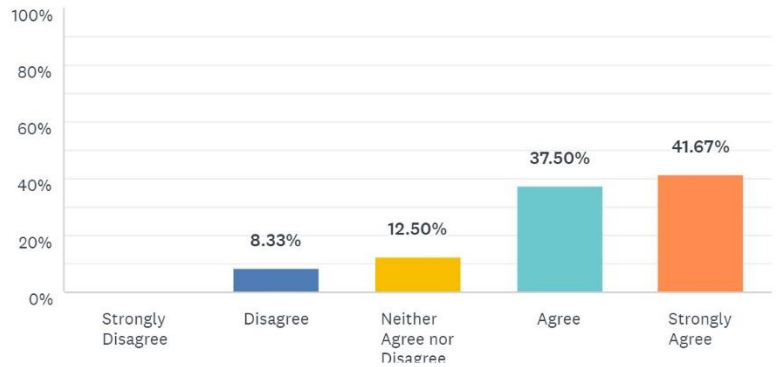
LCC acts as a maintenance guide

Answered: 24 Skipped: 3



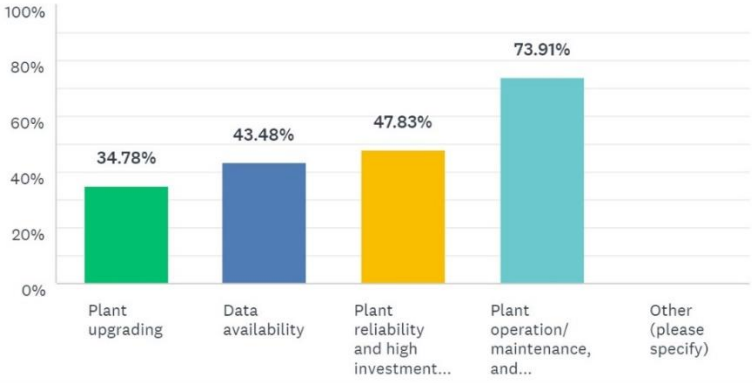
LCC indicates cost category and presents a possibility for investigation into the inter-relationship between the performance of an engineering asset and its running costs

Answered: 24 Skipped: 3

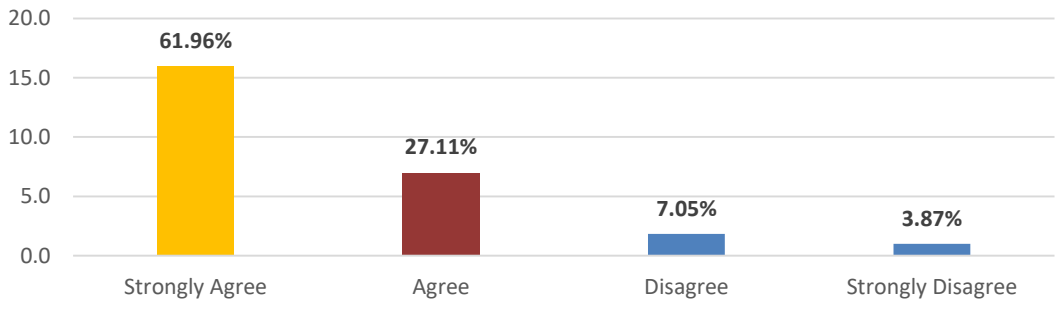


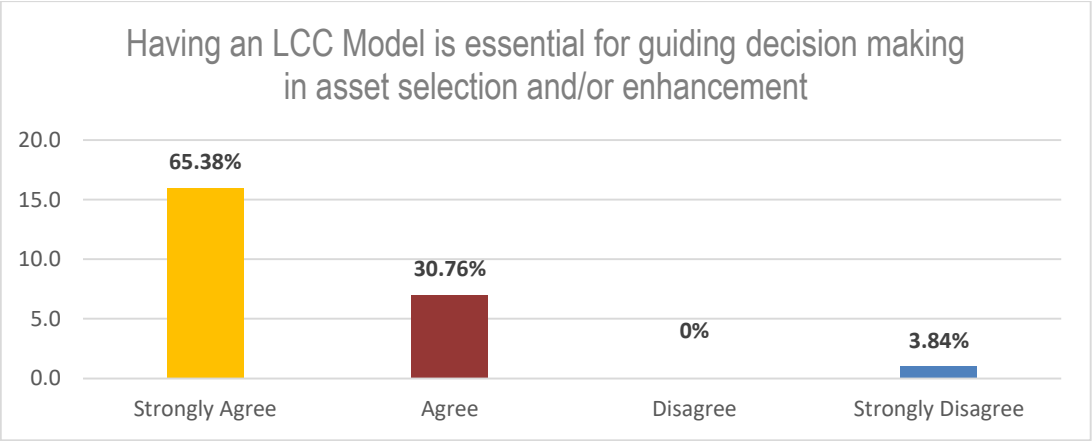
What are the significant risks associated to the plant and is reflected in the life cycle costing?

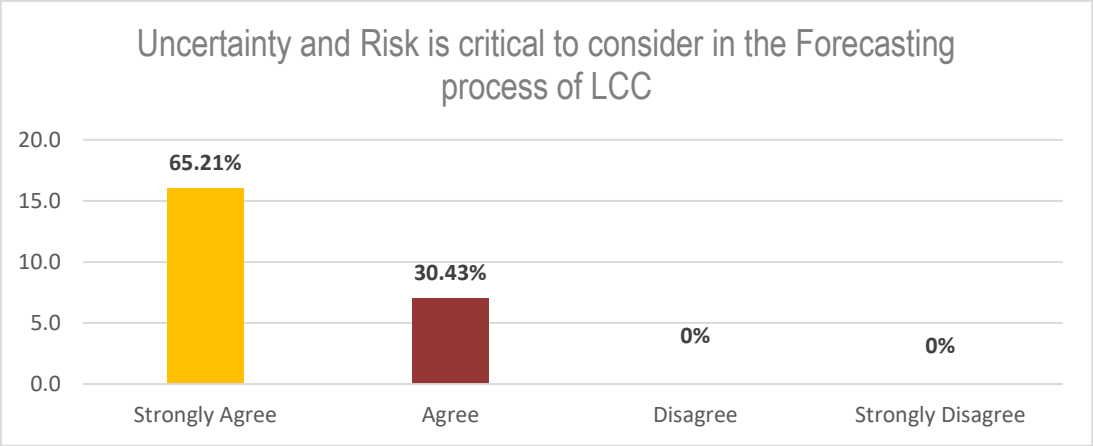
Answered: 23 Skipped: 4

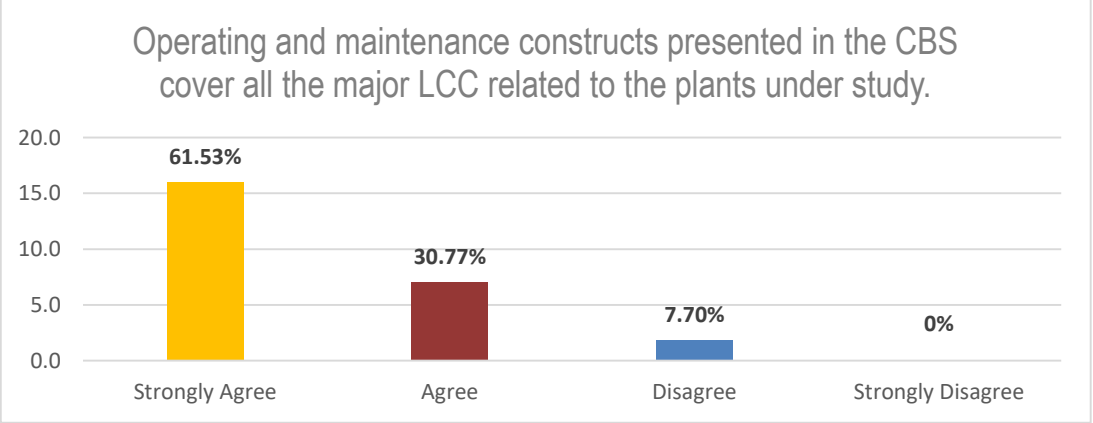


The presented Uncertainty Factors are covering the risks associated to operations and maintenance for the plant under study




Having an LCC Model is essential for guiding decision making in asset selection and/or enhancement
20.0
15.0
10.0
5.0
0.0
65.38%
30.76%
0%
3.84%
Strongly Agree
Agree
Disagree
Strongly Disagree


Uncertainty and Risk is critical to consider in the Forecasting process of LCC
20.0
15.0
10.0
5.0
0.0
65.21%
30.43%
0%
0%
Strongly Agree
Agree
Disagree
Strongly Disagree


Operating and maintenance constructs presented in the CBS cover all the major LCC related to the plants under study.
20.0
15.0
10.0
5.0
0.0
61.53%
30.77%
7.70%
0%
Strongly Agree
Agree
Disagree
Strongly Disagree

Appendix E Cronbach's Alpha Reliability Results

Cronbach's Alpha	0.750440643
Split-Half (odd-even) Correlation	0.699703384
Split-Half with Spearman-Brown Adjustment	0.823324105
Mean for Test	11.76923077
Standard Deviation for Test	4.361613078
KR21 (use only 0 and 1 to enter data for this)	1.658424054
KR20 (use only 0 and 1 to enter data for this)	1.66091239

Reliability Calculator

Questions	Subjects
7	26

	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6	Question 7
Subject1	1	1	1	1	1	2	1
Subject2	1	1	2	1	5	1	3
Subject3	1	1	1	1	1	1	1
Subject4	2	1	1	2	1	2	1
Subject5	1	4	5	1	2	1	1
Subject6	1	1	1	2	3	5	3
Subject7	1	1	2	1	2	1	2
Subject8	4	2	3	4	1	2	3
Subject9	3	1	3	3	3	3	3
Subject10	4	3	2	1	4	3	2
Subject11	2	1	2	3	1	4	3
Subject12	1	1	1	1	1	1	1
Subject13	1	1	1	1	1	1	1
Subject14	2	2	1	2	2	2	1
Subject15	1	1	1	1	1	1	1
Subject16	1	2	2	2	2	2	1
Subject17	1	1	1	1	1	1	1
Subject18	1	2	1	2	2	2	2
Subject19	2	1	2	1	2	1	1
Subject20	1	1	1	1	1	1	1
Subject21	1	1	1	1	1	1	1
Subject22	1	3	3	1	1	2	3
Subject23	3	2	3	3	3	3	3
Subject24	1	1	1	1	1	1	1
Subject25	5	4	1	1	1	1	1
Subject26	1	1	2	2	2	1	1

Cronbach's alpha	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

LIST OF PUBLICATIONS

1. Mohd I. Elnaeim, Mohd Salman Leong & M S Somia Alfatih, Life Cycle Costing In Engineering Asset Management: A Study In The Steel Fabrication Industry, International Journal of Mechanical Engineering and Technology (IJMET), Volume 8, Issue 6, June 2017, pp. 348–359 Article ID: IJMET_08_06_036. Available online at http://iaeme.com/Home/issue/IJMET?Volume=8&Issue=6