

Modeling Equipment Acquisition with Life Cycle Costing Decision (Case in Ethio-Plastic Industry)

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Declaration

I hereby declare that the work which is being presented in this thesis entitled “Modeling Equipment Acquisition with Life Cycle Costing Decision” is original work of my own and has not been presented for a degree of any other university and all the resources of references used for the thesis have been duly acknowledged.

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This is to certify that the above declaration made by the author is correct to the best of my knowledge.

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ABSTRACT

Improving the quality of an organization's products and services is fundamental to business success. This requires the engagement of highly skilled human labor as well as financial resources, given the appropriate technological, organizational, institutional and cultural infrastructure. Furthermore, the equipments or machineries in the organization must be able to make the owner more competitive and profitable in terms of lower unit costs. In this regard, the present research is a case study which reveals the challenges related to cost escalation while the equipment selection decision making is done based on the traditional least cost approach. Hence, LCC analysis is performed to pin point where the cost escalation will be. Based on the collected data (cost history of the case machinery), the outcome of the analysis demonstrated that the traditional approaches adopted for equipment selection leads to a biased decision. As a result, the company is incurring a blown up unexpected cost because economical criteria outweigh other factors in their decision making process for equipment selection. The problem with the traditional approach is that it mainly concentrates on the purchasing price of the equipment and often ignores those costs that appear when it becomes operational. Nevertheless, in addition to the purchasing cost, equipment cost is also highly related with operational and maintenance costs. Moreover, those unexpected costs are also related with the unforeseen quality cost drivers.

Consequently, quality based life cycle costing framework is developed to solve this problem. The framework is developed customizing/ improving the Fabrycky and Blanchard's life cycle cost framework integrating it with the quality cost drivers. When the selection is made with LCC analysis, it will be only based on the overall minimum life cycle cost. Generally low quality equipments will have low cost and high quality equipments will have high cost. The new framework will optimize these costs considering quality cost drivers in addition to minimum life cycle cost as a selection criterion in their decision making. Above all, taking into account quality dimensions in the framework may certainly resolve the occurrence of such unexpected cost.

Since practical validation of the framework with real data requires a long period of time, at least equal to the life span of the equipment, the researcher tried to validate it via expert opinions; and it is found to be appropriate.

CHAPTER ONE: BACKGROUND OF THE STUDY

1.1 INTRODUCTION

When one looks today's business environment, the word quality is prevalent. Quality is an essential component to the competitive position of today's most successful companies. It has become one of the most important consumer and producer decision factors in the selection among competing products and services. The phenomenon is widespread, regardless of whether the consumer is an individual, an industrial organization, a retail store, a bank or financial institution, or a military defense program. There is a substantial return on investment from improved quality and from successfully employing to consider it as an integral part of overall business strategy [1].

Consequently, understanding and improving quality are key factors leading to business success, growth, and enhanced competitiveness. This requires the engagement of highly skilled human labor as well as financial resources, given the appropriate technological, organizational, institutional and cultural infrastructure. Furthermore, the equipments or machineries in the organization must be able to make the owner more competitive and profitable in terms of lower unit costs.

It is obvious that equipment is purchased almost by all companies to perform their business activities. At the smallest extent, companies are expected to purchase computers that are technologically fit for the business activities of smaller companies. In the extreme cases, companies purchase equipments that are well advanced and that are more capital intensive.

In order to utilize the equipment or machineries to the full extent possible, equipment or machineries acquisition has been a process of much importance to most companies. This has been achieved through equipment or machineries purchasing process designed by each company. Equipment or machineries purchasing is thus critical in determining appropriate and cost effective equipment or machineries from presented alternatives. Such selection of appropriate equipment or machinery needs to present cost advantage and opportunity for the company that ultimately uses it.

Current practice of equipment purchasing looks into specification requirements set by experts and initial purchasing cost of the equipment. However, equipment lifecycle costs are critical as

they indicate amount of expense expected to be incurred by the owner to sustain the equipment. As it has been stated by Barringer [2], 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. Advanced and complex equipment tend to incur companies huge initial investment and also significant life cycle cost afterwards through operation, training, maintenance and downtime costs.

Owing to the difference in equipment requirements of various companies, this paper argues that companies need to look into the equipment lifecycle cost estimate during making a purchasing decision. Therefore, the present research is a case study taking Ethio-plastic industry, a manufacturing sector, to demonstrate the challenges of traditional decision making approach while selecting equipment to purchase and to propose optimized equipment selection criteria to support a reasonable decision-making process. The data for this study is gathered from machinery which is being used for manufacturing purpose within the organization.

1.2 PROBLEM STATEMENT

Improving the quality of an organization's products and services is fundamental to business success. This requires the engagement of highly skilled human labor as well as financial resources, given the appropriate technological, organizational, institutional and cultural infrastructure. Furthermore, the equipments or machineries in the organization must be able to make the owner more competitive and profitable in terms of lower unit costs.

In deciding which equipment or machinery to choose from different alternatives, the purchasing principle followed by most companies (purchasers) only spotlight in fulfilling the required technical specifications with minimum initial purchase price.

Most of the time, economical criteria outweigh other factors in their equipment selection decision making process. The problem with this approach is that it mainly concentrates on the initial purchasing price of the equipment. However, a machinery's or equipment's cost has more to do with operational and maintenance costs in addition to the purchasing cost. The current trend in the case company's purchasing decision often ignores those costs that appear when it becomes operational and beyond.

In addition, according to Birhanu B. and Eshete B. [3], manufacturers basically take care of quality up to the point where a product is delivered to a customer even if product or equipment failure occurs due to various reasons after purchase. However, this happened or discovered during operational phase of the equipment which subsequently results in unexpected ownership or sustaining cost for the users after purchase. Therefore, conducting further investigation on the above problems and assessing the highest cost contributors and then proposing a possible solution is found to be an interesting research area.

1.3 OBJECTIVE OF THE STUDY

The aim of this study is to assess the highest cost contributors throughout the life cycle of equipment and to identify an improvement point based on the assessment for higher competitive advantage and customer satisfaction in the case of Ethio-plastic Industry.

Specific Objective

More specifically this paper intended to:

- Assess the overall life cycle cost scenarios in Ethio- Plastic Industry by considering conduit making extrusion machine as an example;
- Identify and prioritize the cost escalation components of the investigated machinery;
- Distinguish the inherent problems associated with current life costs incurred;
- Propose Life Cycle Cost management framework that takes into account overall machine lifecycle concerns.

1.4 BASIC RESEARCH QUESTIONS

To meet the objective of the study the following basic research questions are addressed.

- What is the overall life cycle cost scenario in Ethio- Plastic Industry considering conduit making extrusion machine as an example from the company?
- What could be the highest cost escalation components of the investigated machinery?
- What are the inherent problems associated with current life costs incurred?
- What type of Life Cycle Cost management framework will be a solution to eliminate or minimize the problem?

1.5 SIGNIFICANCE OF THE STUDY

The present study helps the purchasers to be aware of the disadvantages of the traditional purchasing trend which prioritize low initial purchase price rather than considering the life cycle sustaining costs. It will also help purchasers of a given product or equipment during their decision making process on how to set alternatives and select an equipment having an optimized purchase price. Above all, by applying the proposed quality based life cycle framework, the purchasers can set an equipment purchase price by considering all the upcoming sustaining costs with the intention that they can be competent in today's furious market.

1.6 SCOPE OF THE STUDY

The issue of Life Cycle Costing (LCC) can be seen from different perspectives; for instance, it can be seen from the design point of view to minimize the overall LCC cost; it can also include detailed cost history including all parameters in a product/ machinery throughout its life time. However, the focus of this thesis is confined only with analyzing the life cycle cost analysis of equipment from customers' or purchasers' perspective. In addition, even though the company has different types of equipments within the five factories/ sections, the data gathered is focused on Conduit making twin line extrusion machine.

1.7 LIMITATIONS

Since this type of research i.e. LCC analysis requires detailed cost data and cost related documents are perceived as confidential by most companies, the researcher could not demonstrate the research with multiple cases.

In addition, the data collected for this study was based on the documents that were provided by the selected case company, but there are some problems related with the documents. First of all, it was too hard to obtain a document which is well recorded for a long period of time and that vividly reflects the life history of a given machine. There is a high disposal of documents in the case company considering the old data records as they are irrelevant. The second problem was related with the legibility of the documents. Even the existing documents are not well recorded; there is a high negligence in recording them. Besides, it was hard to attain full information about

a given machine; rather pieces of information were collected from different department documents.

Regardless of all these problems the researcher tried to make a meaningful study based on the available documents. Moreover, the research result is adequate to reach on a conclusion though the availability of full and well recorded document would make the result much better and strong than it is now. Lastly, even though it is difficult to implement and test the validity of the proposed framework in practice, the researcher used expert opinion for preliminary validation.

CHAPTER TWO: LITRATURE REVIEW

2.1 INTRODUCTION

In present global competitive market place, the demands of customers are forever increasing as they require improved quality of products and services. Continuous improvement in total business activities with a focus on the customer throughout the entire organization and an emphasis on flexibility and quality is one of the main means by which companies face up to competitive threats. This is why quality and its management and the associated continuous improvement are looked upon by many organizations as the means by which they can survive in increasingly aggressive markets and maintain a competitive edge over their rivals. The companies that do not manage this change will fail. As a result of the efforts made by organizations to respond to these market place demands the quality of products, services and processes has increased considerably during the last two decades [4].

2.2 HISTORY OF QUALITY

It is helpful to examine the history of quality, for history provides experiences and learning to deal with the future, to have good understanding on the new paradigm, Lifecycle Quality, and its importance over the others.

2.2.1 What is Quality?

The word ‘quality’ is often used to signify ‘excellence’ of a product or service – when we talk about ‘Rolls-Royce quality’ and ‘top quality’ [5]. In some manufacturing companies quality may be used to indicate that a product conforms to certain physical characteristics set down with a particularly ‘tight’ specification. But if we are to manage quality it must be defined in a way which recognizes the true requirements of the ‘customer’. The ability to meet the customer requirements is vital, not only between two separate organizations, but within the same organization. There exists in every factory, every department, every office, a series of suppliers and customers.

For industrial and commercial organizations, which are viable only if they provide satisfaction to the consumer, competitiveness in quality is not only central to profitability, but crucial to business survival. The consumer should not be required to make a choice between price and

quality, and for manufacturing or service organizations to continue to exist they must learn how to manage quality. In today's tough and challenging business environment, the development and implementation of a comprehensive quality policy is not merely desirable – it is essential.

The problems are often a symptom of the real, underlying cause of this type of behavior, the lack of understanding of quality management [5].

It is generally agreed that high quality products or services are the essence of a company's survival and competitiveness in the highly competitive global market. To meet the increasing expectations and demands of the customers, companies strive to provide their customers with the highest quality products and services. Most importantly, there has been a growing realization that continual improvements in quality are often necessary to achieve and sustain good financial and operational performance. Thus continuous quality improvement has become an important strategic objective for business firms which strive to be successful. Companies employ different quality management systems in order to meet these requirements [6].

Quality can be defined in many ways, ranging from “satisfying customers’ requirements” to “fitness for use” to “conformance to requirements.” It is obvious that any definition of quality should include customers, satisfying them must be the primary goal of any business. Experience during the last two decades in the U.S. and world markets has clearly demonstrated that quality is one of the most important factors for business success and growth. Businesses achieving higher quality in their products enjoy significant advantage over their competition; hence, it is important that the personnel responsible for the design, development, and manufacture of products understand properly the concepts and techniques used to improve the quality of products [7].

Of the many meanings of the word quality, two of them are critically importance for managing quality [4]; they are:

1. "Quality" means those features of products, which meet customer needs and thereby provide customer satisfaction. In this sense, the meaning of quality is oriented to income. The purpose of such higher quality is to provide greater customer satisfaction and, one hope, to increase income. Higher quality in this sense usually "costs more". In this case, higher quality enables the

companies to: increase customer satisfaction, make products salable, meet competition, increase market share, and provide sales income.

2. "Quality" freedom from deficiencies - freedom from errors that requires doing work over again (rework) or that result in field failures, customer dissatisfaction, customer claims and so on. In this sense, the meaning of quality is oriented to costs, and higher quality usually "costs less".

Generally the concept of quality is an integral part of human activity. Conceptually, there are three hypotheses to the origin and development of quality [8]. The first is that quality is a recent development which evolved from pre and post classical management theories. Early management theory consisted of numerous attempts at getting to know industrial life at before the nineteenth century. After the Second World War different management theories were developed. Management science, system approach, contingency approach and dynamic engagement were the most important management theories by the end of the 20th centuries.

The second is that quality is an outcome of a revolutionary scientific development. It is based on Thomas Khun's theory of scientific advancement [9] i.e. scientific development is revolutionary but not evolutionary. The theory proposed three eras within the revolution of quality management pre-industrial paradigm which is an industrial paradigm of quality control, and a post-industrial paradigm of total quality management. This model suggests that each paradigm was the result of the discipline's adaptation to environmental contingencies.

The third is that quality is an evolutionary development of quality inspection. It emphasizes that the concept of quality started as early as human existence. But quality management movement started in Japan during the 1950s. Since the 1990s, quality management become one of the main issues in many organizations and was widely accepted. However, these organizations categorize the development of quality management into four stages; Quality Inspection, Quality control, Quality assurance, and Quality management. Overview of these stages is described below [1, 8].

❖ **Quality Inspection**

At one time, inspection was thought to be the only way of ensuring quality. Inspection can be defined as the examination or review of raw materials, in-process components and completely finished products in relation to some standard specifications, or requirements. Products which do not conform to specification may be scrapped, reworked, modified or passed on concession. In some cases, inspection is used to grade the finished product. The system is an after-the event screening process with no prevention content. Simple inspection based systems usually do not directly involve suppliers or customers in the activity.

❖ Quality Control

Quality control is concerned with the operational techniques for detecting, recording, and taking actions to eliminate quality problems. It focuses on finding and eliminating sources of defects and monitoring the manufacturing process. With quality control there is some development from the basic inspection activity in terms of the sophistication of methods, systems, tools and techniques employed. While the main mechanism for preventing off-specification products and services from being delivered to a customer is again screening inspection. Quality control measures help increase process control and to lower incidence of non-conformances. Quality control will not improve quality but just highlight when products and services do not conform to requirements. An over emphasis on quality control will result in people relying on their work to be checked and tends to stop them from taking responsibility for improving the processes for which they are responsible.

❖ Quality Assurance

Quality assurance is a prevention-based system which improves product and service quality, and increases productivity by placing the emphasis on product, service and process design. By concentrating on source activities and integrating quality into the planning and design stage, it stops non-conforming product being produced or non-conforming services being delivered in the first place; even when defects occur they are identified early in the process. This is a proactive approach compared with detection, which is reactive [10].

Finding and solving a problem after a non-conformance has been created is not an effective means of eliminating the root cause of a problem. Continuous improvement can only be achieved

by directing organizational efforts towards planning and preventing problems occurring at source. This concept leads to the third stage of quality management development which is quality assurance. In short, more emphasis is placed on advanced quality planning, improving the design of the product, process and services, improving control over the process, and involving and motivating people.

Other activities such as comprehensive quality manuals, use of cost of quality, development of process control and auditing of quality systems are also developed in order to progress from quality control to the quality assurance era. At this stage there was also an emphasis of change from detection activities towards prevention of bad quality.

❖ **Quality Management**

Quality management is an approach for achieving and sustaining high quality output. The quality management philosophy can be characterized by its principals, practices and techniques. Quality management is based on three major principles which are customer focus, continuous improvements, and teamwork [11]. Group culture and the rational culture are proven to be of most important for successful implementation of quality management practices.

2.2.2 Quality Gurus

There have been many contributors to the concepts of quality during this century. The next paragraphs summarize the views of the quality gurus [11].

W. Edwards Deming is best known for his "Fourteen Points", [12] a broad set of simple but profound quality principles that apply to any organization. In his opinion, his model can be applied in service industries as well as in manufacturing. Deming also applies the model to medical services and hospitals. The famous 14 points are the following:

- ❖ Create constancy purpose toward improvement.
- ❖ Adopt the new philosophy.
- ❖ Cease dependence on inspection to achieve quality.
- ❖ Stop evaluating activities on the basis of price tag alone.

- ❖ Improve constantly and forever the system of production and service to improve quality and productivity and thus constantly decrease costs.
- ❖ Institute training on the job.
- ❖ Institute leadership which aims at helping people, machines and gadgets to a better job.
- ❖ Drive out fear so that everyone may work effectively for the company.
- ❖ Break down barriers between departments.
- ❖ Eliminate exhortations and targets for work force asking zero defects and new levels of productivity, because the bulk of the causes of low quality and low productivity belong to the system and thus lie beyond the power of the work force.
- ❖ Eliminate work standards on the factory floor and management by objective and numerical goals and substitute leadership.
- ❖ Make it possible to feel pride of workmanship. The responsibility of supervisors must be on quality and there should not be annual merit ratings or management by objective for people in management and engineering.
- ❖ Institute vigorous program of education and self-improvement.
- ❖ Everybody should be put to work to accomplish the transformation in the company. The transformation is everybody's responsibility.

Joseph Juran: - moved quality control forward to the idea of quality assurance and introduced the concept of quality as a means for cost control. Dr. Juran, [7] wrote the Quality Control Handbook, which has served as the bible in this field. In this book, he articulated that quality is not an expense but an investment in profitability. Like Deming, Juran helped bring TQM to Japan and later to the United States.

He defines quality in two principal ways; product features which meet the customers' needs, and freedom of deficiencies. The former means that the better the product features, the higher the quality. The latter means that the fewest the deficiencies the better the quality. Nevertheless, there is no universally accepted definition on the dimensions of quality. This may be connected to the fact that we can also find many perspectives of quality and we can see quality from a product-oriented perspective, production oriented or planning-oriented perspective, customer-oriented perspective, competition oriented, value-oriented or environmental or systems perspective.

Kaoru Ishikawa: - led the movement in Japan to adapt the teachings of the American quality experts and synthesized these concepts into his Company Wide Quality Control (CWQC), successfully championing the integration of quality methods into Japanese engineering and management education curricula. [13] These methods have been used successfully for several decades, and are an integral part of the Japanese industrial culture.

Armand Feigenbaum: - advocated expanding quality control beyond inspectors to every employee and vendor. He believed that quality was too central to be delegated to an inspection corps because this was too limited approach [14]. He defines quality in two different ways, narrowly and broadly. Narrowly interpreted, quality means quality of product. Broadly interpreted, it means quality of work, service, information, process, division, system, company, objectives etc. For over twenty years after Ishikawa, there has been a discussion concerning the wideness of total quality. Should we talk about business excellence or total quality management, and one suggestion has been that quality management should focus on customers and their satisfaction. According to this, the aforementioned customer-oriented perspective could be the best perspective to quality management.

Philip B. Crosby: - espoused "zero defects" and the principle that quality is the conformance to requirements. While initially real, the costs of quality disappear as the very real and measurable benefits of quality emerge.

By large, quality is a holistic concept and includes two different ideas of quality, i.e. quality as 'consistency' and quality as 'fitness for purpose'. The above two ideas are brought together to create quality as perfection within the context of quality culture. Quality philosophy reflects various perspectives of individuals, groups of people and society [15].

2.2.3 Dimensions of Quality

Quality can be used in a strategic way to compete effectively, and an appropriate quality strategy should consider the following eight various important dimensions of quality proposed by Mc George and Palmer [52]

Conformance: Conformance of products or equipments is the ability of equipment to meet its design specifications. Equipment having high quality of conformance may not be perceived by

a customer being an acceptable product unless it is clearly stated. Conformance can be measured within an acceptable tolerance range. The two most common measures of failure in conformance are defect rates in the factory and, once a product is in the hands of the customer, the incidence of service calls.

Perceived Quality: is the most important determinant factor affecting customer purchase intention.[16] Consumers do not always have complete information about a product's or service's attributes; indirect measures may be their only basis for comparing brands. A product's durability for example can seldom be observed directly; it must usually be inferred from various tangible and intangible aspects of the product. In such circumstances, images, advertising, and brand names have critical inferences on quality rather than the reality itself.

Reliability: Reliability as a design parameter and a major cost driver that can reduce maintenance cost when optimised. It can be described as the probability that an item can perform a required function under specified conditions for a given time interval. Reliability reflects the probability of a product malfunctioning or failing within a specific time period. It normally becomes more important to consumers as down time and maintenance become more expensive. Among the most common measures of reliability is the mean-time-between-failure (MTBF).

Maintainability: Maintainability refers to the ease with which maintenance work can be done. In other words, it 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. It involves the process of ensuring that equipment can be easily and safely maintained, and the maintenance support required can be minimized. Maintainability is a design attribute while maintenance is a consequence of design. Maintainability is a key business objective and cost driver that impact on equipment's availability. In maintainability, the random variable is mean-time-to-repair (MTTR).

Durability: Durability is a measure of product life; it has both economic and technical dimensions. In economics, a durable product is one that does not quickly wear out. Technically, durability can be defined as the amount of use one gets from a product before it deteriorates. Alternatively, it may be defined as the amount of use one gets from a product before it breaks down and replacement is preferable to continued repair. According to Cooper [18], durability is

the ability of a product to perform its required function over a lengthy period under normal conditions of use without excessive expenditure on maintenance or repair.

Flexibility: the ability to customize changes in requirement is recognized as flexibility. Its main intention is coping with uncertainty to respond effectively and efficiently to changes result from uncertain business environment. Flexibility can be realized through the ability to expand the production facility. Flexibility and capacity are major cost drivers that have direct impact on the purchasers/ user's business sustainability.

2.3 LIFE CYCLE COST

2.3.1 Introduction to Life Cycle Cost

Procurement costs are widely used as the primary (and sometimes only) criteria for equipment or system selection. This single purpose criterion is simple to use but often results in bad financial decisions. Procurement costs tell only one part of the story—most frequently the story is so simple, the results may be damaging to the financial well-being of the business enterprise. Often the initial procurement costs, based on simple rules, are so cheap they are not affordable. Simple tools (meaning composed on only one thing) usually give simple results (meaning insubstantial, superficial, and not to be taken seriously) [19].

Value for money is a concept that is frequently considered when an individual or an organization is seeking to make a purchase or investment. When acquiring a new car, for example, we may consider the costs of ownership; fuel economy, insurance, maintenance, availability of replacement parts, etc. when deciding between options. Implicitly then, we consider the long-term costs of ownership in the decision making process. Furthermore, it could be argued that the larger the capital cost of a product, the more important it is to consider these long-term costs.

Today, in the global economy and due to various other market pressures, the acquisition decisions of many engineering product or systems, particularly the expensive ones, are not made based on initial procurement costs but rather on their life cycle costs. Past experiences indicate that often ownership costs exceed acquisition costs. In fact, according to various studies, the ownership cost, logistic and operating cost, can vary from 10 to 100 times the original

acquisition cost [8]. The life cycle cost of a system may be defined simply as the sum of all costs incurred during its life span i.e., the total of acquisition and ownership costs.

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 [20]. Since then it has progressed into other industries. For instance, a structured life-cycle cost estimating methodology was developed for air traffic control [21]; according to the research the following three areas were found to be crucial to the methodology: coverage of all cost factors, developing/selecting appropriate cost estimating methods for different cost factors, and correct timing of all costs. The use of the methodology was illustrated with some examples. A key issue is data collection. The parameters in parametric models and cost estimating relationships must reflect the attributes of the organizations involved.

Other researchers, Hiroshi Y. [22] conducted a study on Lifecycle Management Methodology using Lifecycle Cost Benefit Analysis for electronic equipments aim to develop a technique to evaluate the health risk from hazardous chemicals and the social economic risk by the consumption of the rare metal as peculiar environmental risks for the electric and the electronic equipments, and to construct the decision support system able to perform Life Cycle Cost. Moreover, as cited by Okechukwu P. [23], it has been used in different circumstance such as aerospace, power plants, oil and gas, railways, and building construction.

In general, a survey done by Yash Gupta and Wing Sing Chow [24], shows that around 667 literatures have been published on different theories and applications of LCC within 25 years. Subsequently, the scope of LCC has evolved along with this movement.

2.3.2 Life Cycle Cost Definitions

Life cycle costs are summations of cost estimates from inception to disposal for both equipment and projects as determined by an analytical study and estimate of total costs experienced during their life. The objective of LCC analysis is to choose the most cost effective approach from a series of alternatives so the least long term cost of ownership is achieved [19].

LCC analysis helps engineers justify equipment and process selection based on total costs rather than the initial purchase price. Life cycle costs are the total costs estimated to be incurred in the

design, development, production, operation, maintenance, support, and final disposition of a major system over its anticipated useful life span [25].

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. The following figure is a representation of life cycle cost comprising of acquisition cost and ownership cost.



Figure 2.1 Life cycle costing consisting of acquisition cost and ownership cost

Source- Kawauchi and Rausand [26]

2.3.3 Terms and Definitions

Many terms and definitions are used in the area of life cycle costing. Some of the frequently used terms and definitions that are directly or indirectly related to life cycle costing include the following: [8]

- ❖ Cost is the amount of money paid or payable for the acquirement of materials, property, or services.
- ❖ Procurement cost is the total of investment or acquisition costs (nonrecurring and recurring).
- ❖ Ownership cost is the total of all costs other than the procurement cost during the life span of an item.
- ❖ Life cycle cost is the sum of all costs incurred during the life span of an item or system (i.e., the total of procurement and ownership costs).
- ❖ Recurring cost is the cost that recurs periodically during the life span of a project or item.

- ❖ Nonrecurring cost is the cost that is not repeated.
- ❖ Reliability is the probability that an item or system will perform its function satisfactorily for the desired period when used according to specified conditions.
- ❖ Maintainability is the probability that a failed item or system will be restored to its satisfactory working state within a stated total downtime when maintenance action is started per specified conditions.
- ❖ Downtime is the total time during which the item or system is not in a condition to perform its specified mission or function.
- ❖ Manufacturing cost is the sum of fixed and variable costs chargeable to the manufacture of a specified item or system.
- ❖ Maintenance is all scheduled and unscheduled actions necessary to keep an item or system in a serviceable state or restore it to serviceability. It includes inspection, servicing, modification, repair, etc.

2.3.4 Life Cycle Costing Advantages and Disadvantages

LCC helps change different perspectives for business issues with emphasis on enhancing economic competitiveness by working for the lowest long term cost of ownership which is not an easy answer to obtain.[2] Nevertheless, various advantages and disadvantages of life cycle costing have been identified by various professionals.

Among the advantages, when it is used as a comparison tool between possible design or overhaul alternatives, the LCC process will show the most cost-effective solution within the limits of the available data. In addition, it is understood that existing systems provide a greater opportunity for savings through the use of LCC [27].

Besides, LCC helps to explicitly incorporate cost considerations to reach design decisions that gradually converge on the “best” feasible product or infrastructure system relevant to the challenge at hand [28].

After all, according to a draft review made by Davis Langdon Management Consulting [29], the ultimate goal for carrying out LCC calculations is to support decision-making in assessing and controlling costs and identifying cost significant items; and producing selection of work and expenditure planning profiles. Implementing LCC in planning for construction projects over a project’s life shows that integration of sustainable elements confirms its cost-effectiveness as

well as environmental benefit. It implies that LCC allows economical justification to sustainability considerations [29]. In general, LCC is useful to reduce the total cost; make a selection among the competing contractors/manufacturers; compare the cost of competing projects; make decisions associated with equipment replacement, planning, and budgeting.

In contrast, some of the main disadvantages of life cycle costing include that it is time consuming, is costly, has doubtful data accuracy, and is a trying task when attempting to obtain data for analysis.

2.3.5 Life Cycle Costing Application Areas

Life cycle costing can be used in a large number of areas. The six primary uses of life cycle cost include selecting among competing bidders for a project; long-range planning and budgeting controlling an ongoing project; comparing competing projects; deciding the replacement of aging equipment; and Comparing logistics concepts.

Lamar W. E. 1981 has presented the following somewhat more specific applications of life cycle cost analyses: [30]

- ❖ Determining cost drivers and forecasting future budget needs
- ❖ Selecting the most effective procurement strategy and choosing among options
- ❖ Improving comprehension of fundamental design-related parameters in equipment or system product design and development
- ❖ Formulating contractor incentives and making strategic decisions and design trade-offs
- ❖ Optimizing appropriate training needs
- ❖ Providing effective objectives for program control
- ❖ Assessing new technology application; and carrying out source selections.

2.3.6 Life Cycle Stages

Life-cycle studies range from highly detailed and quantitative assessments that characterize and sometimes assess the environmental impacts of energy use, raw material use, wastes and emissions over all life stages, to assessments that qualitatively identify and prioritize the types of impacts that might occur over a life cycle. Different levels of detail and effort are appropriate for the different uses to which life-cycle information is put.

Products, services, and processes all have a life cycle. For products, the life cycle begins when raw materials are extracted or harvested. Raw materials then go through a number of

manufacturing steps until the product is delivered to a customer. The product is used, then disposed off or recycled. Traditionally, product designers have been concerned primarily with product life cycles up to and including the manufacturing step. Effective product and process stewardship requires designs that optimize performance throughout the entire life cycle [31].

Three different life cycle perspectives are often considered by decision-makers depending on their interpretation of the term 'life cycle' [31]. A marketing executive will think in terms of the marketing perspective; which consists of four stages, introduction, growth, maturity, and decline.

A manufacturer will consider the production perspective, which consists of five main stages, Product conception, design, production and process development, production, and logistics. When the product has reached the customer a different customer perspective will be considered. This perspective includes five stages, purchase, operating, support, maintenance, and disposal.

The product life cycle is all activities that the product undergoes without specific attention to which decision maker is involved. Fabrycky and Blanchard [17] suggested a product life cycle 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 the need.



Figure 2.2 Product life cycle (Source: Fabrycky and Blanchard, 1991)

Life-cycle studies are a uniquely useful tool for assessing the impact of human activities. These impacts can only be fully understood by assessing them over a life cycle, from raw material

acquisition to manufacture, use, and final disposal. Life-cycle techniques have been adopted in industry and the public sector to serve a variety of purposes, including product comparison, strategic planning, environmental labeling, and product design and improvement [32, 33]. Moreover, it is essential to note that different kinds of life cycle are considered in life cycle costing.

2.3.7 LCC Methods

Dhillon, B. S. [34, 35], argued that a large number of life cycle cost models have been developed. According to these scholars, there is no single life cycle cost model that has been accepted as a standard model in the industrial sectors due to many reasons such as the, the nature of the problem, inclinations of users, the existence of many different cost data collection systems, and many different types of equipment, devices, or systems.

Through time, life cycle cost models have been classified under various categories. For example, Gupta Y.P., [36] and Sherif Y.S. and Kolarik W.J., [37] have classified life cycle cost models under three categories: conceptual models, analytical models, and heuristic models. Even though they have limited applications, the conceptual models are quite flexible; they are usually based on the hypothesized relationships of variables given in a qualitative fashion.

The analytical models are based on some sort of mathematical relationship and their subcategories include logistic support models, design trade models, and the total cost models. At last, the heuristic models can be described simply as the ill-structured version of the analytical models.

Generally, B.S. Dhillon [8] simply classified the life cycle cost models under two categories: general life cycle cost models and specific life cycle cost models.

GENERAL LIFE CYCLE COST MODELS

The general life cycle cost models are not tied to any specific system or equipment. Some of these models are presented next.

➤ General Life Cycle Cost Model I

In this case, the equipment or system life cycle cost is divided into two main parts: recurring cost and nonrecurring cost. Thus, the system or equipment life cycle cost is expressed by:

$$LCC = RC + NRC$$

Where:

LCC is item or system life cycle cost.

RC is recurring cost.

NRC is nonrecurring cost.

Recurring costs include operating cost, inventory cost, support cost, manpower cost, and maintenance cost; and nonrecurring cost includes costs associated with, procurement, installation, qualification approval, research and development, training, reliability and maintainability improvement and support.

➤ General Life Cycle Cost Model II

In this case, the equipment or system life cycle cost is divided into three main parts: procurement cost, initial logistic cost, and recurring cost. Thus, the system or equipment life cycle cost is expressed by:

$$LCC = C_1 + C_2 + C_3$$

Where:

LCC is item or system life cycle cost.

C_2 is initial logistic cost.

C_1 is acquisition or procurement cost.

C_3 is recurring cost

The initial logistic cost is composed of one-time costs such as the cost of procurement of new support equipment not accounted for in the life cycle costing solicitation and training, the cost of existing support equipment modifications, and the cost of initial technical data management. The three main components of the recurring cost are operating, management, and maintenance cost.

➤ General Life Cycle Cost Model III

This model was developed by the U.S. Navy to estimate life cycle cost of major weapon systems. The system life cycle cost is divided into five main parts: research and development cost, the cost of associated systems, investment cost, termination cost, and operating and support cost. Thus, the system life cycle cost is expressed by:

$$LCC = C_1 + C_2 + C_3 + C_4 + C_5$$

Where:

LCC is system life cycle cost.

C_1 is research and development cost.

C_2 is cost of associated systems.

C_3 is investment cost.

C_4 is termination cost.

C_5 is operating and support cost.

The two main components of the research and development cost are full-scale development cost and validation cost. Similarly, elements of the cost of associated systems are their investment cost and operating and support cost. The investment cost is also made up of two main components: the government investment cost and the procurement cost.

Finally, the elements of the operating and support cost are depot supply cost, depot maintenance cost, operating cost, personnel support and training costs, sustaining investment cost, installation support cost, second destination transportation cost, and organizational and intermediate maintenance activity cost.

➤ General Life Cycle Cost Model IV

In this case, the life cycle cost is expressed by:

$$LCC = C_{cp} + C_{dp} + C_{pp} + C_{op}$$

Where:

LCC is life cycle cost.

C_{cp} is cost associated with the conceptual phase.

C_{dp} is cost associated with the definition phase.

C_{pp} is cost associated with the procurement phase.

C_{op} is cost associated with the operational phase.

The costs of conceptual and definition phases are relatively small in comparison to the costs of procurement and operational phases. They are basically associated with the labor effort. The four main elements of the procurement phase cost are the cost of the prime equipment or system, acquisition personnel, support equipment, and program management.

➤ General Life Cycle Cost Model V

In this case, the life cycle cost is expressed by:

$$LCC = C_{rd} + C_{pc} + C_{os} + C_{rt}$$

Where:

LCC is life cycle cost.

C_{rd} is research and development cost.

C_{pc} is production and construction cost.

C_{os} is operation and support cost.

C_{rt} is retirement and disposal cost

➤ General Life Cycle Cost Model VI

This model was developed by the Material Command of the U.S. Army and is composed of three main components: investment cost, research and development cost, and operating and support cost. Thus, the life cycle cost is expressed mathematically by:

$$LCC = C1 + C2 + C3$$

Where:

LCC is life cycle cost.

C1 is research and development cost.

C2 is investment cost.

C3 is operating and support cost.

SPECIFIC LIFE CYCLE COST MODELS

➤ Specific Life Cycle Cost Models I

This model is concerned with estimating the life cycle cost of switching power supplies.

$$LCC_s = IC + FC$$

Where, LCC_s is life cycle cost of switching power supplies.

IC is initial cost.

FC is failure cost.

➤ **Specific Life Cycle Cost Model II**

This model is concerned with estimating the life cycle cost of health care facilities. The health care facility life cycle cost is expressed by:

$$LCC_h = C_C + C_O$$

Where, LCC_h is health care facility life cycle cost.

C_C is capital cost.

C_O is operating cost.

➤ **Specific Life Cycle Cost Model III**

This model is concerned with estimating the life cycle cost of an early warning radar system. The radar life cycle cost is expressed by:

$$LCC_r = C_p + C_o + C_s$$

Where, LCC_r is early warning radar life cycle cost.

C_p is radar procurement cost.

C_o is radar operation cost.

C_s is radar logistic support cost.

➤ **Specific Life Cycle Cost Model IV**

This model is concerned with estimating the life cycle cost of inertial systems. The inertial systems life cycle cost is expressed by:

$$LCC_{is} = RDTC + PC + OMC$$

Where, LCC is inertial systems life cycle cost.

$RDTC$ is research, development, test, and evaluation cost.

PC is procurement cost.

OMC is operation and maintenance cost.

➤ **Specific Life Cycle Cost Model V**

This model is concerned with estimating the life cycle cost of software. Sometimes, the model is called the “Boeing C-14 model”. It is expressed by:

$$LCC_s = AC_s + SC_s$$

Where, LCC is life cycle cost of software.

AC_s is acquisition cost of software.

SC_s is support cost of software.

On the other hand, Okechukwu P. [23] has reviewed about seven literatures on Life Cycle methodologies. He conducted the review involving the analysis of the methodologies and comparing the elemental features of each methodology. A glimpse on Life Cycle Costing methodologies reviewed by him is presented as follow.

- **Fabrycky and Blanchard** [17] - 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. This methodology encompasses all basic features that can be used to analyze a life cycle as well as evaluate the total cost of any product
- **Dahlen and Bolmsjo** [38] - the methodology developed by these authors intends to expand the area of application to include analysis of investments done when increasing the production factor (labor). It includes the cost of an employee over the whole employment cycle, from recruitment to retirement. Estimating the costs of labor for an employee can be presented in a similar fashion as the costs over the life of production equipment
- **Woodward** [39] - his methodology concerns the optimization 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
- **Kawauchi and Rausand** [26] - 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. 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.
- **Iwawaki et al** [40] - their 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 hydro-processing unit in a refinery. According to them, the methodology could be used to support decision makers in optimizing the life cycle costs associated with operation and maintenance activities affecting some refinery components.
- **Emblemsvag** [41] - This methodology could be used to supply an efficient and effective decision support in life cycle design. It has the best potential for effective cost evaluation in the context of life cycle design. 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 that require extensive activity-cost databases

- **Petroleum and Natural Gas Industries** [42] - 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 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.

Moreover, the detail review of the most known life cycle costing frameworks developed by Emblemssvag [41], and Fabrycky and Blanchard [17] is presented as follows.

I. Activity-Based Life Cycle Costing Methodology of Emblemssvag [41]

An efficient and effective decision support in life cycle design can be carried out by using Activity-Based Life Cycle Costing methodology. The best potential that this methodology has is it is helpful for effective cost evaluation in the context of life cycle design. Uncertainty conditions have to be used in this methodology in circumstances where there is lack of data and the presence of unexpected activities. The methodology has ten steps that can be applied whenever the activities are described in detail as shown in Figure 2.3.

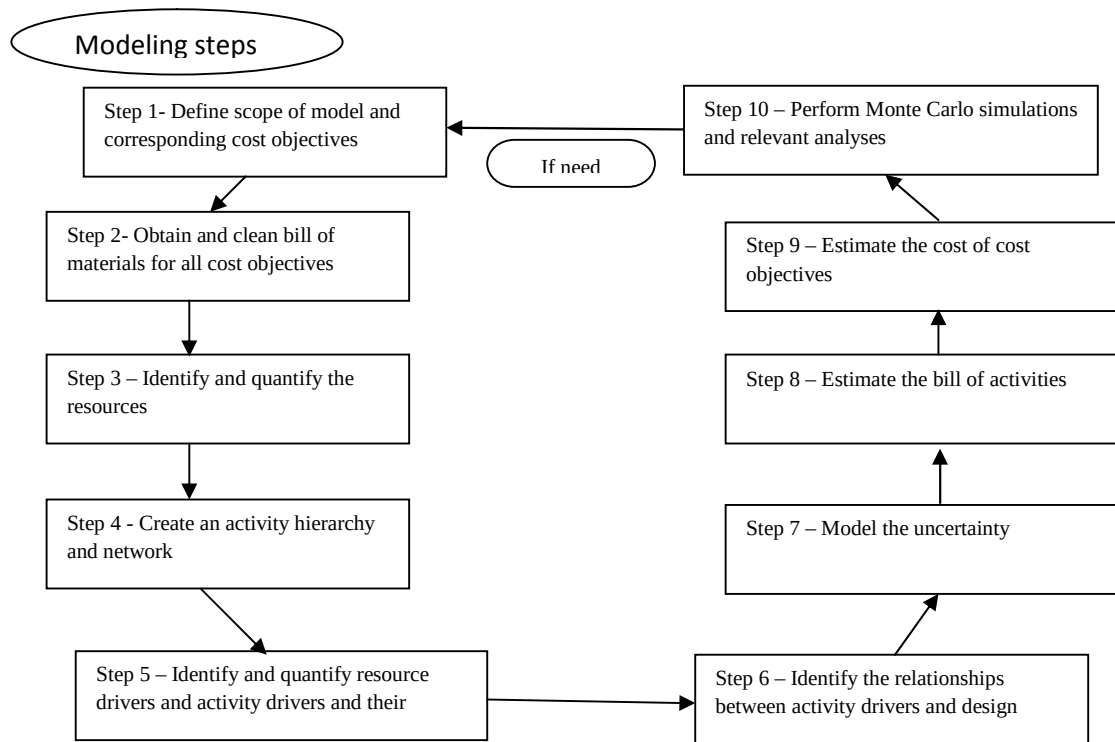


Figure 2.3 Activity-Based Life Cycle Costing Methodology (Source: Emblemvag) [38]

The method may not be easily adopted in conjunction with unique investments that require extensive activity-cost databases because it can only be used whenever the activities are described in detail. Therefore, it is 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.

II. Life Cycle Costing Methodology of Fabrycky and Blanchard [17]

In this methodology, a holistic life cycle costing approach is considered to insure the detailed analysis of the costs related with the entire life cycle of any product are considered. In general, the researchers 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 demonstrated in Figure 2.4.

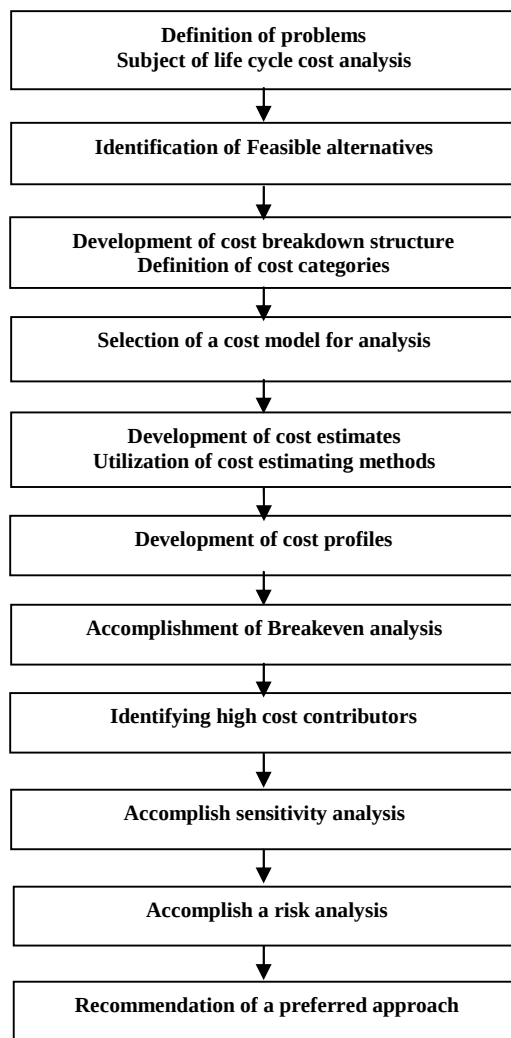


Figure 2.4 Life Cycle Costing Methodology (Source: Fabrycky and Blanchard) [17]

This methodology includes all basic elements that can be used to analyze a life cycle and evaluate the total cost of any product. It also addresses several issues at different stages of the system's life cycle. Its product life cycle in the above figure created a cost emphasis by the establishment of statement of need. The methodology can be appropriately applied to evaluate the capability of an existing system by the identification of cost drivers and costly problem areas.

2.4 PURCHASING PRINCIPLES

Different literatures describe lots of methods for estimating the costs of a product. Adnan and Jian categorize equipment cost estimation techniques into qualitative and quantitative. [43]

Qualitative cost estimation techniques are primarily based on a comparison analysis of a new product with the products that have been manufactured previously in order to identify the similarities in the new one. On the other hand, quantitative techniques, are based on a detailed analysis of a product design, its features, and corresponding manufacturing processes instead of simply relying on the past data or knowledge of an estimator. Costs are, therefore, either calculated using an analytical function of certain variables representing different product parameters or as the sum of elementary units representing different resources consumed during a whole production cycle of a given product [44].

Understanding successful purchase decisions helps both the enterprises that adopt these technologies and the vendors that sell these products. Ross Dawson and et al. [45] argues that the expertise of individuals involved and the processes used to evaluate and approve product or equipment purchases play a substantial role. What is often underappreciated is how relationships and networks in organizations influence these critical decisions.

Chris F. [46] gives an emphasis on an empirical validation of four algorithmic models from the literature (SLIM, COCOMO, Function Points, and ESTIMACS) that are proposed as general software-development cost estimators. He has built a database of completed software-development projects and focuses on comparing the actual costs with the ex-post estimates obtained from the four models. His particular interest was the comparison of the results of the four models' use of different measures (metrics) of the outputs underlying their productivity calculations. But the focus of all the four models while estimating the cost of a software technology was only up to the development of the software.

Alexander Layer et al. [47] try to give a comprehensive overview of the state of the art in the field of cost estimation. All the researches they cover emphasize only on the calculation process such as, the accuracy, their calculation integration system/model and its ability to solve different type of problems, their coverage in the cost calculation workflow and the like. Most of the methods currently deployed do not consider that manufacturing technology is company specific. In addition, not all the processes needed are taken into account, so that the costs calculated end up too low. As a final point, none of the methods currently employed for the design-concurrent

and continuous calculation of both production and lifecycle costs is as effective and efficient as needed.

2.5 SUMMARY

This chapter presented a review of the quality concepts and several concepts relating to life cycle costing and its applicability. Numerous notions were explored about Life Cycle Costing and its application areas, purchasing principles, cost estimating techniques, product life cycle stages, and life cycle costing methodologies are required for the successful accomplishment of life cycle costing analysis.

However, it was recognized that there is no formal and comprehensive life cycle costing framework that considers quality dimensions in the life cycle analysis to optimize the evaluation of available alternatives in purchasing decision making.



Fig 2.3 Life Cycle cost components (Source: own)

Moreover, life cycle stages can be customized to the need of a particular life cycle costing requirement. Based on the above review, the above figure is developed to show a general life cycle stage of equipment and the life cycle cost components to be considered for this study from customer's perspective.

CHAPTER THREE: METHODOLOGY

3.1 RESEARCH METHOD

It is generally agreed that high quality products or services are the essence of a company's survival and competitiveness in the highly competitive global market. [5] Even though there are different elements required to make a company competitive, equipments or machineries must be able to make the owner more competitive and profitable in terms of lower unit costs.

In deciding which equipment or machinery to choose from different alternatives, the purchasing principle followed by most companies (purchasers) only spotlight in fulfilling the required technical specifications with minimum initial purchase price. This results in unexpected sustaining cost. Therefore, Life Cycle Costing is used as a tool to reveal the cost escalation points that appear throughout the life span of equipment.

Though there are varies application areas of life cycle cost analysis, as mentioned in the literature review, some of them are addressed here. Among the application areas of life cycle costing analysis, Lamar has presented somewhat more specific applications; determining cost drivers and forecasting future budget needs. [30] This research assesses the life cycle cost of the existing equipment and identifies the highest cost drivers. The study analyses the foundation for the occurrence of high life cycle cost from the quality point of view. The identification process using life cycle cost analysis may help the company to consider the factors that affect or increase the life cycle cost, for future improvement and budget forecasting. In addition, the manufacturers will focus in improving comprehension of fundamental design-related parameters in equipment or system product design and development.

In order to perform effective life cycle cost analysis, the availability of reliable cost data is vital. This means that the existence of good cost data banks is very important. Thus, in developing a new cost data bank, careful attention must be given to factors such as comprehensiveness, size, uniformity, flexibility, responsiveness, ready accessibility, orientation, and expansion or contraction capability [48]. Furthermore, at a minimum, a life cycle costing data bank should incorporate information such as user pattern records, descriptive records (hard ware and site), cost records, and procedural records (operation and maintenance).

Although data for life cycle cost analysis can be obtained from many sources, their amount and quality may vary quite considerably. Therefore, prior to starting a life cycle cost study, it is important to examine carefully factors such as data bias, data applicability, data availability, data orientation toward the problem under consideration, and data coordination with other information [8]. However, the data is expected to be somewhat biased due to recorders' carelessness and it might lack its accuracy. The availability of data is also limited for the same reason and recorded data are discarded after some time considering them as garbage. Other things being remain constant, the available data and its orientation toward the problem under consideration is found to be sufficient for analysis for this case. The general workflow of the study is shown in figure 3.1 below.

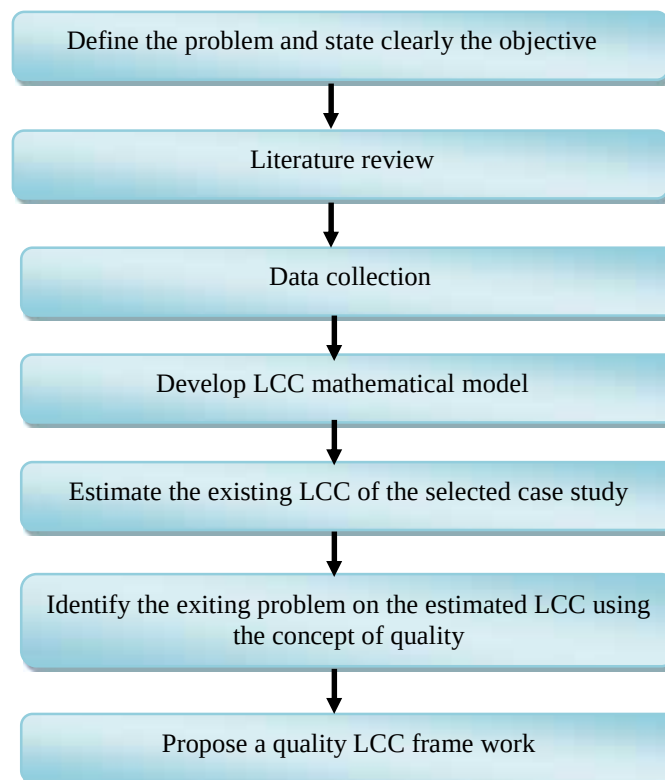


Figure 3.1 The general workflow of the study

- **Define the problem and state clearly the objective:** This study aims at assessing the cost escalation points in life cycle quality application and to identify where should the center of attention be to eliminate or minimize those unnecessary costs. The objective is achieved

through literature survey, data collection, analysis and interpretation, solution proposal. These are discussed in detail below.

- **Literature Survey:** - Literature review of relevant materials from different books, internet, research papers, journals and magazines which are related to life cycle quality, life cycle costing, and purchasing principles are used.
- **Data collection:** - The essential data which are required for the accomplishment of the present study are of two types :
 - As primary source of information, informal discussions are held with pipe factory production manager, senior and junior operators in the pipe factory, finance department staff, and record officers to acquire additional information that can substantiate the collected data.
 - The secondary sources are official documents of the industry and reports of task forces; in addition review of related literature and publications on life cycle quality and life cycle costing. The case companies' documents wherein the purchase cost, maintenance, operation and downtime cost are collected to be analyzed thoroughly.
 - Data analysis and synthesis/ interpretation: After the collection of data on the existing conditions of the case companies, data are organized and evaluated for analysis and identification of the problems. Findings are analyzed and described in light of relevant theoretical frameworks. Life cycle costing method is used as a tool to assess areas where special attention should be given while applying life cycle quality regarding to cost analysis and least square method is used for estimation purpose.

3.2 DEVELOPING MATHEMATICAL COST MODEL FOR LIFE CYCLE COST (LCC) ESTIMATION

Different scholars and organization use their own standards and nomenclature for describing the life stage of equipment. Equipment life cycle refers to sequential phases from need identification to disposal. The major life cycle stage of equipment includes: concept, design, development and verification, pattern making and tool engineering, manufacturing and assembly, installation and commissioning, transportation and storage, packaging and dispatch, testing, operation, maintenance and repair, downtime, and disposal.

As it has been explained in the literature review (section 2.3.6) there are different perspective of life cycle phase from marketing, manufacturer, and customer's point of view. This research is conducted from customer's point of view. Acquisition or purchasing costs comprise of all the manufacturing related costs up to product delivery including the profit. Therefore, the components of acquisition cost are not discussed in this paper. The following phases are considered under acquisition phase.

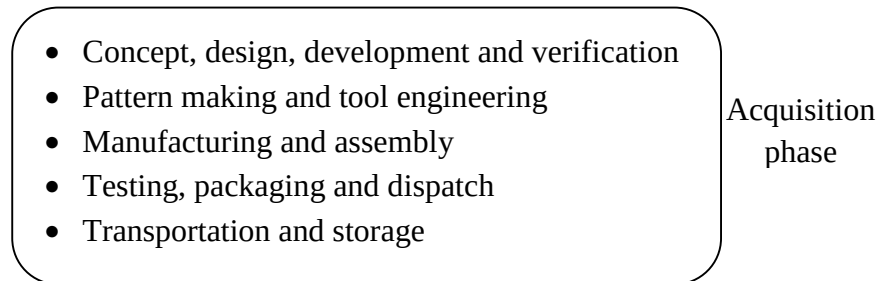


Figure 3.2 Cost elements included in acquisition phase (own)

Initial costs include engineering, bid process (“bid conditioning”), purchase order administration, testing, inspection, spare parts inventory, training and auxiliary equipment. Initial cost is also influenced by such critical factors as the size and design of the equipment, the quality and/ or duty rating of the equipment being selected, materials of construction and control system. All of these choices can substantially affect the life cycle cost and working life of the equipment.

There are two major cost categories by which equipments are to be evaluated in life cycle costing. They are initial costs and future costs. Initial expenses are all costs incurred prior to purchasing the asset. Future expenses are all costs incurred after commissioning the asset/facility. This is also specified by Barringer P. [2]. He divides the life cycle cost tree into two major parts: Acquisition Costs and Sustaining Costs.

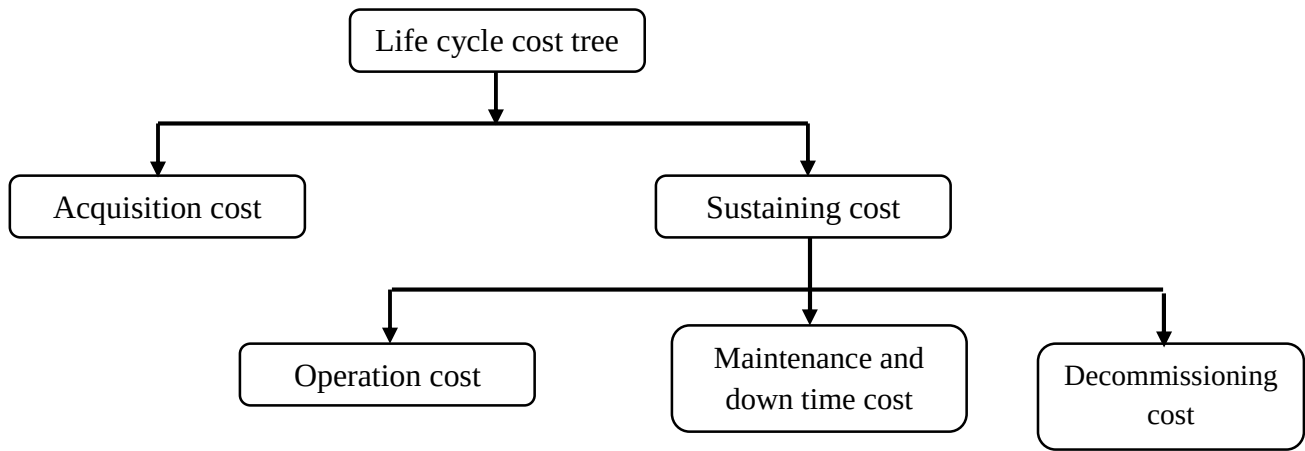


Figure 3.3 Life cycle cost tree (Source: Barringer) [2]

Barringer [2] defines the initial costs as acquisition costs. His figure shows that the cost tree can be divided into two parts: acquisition costs & sustaining costs. Compared to the perspectives that Emblemavag [41] describes, the setup of Barringer's cost tree suggests that his perspective on conducting a life cycle cost analysis is a customer perspective. Emblemavag's describes different perspectives. From the viewpoint of the constructor, sustaining costs are not of prior concern related to the installation. From the customer's viewpoint however, as Barringer clearly states, sustaining costs are taken into account. Emblemavag in fact confirms that Barringer visualizes a customer perspective.

Although acquisition costs can be very important for an LCC analysis, they can be seen as simple input parameters resulting from a set of requirements which have to be met. A refined investigation into the acquisition cost tree is therefore not of primary concern. Insight into the costs to keep the installation in operating condition is more important.

A mathematical model was developed for the estimation of LCC [54]. Estimating the total LCC requires breakdown of the equipment cost into its constituent elements over time. The level to which it is broken down will depend on the purpose and scope of the LCC study. In this study, the cost elements are breakdown into six; acquisition, installation, operation, maintenance, downtime, and disposal as it has been indicated in the literature review in section (2.3.6). The general LCC of an equipment or machinery is therefore shown in Equation 3.1.

$$LCC = C_{aq} + C_l + C_{op} + M_c + P_L + D_c \quad (3.1)$$

where LCC is life cycle costing, C_{aq} is acquisition cost, C_l is installation cost, C_{op} is operating cost, M_c is maintenance cost, P_L is production loss due to down time and D_c is the disposal cost.

Acquisition cost contains C_1 purchasing price, C_2 transportation cost, and C_3 training cost. The general expression for the acquisition cost is;

$$C_{aq} = \sum_{j=1}^{j=3} C_j \quad (3.2)$$

The main activities in the installation process are, location identification including ground type condition where optimal performance is required, building a foundation, floor anchoring, machine leveling and alignment, vibration isolation, machine safeguarding, electric connection and commissioning. The cost driver for these activities are the number of labors needed to perform these activities, time spend on each activities, the cost of labor, the materials and tools, and manuals and guides used in the installation process. The installation cost of all these activities can be presented as follow.

$$C_l = \sum_{i=1}^{i=m} [(t_a \cdot n_p \cdot C_{li}) + C_{ti} + C_{mi} + C_{gi}] \quad (3.3)$$

where C_l is the cost of installation, t_a is the estimated time for each activities, n_p is the number of labor needed for each activity, C_{li} is the labor cost for installation, and C_{ti} is the cost of tooling for installation, C_{mi} is the cost of materials used in the installation and C_{gi} is the cost of guides and materials for installation.

The high impact cost drivers in the operation phase are number of operation hours, personnel, and cost of energy. By integrating these factors the following equation is developed to estimate the operation cost. Mathematically, it is expressed as shown in Equation 3.4:

$$C_{op} = t * (C_e + C_l) \quad (3.4)$$

Where, t is total operation hour, C_e is cost of energy per hour and C_l is cost of labor per hour. One of the main factors which affect the reliability of the system is proper maintenance. Uncertainties arise from maintenance cost determination, because the failure of the system can happen stochastically. The general equation of maintenance cost is as follows:

$$M_c = C_c N + C_p N_p \quad (3.5)$$

Where, M_c is the maintenance cost, N is the number of failure (failure frequency), N_p is the number of preventive maintenance and C_c is the cost of repair and C_p is the preventive maintenance cost.

Number of preventive maintenance, N_p can be estimated based on the type of maintenance policy the plant is following. There are two types of preventive maintenance; scheduled and condition-based. The cost of scheduled or time based maintenance is fixed. But the condition-based is probabilistic. In order to determine the time of preventive maintenance, the condition of the equipment will be determined based on the trend of its failure. Predicting the schedule maintenance is not the scope of this study.

The corrective maintenance is conducted whenever there is a failure and the cost of repair C_c is estimated by the activities performed.

$$M_c = N(C_{s,p} + C_t) + N(MTTR(l)(n)) \quad (3.6)$$

Where: $C_{s,p}$ is cost of spare part for repairing a failure. If the equipment is repaired without replacing any parts, $C_{s,p}$ is going to be zero. C_t is cost of tools, N is the number of failure, $MTTR$ is mean time to repair, l is cost per labor and n is number of labor for each activity.

The failure of the system associates not only with maintenance but also with down time. Due to down time, the system is unavailable, which results in the loss of production and can be calculated as shown in Equation 3.7.

$$P_L = D_t Q C \quad (3.7)$$

Where P_L the loss of production is, D_t is the down time due to failure, Q is production per hour and C is cost of production per unit.

The disposal cost can be estimated from all activities conducted. The major activities identified include equipment disassembly, separation, material recovery, and dumping. The cost drivers associated with these activities such as time to disassemble the equipment, weight of the

equipment, distance of transportation, quantity of material to be recovered, quantity of material to be dumped, and numbers of persons involved should be identified.

Note: In this study, due to shortage of data, disposal cost cannot be estimated; and as per the data gathered from the case company, installation cost is included in the acquisition cost.

CHAPTER FOUR: ANALYSIS AND DISCUSSION

4.1 OVERVIEW OF THE CASE COMPANY

Ethiopia Plastic Industry (EPI) is a government owned public enterprise which was established by five Italian private entrepreneurs in 1960 EC. Five years later, due to the change in the political situation of the country, the government has taken 55% of the share of the company. Since then the company passed through different organization setups and structures under different supervisory government bodies. In 1978 EC the Government became full owner of the company. In 2000 E.C EPI was established as a new share company and works under the control of Privatization and State Owned Enterprises Authority with a capital of 29,670,000.00 Birr. And finally, since 2003 E.C the Company operates under Metals and Engineering Corporation.

Currently, the company is upgrading and expansion works are in progress to assure better customer satisfaction and business development. The management team and employees believe in the importance of system improvement efforts for the company development.

The main objective of EPI is production and sales of plastic related construction materials, packaging, and household materials. It is located in Addis Ababa. There are currently 394 workers, including highly professional plastic technologists, engineers, and management and marketing Professionals.

According to the quality policy information collected from the company, the management of EPI is committed to:

- Implement, maintain and improve quality management system as per ISO 9001:2008 requirement.
- Assure and maintain the quality reputation of their products and consider contribution of suppliers and other related parties.
- Consistently meet & exceed the continuous needs and expectation of customers and stake holders. Consider and respect contribution of suppliers and other related parties.
- Define quality objectives and relevant process of industry and revise at least once per year.
- Promote the creativity, initiative, and team work sprits among employees in a problem solving and the continuous improvement activities.

- Conduct internal audit and management review at planed interval and initiate corrective action.
- Assure communication, implementation and revision of this policy throughout the industry.

The reputation of EPI products is built on an absolute insistence on high quality. In pursuit of that deal EPI has maintained stringent quality management programs and has attained ISO 9001-2000 and ISO 9001-2008 QMS certification.

4.1.1 Main Products and Services

There are five Manufacturing sections with in EPI. These are: Pipe, Polyethylene, Injection, Wire and cable, and Profile manufacturing sections. Nowadays the company plans to produce polyethylene based, flouro-plastic based, polycarbonate based and, rubber based products of airplane, automobile, building parts. Construction materials cover about 75% of the company Production and sales.

4.1.2 Main Customers and Suppliers

Main customers of EPI are EEPCO, Housing development project offices, Construction Industries, Water work Enterprises, agricultural farms, etc. The main suppliers are Pinacle Trading, Aprirose, Asia Foucsind Co. Ltd., Elsewdy Cables Ethiopia, Euro Chem, Techno Service, Thai Plastic, and Quantum Chemical.

4.1.3 The Case Company's Purchasing Trend

According to the information obtained from case company, the company's purchasing or equipment selection method is traditional; meaning The office prepares a specification for the equipment or machinery in need and through bid release process the minimum acquisition proposal offer will be selected.

This indicates that EPI do not apply life cycle cost analysis to support or justify the selection decision rather simply took the minimum initial purchase cost which has a greater negative impact in the future ownership cost.

The challenges of not considering the life time expense of a product or technology is assessed in this paper by taking Conduit making twin line extrusion machine as an example from the pipe factory in the case company.

Since construction is rising in an alarming rate in Ethiopia, it is obvious that the market demand for rigid conduit is very high. Though there are other machineries which can produce conduit, Conduit making twin line extrusion machine has high production rate (2500-3000Kg per day) with twin production line and is equipped with recent technologies to produce different size products (ranging from 16cm - 50cm diameter). Due to this, rigid conduit making extrusion machine is vital for the company; hence, it is selected for an illustration in this paper.

4.2 DATA COLLECTION AND ANALYSIS

As it has been mentioned in the previous chapters, an equipment or machinery has its own life cycle cost components. Thus, this portion illustrates the necessary data gathered on those life cycle cost components from the case machinery cost history followed by the analysis of each cost component. The steps used for estimating the LCC of the selected case is shown in the figure 4.1 below.

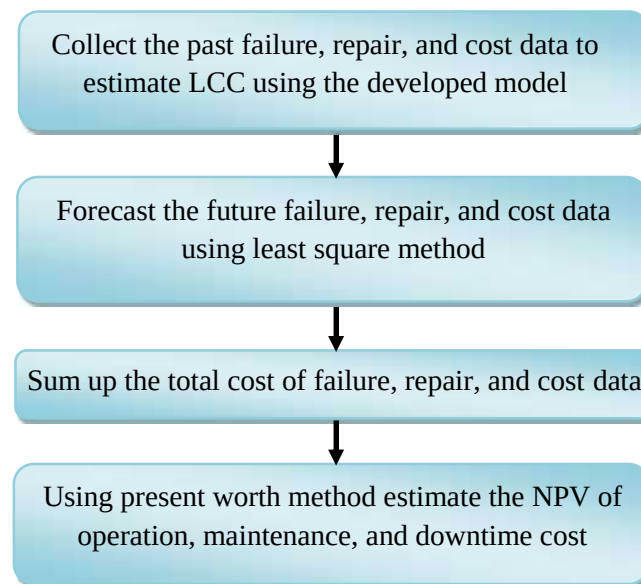


Figure 4.1 Steps for estimating LCC

4.2.1 Acquisition Cost

The machine was purchased in 2002 E.C with an initial purchase price of **1,053,000.00** Ethiopian Birr. It is still working but the operating and maintenance costs are increasing from time to time. Unfortunately, those costs were not considered while selecting the machinery at the time of purchase. As a result, the company is still incurring a blown up unexpected cost. Therefore, it is necessary to have estimates of such costs available when considering decisions as to the type of equipment to use.

The life cycle cost of a particular plant, equipment or facility depends in part on the amount of time it operates in a satisfactory manner and for how long the facility is down for maintenance. The everyday usage term "quality of a product" is loosely taken to mean its inherent degree of excellence. In industry, this is made more precise by defining quality to be "conformance to requirements at the start of use". Assuming the product specifications adequately capture customer requirements, the quality level can now be precisely measured by the fraction of units shipped that meet specifications.

Nevertheless, how many of these units still meet specifications after a week of operation or after a month; or at the end of a one year warranty period? That is where reliability comes in. Quality is a snapshot at the start of life and reliability is a motion picture of the day-by-day operation. Time zero defects are manufacturing mistakes that escaped final test. The additional defects that appear over time are reliability defects or reliability fallout. The quality level might be described by a single fraction defective. With a good grasp of the reliability of components and systems, it is possible to devise specifications and designs that result in the optimum level of reliability performance.

Designing a product with inexpensive and unreliable parts will result in a product with low initial costs, but high support and warranty costs. On the other hand, over-designing a product with costly, highly reliable parts will result in a final product with low support and warranty costs, but that may be prohibitively expensive. Application of information from a reliability engineering program can result in a design that balances out both of these factors, resulting in a design reliability that minimizes the overall cost of the product.

4.2.2 Operation Cost

The operation cost for the case machinery has two components, energy cost and labor cost. This is estimated using Equation (3.4). The assumptions taken during the analysis are listed down below.

- The machine works 24 hours per day, 6 days per week, which gives us 144 hours per week. Therefore, annual working hour is 7488.
- According to Ethiopian electric corporation (ELPA), which is the largest Electric utility company in Ethiopia, high voltage industrial tariff charges are Birr 0.3243/kWh.
- The power usage by the extrusion machine is 135.8kW.

Annual energy cost is therefore going to be:

$$\begin{aligned} &= 135.8\text{kW} * \text{Birr } 0.3243 \text{ Birr /kWh} * 7488 \text{ hr/yr} \\ &= \mathbf{329,771.07 \text{ Birr/yr}} \end{aligned}$$

The total annual energy cost for the extrusion machine is **329,771.07 Birr/year**. There are fourteen operators in the station; each has a monthly salary of 4,900.00 birr which gives us a total of 68,600 Birr annual labor cost. The labors are not operating only on the extrusion machine, but they also work on three other machines; therefore, the annual labor cost of the extrusion machine is 68,600 Birr divided by four which will give us **17,150 Birr**.

As a result, the annual operating cost is the summation of the energy and labor cost which is **346,921.07 Birr** per year.

4.2.3 Maintenance Cost

The total cost data of spare part and tool collected covers six years cost history of the case machinery. Among them, the detail cost history of the recent three years is attached in Appendix A. The remaining three years cost history of the data is included in the summary table 4.1 for the whole life time of the machine.

Table 4.1 Total cost of spare part and tool

Maintenance year	Cost of spare part and tool
2007 E.C* ¹	103,231.12 birr
2006 E.C	136,774.05 birr
2005 E.C	111,361.00 birr
2004 E.C	82,024.90 birr
2003 E.C	71,030.00 birr
2002 E.C	69,532.08 birr
Grand total	573,953.15birr

The cost of spare part and tool incurred for the machine in its life time up to 2007E.C is sum up to **573,953.15** Birr.

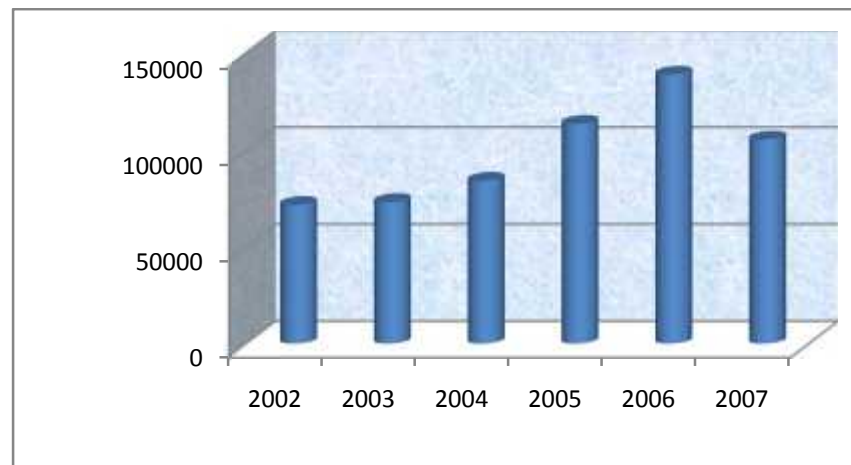


Figure 4.2 Trend of spare part and tool Cost data

In the figure above, the bars line up in an increasing order which show that the data has a trend that indicates spare part and tool costs are increasing from time to time.

*The data for 2007 is not of the whole year, it consists of only seven months cost history.

Table 4.2 Failure and repair time data and estimated repair cost

Year	Failure number	Time to repair (days)	Cumulative time to repair	Number of labor needed to repair	Labor cost per repair	Estimated repair cost
2002	1	0.5	0.5	2	163.33	163.33
	2	0.1	0.6	2	163.33	32.666
	3	1.5	2.1	2	163.33	489.99
	4	0.35	2.45	2	163.33	114.331
	5	0.23	2.68	2	163.33	75.1318
	6	3	5.68	2	163.33	979.98
	7	0.19	5.87	2	163.33	62.0654
	8	1.2	7.07	2	163.33	391.992
	9	0.95	8.02	2	163.33	310.327
	10	0.36	8.38	2	163.33	117.5976
	11	0.7	9.08	2	163.33	228.662
	12	4.2	13.28	2	163.33	1371.972
	13	0.25	13.53	2	163.33	81.665
						4419.7098
2003	14	1	14.53	2	163.33	326.66
	15	0.3	14.83	2	163.33	97.998
	16	2.5	17.33	2	163.33	816.65
	17	0.2	17.53	2	163.33	65.332
	18	1.5	19.03	2	163.33	489.99
	19	0.5	19.53	2	163.33	163.33
	20	2.3	21.83	2	163.33	751.318
	21	0.9	22.73	2	163.33	293.994
	22	0.15	22.88	2	163.33	48.999
	23	0.18	23.06	2	163.33	58.7988
	24	1.5	24.56	2	163.33	489.99
	25	0.17	24.73	2	163.33	55.5322
	26	0.6	25.33	2	163.33	195.996
	27	0.2	25.53	2	163.33	65.332
	28	3.5	29.03	2	163.33	1143.31
	29	0.25	29.28	2	163.33	81.665

	30	1	30.28	2	163.33	326.66
	31	0.02	30.3	2	163.33	6.5332
	32	1.5	31.8	2	163.33	489.99
	33	0.25	32.05	2	163.33	81.665
	34	2	34.05	2	163.33	653.32
	35	0.81	34.86	2	163.33	264.5946
						6967.6578

The table above shows the first two years failure and repair time collected data along with the estimated repair cost. The remaining three years is attached in Appendix B. The seven years estimated cost is summarized in table 4.3.

Table 4.3 Summary of estimated repair cost

Year	Estimated repair cost
2002	4419.7098
2003	6967.6578
2004	11449.433
2005	11661.762
2006	14634.368
2007	12942.2792
	62,075.20

The plot in the figure bellow, the y-axis is chronological time which is also known as cumulative time and x-axis is known as cumulative events or cumulative failures. This plotted data provides information about two statistics; trend line slope is very strong indicator which provide information regarding increasing, decreasing or no improvement. In this figure, the data points line up near the straight line shows that the data has a trend which means failures are increasing or it may also mean that system is showing no improvement.

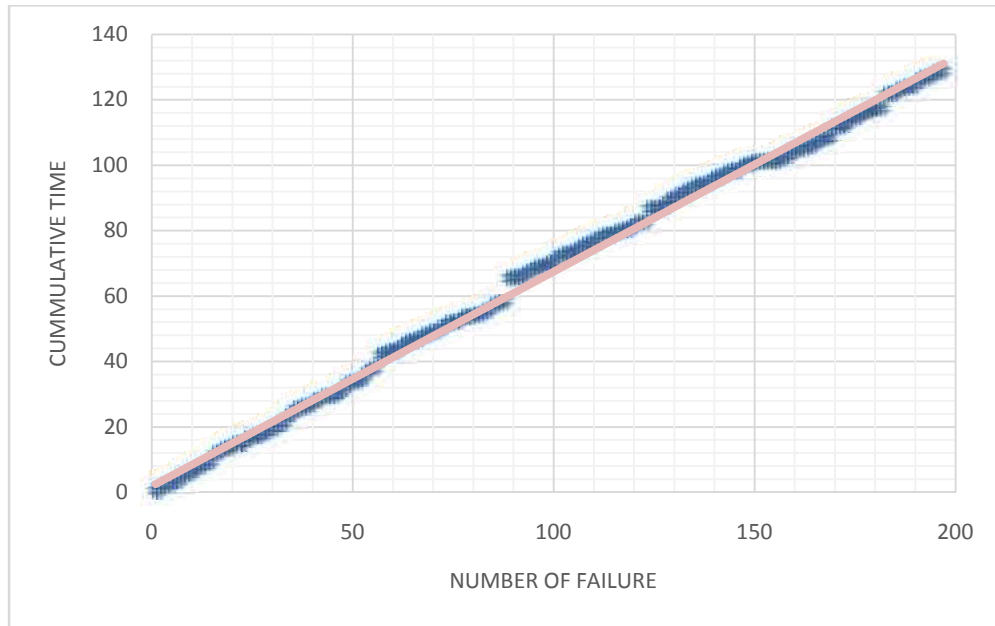


Figure 4.3 Cumulative failures Vs Time

Total maintenance cost is therefore the summation of repair cost and cost of spare part and tool.

Table 4.4 Total maintenance cost

Year	Total spare part cost	Total repair cost	Total maintenance cost
2002	69,532.08	4419.7098	73,951.79
2003	71,030.00	6967.6578	77,997.66
2004	82,024.90	11449.433	93,474.33
2005	111,361.00	11661.762	123,022.76
2006	136,774.05	14634.368	151,408.42
2007	103,231.12	12942.2692	116,173.39
	573,953.15	62,075.2	636,028.35

The above table shows, the six year cumulative maintenance cost of the case machinery is more than half of the initial purchase price. This reveals that the case company is exposed to unforeseen repair costs.

❖ Forecasting Method

Forecasts are estimates of occurrence, timing, cost, or magnitude of uncertain future events. The purpose of forecasting is to use the best available information to guide future activities toward organizational goals. Basically, there are two broad categories of forecasting techniques namely qualitative and quantitative methods. [49] Least square method is one of the quantitative methods used for future prediction. This method is deterministic in nature. Suppose there is a group of experiment data, $(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)$ and they make up a scatter diagram on the (x, y) plane. In the scatter graph, if these points scatter near a certain straight line, the relation between x and y can be considered as linear relation, and it can be demonstrated with the linear equation $y = ax + b$, here a and b are undetermined constants. The key step to use least square method is determining the constants a and b in the function $y = ax + b$ so as to obtain the minimum calculated value of the following equation. $F(a, b) = \sum_{i=1}^n E^2(i) = \sum_{i=1}^n (y_i - ax_i - b)^2$.

The normal equations are:

$$\sum Y = na + b\sum X \quad (4.1)$$

$$\sum XY = a\sum X + b\sum X^2 \quad (4.2)$$

Where:

X = given values of independent variables (year code)

Y = given values of dependent variables

n = number of given period of observation

The values of a and b can be calculated as follows.

$$\left\{ \begin{array}{l} a = \frac{n \sum_{i=1}^n x_i y_i - \sum_{i=1}^n x_i \sum_{i=1}^n y_i}{\sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2} \\ b = \frac{1}{n} \sum_{i=1}^n y_i - \frac{a}{n} \sum_{i=1}^n x_i \end{array} \right. \quad (4.3)$$

Accordingly, even though the life span of the case machinery is not clearly known, the researcher assumed as it will have ten years life span based on the information gathered from the finance department.

As it has been mentioned above, the data has a trend which indicates that least square method can be used to estimate the remaining future maintenance cost. Consequently, this method is used to estimate or forecast the total cost of maintenance for the next four years up to 2011 as shown in table 4.5 below.

Table 4.5 Forecasted maintenance cost

Year	X	Y	X ²	XY	Forecasted cost of maintenance ($\hat{Y}$)
2002	-3	73,951.79	9	-221,855.37	73,536.72
2003	-2	77,997.66	4	-155,995.32	84,359.39
2004	-1	93,474.33	1	-93,474.33	95,182.06
2005	1	123,022.76	1	123,022.76	116,827.39
2006	2	151,408.42	4	302,816.84	127,650.06
2007	3	116,173.39	9	348,520.17	138,472.73
2008	4	-	-	-	149,295.40
2009	5	-	-	-	160,118.07
2010	6	-	-	-	170,940.74
2011	7	-	-	-	181,763.41

One form of tracking signal is the ratio of the cumulative sum of forecast errors (the deviations between the estimated forecasts and the actual values) to the mean absolute deviation (MAD) [46]. Due to the fact that tracking signal is a simple indicator that whether bias is present in the forecast values or not, it is calculated for the above forecasted maintenance costs in the table 4.6 using the following formula.

$$\text{Tracking signal} = \Sigma (\text{Actual value} - \text{forecasted value}) / \text{MAD}$$

The formula for the MAD is:

$$\text{MAD} = \Sigma |\text{Actual value} - \text{forecasted value}| / n$$

Where n is the number of periods. Plugging this in, the entire formula for tracking signal is:

$$\text{Tracking signal} = \frac{\sum (\text{actual value} - \text{forecasted value})}{(\sum |\text{Actual value} - \text{forecasted value}| / n)}$$

Table 4.6 Tracking signal calculation for estimated maintenance cost

Year	Actual cost of maintenance	Forecasted cost of maintenance	Error= Actual - forecasted cost	Summation of error	Absolute error	Summation of absolute error	Tracking signal
2002	73,951.79	73,536.72	415.07	415.07	415.07	415.07	1
2003	77,997.66	84,359.39	-6,361.73	-5,946.65	6,361.73	6,776.80	-1.7550033
2004	93,474.33	95,182.06	-1,707.72	-7,654.38	1,707.72	8,484.52	-2.706472509
2005	123,022.76	116,827.39	6,195.37	-1,459.01	6,195.37	14,679.89	-0.397553207
2006	151,408.42	127,650.06	23,758.35	22,299.34	23,758.35	38,438.25	2.900671483
2007	116,173.39	138,472.73	-22,299.34	0.00	22,299.34	60,737.59	0

As can be seen in the table above, the predicted value gave a mean absolute deviation of 10122.93 and tracking signal between -2.7 to 2.9. As long as the tracking signal is between -4 and 4, it is assumed that the model is working correctly and no need of revision.

4.2.4 Downtime Cost or Cost of Production Loss

The cost of production loss is estimated considering the time to repair the machine during failure as a down time; it is difficult to estimate the exact down time due to shortage of data, scheduled maintenance, and power interruption. Hence, cost of production loss is estimated using Equation (3.7).

Table 4.7 Total cost of production loss

Year	Failure number	Time to repair (days)	Production per Day	Price per unit (Birr)	Total cost of production loss
2002	1	0.5	250	39.19	4898.75
	2	0.1	250	39.19	979.75
	3	1.5	250	39.19	14696.25
	4	0.35	250	39.19	3429.125
	5	0.23	250	39.19	2253.425
	6	3	250	39.19	29392.5

	7	0.19	250	39.19	1861.525
	8	1.2	250	39.19	11757
	9	0.95	250	39.19	9307.625
	10	0.36	250	39.19	3527.1
	11	0.7	250	39.19	6858.25
	12	4.2	250	39.19	41149.5
	13	0.25	250	39.19	2449.375
					132560.175
	14	1	250	39.19	9797.5
	15	0.3	250	39.19	2939.25
2003	16	2.5	250	39.19	24493.75
	17	0.2	250	39.19	1959.5
	18	1.5	250	39.19	14696.25
	19	0.5	250	39.19	4898.75
	20	2.3	250	39.19	22534.25
	21	0.9	250	39.19	8817.75
	22	0.15	250	39.19	1469.625
	23	0.18	250	39.19	1763.55
	24	1.5	250	39.19	14696.25
	25	0.17	250	39.19	1665.575
	26	0.6	250	39.19	5878.5
	27	0.2	250	39.19	1959.5
	28	3.5	250	39.19	34291.25
	29	0.25	250	39.19	2449.375
	30	1	250	39.19	9797.5
	31	0.02	250	39.19	195.95
	32	1.5	250	39.19	14696.25
	33	0.25	250	39.19	2449.375
	34	2	250	39.19	19595
	35	0.81	250	39.19	7935.975
					208980.675

Down time cost or cost of production lost data for the first two years and the estimated down time cost is presented in table 4.7 above. The remaining three years' data is attached in Appendix C. The seven years estimated down time cost is summarized in table 4.8.

Table 4.8 Summary of estimated cost of production lost

Year	Estimated repair cost
2002	132,560.18
2003	208,980.68
2004	343,402.38
2005	349,770.75
2006	438,928.00
2007	388,176.95
Total	1,861,818.93

Similar to cost of maintenance, the total cost of production loss for the next four year up to 2011 is estimated using least square method as shown in table 4.9 below.

Table 4.9 Forecasted Cost of production lost

Year	Time Period (X)	Actual cost of production lost (Y)	X ²	XY	Forecasted Cost of production lost ($\hat{Y}$)
2002	-3	132,560.18	9	-397,680.53	178,183.87
2003	-2	208,980.68	4	-417,961.35	222,223.63
2004	-1	343,402.38	1	-343,402.38	266,263.39
2005	1	349,770.75	1	349,770.75	354,342.92
2006	2	438,928.00	4	877,856.00	398,382.68
2007	3	388,176.95	9	1,164,530.85	442,422.44
2008	4	-	-	-	486,462.20
2009	5	-	-	-	530,501.97
2010	6	-	-	-	574,541.73
2011	7	-	-	-	618,581.49

Similar to the forecasted maintenance, tracking signal is calculated for the lost production estimated cost in table 4.8 and its tracking signal is found to be between -2 to 1.49. As long as the tracking signal is between -4 and 4, it is assumed that the model is working correctly and no need of revision.

Table 4.10 Tracking signal estimation for cost of production loss

Year	Actual cost of maintenance	Forecasted cost of maintenance	Error = Actual -forecasted cost	Summation of error	Absolute error	Summation of absolute error	Tracking signal
2002	132,560.18	178,183.87	-45,623.69	-45,623.69	45,623.69	45,623.69	-1
2003	208,980.68	222,223.63	-13,242.95	-58,866.65	13,242.95	58,866.64	-2
2004	343,402.38	266,263.39	77,138.98	18,272.34	77,138.98	136,005.62	0.40305
2005	349,770.75	354,342.92	-4,572.17	13,700.17	4,572.17	140,577.79	0.389825
2006	438,928.00	398,382.68	40,545.32	54,245.49	40,545.32	181,123.11	1.497476
2007	388,176.95	442,422.44	-54,245.49	0.00	54,245.49	235,368.60	0

❖ Present Worth Value

Present worth method discount future amounts to the present by using the interest rate over the appropriate study period; therefore, before conducting an LCC, the analyst must define the general parameters, such as analysis period and discount rate. The formulas for calculating the net present value and the net present value are shown below.

$$PWF = \left(\frac{P}{A}, i\%, t \right) = \frac{1 - (1 - i)^{-t}}{i} \quad (4.4)$$

$$PWF = \left(\frac{P}{F}, i\%, t \right) = (1 + i)^{-t} \quad (4.5)$$

$$PW = \frac{FC}{(1 + i)^t} \quad (4.6)$$

$$NPW = IC + \sum [A * \left(\frac{P}{A}, i\%, t \right)] + \sum FC * \left(\frac{P}{F}, i\%, t \right) \quad (4.7)$$

Where: PWF is the present worth factor, P/A is a notation used to represent “calculating the present value given the annual cost”. P/F is a notation used to represent “calculating the present value given the future cost”, PW is “present worth”, FC is “future cost”, NPW is the net present worth, IC is the initial cost, A is annual cost, i is the interest rate and t is the time.

Therefore, since the aforementioned forecasted costs are calculated assuming they are the coming four years cost data, the results are future cost and they have to be changed to the present time value. Consequently, the present worth (PW) value of operation cost, maintenance cost, and downtime cost are calculated using Equation (4.6). The present worth value of the four years forecasted costs and their LCC is shown in table 4.9 for the predicted cost and in table 4.10 for the actual and predicted cost together.

Table 4.11 Cumulative LCC for predicted cost

Year	Interest rate	Operating cost	PW (i=10%) for Operating cost	Cumulative Operating PW (i=10%), (Birr)	Forecasted Maintenance cost (Birr)	PW (i=10%) for Maintenance Cost (Birr)	Cumulative Maintenance PW (i=10%), (Birr)	Forecasted Down time cost (Birr)	PW (i=10%) for Down time Cost (Birr)	Cumulative Down time PW (i=10%), (Birr)	Net LCC (Birr)	Cumulative LCC (Birr)
2008	1	346,921.07	346921.0707	346921.0707	149,295.40	149295.4032	149295.4032	486,462.20	486,462.20	486,462.20	982,678.68	982,678.68
2009	0.966183575	346,921.07	335189.4404	682110.5111	160,118.07	154703.452	303998.8551	530,501.97	512,562.29	999,024.49	1,002,455.18	1,985,133.86
2010	0.9335107	346,921.07	323854.5316	1005965.043	170,940.74	159575.012	463573.8672	574,541.73	536,340.85	1,535,365.34	1,019,770.40	3,004,904.25
2011	0.901942706	346,921.07	312902.9293	1318867.972	181,763.41	163940.1836	627514.0507	618,581.49	557,925.06	2,093,290.41	1,034,768.18	4,039,672.43
			1318867.972			627514.0507			2,093,290.41		4,039,672.43	

Table 4.12 Cumulative LCC for Actual and predicted cost

Year	Capital cost	Operating cost	Cumulative operating cost	Cost of Maintenance	Cumulative cost of Maintenance	Cost of Downtime	Cumulative cost of Downtime	Life cycle cost	Cumulative LCC
2002	1,053,000.00	346,921.07	346,921.07	73,536.72	73,536.72	178,183.87	178,183.87	1,651,641.65	1,651,641.65
2003		346,921.07	693,842.14	84,359.39	157,896.10	222,223.63	400,407.50	653,504.09	2,305,145.74
2004		346,921.07	1,040,763.21	95,182.06	253,078.16	266,263.39	666,670.89	708,366.52	3,013,512.26
2005		346,921.07	1,387,684.28	116,827.39	369,905.55	354,342.92	1,021,013.80	818,091.38	3,831,603.64
2006		346,921.07	1,734,605.35	127,650.06	497,555.62	398,382.68	1,419,396.48	872,953.81	4,704,557.45
2007		346,921.07	2,081,526.42	138,472.73	636,028.35	442,422.44	1,861,818.93	927,816.25	5,632,373.70
PW value of future cost (2008-2011)		1318867.972	3,400,394.40	627,514.05	1,263,542.40	2,093,290.41	3,955,109.33	4,039,672.43	9,672,046.13
	1,053,000.00	3,400,394.40		1,263,542.40		3,955,109.33		9,672,046.13	

4.3 RESULT AND DISCUSSION

As can be seen from Figure 4.4, the cost of maintenance and downtime for the first three years, since the machine is purchased, is not that much exaggerated compared with the other years. It should not be forgotten that since the machine is new at that time, it might not be strange or surprising if the maintenance and downtime costs of the machine are not that much exaggerated. Whereas, the chart below indicates that the cost of maintenance and downtime trend is increasing from time to time.

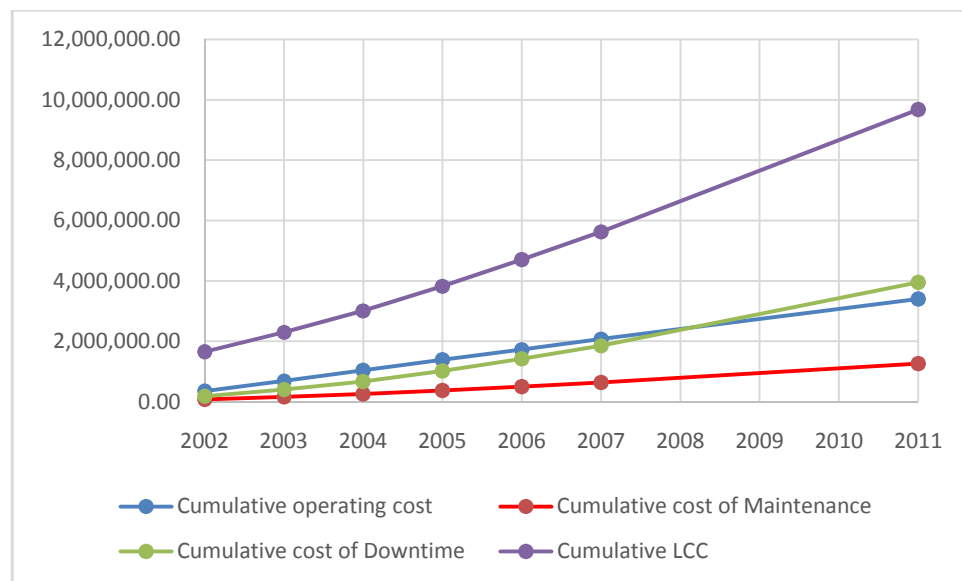


Figure 4.4 Cumulative LCC, operating, maintenance, and downtime cost

In addition, even if the data for 2007 is not complete and consists of only seven months, it is almost the same as that of 2006 which is a full year data. This indicates that the maintenance and downtime costs are increasing from time to time. Particularly, the above figure shows that the downtime costs overrun the operating cost as the life of the equipment increases.

When we come to the cumulative cost percentage distribution of the LCC components, the pie chart below indicates that the total LCC of the extrusion machine from 2002 to 2011 is estimated and is found to be **9,672,046.13 Birr**. The acquisition cost is found to be 10.88% of the total LCC which is **1,053,000 Birr**. This shows that it is necessary to have a long-term outlook to the investment decision-making process rather than trying to save money in the short-term by simply purchasing assets with lower initial acquisition costs.

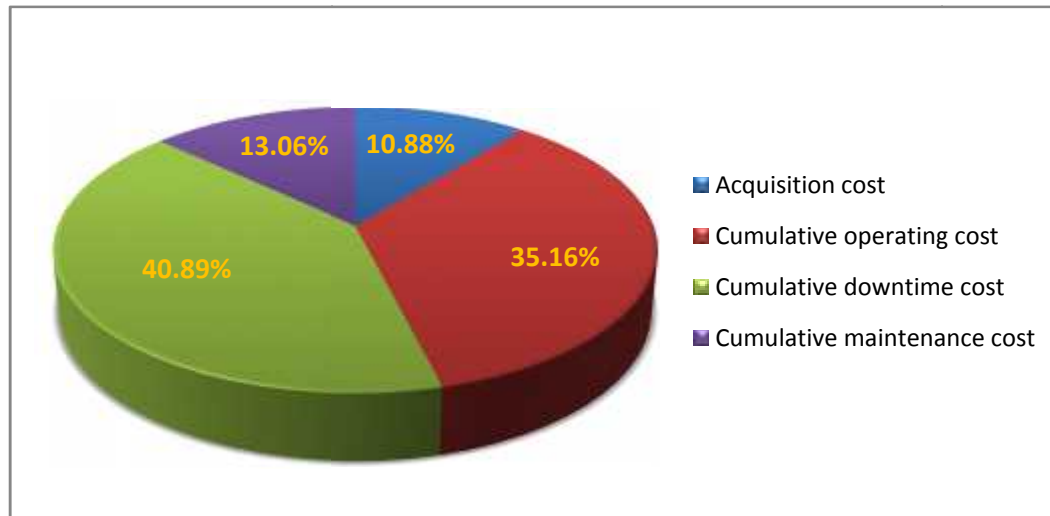


Figure 4.5 Percentage contributions of capital cost and cumulative operating, maintenance and down time cost

The failure cost (maintenance and down time cost) is the highest cost which is 53.96% (5,218,651.73 **Birr**) of the total LCC followed by the operating cost 35.16% (3,955,109.33) of the total LCC. It is known that the power consumed depends on efficiency of motor/bearing, and extrusion machine. Thus, purchasing high efficiency motors can save the total LCC by reducing the operating cost.

In general, the down time cost and the maintenance cost incurred due to the high frequency of the failure. When a product or system is on its operation phase, it will fail and be repaired to restore it to its operating condition. The number of failure, why it fails, when it fails and the time to repair all depends on its reliability and maintainability. Since failure of a system can be occurred unexpectedly when equipments run under rigorous conditions, it leads to aging, erosion, wear etc. These failures have direct impact on LCC; the less the number of failure the less the cost of failure.

4.3.1 Identify the Exiting Problem on the Estimated LCC using the Concept of Quality

As stated by Birhanu B. and Eshste B, 2014, quality improvement efforts should have been equally applied on the design, manufacturing and operation phases of a product lifecycle [3]. Quality concepts should be equally applied throughout the life time of any equipment or machinery in order to optimize the overall acquisition and also the sustaining or owner ship cost.

However, since the existing traditional equipment selection does not consider the above quality dimensions for instance reliability and maintainability, its effect leads to high failure cost. In addition the purchasing decision according to the information gathered from the case company was biased by brand and advertisement that means perceived quality had a greater impact on the overall sustaining cost.

This means, contrasting to the traditional quality improvement method which entirely focuses on the product design and manufacturing, quality subject must be included in the operation phase. This gives equal attention on the product quality in operation as do the design and manufacturing phases. In principle, focusing on the design and manufacturing phases is acceptable/ appropriate because the most important quality indicators are determined in these stages. Practically, however, as it is found from the analysis that almost 90% of the equipment's lifecycle cost is associated with the operation stage where the devils reside. This indicates the aim of quality improvement was supposed to encompass the entire spectrum of the product lifecycle.

Accordingly, before purchasing the machine, Ethiopian Plastic Industry, as a customer, was supposed to consider the anticipated life of the machine, the expected number of failure, whether it can be maintained easily or not, and also its energy consumption.

On the other side, the manufacturer of the machine was expected to examine and give detail information for the purchasers on: the anticipated lifespan of the machine, its function, whether it might become redundant in some capacity before the end of its useful lifespan, and the major failures predicted along with their frequency.

Since the above issues were not addressed well prior to the machine acquisition, the customer or owner of the machine is exposed to unexpected exaggerated sustaining cost.

4.3.2 Quality Costing and its Methods

Quality has traditionally been defined either subjectively in terms of excellence or performance or objectively in terms of conformance. Differentiating the meaning of quality in this manner leads to conflicting perspectives when trying to determine the impact of quality upon life cycle costs.

A user may have different requirements than an owner or may not realise that what he considers poorer quality components, actually does meet the owners requirement for a low cost. Whose perspective is most important, the user, the designer, or the manufacturer? Arditi and Gunaydin [47] found that there was strong agreement between design professionals, constructors, property (facility) managers and construction managers in ranking factors that affect quality in their respective involvement in the phases of the life cycle of building projects. Their work however, did not consider the user.

Mc George and Palmer [48] propose that quality is not defined through isolated perspectives but, is a combination of the following:

- manufacturing based - conformance to requirements or a specification
- product based - based on a specific measure or characteristic such as durability
- user based - extent to which the user is satisfied
- value based - what is the “best buy”

This diversification in turn leads to an objective list of principal quality dimensions. Accepting that the meaning of quality is not one dimensional removes the constraint of perspective imposed when quality is evaluated based on one definition or another. The dimensions proposed by Mc George and Palmer [48] are: performance, reliability, conformance, durability, flexibility, serviceability, aesthetics and perceived quality (see section 2.2.3).

Using this broad meaning of quality, the question that must now be addressed is how quality costs should be integrated in life cycle cost analysis in order to determine their impact. The four most common quality costing methods, based on ISO 9004-1, are:

- ❖ Fiegenbaum’s quality costing method.
- ❖ Crosby and Philips’ process costing method which examines the costs of conformance and non-conformance.
- ❖ Taguchi and Genichi’s quality loss method which is founded on a loss function model
- ❖ PAF (prevention, appraisal, failure) method which associates costs with each activity and allocated those costs according to the categories of prevention, appraisal or failure.

The first problem with using the above methods is that the methods are strictly based on conformance. While quality related activities can be tracked during design and production or manufacturing to provide a quality cost for these two phases, the models are too detailed to be used in a general prediction of the impact of quality on operation and maintenance costs. The other challenge to use these methods is that the life cycle costing methods don't consider quality in analysing the life cycle cost. Lastly, when it comes to shortage of data, both methods have drawback. These methods only function with the adequate historical data. Accordingly, a solution has been proposed that integrates quality in life cycle cost analysis.

4.4 PROPOSED QUALITY BASED LIFE CYCLE COSTING FRAMEWORK

The life cycle cost model of Fabrycky and Balanchard's [15] is iterative, ongoing and could be customized to the specific application. For example, with a slight amendment to this methodology's conceptual LCC model, a quality concept upgrading can incorporate additional quality cost drivers into its cost breakdown structure (CBS) because of the methodology's conformity with the usual steps to be followed irrespective of applications. The proposed framework upgrades this model by integrating quality dimensions: reliability, conformance, maintainability, durability, flexibility, perceived quality; which are considered as the high level of cost drivers. When equipment selection is made with LCC analysis, it will be only based on the overall minimum life cycle cost. The framework will optimize these costs considering quality cost drivers in addition to minimum life cycle cost as a selection criterion in their decision making. Above all, taking into account quality dimensions in the framework will certainly resolve the occurrence of such unexpected cost. The high level of cost drivers are discussed in the next section. The approach has been formulated in such a way that it provides where possible a simple yet practical mean for decisions making. The detail of the framework is discussed below.

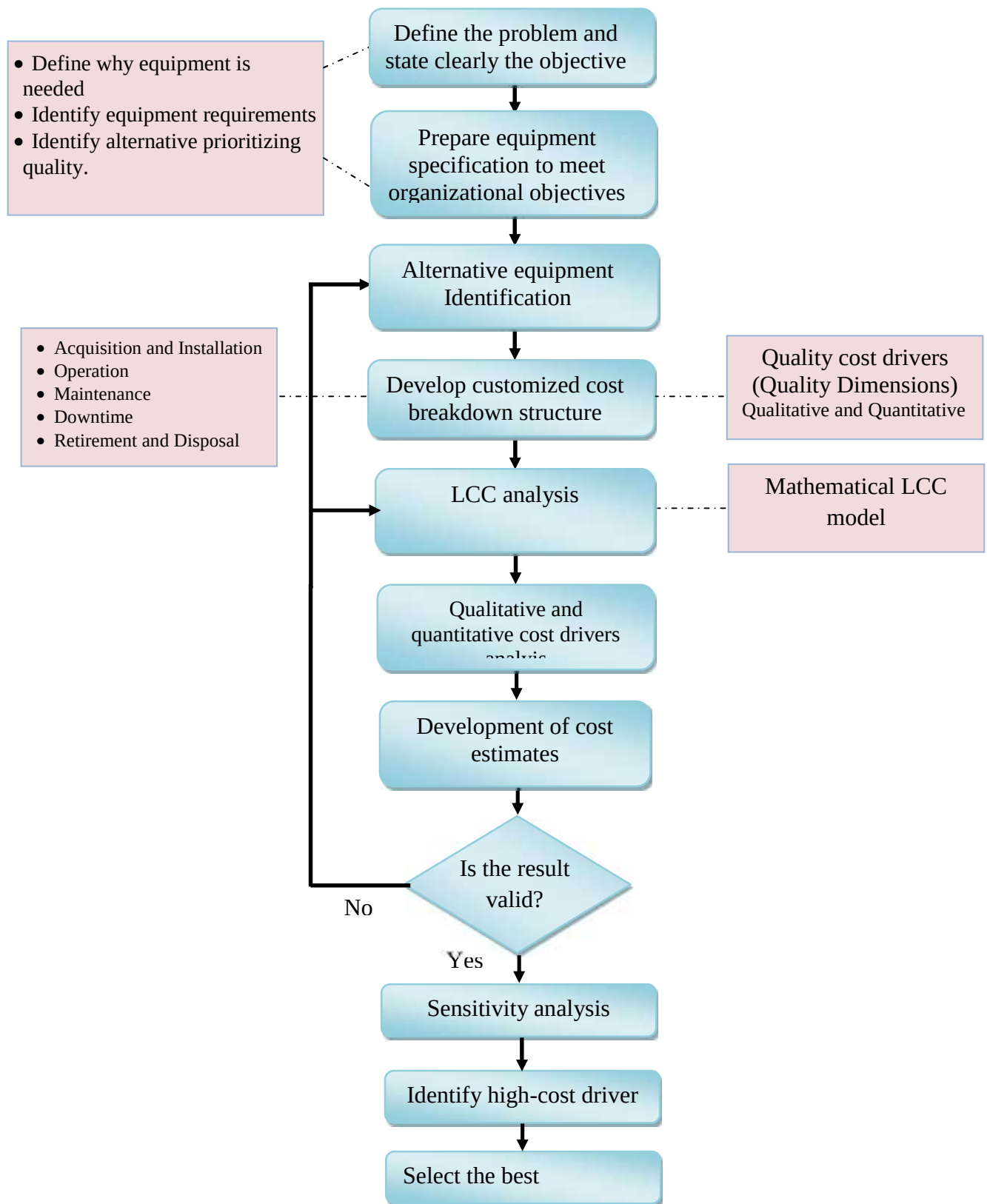


Figure 4.6 Proposed Quality based life cycle costing framework

4.4.1 Selecting the Objective and Identifying Alternative Options

The most important factor in decision making is the identification of specific purpose to achieve at the end of a study. Once an objective is identified and consistently followed throughout the study, it will give a successful analysis. There should be available alternatives to be evaluated based on the stated objective. Each available alternative has its own strength and weakness depending on the characteristics of the equipment or machinery under study. Therefore, it should be analyzed and evaluated before selecting the options. The primary interest of the owner is optimum productivity and a quality product at a low cost. Purchasing machineries with high cost is perceived as a necessary evil that takes too much time and effort. It is rarely viewed as an opportunity to improve the company's bottom line by improving long-term productivity. The goal of this thesis is to highlight that high initial expense is an investment in the future and ensures that it has to be seen as an asset. The selection of one of these options highly depends on numerous factors which in turn affects the cost and time of it. The framework shows how to identify alternative options and sets for alternatives.

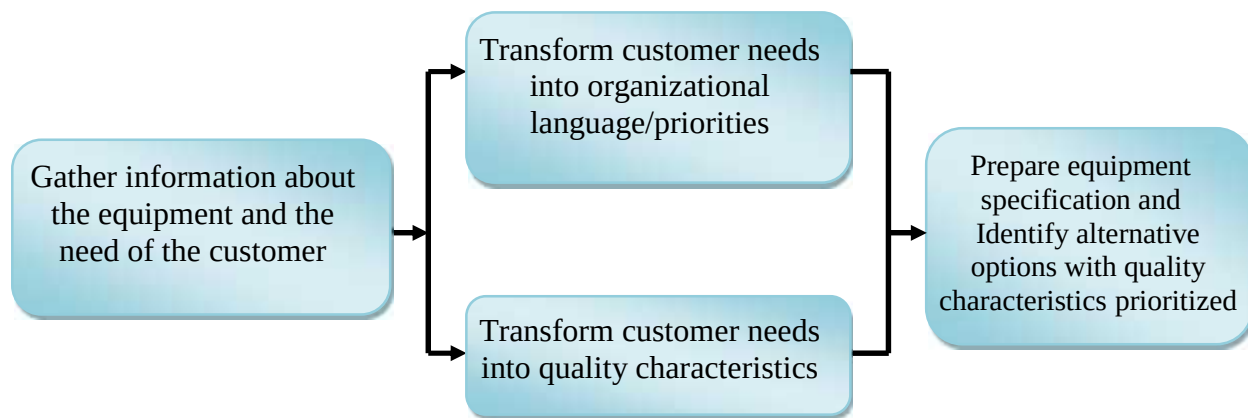


Figure 4.7 How to identify alternative options and set for alternatives.

Gathering information on customer's need involves listening to the customer's requirements which can be developed in many forms. Then, the gathered information must be transformed to organizational priorities for a better understanding of internal and external customers demand and to identify areas for organizational focus.

The quality characteristics represent how the organization will measure or control the characteristics of its production to meet or exceed customer demands. These characteristics are

attributes of the production that directly relate to the quality required by the customer. This is done by reviewing customer demand from the above requirements and identifying and sort quality characteristics that are related to each demand.

After examining the quality characteristics and conducting competitive analysis on customer demands generated in the previous steps, the next step is identification of the priorities among the quality characteristics. This can be accomplished considering availability of fitted equipments to be purchased; availability of qualified employee to compare and analyze the equipment to be purchased based on quality characteristics; implementation of salutatory and regulatory requirement; finally by assigning a budget for the required facilities.

4.4.2 Customized Cost Breakdown Structure for the Integration of Quality Dimensions

Cost driver with respect to life cycle costing is defined by Kawauchi and Rausand [23] as “life cycle cost element which has a major impact on the life cycle costing or any factor that significantly affects cost”. Cost drivers can be quantitative and qualitative. The former is one that has a numerical value attached to it and its primary data is in form of a number like reliability, maintainability, and conformance; and the later is one which cannot be assigned a value, and its primary data is in the form of expert opinion or judgment, e.g. flexibility, durability, perceived quality.

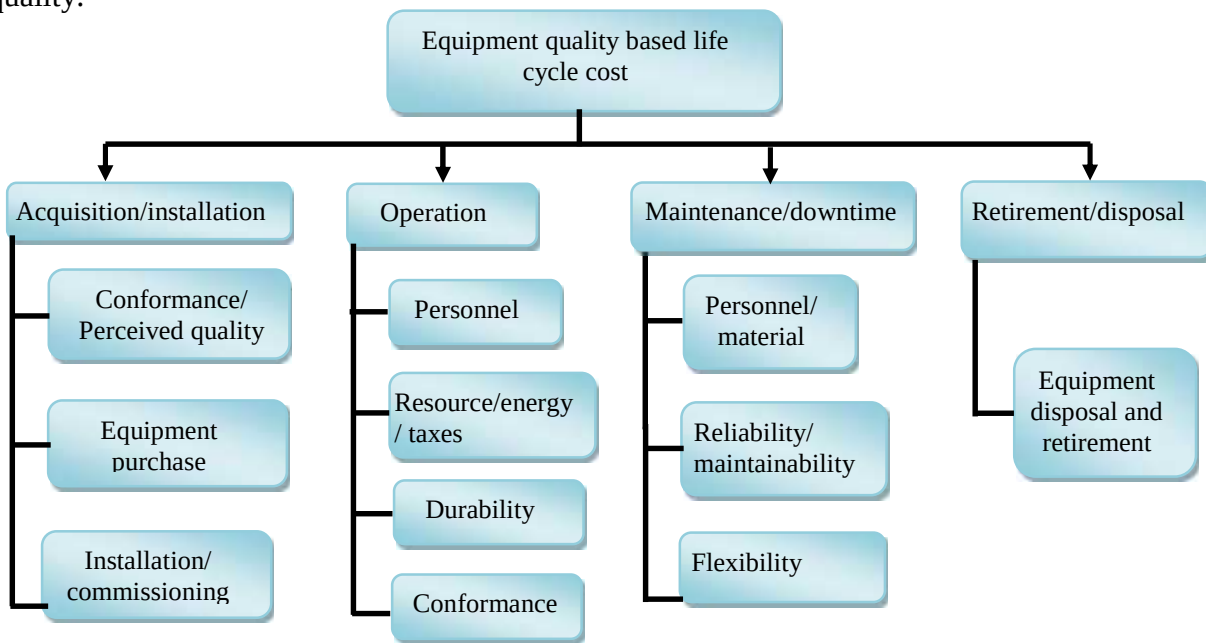


Figure 4.8 Customized cost breakdown structure for the integration of quality dimensions

Most of the cost break down structure components listed in figure 4.8 are discussed in chapter three, section 3.2 and the quality related cost drivers are also discussed in the literature review.

4.4.3 Selection of Cost Model for Analysis

➤ Cost model for LCC components

Estimating the total LCC requires breakdown of the equipment into its constituent cost elements over time. The level to which it is broken down will depend on the purpose and scope of the LCC analysis. The developed model in chapter three, section 3.2, contains a cost elements which are breakdown into six; acquisition, installation, operation, maintenance, downtime and disposal. This model is upgraded in this section to include the quality parameters inside each cost. The general LCC of a customer was shown in Equation 3.1. Furthermore, the mathematical expressions of all components are shown in same section from Equation 3.2 to 3.7 in detail.

As it has been mentioned in the literature review, there are many cost estimating methods available. Among them are; Activity based costing, detailed costing, Parametric costing, Analogue costing, and Engineering costing. For this case, since the cost estimation for the quantitative cost drivers depend on the case wherein the framework is to be applied, the user can choose the best estimation method that fits the case.

➤ Decision making for Qualitative Cost Drivers

Evaluating possible solutions qualitatively and making a decision on them can be achieved by recording non-numeric and language specific inputs or opinions about the equipment. This can be done, as stated by Ocker R., et al. [49], by following the pattern of questionnaires, qualitative-quantitative evaluation scales such as the Likert scale, which interpret qualitative inputs to quantitative ratings.

In order to understand a complex environment, one should begin with a qualitative assessment of its characteristics since qualitative information have a great value to offer to those seeking to extract information, knowledge and wisdom from it. However, even if it appears valuable on the surface, once collected, it must be effectively analyzed to yield meaningful information.

According to J. Fulop [50], it is very important to make distinction between the cases whether we have a single or multiple criteria before selecting a qualitative tool to deal with the gathered data. Multiple criteria optimization incorporate cases like when there is a finite number of criteria but number of the feasible alternatives (the ones meeting the requirements) is infinite. In addition, techniques of multiple criteria optimization can be used when the number of feasible alternatives is finite but they are given only in implicit form [51]. In general, there exist two distinctive types of multiple criteria optimization problems due to the different problems settings: one type having a finite number of alternative solutions and the other an infinite number of solutions. Normally in problems associated with selection and assessment, the number of alternative solutions is limited. In this research, the focus of new framework is on decision making problems when the number of the criteria and alternatives is finite, and the alternatives are given explicitly. Problems of this type are called multi-criteria decision making problems (MCDM). There are numerous MCDM methods; the most currently used 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).

For this case, Analytical Hierarchy Process (AHP) is preferable amongst other multi-criteria decision making technique since it provides a convenient way to quantify the qualitative attributes of the existing alternatives removing subjectivity in the result [52].

The AHP assists the analyst to organize the essential aspects of a problem into a hierarchical pattern. Moreover, it helps to reduce complex decisions to a series of simple comparison and to rank and synthesize the results. AHP not only assists the analyst to arrive at the best decision but provides clarity in the manner the choices are made.

4.4.4 Development of Cost Estimates

As it has been mentioned earlier in the methodology part, it is essential to discount all expenditures to a specific decision point when considering costs that will be incurred in the future. Present worth method discounts future amounts to the present by using the interest rate over the appropriate study period. Before conducting LCC, therefore, the analyst must define the general parameters, such as analysis period and discount rate.

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 for present worth value is:

$$PW = \frac{FC}{(1+i)^t} \quad (4.6)$$

$$NPW = IC + \sum [A * (\frac{P}{A}, i\%, t)] + \sum FC * (\frac{P}{F}, i\%, t) \quad (4.7)$$

Where, PW is “present worth”, FC is “future cost” P/A is a notation used to represent “calculating the present value given the annual cost”. P/F is a notation used to represent “calculating the present value given the future cost”, PW is “present worth”, FV is “future value”, NPW is the net present worth, IC is the initial cost, A is annual cost, i is the interest rate and t is the time.

4.4.5 Sensitivity Analysis and Identification of High-Cost Driver

In order to determine which parameters are the key drivers of a given model, sensitivity analysis is very important. A sensitivity analysis uses to recognize how sensitive the output is to changes in the input and to determine which parameters are the key drivers. Sensitivity analysis can answer the “what if” questions by simply altering the value of each input upper or down holding all others constant. By applying extensive outputs from sensitivity analysis, modellers can be able to consider a wide range of scenarios and can raise the level of confidence that a reviewer will have in the model. Although sensitivity analysis can be accomplished either in one way or multi-way, the simplest form of it can be done simply varying one value in the model by a given amount, and examining the impact that the change has on the model’s results. The one-way sensitivity analysis is useful in demonstrating the impact of one parameter varying in the model; however, it may be essential to inspect the relationship of two or more different parameters changing simultaneously. This approach involves the changing of, for example, two key parameters showing the results for each potential combination of values within a given range. In applying the framework, multi-way sensitivity analysis is preferred to be conducted in order to

determine potential combination of values within a given range to figure out the most sensitive input and the high cost drivers.

4.4.6 Select the Best Alternative

The last section of the framework is to select the best alternative based on the conducted analysis. Since the cost analysis is conducted to optimize the overall acquisition and sustaining cost, among the alternative machineries, the one having the minimum cumulative life cycle cost is the best alternative.

4.5 VALIDATION OF THE PROPOSED FRAMEWORK

Practical validation of the the proposed quality based life cycle costing framework requires applying the framework for new equipment selection decision making and comparing the result with the output of those decisions made by the traditional approaches. This needs a long period of time at least equal to the life span of the equipment. As a result, validation of the framework was carried out using expert opinion. Questionnaire was developed and distributed for nine academicians in the field of engineering who are teaching in higher institutions and other three experts working in the case company. The list of the questions used to elicit the opinions of the experts is presented in Appendix D. Among the distributed questioners only five were returned. The questions asked, as well as the responses from the experts are summarised in the following paragraphs.

For the first question which reads as, “What can you say about the appropriateness of the proposed framework?” almost all the respondents agree that the frame work looks sound enough; especially, it is useful for alleviating quality related problems which were not addressed by the traditional approach. One of the respondents, however, suggested that the framework needs to see some aspects of decision areas like identifying alternative options could be the area where error can happen. Therefore, he commented that it is better if the decision for “is the result valid” also loops back starting from identifying alternative options.

For the second question, “Do you think the framework is helpful to prepare a good life cycle cost estimate?” they responded that it is very interesting and helpful particularly it enables to solve problems that most companies are facing while selecting equipments on the list cost approach. In

addition they stated that the framework can give an insight for a better decision in equipment selection considering the life time operation and maintenance cost.

In the third question the respondents were also asked to express their opinion whether the cost elements in the customized cost breakdown structure of the framework are adequate or not. Almost all of them reacted that the elements listed are enough; especially, including the quality dimensions in the cost breakdown structure will make the framework helpful to make a better decision during equipment selection.

The fourth question was intended to address how logical the steps in the framework are. Except two respondents who recommended to include equipment specification preparation based on the organizational objectives in the framework, the remaining respondents argue that the steps are logical.

Lastly the respondents were asked if they have a suggestion on what to include in the framework to enhance its validity. For this question, all respondents commented that the proposed framework is good as it is but some of them suggested that it is good to test the validity of the framework practically.

In general, the respondents affirmed that the framework is valid and applicable with little modification. Therefore, the researcher tried to update the framework incorporating all constrictive suggestions forwarded by the respondents. The researcher found it hard to test the framework practically for the reason that it requires a long period of time; however, validating it practically will make it more convenient and it is recommended as a future work.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This research presents an analysis which studies the life cycle cost analysis and proposed a framework which integrates quality dimensions to life cycle costing estimation. In order to assess the overall life cycle cost scenarios a selected case study, Ethio- Plastic Industry, was used to explore the practical problems a decision maker faced in the industry by considering specific machinery used. Even if the result and discussion were performed on the conduit machine the proposed quality based life cycle costing framework, can be used in other equipment. The life cycle cost of the conduit machine is estimated through a developed mathematical model in chapter three.

The life cycle cost of the conduit machine is estimated for acquisition, operation, maintenance and downtime cost. From the analysis the cost escalation components of the conduit machine were identified and prioritized. It is found that acquisition cost contributes 10.88%, maintenance cost contributes 13.06%, operation cost contributes 35% and downtime cost contributes 40.89% of the total LCC. As it can be seen from the analysis, the performance of the conduit machine is degrading; the plant managers need to make a decision whether to continue with the existing machine or to replace these machines with a new one. From this research, it can be concluded that unexpected costs arise at the forgotten areas i.e. after purchase, the ownership cost of the equipment which is around 90%. The acquisition cost is found to be 10.88% of the total LCC which is 1,053,000 Birr. This shows that it is necessary to have a long-term outlook to the investment decision-making process rather than trying to save money in the short-term by simply purchasing assets with lower initial acquisition costs.

The research distinguishes the inherent problems associated with the estimated life cycle cost. In general, the down time cost and the maintenance cost incurred due to the high frequency of the failure. When a product or system is on its operation phase, it will fail and be repaired to restore it to its operating condition. The number of failure, why it fails, when it fails and the time to repair all depends on its reliability and maintainability. Since failure of a system can be occurred unexpectedly when equipment run under rigorous conditions, it leads to aging, erosion, wear etc.

These failures have direct impact on LCC; the less the number of failure the less the cost of failure.

The proposed quality based life cycle cost framework takes into account all the quality dimension that are missed from the Fabrycky and Balanchard's life cycle costing frame work. The proposed framework upgrades this model by integrating quality dimensions; reliability, conformance, maintainability, durability, flexibility, perceived quality; which are considered as the high level of cost drivers. When equipment selection is made with LCC analysis, it will be only based on the overall minimum life cycle cost. The framework will optimize these costs considering quality cost drivers in addition to minimum life cycle cost as a selection criterion in their decision making. Above all, taking into account quality dimensions in the framework will certainly resolve the occurrence of such unexpected cost.

5.2 RECOMMENDATION

The main aim of Ethiopian plastic industry regarding quality system is to implement, maintain, and improve quality management system as per ISO 9001:2008 requirement and assure and maintain the quality reputation of their products and consider contribution of suppliers and other related parties. However from the analysis conducted one of the machines (conduit machine) is incurring a very high failure cost which shows that the machine is not available which in turn indicates that the company cannot fulfill customer requirement and is exposed to unexpected machinery ownership cost. To fill the gap and to effectively solve these problems, Ethiopian Plastic industry, as well as other similar companies having similar challenges, is highly recommended to apply or use the above proposed life cycle costing framework in their equipment selection decision making.

5.3 Future work

1. Adaptation of the developed quality based life cycle costing framework in a real case.
2. Developing a general mathematical model for estimating the quantitative quality cost drivers.

Reference

1. Alem Gemechu, 2009. Measuring national quality cost in Ethiopian import export products- (Thesis-Unpublished).
2. H. Paul Barringer, P.E., 2003. A Life Cycle Cost Summary, International Conference of Maintenance Societies, <http://www.icoms.org.au>.
3. Birhanu Beshah and Eshetie Berhan, 2014. 'Life Cycle Quality', International Journal for Quality Research 8(2), pp. 143–154.
4. Everett E. Adam Jr, 1997. 'An International Study of Quality Improvement Approach and Firm Performance', International Journal of Operations & Production Management, 17 (9), pp. 842-873.
5. C. Lee, and T. Lee, 2001. 'Quality/Productivity Practices and Company Performance in China', International Journal of Quality & Reliability Management, 18 (6), pp. 604-625.
6. M. Jeya Chandra, 2001. Statistical Quality, The Pennsylvania State University; CRC Press LLC.
7. Joseph M. Juran, 1999. Juran's Quality Hand book, 5th Edition, R.R Donnelly & Sons Co.
8. B.S. DHILLON, 2010. Life Cycle Costing for Engineers, Taylor and Francis Group, LLC, CRC Press,
9. Flynn, B., Roger G. Schroeder, and Sadao S., 1994. 'A framework for quality management research and an associated measurement system', Journal of Operations Management, 11 (5), pp 339-366.
10. Stephen J. Andrie, 1994. Total quality management in public transportation
11. W. Edward Deming, 2000. Out of the Crisis: Quality, Productivity and Competitive Position, MIT Press, ISBN 1461932173
12. Kaoru Ishikawa, 1989. Introduction to Quality Control, JUSE Press Ltd.
13. Jens J. Dahlgaard et.al, 2007. Fundamentals of total quality management, Taylor & Francis e-Library, ISBN 0 7487 7293 62007.
14. Thuy T.N Vo & Chi T.K Nguyen, 2015. 'Factors Influencing Customer Perceived Quality and Purchase Intention toward Private Labels in the Vietnam Market: The Moderating Effects of Store Image', International journal of marketing studies, 7(4), Canadian center of science and education

15. Fabrycky, W. J. and Blanchard, B. S. 1991. Life Cycle Cost and Economic Analysis, published by Prentice Hall, Englewood Cliffs, New Jersey, USA.
16. Coope, Tim, 1994. Beyond recycling: the longer life option, London, The new economic foundation.
17. H. Paul Barringer, P.E. and David P. Weber, 1996. Life Cycle Cost Tutorial, Fifth International Conference on Process Plant Reliability, Marriott Houston Westside Houston, Texas.
18. Kawauchi, Y. and Rausand, M., 1999. Life Cycle Cost (LCC) Analysis in Oil and Chemical Process Industries, Department of Quality and Production Engineering, Norwegian University of Science and Technology, Trondheim, Norway
19. A Life-Cycle Cost Estimating Methodology for NASA Developed Air Traffic Control Decision Support Tools. NASA Ames Research Center Moffett Field, CA 94035
20. Hiroshi YAMAGUCHI (-) Life Cycle Management Methodology using Lifecycle Cost Benefit Analysis for Washing Machines, Norihiro ITSUBO, National Institute of Advanced Industrial Science and Technology.
21. Okechukwu P. 2001. Development of a Life Cycle Cost estimating framework for oil refineries, (Thesis-Un published).
22. Department Of Energy (DOE) 1995. <http://www.em.doe.gov/ffcabb/ovpstp/life.html>, posted, 4/12/1995, on the World Wide Web.
23. Kawauchi, Y. and Rausand, M. 1999. Life Cycle Cost (LCC) Analysis in Oil and Chemical Process Industries, Department of Quality and Production Engineering, Norwegian University of Science and Technology, Trondheim, Norway,
24. Department of Energy Office of Industrial Technologies, 2001. Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems, Executive Summary; available online at: [www .oit.doe.gov](http://www.oit.doe.gov)
25. Blanchard, B.S. 1979. 'Life Cycle Costing– a review' Terotechnica, 1: 9–15.
26. Davis Langdon Management Consulting, 2006. Literature Review of Life Cycle Costing (LCC) and Life Cycle Assessment (LCA)
27. Lamar, W. E. 1981. Technical Evaluation Report on Design to Cost and Life Cycle Cost. North Atlantic Treaty Organization Advisory Group for Aerospace Research and

- Development (AGARD) Advisory Report no. 165. Available from the National Technical Information Service (NTIS), Springfield, VA.
28. Emblemavag, J. 2003. Life Cycle Costing – Using Activity-Based Costing and Monte Carlo Methods to Manage Future Costs and Risks, published by John Wiley & Sons, Inc., Hoboken, New Jersey.
29. Kirsten Rosselot and David T. (No date). Allen Life-Cycle Concepts, Product Stewardship and Green Engineering.
30. Gluch, P. and Baumann, H., 2004. ‘The Life Cycle Costing (LCC) Approach: A Conceptual Discussion of its Usefulness for Environmental Decision-Making’, Building and Environmental 3(9), pp.571-580.
31. Dhillon, B. S. 1980. ‘Life Cycle Cost: A survey. Microelectronics and Reliability’, An International Journal 20, pp.737–742.
32. Dhillon, B. S. 1983. Reliability Engineering in System Design and Operation. New York: Van Nostrand Reinhold Company.
33. Gupta, Y. P. 1983. Life Cycle Cost Models and Associated Uncertainties. In Electronic Systems Effectiveness and Life Cycle Costing, ed. J. K. Skwirzyski, 535–549. Berlin: Springer–Verlag.
34. Sherif, Y. S., and Kolarik, W. J. 1981. Life Cycle Costing Concepts and Practice. OMEGA 9:287–296.
35. Dahlen, P. and Bolmsjo, G. S. 1996. ‘Life Cycle Cost Analysis of the Labor Factor’, International Journal of Production Economics, 46(47), pp.459-467.
36. Woodward, D. G. 1997. ‘Life Cycle Costing- Theory, Information Acquisition and Application’, International Journal of Project Management, 15(6), pp.335-344.
37. Iwawaki, H.; Kawauchi, Y.; Muraki, M.; Matsuoka, S.; Evans, D. 2002. “Life Cycle Costing Based Decision Making for Reactor Effluent Air Coolers in Refineries”, Corrosion 2002, Paper No. 02483, pp.1-10.
38. Emblemavag, J. 2003. Life Cycle Costing – Using Activity-Based Costing and Monte Carlo Methods to Manage Future Costs and Risks, published by John Wiley & Sons, Inc., Hoboken, New Jersey.

39. EN ISO 15663-1&2 2006. 'Petroleum and Natural Gas Industries-Life Cycle Costing', prepared and approved by Technical Committee CEN/TC 12 (European Committee for Standardisation) .
40. Adnan Niazi, Jian S. Dai, Stavroula Balabani and Lakmal Seneviratne, 2006. 'Product Cost Estimation. Technique Classification and Methodology Review', Journal of Manufacturing science and engineering, 128(563)
41. Hassan Gurak, 2003. Hidden Cost of Technology Transfer, YK Economic review.
42. Ross Dawson, Andrew Parker, Robert Cross, Ted Smith, Liz Lightfoot, 2005. How Technology-Purchasing Decisions Are Really Made. The network roundtable at the University of Virginia
43. Alexander Layer , Erik Ten Brinke , Fred Van Houten , Hubert Kals & Siegmund Haasis, 2002. 'Recent and future Trends in Cost Estimation', International Journal of Computer integrated manufacturing, vol.15
44. Bowen, B., and Williams, J. 1975. Life Costing and Problems of Data, Industrialization Forum 6:21–24.
45. Daniel Kitaw (Dr.-Ing.), 2009. Industrial Management and Engineering Economy, An Introduction to Industrial Engineering Text Book, Addis Ababa University press.
46. R. Dan Raid & Nada R. Sanders, 2010. Operations Management, 4th edition
47. Arditi, D. and Gunaydin, H. M. 1998. Factors That Affect Process Quality in the Life.
48. McGeorge, D. And Palmer, A. 1997. Construction Management New Directions. Blackwell Science Ltd., Oxford.
49. Ocker R., Fjermestad J. et al, 1998. 'Effects of four Models of Group Communication on the Outcomes of Software Requirements Determination', Journal of management information system, 15(1).
50. J. Fulop, 2005, Introduction to Decision making methods, in BDEI- Workshop, 1-15
51. Dr. Ling Xu & Dr. Jian-Bo Yang, 2001. 'Introduction to Multi-Criteria Decision Making and the Evidential Reasoning Approach', Working Paper No. 0106 , Manchester School of Management
52. Xu, L. and Yang, J. 2001. 'Introduction to Multi-Criteria Decision Making and the Evidential Reasoning Approach', Working Paper No. 0106

53. Tiwari, N. (2006), "Using the Analytic Hierarchy Process (AHP) to identify Performance Scenarios for Enterprise Application".
54. Imad Alsyoud, 2004, Cost Effective Maintenance for Competitive Advantages, Desertation, Printed by Intellecta Docusys, Göteborg, Sweden

Appendix A: Detail cost history of spare part and tool

2005E.C	No.	SPARE PART AND TOOL	PCS	TOTAL COST	
				Unit price	Total price
	1	Elbow 1+1/4	14	50	700
	2	Over load relay	6	304.35	1826.1
	3	Conical twin screw	2	2096.75	4193.5
	4	Allen bolt 12*70	10	32	320
	5	Allen bolt 12*60	5	32	160
	6	Round heating band200*90	2	3988	7976
	7	Thermo regulator	2	1250	2500
	8	25 ampere contactor	7	187.6	1313.2
	9	Iron plug	21	41	861
	10	Round heating band 230*60	3	4437	13311
	11	Thermo couple	12	300	3600
	12	Potentiometer	2	1651.4	3302.8
	13	Push button	15	78.26	1173.9
	14	Allen bolt 18*50	3	32	96
	15	Nipples-1+1/2	12	35	420
	16	Air hose 8 inch	23	34	782
	17	Boll valve	13	116	1508
	18	Round heating band 156*100	3	2900	8700
	19	Termo Regulator	3	3016.16	9048.48
	20	Hose clamp	33	2.6	85.8
	21	Coupling rubber	3	590	1770
	22	Cotactor-220v-25A	8	208.69	1669.52
	23	Union 1=1/2	9	56.48	508.32
	24	Air solenoid valve	2	2800	5600
	25	Clamp 1 inch	17	104	1768
	26	T-joint ¾	3	44.34	133.02
	27	On-off switch	1	230	230
	28	Allen bolt-12=90	14	50	700
	29	Get valve -1+1/4	11	50	550
	30	Solenoid valve	3	2300	6900
	31	Selector switch	4	330	1320
	32	Variable resistance	8	450	3600
	33	Ball valve 1 inch	10	116	1160

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	34	Round heating band -270=50	3	4437	13311
	35	Reducer -3/4-1/2	8	33.04	264.32
	TOTAL				111,361.00
2006	1	Round heating band, 150*70	3	2900	8700
	2	Allen bolt, 12*40	22	28	616
	3	Allen bolt, 12*70	27	28	756
	4	Get valve 1 inch	19	25	475
	5	Allen bolt, 12*70	17	28	476
	6	Round heating band, 270*50	2	4437	8874
	7	Ball bearing, 62*60	4	1490	5960
	8	Round heating band, 270*50	2	4437	8874
	9	Round heating band,110*40	2	2900	5800
	10	Allen bolt, 12*70	18	28	504
	11	Allen bolt, 12*90	26	32	832
	12	Round heating band, 230*70	2	4437	8874
	13	Round heating band, 230*70	2	4437	8874
	14	Gate valve 1 inch	13	25	325
	15	Round heating band, 270*50	3	4437	13311
	16	Gate valve 1 inch	16	25	400
	17	Allen bolt, 12*70	20	32	640
	18	Gate valve 1 inch	6	25	150
	19	Allen bolt, 14*60	14	15	210
	20	Gate valve 1 inch	2	25	50
	21	Reducer , 1 1/2 - 1 1/2	13	29.98	389.74
	22	Reducer , 1 1/2 - 1	2	28.08	56.16
	23	Allen bolt, 12*40	8	28	224
	24	Allen bolt, 12*70	20	32	640
	25	Reducer, 1 1/2 - 1	4	33.04	132.16
	26	T-joint, 1 1/2 - 1	19	44.34	842.46
	27	Thermo couple	9	402.07	3618.63
	28	Allen bolt, 12*90	26	32	832
	29	Allen bolt, 12*80	16	28	448
	30	Air hose 8 inch	30	34	1020
	31	Gate valve 1 inch	16	25	400
	32	Coupling rubber	9	590	5310
	33	Union	18	56.48	1016.64

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	34	Reducer 1-	12	31.06	372.72
	35	Allen bolt, 14*60	20	15	300
	36	Thermo regulator	9	1250	11250
	37	Round heating band, 230*60	3	4437	13311
	38	Potentio meter	3	1651.48	4954.44
	39	Thermo couple	9	300	2700
	40	Iron plug	13	41	533
	41	Selector switch	3	330	990
	42	Push button	11	117	1287
	43	Ball valve 1 inch	17	116	1972
	44	Thermo regulator	3	3016.16	9048.48
	45	Clamp 1 inch	4	104	416
	TOTAL				136,774.05
2007	1	Round heating band,182*70diam	1	2900	2900
	2	Allen bolt,14*40 diameter	16	15	240
	3	Get valve, 1	11	50	550
	4	Contactor, 220v, 25A	7	208.69	1460.83
	5	Allen bolt, 12*90 diameter	15	28	420
	6	Overload relay	3	304.35	913.05
	7	Allen bolt, 12*90 diameter	17	50	850
	8	Round heating band,120*40diam	1	2900	2900
	9	Allen bolt, 12*70 diameter	17	32	544
	10	On-off switch	3	230	690
	11	Round heating band, 150*70,diam	1	2900	2900
	12	Allen bolt, 12*70 diameter	10	28	280
	13	Round heating band, 150*30	1	2900	2900
	14	Get valve 1 inch	16	25	400
	15	Ball bearing 6216	2	950	1900
	16	Get valve 1 inch	15	25	375
	17	Nipples, 1	25	7.59	189.75
	18	Union, 1	16	56.48	903.68
	19	Solenoid valve	10	2300	23000
	20	Reducer	17	26.05	442.85
	21	Solenoid pneumatic valve	11	2300	25300
	22	Thermo couple	3	1200	3600

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	23	Round heating band	2	2900	5800
	24	Allen bolt12*40	18	17	306
	25	Allen bolt12*80	9	28	252
	26	Roll gasket	13	380	4940
	27	Allen bolt 12*90	8	28	224
	28	Air solenoid valve	5	2800	14000
	29	Variable resistance	9	450	4050
	TOTAL				103,231.12

Appendix B: Repair time collected data along with the estimated repair cost.

Year	Time to repair (days)	Number of labor needed to repair	Labor cost per repair	Estimated repaired cost
2004	1.5	2	163.33	489.99
	0.2	2	163.33	65.332
	0.5	2	163.33	163.33
	2.25	2	163.33	734.985
	0.5	2	163.33	163.33
	1.2	2	163.33	391.992
	0.2	2	163.33	65.332
	1	2	163.33	326.66
	0.1	2	163.33	32.666
	1.8	2	163.33	587.988
	3	2	163.33	979.98
	0.9	2	163.33	293.994
	2.2	2	163.33	718.652
	1.5	2	163.33	489.99
	0.45	2	163.33	146.997
	0.2	2	163.33	65.332
	0.5	2	163.33	163.33
	0.75	2	163.33	244.995
	2	2	163.33	653.32
	0.8	2	163.33	261.328
	1.15	2	163.33	375.659
	4	2	163.33	1306.64
	0.3	2	163.33	97.998
	0.7	2	163.33	228.662
	0.25	2	163.33	81.665
	0.3	2	163.33	97.998
	0.65	2	163.33	212.329
	1.2	2	163.33	391.992
	0.8	2	163.33	261.328
	0.25	2	163.33	81.665
	2.2	2	163.33	718.652
	0.7	2	163.33	228.662
	1	2	163.33	326.66
2005	0.15	2	163.33	48.999
	0.8	2	163.33	261.328

Modeling Equipment Acquisition with Life Cycle Costing Decision

	0.25	2	163.33	81.665
	0.9	2	163.33	293.994
	0.5	2	163.33	163.33
	1.15	2	163.33	375.659
	0.19	2	163.33	62.0654
	0.5	2	163.33	163.33
	1.9	2	163.33	620.654
	1	2	163.33	326.66
	0.5	2	163.33	163.33
	1.1	2	163.33	359.326
	0.6	2	163.33	195.996
	0.15	2	163.33	48.999
	0.8	2	163.33	261.328
	0.25	2	163.33	81.665
	1.5	2	163.33	489.99
	0.5	2	163.33	163.33
	0.75	2	163.33	244.995
	0.25	2	163.33	81.665
	7	2	163.33	2286.62
	0.3	2	163.33	97.998
	0.25	2	163.33	81.665
	0	2	163.33	0
	0.15	2	163.33	48.999
	2.2	2	163.33	718.652
	0.6	2	163.33	195.996
	0.84	2	163.33	274.3944
	0.2	2	163.33	65.332
	1.7	2	163.33	555.322
	0.7	2	163.33	228.662
	0.3	2	163.33	97.998
	1.5	2	163.33	489.99
	0.9	2	163.33	293.994
	0.22	2	163.33	71.8652
	0.1	2	163.33	32.666
	0.7	2	163.33	228.662
	2.5	2	163.33	816.65
	1.8	2	163.33	587.988
2006	0.9	2	163.33	293.994

Modeling Equipment Acquisition with Life Cycle Costing Decision

	0.1	2	163.33	32.666
	0.9	2	163.33	293.994
	0.4	2	163.33	130.664
	0.9	2	163.33	293.994
	3.2	2	163.33	1045.312
	0.1	2	163.33	32.666
	1.2	2	163.33	391.992
	0.8	2	163.33	261.328
	0.5	2	163.33	163.33
	1.6	2	163.33	522.656
	0.3	2	163.33	97.998
	0.7	2	163.33	228.662
	2.5	2	163.33	816.65
	0.1	2	163.33	32.666
	0.55	2	163.33	179.663
	4	2	163.33	1306.64
	0.1	2	163.33	32.666
	0.25	2	163.33	81.665
	0.1	2	163.33	32.666
	0.5	2	163.33	163.33
	2.5	2	163.33	816.65
	0.1	2	163.33	32.666
	1.5	2	163.33	489.99
	0.3	2	163.33	97.998
	7	2	163.33	2286.62
	0.5	2	163.33	163.33
	0.9	2	163.33	293.994
	0.6	2	163.33	195.996
	1.2	2	163.33	391.992
	0.25	2	163.33	81.665
	0.5	2	163.33	163.33
	1	2	163.33	326.66
	0.6	2	163.33	195.996
	0.1	2	163.33	32.666
	0.9	2	163.33	293.994
	0.7	2	163.33	228.662
	0.2	2	163.33	65.332
	0.15	2	163.33	48.999

Modeling Equipment Acquisition with Life Cycle Costing Decision

2007	1.1	2	163.33	359.326
	0.5	2	163.33	163.33
	0.4	2	163.33	130.664
	0.28	2	163.33	91.4648
	0.2	2	163.33	65.332
	0.12	2	163.33	39.1992
	3.3	2	163.33	1077.978
	0.09	2	163.33	29.3994
	0.1	2	163.33	32.666
	0.01	2	163.33	3.2666
	0.7	2	163.33	228.662
	0.9	2	163.33	293.994
	0.1	2	163.33	32.666
	2.3	2	163.33	751.318
	0.6	2	163.33	195.996
	0.1	2	163.33	32.666
	0.1	2	163.33	32.666
	3.5	2	163.33	1143.31
	0.3	2	163.33	97.998
	0.75	2	163.33	244.995
	0.9	2	163.33	293.994
	0.2	2	163.33	65.332
	0.55	2	163.33	179.663
	4.5	2	163.33	1469.97
	0.2	2	163.33	65.332
	0.3	2	163.33	97.998
	0.4	2	163.33	130.664
	1.5	2	163.33	489.99
	0.5	2	163.33	163.33
	1.3	2	163.33	424.658
	0.8	2	163.33	261.328
	0.25	2	163.33	81.665
	0.15	2	163.33	48.999
	3.2	2	163.33	1045.312
	0.2	2	163.33	65.332
	0.2	2	163.33	65.332
	4	2	163.33	1306.64
	0.3	2	163.33	97.998

Modeling Equipment Acquisition with Life Cycle Costing Decision

	0.22	2	163.33	71.8652
	0.9	2	163.33	293.994
	0.4	2	163.33	130.664
	0.75	2	163.33	244.995
	2.2	2	163.33	718.652
	0.1	2	163.33	32.666
	1.5	2	163.33	489.99
	0.9	2	163.33	293.994
	1.1	2	163.33	359.326
	0.5	2	163.33	163.33
	0.8	2	163.33	261.328
	0.55	2	163.33	179.663
	0.9	2	163.33	293.994

Appendix C: Repair time collected data along with the estimated downtime cost.

Year	[Failure number]	Time to repair (days)	Production per Day	Price per unit (Birr)	Total cost of production loss
2004	36	1.5	250	39.19	14696.25
	37	0.2	250	39.19	1959.5
	38	0.5	250	39.19	4898.75
	39	2.25	250	39.19	22044.375
	40	0.5	250	39.19	4898.75
	41	1.2	250	39.19	11757
	42	0.2	250	39.19	1959.5
	43	1	250	39.19	9797.5
	44	0.1	250	39.19	979.75
	45	1.8	250	39.19	17635.5
	46	3	250	39.19	29392.5
	47	0.9	250	39.19	8817.75
	48	2.2	250	39.19	21554.5
	49	1.5	250	39.19	14696.25
	50	0.45	250	39.19	4408.875
	51	0.2	250	39.19	1959.5
	52	0.5	250	39.19	4898.75
	53	0.75	250	39.19	7348.125
	54	2	250	39.19	19595
	55	0.8	250	39.19	7838
	56	1.15	250	39.19	11267.125
	57	4	250	39.19	39190
	58	0.3	250	39.19	2939.25
	59	0.7	250	39.19	6858.25
	60	0.25	250	39.19	2449.375
	61	0.3	250	39.19	2939.25
	62	0.65	250	39.19	6368.375
	63	1.2	250	39.19	11757
	64	0.8	250	39.19	7838
	65	0.25	250	39.19	2449.375
	66	2.2	250	39.19	21554.5
	67	0.7	250	39.19	6858.25
	68	1	250	39.19	9797.5
2005	69	0.15	250	39.19	1469.625
	70	0.8	250	39.19	7838

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	71	0.25	250	39.19	2449.375
	72	0.9	250	39.19	8817.75
	73	0.5	250	39.19	4898.75
	74	1.15	250	39.19	11267.125
	75	0.19	250	39.19	1861.525
	76	0.5	250	39.19	4898.75
	77	1.9	250	39.19	18615.25
	78	1	250	39.19	9797.5
	79	0.5	250	39.19	4898.75
	80	1.1	250	39.19	10777.25
	81	0.6	250	39.19	5878.5
	82	0.15	250	39.19	1469.625
	83	0.8	250	39.19	7838
	84	0.25	250	39.19	2449.375
	85	1.5	250	39.19	14696.25
	86	0.5	250	39.19	4898.75
	87	0.75	250	39.19	7348.125
	88	0.25	250	39.19	2449.375
	89	7	250	39.19	68582.5
	90	0.3	250	39.19	2939.25
	91	0.25	250	39.19	2449.375
	92	0	250	39.19	0
	93	0.15	250	39.19	1469.625
	94	2.2	250	39.19	21554.5
	95	0.6	250	39.19	5878.5
	96	0.84	250	39.19	8229.9
	97	0.2	250	39.19	1959.5
	98	1.7	250	39.19	16655.75
	99	0.7	250	39.19	6858.25
	100	0.3	250	39.19	2939.25
	101	1.5	250	39.19	14696.25
	102	0.9	250	39.19	8817.75
	103	0.22	250	39.19	2155.45
	104	0.1	250	39.19	979.75
	105	0.7	250	39.19	6858.25
	106	2.5	250	39.19	24493.75
	107	1.8	250	39.19	17635.5
2006	108	0.9	250	39.19	8817.75

Modeling Equipment Acquisition with Life Cycle Costing Decision

	109	0.1	250	39.19	979.75
	110	0.9	250	39.19	8817.75
	111	0.4	250	39.19	3919
	112	0.9	250	39.19	8817.75
	113	3.2	250	39.19	31352
	114	0.1	250	39.19	979.75
	115	1.2	250	39.19	11757
	116	0.8	250	39.19	7838
	117	0.5	250	39.19	4898.75
	118	1.6	250	39.19	15676
	119	0.3	250	39.19	2939.25
	120	0.7	250	39.19	6858.25
	121	2.5	250	39.19	24493.75
	122	0.1	250	39.19	979.75
	123	0.55	250	39.19	5388.625
	124	4	250	39.19	39190
	125	0.1	250	39.19	979.75
	126	0.25	250	39.19	2449.375
	127	0.1	250	39.19	979.75
	128	0.5	250	39.19	4898.75
	129	2.5	250	39.19	24493.75
	130	0.1	250	39.19	979.75
	131	1.5	250	39.19	14696.25
	132	0.3	250	39.19	2939.25
	133	7	250	39.19	68582.5
	134	0.5	250	39.19	4898.75
	135	0.9	250	39.19	8817.75
	136	0.6	250	39.19	5878.5
	137	1.2	250	39.19	11757
	138	0.25	250	39.19	2449.375
	139	0.5	250	39.19	4898.75
	140	1	250	39.19	9797.5
	141	0.6	250	39.19	5878.5
	142	0.1	250	39.19	979.75
	143	0.9	250	39.19	8817.75
	144	0.7	250	39.19	6858.25
	145	0.2	250	39.19	1959.5
	146	0.15	250	39.19	1469.625

Modeling Equipment Acquisition with Life Cycle Costing Decision

2007	147	1.1	250	39.19	10777.25
	148	0.5	250	39.19	4898.75
	149	0.4	250	39.19	3919
	150	0.28	250	39.19	2743.3
	151	0.2	250	39.19	1959.5
	152	0.12	250	39.19	1175.7
	153	3.3	250	39.19	32331.75
	154	0.09	250	39.19	881.775
	155	0.1	250	39.19	979.75
	156	0.01	250	39.19	97.975
	157	0.7	250	39.19	6858.25
	158	0.9	250	39.19	8817.75
	159	0.1	250	39.19	979.75
	160	2.3	250	39.19	22534.25
	161	0.6	250	39.19	5878.5
	162	0.1	250	39.19	979.75
	163	0.1	250	39.19	979.75
	164	3.5	250	39.19	34291.25
	165	0.3	250	39.19	2939.25
	166	0.75	250	39.19	7348.125
	167	0.9	250	39.19	8817.75
	168	0.2	250	39.19	1959.5
	169	0.55	250	39.19	5388.625
	170	4.5	250	39.19	44088.75
	171	0.2	250	39.19	1959.5
	172	0.3	250	39.19	2939.25
	173	0.4	250	39.19	3919
	174	1.5	250	39.19	14696.25
	175	0.5	250	39.19	4898.75
	176	1.3	250	39.19	12736.75
	177	0.8	250	39.19	7838
	178	0.25	250	39.19	2449.375
	179	0.15	250	39.19	1469.625
	180	3.2	250	39.19	31352
	181	0.2	250	39.19	1959.5
	182	0.2	250	39.19	1959.5
	183	4	250	39.19	39190
	184	0.3	250	39.19	2939.25

	185	0.22	250	39.19	2155.45
	186	0.9	250	39.19	8817.75
	187	0.4	250	39.19	3919
	188	0.75	250	39.19	7348.125
	189	2.2	250	39.19	21554.5
	190	0.1	250	39.19	979.75
	191	1.5	250	39.19	14696.25
	192	0.9	250	39.19	8817.75
	193	1.1	250	39.19	10777.25
	194	0.5	250	39.19	4898.75
	195	0.8	250	39.19	7838
	196	0.55	250	39.19	5388.625
	197	0.9	250	39.19	8817.75

Appendix D: Questionnaires for validation

The following questions are designed to gather expert opinions on the validation of the proposed framework. I therefore politely request you to answer the questions so as to enrich the framework.

Academic rank _____ **Position** _____

Place of work _____ **Year of experience** _____

Question 1: What can you say about the appropriateness of the proposed framework?

Question 2: Do you think the framework is helpful to prepare a good life cycle cost estimate?

Question 3: Do you think the cost elements in the customized cost breakdown structure are adequate?

Question 4: How logical are the steps in the framework?

Question 5: What should be included to enhance the validity of the framework?

Any other comment

Thank you