Study on efficient forklift utilization, cost & life cycle analysis

by

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Executive Summary

Forklifts are classified as indispensable equipment utilized in manufacturing and warehousing operations. This equipment contributes a large percentage towards any warehouse and manufacturing operation. Industry surveys confirm that 94% of materials handling businesses do not have an accurate record of their forklift fleet. Inflated costs are usually incurred due to the lack of knowledge or little insight into the true drivers of forklift operating expenses, maintenance, life cycle and efficient utilization.

A comprehensive study on all abovementioned aspects affecting forklifts would prove beneficial on the long run for any business that utilizes such fleet. This project will aim at assisting Sasol Dyno Nobel in developing models and providing recommendations for:

- Effective utilization and operational efficiency of forklifts
- Allocating forklifts to the respective departments within the Sasol Dyno site
- Maintaining and servicing forklifts
- Cost and life cycles of forklifts

Upon completion of this project, a detailed report of all the work done in achieving the set deliverables will be compiled and sent to the relevant stakeholders. All recommendations will be used at the owners' discretion.

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List of acronyms

TDS5: Technical Data System

LCD: Liquid Crystal Display

RFID: Radio Frequency Identification

GUI: Graphical User Interface

CAD: Computer Aided Design

VRSP: Vehicle Routing Scheduling Problem

CVRP: Capacitated Vehicle Routing Problem

LCA: Life Cycle Analysis

ESL: Economic Service Life

EUAW: Equivalent Uniform Annual Worth

AW: Annual Worth

AHP: Analytical Hierarchy Process

PV: Present Value

AE: Annual Equivalence

KPI: Key Performance Indicator

FIFO: First in First out

MV: Market Value

AOC: Annual Operating Cost

ACR: Annual Capital Recovery

AW of OC: Annual Worth of Operating Cost

Total AW: Annual Worth

LPG: Liquid Petroleum Gas

CHAPTER 1: INTRODUCTION

1.1. Company background

Sasol Dyno Nobel prides itself by being the leading African non electric explosives accessory manufacturer. Sasol has a 50% share in this joint venture and the other 50% is held by Dyno Nobel a world leader in shocktube initiation technology. The joint venture produces and markets non-electric explosive accessories, including the Primadet range of shocktube systems, Primacord detonating cords and Trojan cast boosters. These products are primarily used in quarrying opencast and underground mining which aim to balance Sasol's range of commercial explosives. All these products are assembled at the Ekandustria facility in Mpumalanga, South Africa. Sales of the products are conducted through appointed local and international distributors. Ekandustria also works at developing products to constantly improve the value proposition. The organisation strives to maintain the standards of the latest technology which is imported from Dyno Nobel USA (www.sasol.com).

1.2. Project background

Sasol Dyno Nobel took the initiative to give the student an opportunity to be part of one of its major projects which would prove beneficial for the company on the long run. The aim of this project is to manage one of its most treasured assets, namely forklifts. Sasol Dyno like most companies uses forklifts to move goods from one point to another. Currently the company has allocated two forklifts operating within the department of interest within this project. These forklifts are operating most of the time carrying all the necessary activities. These activities include; transporting raw material to the place of manufacturing, transporting finished goods and waste material. Due to the nature of products being manufactured at Sasol Dyno such as explosives, forklifts have certain constraints during transportation. This includes transportation speed, handling and carrying capacity. These constraints will be accounted for during the modelling and problem solving process.

1.3. Plant layout

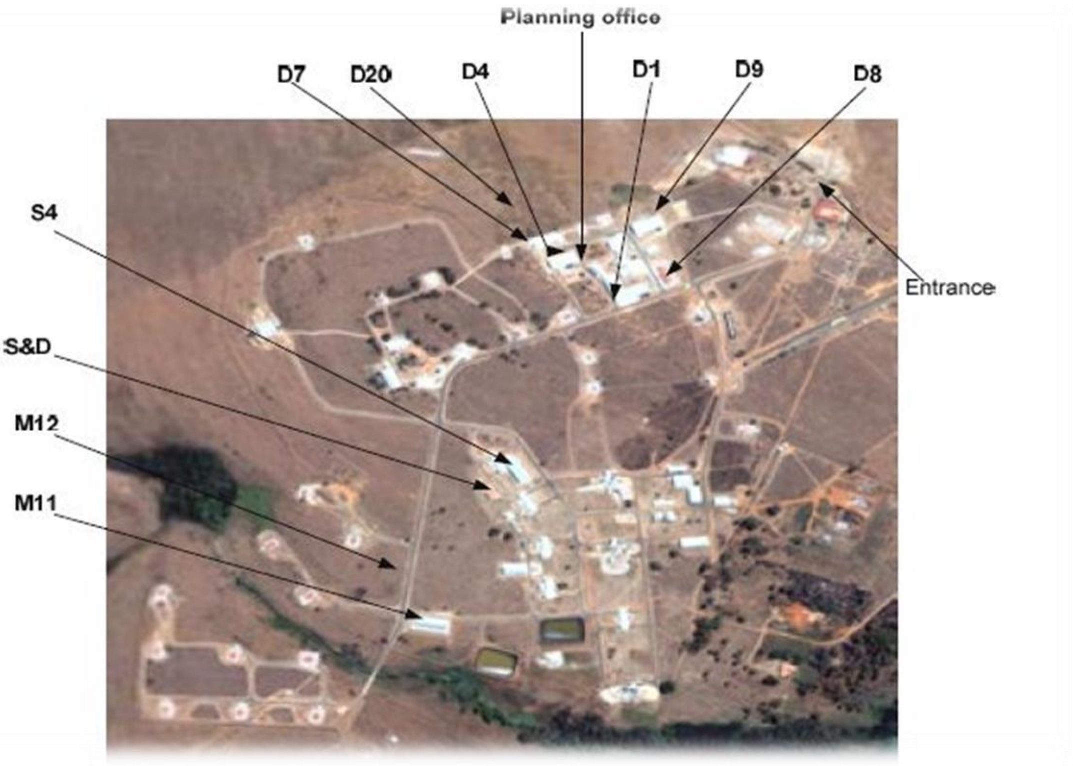


Figure 1: Plant Layout
Source: TC Botha, Optimizing the order fulfillment strategy at Sasol Dyno Nobel (Ekandustria) (2008:7)

D1: Raw materials stores.
D4: Detonator stores.

D7: Detonator assembly.

D8: Finished product store (non-electric initiation systems).

D9: Non-electric initiation systems assembly.

D20: Detonator assembly.

M11: Finished product store (non-electric initiation systems).

M12: Finished product store (non-electric initiation systems).

S4: Non-electric initiation systems assembly.

S&D: Sales and distribution, production planning and needs.

1.4. Problem statement

Forklifts are an essential asset in daily plant operations. The effective, efficient and productive use of forklifts relative to the demand, capacity and availability is required. Maintenance, planned and unplanned, influences the above and is to be planned so as to provide optimal forklift utilisation as far as possible. Currently there is not enough knowledge in terms of how to manage such fleet in order to make the most out of them and ultimately reduce operational costs. Knowledge of current forklift utilization is also a concern. This knowledge will assist in deciding on the number of forklifts required in order to meet the current demand. This would be possible once clear solutions for the problems mentioned above have been generated. The reduction of operational costs is a very important aspect for the company. This can be achieved through the knowledge and implementation of current industry best practices, replacement intervals for forklifts and the use of an economical type of forklift.

1.5. Project aim

The aim of this project is to employ industrial engineering techniques to better manage assets such as forklift by:

- Analysing forklift routes and operations based on determined demand and resource availability
- Designing a simulation which models the movement of forklifts within the various departments at the plant
- Achieve efficient forklift utilization by balancing forklift availability between the mini-warehouses
- Performing a cost and life cycle analysis in order to determine when a forklift should be replaced to reduce maintenance cost.
- Research on available types of forklifts and selecting the one that is most economical

1.6. Project scope

This project will focus on the analysis of the current operational efficiency and life cycle of a forklift. All these aspects are supported by an in-depth literature review. The department within the company responsible for manufacturing non-electric explosive accessories, namely the Primadet range of shocktube systems will be of main focus. Six mini-warehouses within the chosen department have been allocated for the purpose of manufacturing and storing the Primadet range of shocktube systems. Currently there are two forklifts which have been allocated to operate within these mini-warehouses. Maintenance has been excluded from this project mainly because it is a very wide and complex topic on its own. However an element of maintenance will be included in the simulation in order to ensure that the designed simulation is as realistic as possible.

Operational efficiency and utilization

This section will focus on the design and analysis of a simulation model for the purpose of exploiting the current utilization of forklifts and identifying inefficiencies. The results generated will assist in ensuring that enough forklifts have been allocated to the respective department based on demand and availability. A comprehensive study on techniques and best practices used to achieve optimal utilization of forklifts will be documented in the literature study.

Life cycle, cost and decision analysis

The life of a forklift together with its millage and service history will be studied. The cost associated with these attributes will also be analysed. Engineering Economy principles together with the Monte Carlo simulation technique will be applied in order to perform a comprehensive life cycle and cost analysis. This includes deciding on when to replace a forklift. A model to assist in the decision making process for acquiring or replacing a forklift will be documented.

1.7. Deliverables

The project deliverables include:

- A comprehensive study on forklift utilisation and asset management
- Gathering recommendations for optimal efficiency in the use of forklifts and operating strategy
- Knowledge of forklift replacement intervals
- Recommendation on the type of forklift to be procured
- Performing overall cost comparison between alternatives

CHAPTER 2: LITERATURE STUDY

2.1. History of forklifts

Since the beginning of time, man has always searched for easier and efficient ways of accomplishing difficult strenuous tasks. During the Stone Age, man invented the lever which proved to be quite efficient in enabling cave men to lift heavy objects. Archimedes, a Greek mathematician, physicist, engineer and inventor finally recognised the importance of the lever and is well known for his statement “Give me but one spot on which to stand and I will move the earth”. In the 1800’s, basic manually powered sack trucks which are still in use today were introduced. The development of diverse goods later created a need for other types of hand operated equipment such as platform trucks, and four wheeled trailers. During the First World War, electrically powered trucks and trailers were developed mainly as a result of shortage of labour. A high lift version of platform trucks was then created because designers saw that putting loads on top of each other would be a good idea. It was in 1925 when Yale produced the first electric truck with raising forks and an elevated mast. However no tilt was fitted to the machine and the lift was by ratchets and pinions. It was only during the Second World War that the forklift truck became an indispensable piece of equipment for loading vast quantities of war goods. Coventry Climax, a British company produced the very first forklift in 1946. Today’s forklifts have become advanced with complex electronic and hydraulic systems (Sellick, T, 2010:1).

2.2. Efficient forklift utilization

Utilization can be defined as ‘to put to use, especially to find a profitable or practical use for’. Efficient can be defined as ‘achieving maximum productivity within minimum wasted effort or expense’ (Dictionary.com, 2012). Efficient forklift utilization can thus be defined as ‘to put to use forklifts in a manner which strives to achieve maximum productivity with minimum wasted effort or expense’.

2.2.1. Industry best standards

The following literature discussed below serves to document the current best practices employed in industry in the pursuit of achieving optimal forklift efficiency.

2.2.1.1. Forklift daily checks

Transmon Engineering (www.transmon.com) has developed a new method of enforcing daily checks on forklifts before the shift starts. The check list includes components such as chains, tyres, hydraulics, forks and brakes. These daily checks not only ensure that the forklift is in a good condition before its operation but to also identify problems before they propagate and become too costly to manage. Other issues such as downtime due to unplanned repairs can also be avoided. Transmon’s new TDS5 (Technical Data System) fleet management system includes a daily check feature installed on the forklift which disables the engine ignition until every question on the checklist has been answered by the forklift driver. The TDS5 fleet management system also comes with an LCD (Liquid Crystal Display) which contains a customized list of all the questions in the checklist. Each question in the checklist has a time sensitive element to ensure that the operator does not answer the questions ignorantly. Controlled keypads or RFID (Radio Frequency Identification) access also ensures that unqualified operators cannot operate the equipment. A one way text messaging function enables operations managers to communicate job messages directly to the drivers via the TDS5 screens fitted in the trucks. Managers can also receive alerts via email and access information (Transmon Engineering. 2012).

Figure 2: Transmon's TDS5
Source: Transmon Engineering, Checks Please! New system forces forklift drivers to check their trucks (2011)

2.2.1.2. Operator Training

Operator training cannot be over emphasized when it comes to operating a forklift. Safety in any working environment is of great importance especially one that utilizes forklifts for daily operations. It is thus imperative that great measures and investments be made in training forklift operators on how to operate such fleet.

2.3. Simulation modelling

Simulation modelling can be defined as the process of designing and analysing a model with the purpose of mimicking/imitating the behaviour of a real system and ultimately solving a problem. Over the past one hundred years, significant advances have been made in the theory and practice of simulation through problems driven by Industrial Engineering (Goldsman, 2004:9). Today simulation modelling is a technique widely used by Industrial Engineers in the pursuit of solving real life problems and providing decision support. The generic simulation process used to model, analyse and solve a problem can be described by the figure shown below.

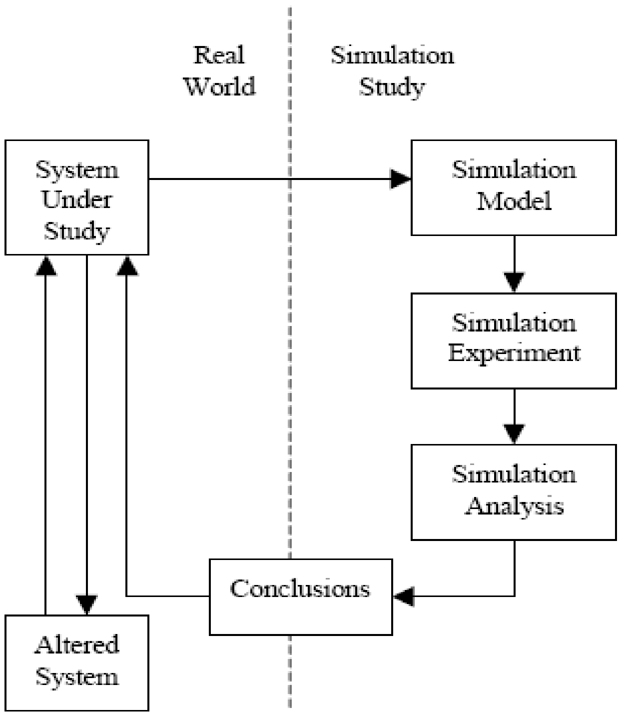


Figure 3: Simulation study schematic
Source: Maria, A, Introduction to modeling and simulation (1997)

2.3.1. Simulation packages

The following simulation packages are available in industry:

AnyLogic

AnyLogic combines three approaches, namely System Dynamics, Process-centric and Agent base within one modeling language that is used in the development environment. It is flexible and the user at the preferred level of detail can capture the heterogeneity and complexity of business, economy and social systems. Animation in AnyLogic consists of interactive GUIs (Graphical User Interfaces). Images and CAD (Computer Aided Design) drawings can be imported and a large variety of graphical shapes and controls are available.

(http://www.xjtek.com/anylogic)

ProModel

ProModel is a simulation technique that strives for constant development of new and innovative modeling and simulation software products. To achieve simulation perfection their products can integrate with one another and third-party software. ProModel has a reputation of offering suitable predictive solutions in logistics,Healthcare, pharmaceuticals, six sigma, and financial services.

(http://www.promodel.com)

Arena

Rockwell automation developed the simulation and automation software Arena. The simulation language it uses is SIMAN. Arena is widely used to simulate processes, such as manufacturing plants. The current performance of the plant as well as promising changes that can be made are analysed. If the process is accurately simulated, observation of changes can be observed without executing them in real life, this saves time and recourses. A model is constructed in Arena by placing modules (boxes of different shapes) that represent logic or processes. Modules are linked by means of connector lines according to the flow of entities. The accurate representation of every module and entity relative to real-life objects is subject to the modeller, although modules have specific actions relative to entities, flow and timing. Statistical data that can be recorded and outputted as reports are for instance cycle time and work in-process levels. Arena integrates outstandingly with Microsoft technologies.

Models can further be automated if specific algorithms are needed with Visual Basic. Microsoft Visio flowcharts can be imported. Excel spread sheets and Access databases can be used to input data from or output data to. It also supports ActiveX controls.

(http://www.arenasimulation.com/about-arena)

Simio

Simio is designed from the ground up to support the object modeling prototype; however it also supports the unified use of multiple modeling prototypes including process and event orientations. It also fully supports both discrete and continuous systems, along with large scale applications based on agent-based modeling. These modeling prototypes can be freely mixed within a single model.

(http//www.simio.com/about-simio)

Selected simulation package and reasons

Simio has been selected as the simulation package to be utilized in generating recommendations for the current forklift utilization problem. The reasons for selecting this package are as follows:

- It is easily accessible
- Very easy to use
- Has built in 3D features
- Results generated are easy to interpret and straight forward

Figure 4 below gives a pictorial view of a working simulation model.

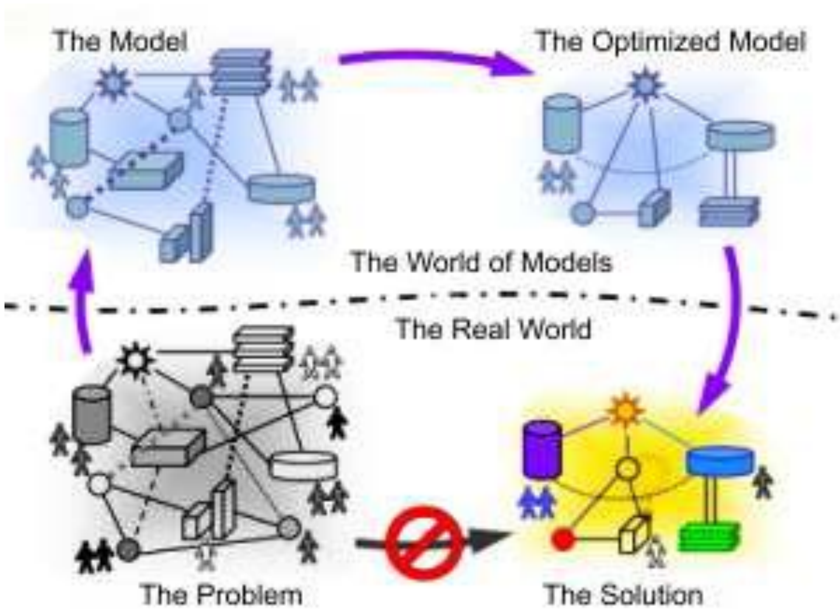


Figure 4: Illustration of a working simulation
Source: VR, Snyman, Sasol Crude Oil Pipeline Study (2008:7)

2.4. Operations research

Operations research is the discipline of applying innovative analytical techniques to help make better decisions. Organizations and industries have been improved through the use of operations research from enhanced scheduling of airline crews to the design of waiting lines at Disney theme parks. There are two areas in operations research which can be used to model and ultimately solve the current forklift operation problem, namely vehicle routing and work scheduling. These techniques are discussed below (The science of better.com, 2012).

2.4.1. Vehicle routing problem

The Vehicle Routing and Scheduling Problem (VRSP) focuses primarily on the determination of routes and schedules for a fleet of vehicles to satisfy the demands of a set of customers. The basic Capacitated Vehicle Routing Problem (CVRP) can be described in the following way. A set of uniform vehicles with a specific capacity 'C', located at a central warehouse and a set of customers with known locations and demands to be satisfied by deliveries from the central depot are given. Each vehicle route must begin and end at the central warehouse and the total customer demand satisfied by deliveries on each route must not exceed the vehicle capacity, 'C'.

The goal is to determine a set of routes for the vehicles that will minimize the total cost. The total cost is usually comparative to the total distance travelled if the number of vehicles is fixed (Sbihi A, Eglese RW 2000:1).

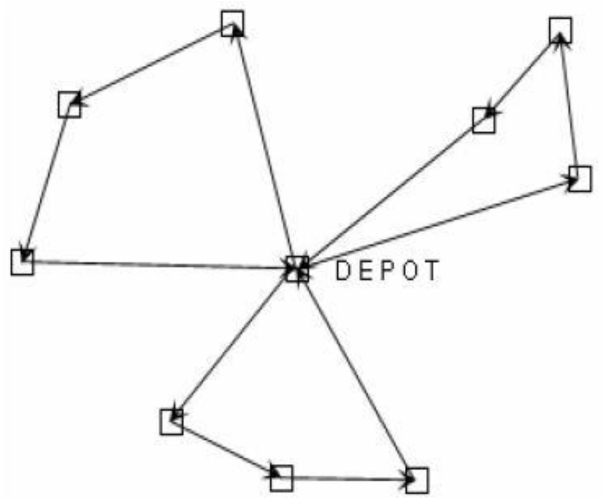


Figure 5: Vehicle routing scheme
Source: Sbihi A, Eglese RWA relationship between vehicle routing and scheduling and green logistics – a literature survey (2000:2)

2.4.2. The vehicle routing problem scheme

The CVRP has been comprehensively studied in the literature since its introduction by Danzig and Ramser in 1959 [17]. Its exact solution is however difficult to determine for large-scale problems. Dedicated algorithms are able to consistently find optimal solutions for case studies with up to about 50 customers; larger problems have been solved to optimality in some cases, but often at the expense of considerable computing time. In practice, other variations and additional constraints that must be taken into consideration usually make the vehicle routing problem even more difficult to solve to optimality. Many solution procedures are based on heuristic algorithms that are designed to provide good feasible solutions within an acceptable computing time, but without a guarantee of optimality (Sbihi A, Eglese RW, 2000:1).

2.4.3. Work scheduling

Work scheduling is the time frame that an employee/equipment works during a certain course of time. These schedules can fluctuate, rotate or remain constant throughout a year. In operations research, a work schedule model is designed for the purpose of obtaining an optimal schedule and ultimately reduces operational costs.

2.5. Monte Carlo simulation

Every decision made in life has some form of risk attached to it. Uncertainty, ambiguity and variability are aspects one cannot avoid in life. The future cannot be accurately predicted even with the vast amount of information at our disposal. It is for this reason that the Monte Carlo simulation technique was invented. This simulation technique enables one to see all possible outcomes of a decision and to assess the impact of risk which ultimately assists in making a better decision under uncertainty (Palisade.com, 2012).

Monte Carlo simulation can also be described as a computerized mathematical technique that enables one to account for risk in quantitative decision making analysis. Various fields such as finance, project management, energy, manufacturing, engineering and research can benefit greatly through the application of Monte Carlo simulation (Palisade.com, 2012).

The simulation produces a range of possible outcomes together with their probabilities of occurrence for any choice of action. The technique dates back during World War II when scientists working on the atom bomb (Palisade, 2012).

2.5.1. Advantages of using Monte Carlo Simulation

Probabilistic Results: Results show not only what could happen, but how likely each outcome (Palisade, 2012).

Graphical Results: Because of the data a Monte Carlo simulation generates, it's easy to create graphs of different outcomes and their chances of occurrence. This is important for communicating findings to other stakeholders (Palisade, 2012).

Sensitivity Analysis: With just a few cases, deterministic analysis makes it difficult to see which variables impact the outcome the most. In Monte Carlo simulation, it's easy to see which inputs had the biggest effect on bottom-line results (Palisade, 2012).

Scenario Analysis: In deterministic models, it's very difficult to model different combinations of values for different inputs to see the effects of truly different scenarios. Using Monte Carlo simulation, analysts can see exactly which inputs had which values together when certain outcomes occurred. This is invaluable for pursuing further analysis (Palisade, 2012).

Correlation of Inputs: In Monte Carlo simulation, it's possible to model interdependent relationships between input variables. It's important for accuracy to represent how, in reality, when some factors go up; others go up or down accordingly (Palisade, 2012).

2.6. Life Cycle Analysis

During the 1960's, scientists developed LCA (Life Cycle Analysis) as a result of an existing concern about the rapid depletion of fossil fuels. This development led to understanding the impacts of energy consumption. A few years later, global-modeling studies predicted the effects of the world's changing population on the demand for finite raw materials and energy resource supplies. Today LCA is used by many companies as a tool for understanding the environmental impacts on assets together with operating costs, optimal asset lifespan and decision making (Svoboda, S, 1995:1). Figure 6 below gives a pictorial view of the basics of a typical asset lifecycle cost analysis.

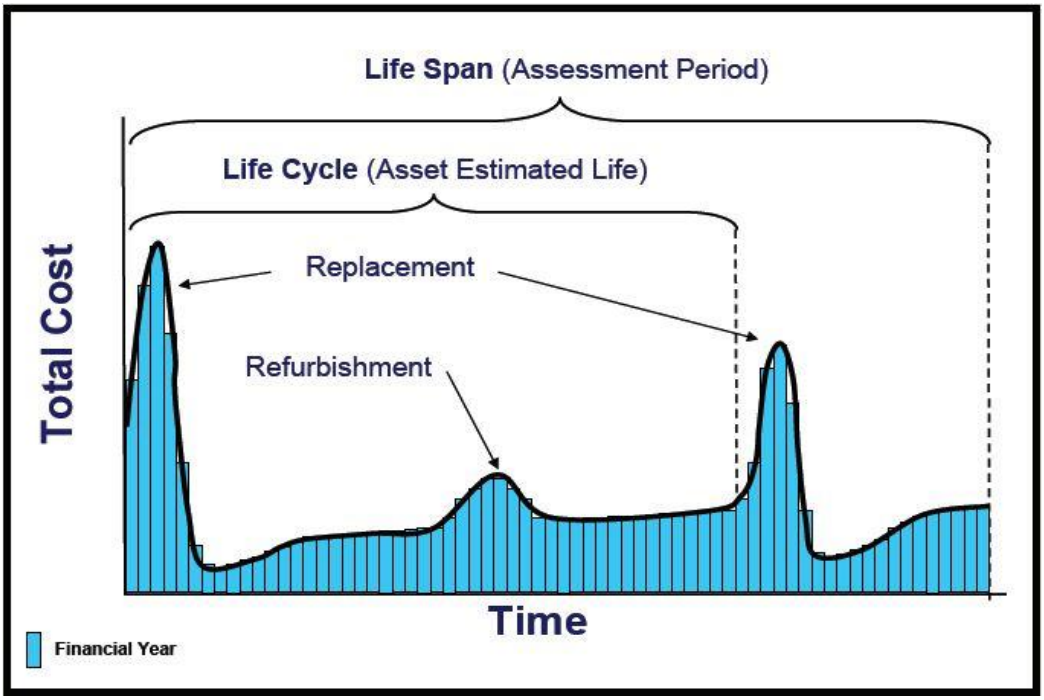


Figure 6: Asset lifecycle cost basics
Source: Taylor, J, Asset life cycle management (2005:3)

2.6.1. Types of life cycle and cost analysis models

The following models have been identified as possible models for performing life cycle and cost analysis on the forklifts at Sasol Dyno Nobel.

2.6.1.1. Optimum Replacement Age

In this model, the main focus is centred on the decision of when is it the right time to replace an asset. This optimal replacement point is mainly influenced by the costs associated with keeping the asset, namely maintenance and operation cost (Taylor, J, 2005:5).

2.6.1.2. Repair / Replacement

In this model, the main focus is centred on the decision of whether it's best to repair the current asset or to replace it with a new one. This decision is mainly influenced by the difference in costs associated with repairing the asset and purchasing a new one (Taylor, J, 2005:5).

2.6.1.3. Alternative Decision Making

In this model, the main focus is centred on the decision of whether it's best to keep the current asset or to replace it with a new one. This decision is mainly influenced by the cumulative difference in costs associated with keeping the asset, namely maintenance and the costs associated with acquiring a new asset (Taylor, J, 2005:5).

2.7. Replacement and Retention Decisions

One of the most commonly performed engineering economy studies is that of replacement or retention of an asset or system that is currently installed. When an asset is currently in use and its function is needed in the future, it will be replaced at some point. A replacement study is usually designed to first make the economic decision to retain or replace now. If the decision is to replace, the study is complete. If the decision is to retain, the cost estimates and decision will be revisited each year to ensure that the decision to retain is still economically correct. A replacement study is an application of the annual worth method of comparing unequal-life alternatives. In a replacement study with no specific study period, the annual worth values are determined by a technique of cost valuation called economic service life (ESL) analysis (Blank & Tarquin, 2005:387).

2.7.1. Basic terminology

Defender and the Challenger

Two mutually exclusive alternatives are defined, namely the DEFENDER and CHALLENGER. The DEFENDER is the currently installed asset and the CHALLENGER is the potential replacement (Blank & Tarquin, 2005:387).

Annual Worth/Equivalent uniform annual cost (EUAC)

Annual worth values are used as the primary economic measure of comparison between the defender and the challenger. The term “Equivalent Uniform Annual Cost” may be used in lieu of AW, because often only costs are included in the evaluation (Blank & Tarquin, 2005:387).

Economic Service Life

This is the number of years at which the lowest AW (Annual Worth) of cost occurs. The equivalent calculations to determine ESL establish the life for the best challenger, and it also establishes the lowest cost life for the defender in a replacement study. The ESL is also referred to as the economic life or minimum cost life. To perform a replacement study correctly, it is important that the ESL of the defender and the challenger be determined, since their n values are usually not pre-established. (Blank & Tarquin, 2005:387). Figure 10 below shows the characteristic shape of a total annual worth of cost curve.

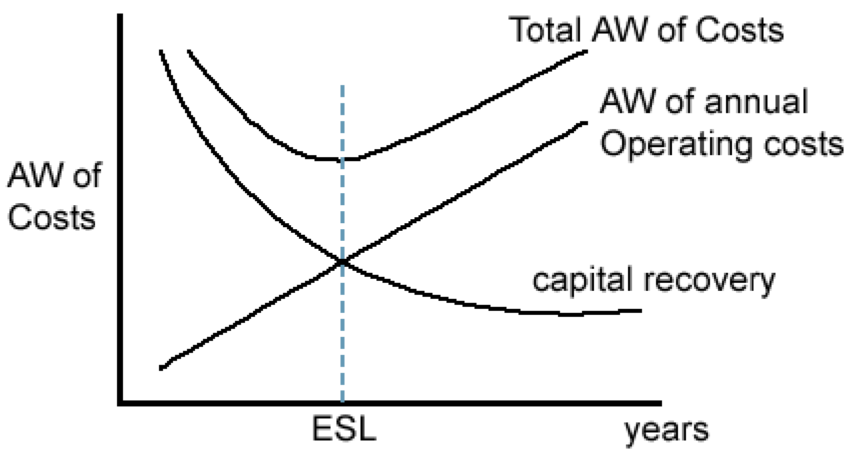


Figure 7: Annual worth curves
Source: Blank, Tarquin, Engineering economy (2005:392)

Operating Costs

The driving force for replacing existing equipment is that it becomes more expensive to operate with time. The total cost of operating a piece of equipment may include repair and maintenance costs, wages for the operators, energy consumption costs, and costs of materials. Increases in any one or a combination of these cost items over a period of time may cause us to find a replacement for the existing asset (Blank & Tarquin, 2005:387).

Selected life cycle analysis techniques and reasons

Monte Carlo simulation has been selected as a tool for generating approximate values annual fuel cost. This is due to the fact that fuel cost varies with time. Monte Carlo simulation has proven to be the BEST tool for generating such values because:

- General results show not only what could happen, but how likely each outcome is
- it’s easy to create graphs of different outcomes
- Easily accessible
- it’s easy to see which inputs had the biggest effect on bottom-line results

Economic service life

The economic service life (ESL) method used in Engineering Economy was selected for the purpose of estimating the optimal replacement interval/period for a forklift. This method was chosen mainly because:

- It is simple
- Does not require complex calculations
- Is easily accessible

2.8. Analytical Hierarchy Process (AHP)

The Analytical Hierarch Process is a structured technique for dealing with complex decisions. Based on mathematics and psychology, it was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. The AHP provides a complete and rational structure for (Kunz Jeff, 2010):

- Organizing a decision problem
- Representing and measuring its elements
- Relating those elements to overall goals and
- Evaluating alternative solutions.

AHP is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare and education.

2.9. Cost comparison calculator

Raymond Handling Solutions, an American company has designed an online open source software aimed at assisting potential forklift buyers in selecting the most economical type of forklift. The programme is very easy to use and requires no calculations from the user as it has its own built-in calculator. All that is required from the user are adjustments made on the programme by simply arranging the knobs associated with a particular attribute such as fuel.

CHAPTER 3: METHODOLOGY STUDY

3.1. Problem solving procedure

Methodology study refers to the different techniques/methods used to achieve a particular goal. Shown in figure 8 below is a procedure to be followed in the pursuit of successfully completing the project.

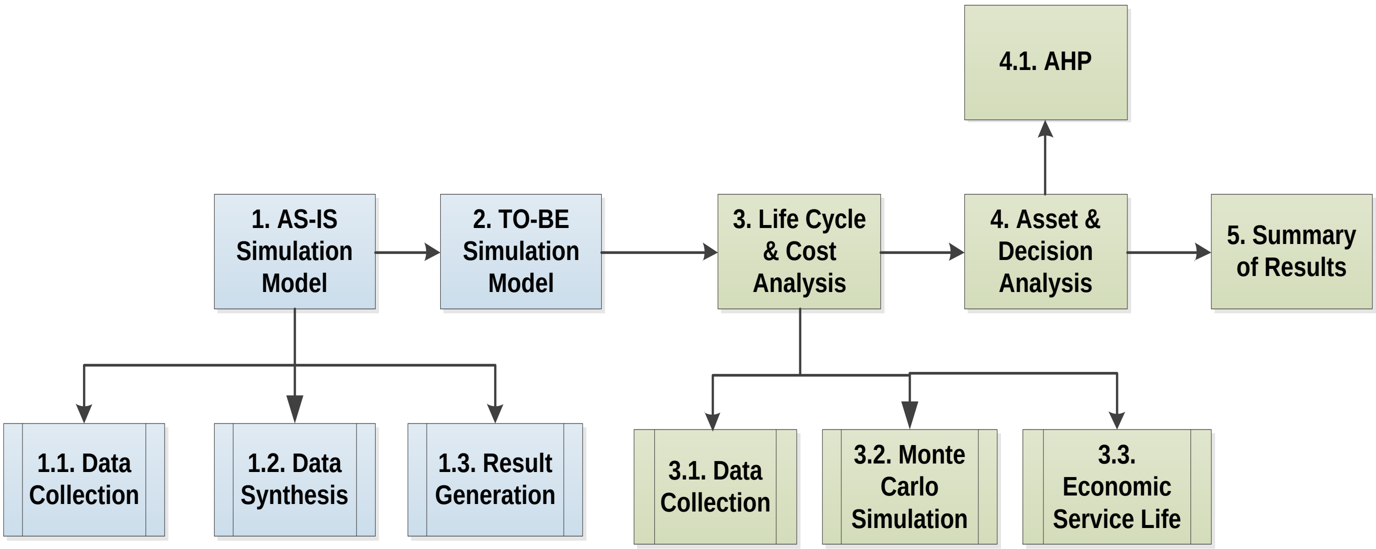


Figure 8: Problem solving procedure

3.2. Simulation modelling

A typical simulation model will consist of the following components: entities, input variables, performance measures and functional relationships. These components are available in almost all simulation packages. The following steps are executed in developing a simulation model (Maria, A. 1997:8).

1. ***Identify the problem:*** This step involves the listing of all problems with the existing system.
2. ***Formulate the problem:*** During this step, the scope of the problem is defined together with the objective of the study. Quantitative criteria such as performance measures are also defined. These measures will assist in deciding on the basis of which system configurations will be compared and ranked. A hypothesis about system performance will be formulated after a brief system configuration of interest has been identified. A time frame for running the model together with the end-user of the model will be defined.

3. ***Collect and process real data:*** Collect system data and performance of existing system.
4. ***Formulate and develop a model:*** develop schematics and network diagrams of the system. Translate these models to simulation software acceptable form. Verify that the model executes as intended.
5. ***Validate the model:*** Compare the model's performance under known conditions with the performance of a real system. Ensure that system experts examine the model and perform statistical tests. Address any problems to the end-user if any.
6. ***Document model for future use:*** Objectives, assumptions and input variables should be documented in detail.
7. ***Select appropriate experimental design:***
   Select performance measures, input variables that are likely to influence and their levels.
8. ***Establish experimental conditions for runs:***
   Address the issue of acquiring accurate information and the most information from each run. Determine whether a termination or a non-termination simulation run is appropriate. Select the run length and starting conditions.

9. ***Perform simulation runs:***

Perform runs according to step 7-8

10. ***Interpret and present results:***

Computer numerical estimates of desired performance measures for each configuration of interest. Test hypothesis about system performance and construct graphical displays of the output data.

11. ***Recommend further course of action:***

This may include further experiments to increase the precision and perform sensitivity analysis.

3.2. Monte Carlo simulation

Risk analysis is performed by building models of possible results, substituting a range of values and a probability distribution for any factor with an inherent uncertainty. Results are then calculated over and over, each time using a set of random values from a probability function. The number of iterations for generating results can be performed more than a thousand times. Distributions in the form of a histogram are then created. These distributions together with variables usually have probabilities of different outcomes and are a much more realistic way of describing uncertainty in variables of a typical risk analysis. Probability distributions may include the following (Palisade, 2012):

1. ***Normal – Or "bell curve:*** The mean or expected value and a standard deviation to describe the variation about the mean are defined. Values in the middle near the mean are most likely to occur. It is symmetric and describes many natural phenomena such as people's heights. Examples of variables described by normal distributions include inflation rates and energy prices (Palisade, 2012).
2. ***Uniform:*** All values have an equal chance of occurring, and the user simply defines the minimum and maximum. Examples of variables that could be uniformly distributed include manufacturing costs or future sales revenues for a new product (Palisade, 2012).
3. ***Triangular:*** The user defines the minimum, most likely, and maximum values. Values around the most likely are more likely to occur. Variables that could be described by a triangular distribution include past sales history per unit of time and inventory levels (Palisade, 2012).
4. ***Discrete:*** The user defines specific values that may occur and the likelihood of each. An example might be the results of a lawsuit: 20% chance of positive verdict, 30% change of negative verdict, 40% chance of settlement, and 10% chance of mistrial (Palisade, 2012).

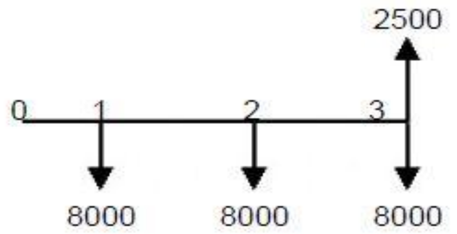
During the simulation, values are sampled at random from the input probability distributions. Each set of sample is called iteration and the resulting outcome is recorded. Monte Carlo simulation does this hundreds or thousands of times, and the result is a probability distribution of possible outcomes. In this way, Monte Carlo simulation provides a much more comprehensive view of what may happen. It tells you not only what could happen, but how likely it is to happen (Palisade, 2012).

3.3. Approaches for Comparing Defender and the Challenger

3.3.1. Cash Flow Approach

The cash flow approach can be used as long as the analysis period is the same for all replacement alternatives. Therefore we consider explicitly the actual cash flow consequences for each replacement alternative and compare them based on either the Present Value (PV) or Annual Equivalent (AE) values (Blank & Tarquin, 2005:387).

Option 1: Keep the defender



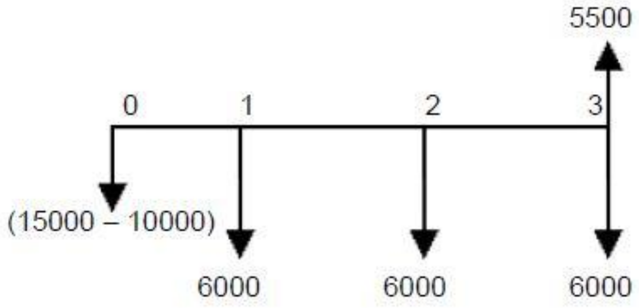
NPV(12%) = +2500(P/F,12,3) – 8000(P/A,12,3)
= -17434.90

AE(12%) = -8000 +2500(A/F,12,3)
= -7259.10

Figure 9: Defender Cash flow analysis

Source: Blank, Tarquin, Engineering economy (2005:392)

Option 2: Replace the defender with the challenger



NPV(12%) = +5500(P/F,12,3) – 5000 - 6000(P/A,12,3)
= -15495.90

AE(125) = -6000 – 5000(A/P,12,3) +5500(A/F,12,3)
= -6451.79

Figure 10: Challenger Cash flow analysis 2
Source: Blank, Tarquin, Engineering economy (2005:392)

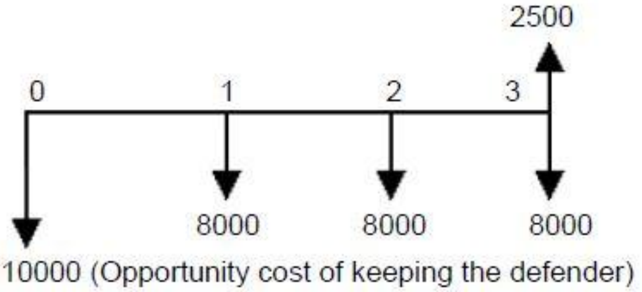
Because of the annual difference of R807.31 in favour of the challenger, the replacement should be made now.

3.3.2. Opportunity cost approach

Instead of deducting the salvage value from the purchase cost of the challenger, we consider the salvage as a cash outflow for the defender (opportunity cost of keeping the defender) (Blank & Tarquin, 2005:387).

Example

Keep the Defender

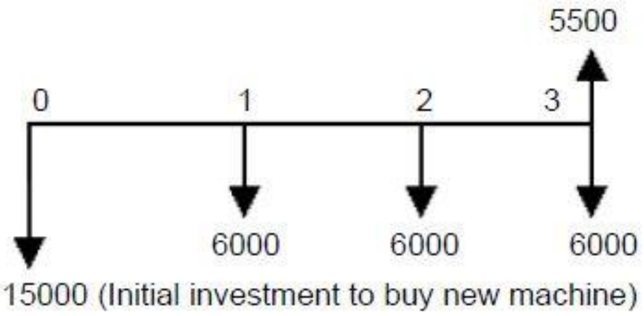


NPV(12%) = -10000 – 8000(P/A, 12,3) + 2500(P/F,12,3)
= -27434.90

AE(12%) = -8000 – 10000(A/P,12,3) + 2500(A/F,12,3)
= -11422.64

Figure 11: Defender Cash flow analysis
Source: Blank, Tarquin, Engineering economy (2005:392)

Challenger



$$NPV(12\%) = -15000 - 6000(P/A, 12,3) + 5500(P/F,12,3)$$
$$= -25495.90$$

$$AE(12\%) = -6000 - 15000(A/P,12,3) + 5500(A/F,12,3)$$
$$= -10615.33$$

Figure 12: Challenger cash flow analysis
Source: Blank, Tarquin, Engineering economy (2005:392)

The decision outcome is the same as for the cash flow approach

3.4. Basic AHP procedure

The following steps have been designed to provide a comprehensive procedure for performing AHP:

Step 1: Structure the decision problem in a hierarchy as shown in figure 13 below.
Step 2: Compare the alternatives based on the criterion that has already been created, i.e. 1, 2 and 3 for less important, moderately important and most important respectively.
Step 3: Synthesize the comparisons to get the priorities of the alternatives with respect to each criterion and the weights of each criterion with respect to the goal. Local priorities are then multiplied by the weights of the respective criterion. The results are summed up to produce the overall priority of each alternative.

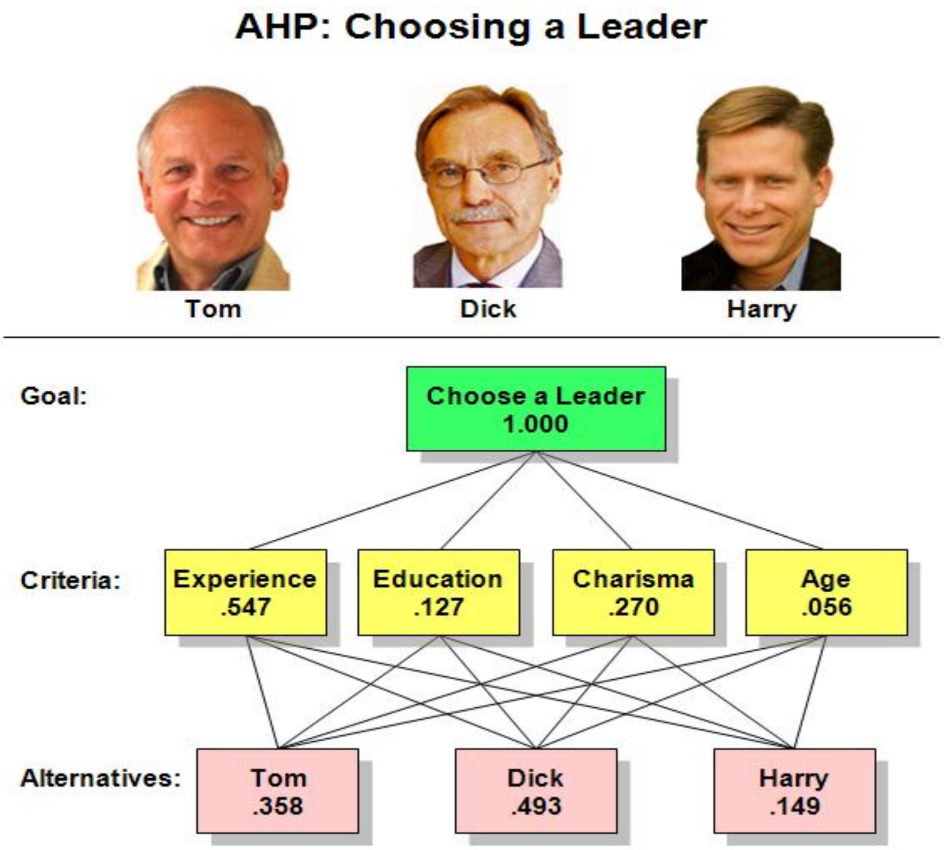


Figure 13: AHP example
Source: www.wikipedia.org

CHAPTER 4: FORKLIFT UTILIZATION ANALYSIS

4.1. Introduction

This chapter will focus on the analysis and documentation of the current process followed by the design and analysis of the simulation. Simulation modelling with Simio has been chosen as the most appropriate tool and technique for designing and solving the current problem at Sasol Dyno Nobel. Upon completion of the simulation, the results will be used to indicate/give an idea of the current system utilization. These results will then be used to suggest potential savings, advantages and improvements.

4.2. Simulation Objective

The purpose of the simulation is to:

- Give management a better understanding and analysis of forklift activities, identification of constraints and reasons for inefficiencies. Given the forklift travelling times and capacity, inefficiencies will easily be identified and analysed.
- The simulation results will enable management to establish an optimal forklift allocation plan. This will ultimately assist in meeting the demands in all departments.
- The simulation results will give management realistic figures/statistics regarding all forklifts and employees. This in turn will result in management setting standards for these entities together with Key Performance Indicators (KPI’s).
- The simulation will open room for new ideas and recommendations to be tried and tested in a new simulation and the results compared between the ‘what if’ and ‘as is’ scenarios

4.3. Problem Formulation

Problem formulation is a technique aimed at identifying a problem by; specifying the undesirable and problematic state, specifying the resources currently available to move away from the problematic state, identifying the available course of action, identifying constraints and defining criteria that needs to be satisfied.

4.4. AS-IS Process analysis

The following departments have been allocated for manufacturing and storing of the Primadet, each grouped according their functions:

GROUP 1	GROUP 2
D23: Manufacturing of Stubbies	**D7:** Consolidation Department
Store 1: Storing of Stubbies	**Store 2:** Storing raw material
BS1: Manufacturing of Stubbies	**D9:** Final Assembly
D3: Delay Preparation	

Table 1: Department grouping

The first group is responsible for manufacturing and storing Stubbies. Stubbies are metal cylinders used in the manufacturing of explosives. The second group is responsible the manufacturing and storing of raw material, detonators and shells used in the manufacturing of explosives. There are currently two forklifts allocated to the Primadet section. Each group has been allocated one forklift. Shown in figure 14 below is an overview of movement for each forklift between the departments together with the relative distances between the departments.

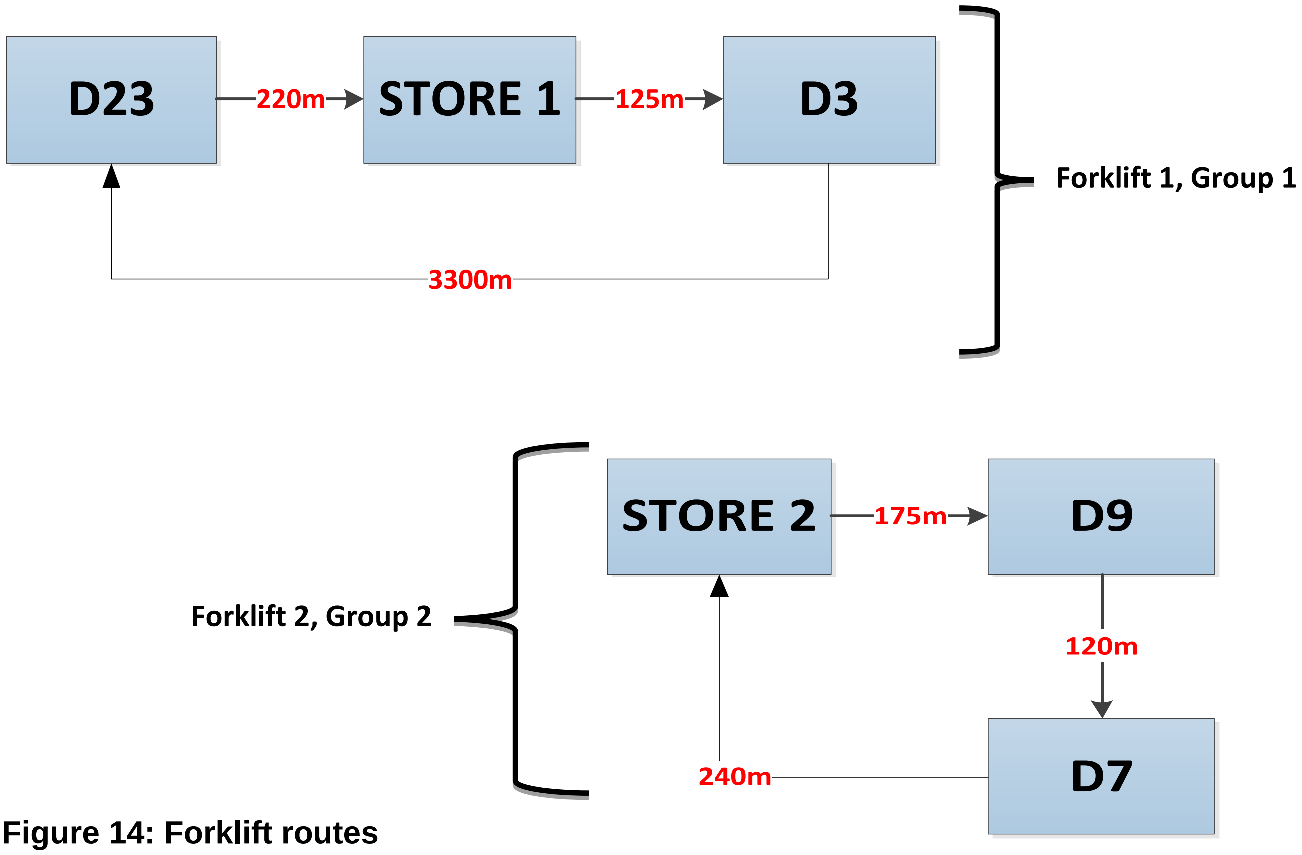


Figure 14: Forklift routes

4.5. Modeling Approach

An entity can be defined as an object that has a real existence i.e. a forklift. Each entity within the site will be allocated an object with specific attributes defining and describing the entity's behavior within the system. The entities identified in the simulation are the forklift, departments and paths. The attributes for these entities are listed in table 2, 3 and 4 below. Shown in figure 15 below is a snapshot of the simulation model.

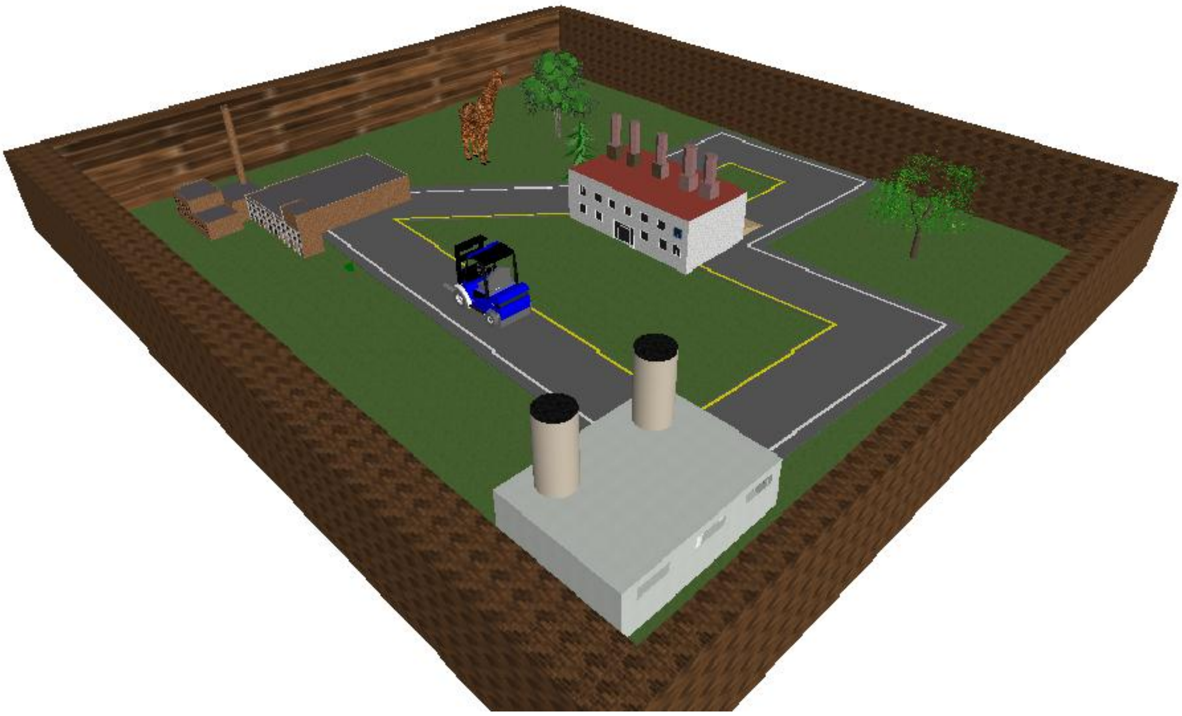


Figure 15: Simulation snapshot

		FORKLIFT 1	FORKLIFT 2
Attributes	Ride Capacity	2	2
	Loading Time(min)	10	10
	Initial node (Home)	Output at D23	Output at Stores 2
	Idle Action	Park at node	Park at node
	Travelling Speed	10km \hour	10km\hour

Table 2: Entities and Attributes (Forklifts)

As shown in table 2 above, each forklift has been allocated a specific attribute. The ride capacity is set to 2 to limit the number of pallets a forklift can carry to 2. Each forklift takes approximately 10min to load 2 pallets. The forklift is also limited to travelling at 10km/h for safety reasons.

		D23	STORE1	STORE2	D3	D7	D9
Attributes	Capacity	Infinite	Infinite	Infinite	N/A	N/A	Infinite
	Processing Time(min)	10	10	10	N/A	N/A	10
	Input buffer	0	0	0	N/A	N/A	0
	Transfer in time(min)	N/A	N/A	N/A	10	10	N/A
	Ranking Rule	N/A	FIFO	FIFO	N/A	N/A	FIFO

Table 3: Entities and Attributes (Departments)

As shown in table 3 above each department has been allocated its specific attribute. D23, Store1, Store2 and D9 are assigned as servers. Servers act like resources capable of performing a service. D3 and D7 have been assigned as 'Sinks'. This ensures that a forklift exit these departments and return to its initial position. 'Transfer in time' acts the same as processing time for a department; it indicates the time it takes to load a forklift. A 'Sink' has different attributes to a server. The input buffer is set to zero to ensure that the departments block the forklift during drop-offs. Finally the capacity is set to infinite to ensure that the departments can store an infinite amount of pallets at once.

		FORKLIFT 1			FORKLIFT 2		
		Path 1	Path 2	Path 3	Path 1	Path 2	Path 3
Attributes	Type	'Uni'	'Bi'	'Uni'	'Uni'	'Bi'	'Bi'
	Logical Length(m)	220	125	3300	175	120	240
	Traveler Capacity	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite
	Allow Passing	True	True	True	True	True	True
	Speed Limit(km/h)	10	10	10	10	10	10

Table 4: Entities and Attributes (Paths)

As shown in table 4 above, each path travelled by the forklift has been allocated a unique attribute. A path can either be 'unidirectional' or 'bidirectional'. A unidirectional path can only allow a forklift to travel in one direction while a bidirectional path allows travelling in both directions. Traveller capacity is set to infinite to ensure that the amounts of forklifts travelling on the path are not limited. Finally the speed limit is set to 10km/h to ensure that the forklift does not exceed the speed limit.

4.6. Assumptions

- Each entity will not undergo a failure during the simulation
- A forklift can only carry 2 pallets at a time
- A sink, server and source are regarded as departments

4.7. Results

Shown in table 5 below is a summary of all results generated and required from the model. The simulation length is set to 8 hours.

	FORKLIFT 1	FORKLIFT 2
Number Entered(pallets)	1905	1908
Number Exited	16	22
Scheduled Utilization (%)	100	100
Transporting Time (hours)	8	8
Transporting Time (%)	100	100

Table 5: Simulation Results

4.8. Conclusion and recommendations

Based on the simulation results, it can be seen that both forklifts are currently over utilized. The 100% utilization suggests that for the forklift to transport the amount of pallets specified, it would have to run continuously in a day. The transporting time of 8 hours also proves that both forklifts are never idle during the 8-hour working day. 'Number exited' refers to the amount of forklift occurrences at a given unique point. 'Forklift 1' has less number of occurrences as compared to 'forklift 2'. This indicates that 'forklift 1' travels more distance than 'forklift 2' in a given day. Over utilization of the forklift is not a desirable condition as it can lead to inflated maintenance costs and reduced replacement intervals. It is for this reason that more forklifts be procured. The estimation of the amount of additional forklifts to be acquired can be determined by changing the amount of forklifts in the current simulation and checking the results of the simulation for every change made. The optimal number of additional forklifts to be acquired will then be determined at the optimal utilization point.

CHAPTER 5: LIFE CYCLE AND COST ANALYSIS

5.1. Introduction

This chapter will focus on the analysis and documentation of a life and cost analysis design for the forklifts currently being utilized. Engineering economy principles such as 'retention and replacement decisions' and 'economic service life' have been chosen as the most appropriate tools and technique for designing a life cycle and cost analysis model for the forklift at Sasol Dyno Nobel. A Monte Carlo simulation will be used to estimate operational costs such as fuel consumption which tend to be probabilistic. Upon completion of the model, the results will be used to indicate/give an idea/estimate of current operational costs and to determine an optimal service life of the forklift. The model will also be used for future decision making.

5.2. Modeling approach and economic service life

A Monte Carlo Simulations was used to generate operational cost estimates for the forklift. The simulation had 1000 iterations. The reason for choosing such a large number of iterations was to increase the accuracy in cost estimation. Due to the fluctuating cost of fuel, a Monte Carlo simulation was used to estimate the annual cost for fuel. Table 6 below shows the input data for all variable and fixed cost costs considered. The mean value for annual fuel consumption was chosen to be R2 640 with standard deviation of R50.00. The interest rate is assumed to be 12%. The market value was chosen based on the current cost of a forklift that has been operating for the past 3 years. Maintenance and insurance costs are assumed to increase annually by 10% and 5% respectively.

Item	Amount
Annual fuel cost	NORM.INV(RAND(),mean, sdev)
Market value(after 10 years)	R0
Annual Maintenance Cost(current)	R11 250
Annual Insurance(current)	R350
Annual depreciation	R10 500
Market value(current: 3 year old forklift)	R160 000

Table 6: Forklift costs

The following model will be used to explain how an economic service life (ESL) for the forklift is determined. In order for the model to work or give accurate results, it is imperative that the correct data is used. This data can be obtained from the departments involved within the site such as the finance department. This data includes market value, annual operating cost and the number of years of operation as shown in table 6 above.

The following annual calculations were made for year 'n':

- **Market value (MV) =** $(MV_{n-1})-(MV_n)$
- **Annual Operating cost (AOC) =** $(AOC_{n-1})*0.1 + (AOC_{n-1})$
- **Annual capital recovery (ACR) =** -P(A/P, i, n) + S(A/F, i, n); P,S = MV
- **Annual worth of annual operating cost (AW of AOC)**
  = - PMT (i , years, NPV(i,year_1_AOC:year_n_AOC) + 0)
- **Total annual worth (Total AW)** = - $(\text{capital recovery})_n$ – $(\text{AW of AOC})_n$

These calculations are shown in table 7 below.

YEAR	MV	AOC	CAPITAL RECOVERY	AW OF AOC	TOTAL AW
1	149500	R 14 239.97	R 29 700.00	R 2 250.22	R 31 950.22
2	139000	R 15 388.37	R 29 105.66	R 2 431.69	R 31 537.35
3	128500	R 16 661.23	R 28 534.99	R 2 632.83	R 31 167.83
4	118000	R 18 086.09	R 27 987.85	R 2 857.99	R 30 845.84
5	107500	R 19 491.34	R 27 464.01	R 3 080.05	R 30 544.06
6	97000	R 21 229.23	R 26 963.22	R 3 354.68	R 30 317.90
7	86500	R 23 181.61	R 26 485.15	R 3 663.19	R 30 148.35
8	76000	R 25 063.49	R 26 029.44	R 3 960.57	R 29 990.01
9	65500	R 27 368.26	R 25 595.65	R 4 324.78	R 29 920.43
10	0	R 29 798.08	R 28 317.47	R 19 507.66	R 47 825.12

ESL

Table 7: ESL Calculation

As seen in table 7 above, the economic service life (ESL) was found at year 9. This is where the total annual worth is at its minimum.

The capital recovery curve in figure 16 below is not a true concave shape because the estimated market value changes each year. If the same market were estimated for each year, the curve would appear concave as depicted in figure 7 above. When several total annual worth (AW) values are approximately equally, the curve will be flat over several periods. This indicates that the ESL is relatively insensitive to cost.

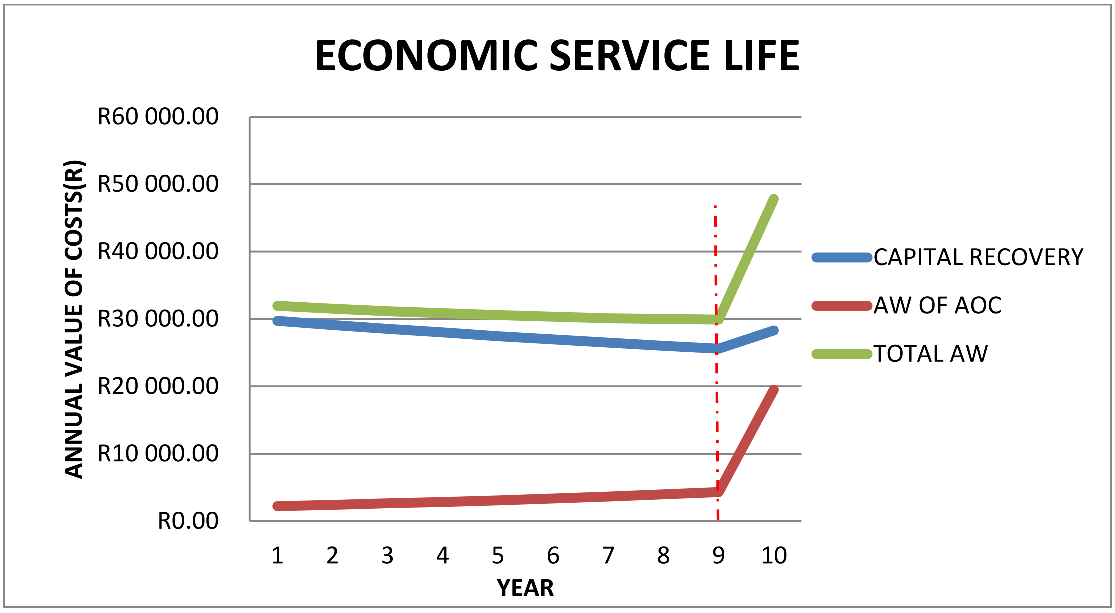


Figure 16: Total AW and cost components

5.3. Operating costs and sensitivity analysis

Figure 17 below shows the annual operating cost for the first 10 years. It can be seen from the graph that as the years progress, the operating costs tend to increase.

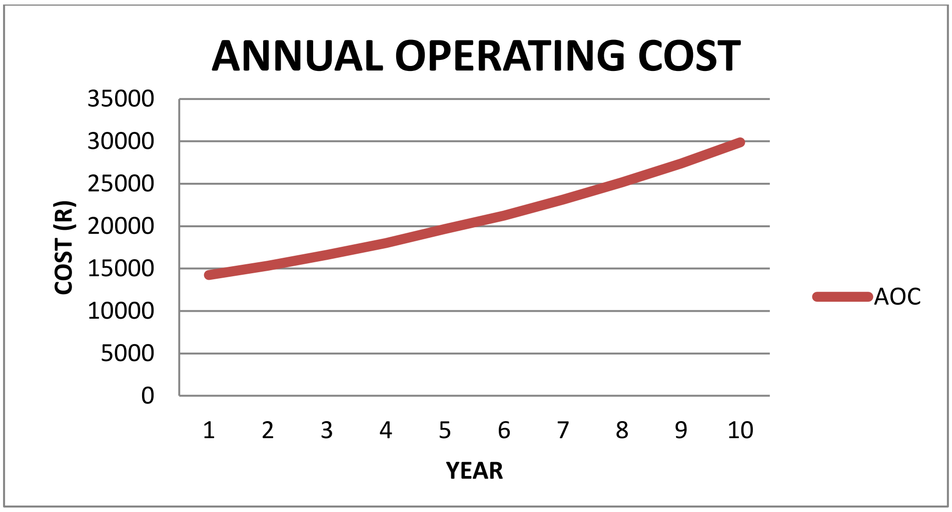


Figure 17: Forklift annual operating cost

Figure 18 below shows the graph which was obtained during sensitivity analysis for the uncertain costs associated with the forklift. The graph was obtained by computing the correlation coefficients for each variable item. It can be seen that maintenance is the most sensitive cost for the forklift. It is for this reason that maintenance costs are taken seriously when considering replacing or keeping a current forklift.

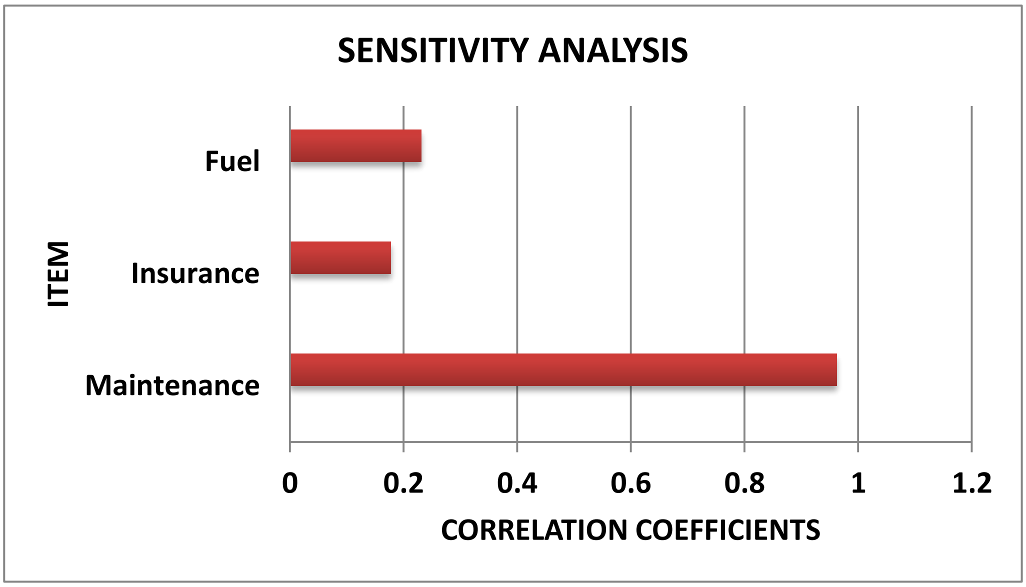


Figure 18: Sensitivity Analysis

5.4. Conclusion

Based on the results generated during the cost and life cycle analysis, it was noted that the economic life or minimum cost life for the forklift occurs at year nine. After these years have passed, the asset should be replaced to minimize overall costs. This model can be used for any other asset used on site given that the correct cost estimations have been taken into account.

CHAPTER 6: FORKLIFT UTILIZATION (TO-BE Process)

6.1. Introduction

Having designed a generic simulation model in chapter 4, alterations will now be made to the model. These alterations will assist in determining the optimal number of forklifts required at the plant.

6.2. Modelling approach

The same modelling approach from chapter 2 will still apply. All minor alterations are listed below. Table 9 below lists the forklift attributes as prescribed in chapter 2.

6.2.1. Forklifts

As shown in table 8 below, a failure has been assigned to the forklifts. The rate of failure and time allocated for repairing a forklift has also been indicated. A failure is necessary to ensure that the simulation is as realistic as possible.

Reliability Logic	
Failure Type	**Calendar Time Based**
⊞ Uptime Between Fail...	**Random.Exponential(2)**
⊞ Time To Repair	Random.Triangular(0.5,1.0,1.5)

Table 8: Forklift reliability logic

		FORKLIFT 1	FORKLIFT 2
ATTRIBUTES	**Ride Capacity**	2	2
	Loading Time(min)	10	10
	Initial node (Home)	Output at D23	Output at Stores 2
	Idle Action	Park at node	Park at node
	Travelling Speed	10km \hour	10km\hour

Table 9: Forklift A and B attributes

6.2.2. Multiple vehicle logic design

In order to ensure that multiple vehicles are assigned to the simulation, a list of vehicles has to be generated. This vehicle-listing-logic is then assigned to the output node where the vehicles will start. Table 10 below is a snapshot of the transport logic taken from the simulation.

Transport Logic	
Ride On Transporter	True
⊟ Transporter Type	From List
Transporter List Name	TransporterList1

Table 10: Node transport logic

6.2.3. Assumptions

- A forklift can only carry 2 pallets at a time
- A sink, server and source are regarded as departments

Shown in figure 19 and 20 below are snapshots of the simulation models for both group 1 and 2 forklifts. An additional forklift has been assigned to each group to ensure that the current forklifts that are in use are not over utilized.

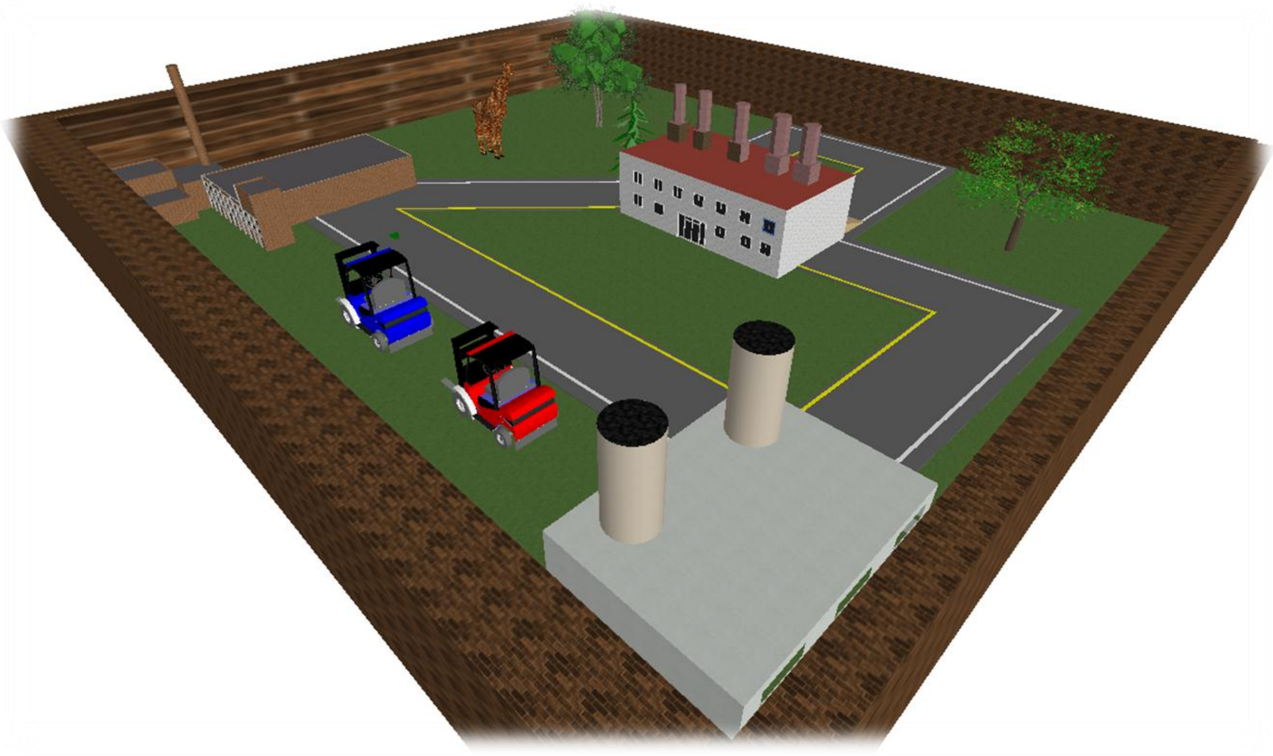


Figure 19: TO-BE Simulation snapshot (group 1 forklift)

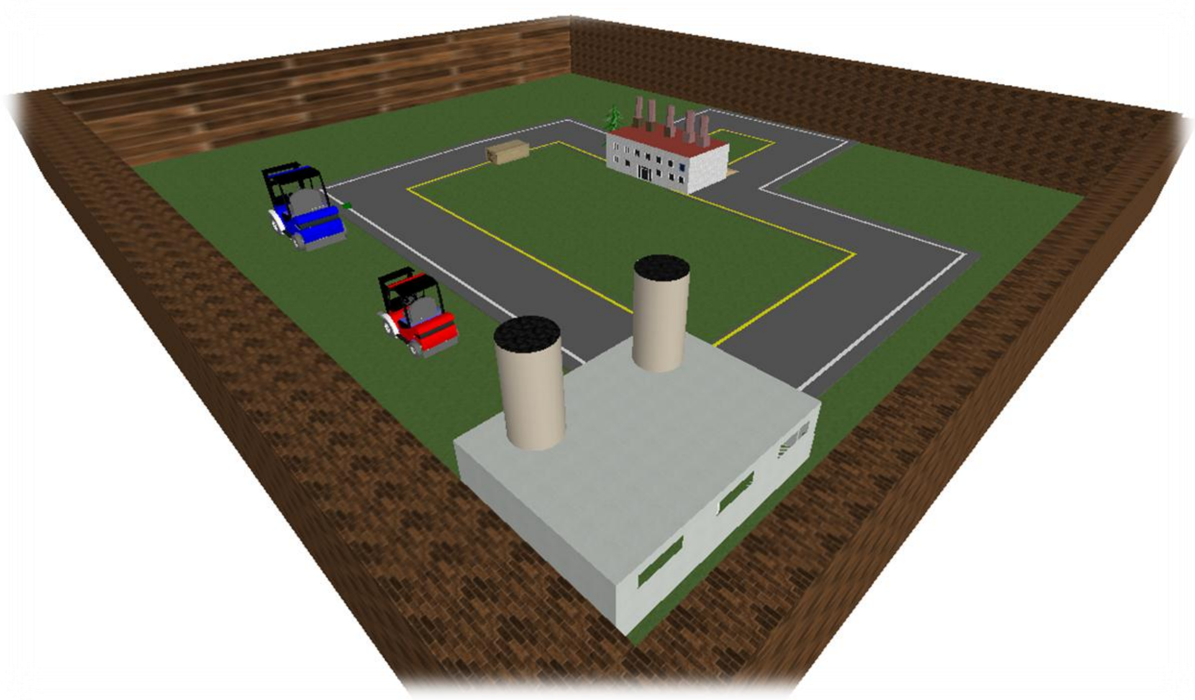


Figure 20: TO-BE Simulation snapshot (group 2 forklift)

6.3. Results

As shown in figure 21 the initial utilization derived from the 'AS-IS' simulation was at full capacity. This means that the current forklifts (labelled A and B) are over utilized. Two more forklifts were then added to the simulation in order to see the effect they would have on the overall utilization. Figure 22 below shows this effect. The utilization is fairy distributed amongst all the forklifts.

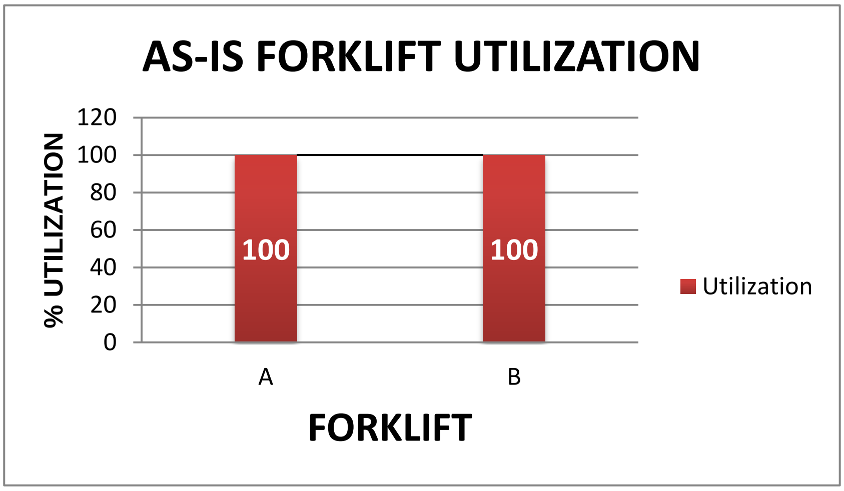


Figure 21: AS-IS simulation results

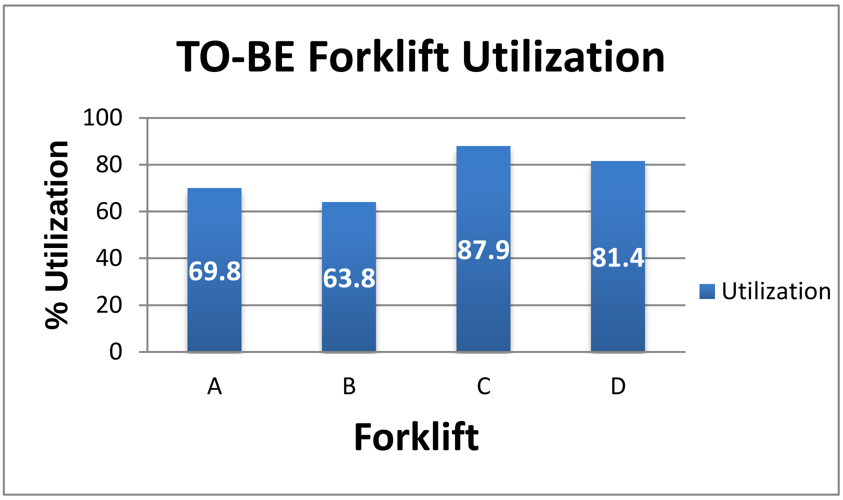


Figure 22: TO-BE simulation results

6.4. Conclusion

The AS-IS simulation design provided a foundation for future modifications and decision analysis. Adding two more forklifts to the simulation proved to be ideal in balancing and reducing overall forklift utilization. This new setup will prove beneficial on the long run when considering the lifecycles and maintenance costs associated with forklifts. The lower the utilization on a forklift, the longer its life.

CHAPTER 7: ASSET AND DECISION ANALYSIS

7.1. Introduction

This chapter will focus on performing a full analysis and comparison of the major types of forklifts available on the market. AHP will then be used to assist in determining the most economical and reliable forklift. Three types of forklifts have been identified, namely the electric powered, diesel powered and LPG (liquid petroleum gas) powered forklift.

7.2. Forklift comparison

A comprehensive study on the different types of forklifts available on the market has been conducted. The aim of this study is to give the company an idea of the major differences between these forklifts and to assist in deciding on the best forklift.

7.3. Electric powered forklifts

Battery electric forklifts are the most environmentally friendly forklifts on the market. This is mainly due to the fact that they are fume free in operation, giving off no harmful emissions. These forklifts are also quiet in use, and due to the weight and concentrated mass of the battery, they are generally more manoeuvrable than engine powered equivalents. The battery weight which acts as an effective counterbalance, enables the truck to be more compact in size. The cost of recharging the battery overnight on low rate tariff is considerably less than replacing gas bottles or filling a tank with diesel fuel. Electric fork lift trucks are generally easier to drive than engine powered machines, because they only have an accelerator and a brake pedal. There is no clutch pedal or inching pedal, and the operator does not have to “rev” the engine for fast lift or hill starting. The maintenance and servicing costs of electric forklifts is considerably less than engine powered alternatives, since there are so few moving parts by comparison (www.bendigomitchell.com, 2012).

Figure 23: Electric forklift
Source: www.bendigomitchell.com

Disadvantages

- Higher initial cost, because of battery and charger.
- Unavailable for use while the battery is being recharged
- Electric forklifts need a better floor surface to work on because the higher point loadings on the axles and wheels can cause them to sink in shale or hard standing.
- Intensive use on gradients will flatten the battery rapidly, but this can be partially overcome by specifying extra heavy duty capacity.
- Battery recharging can be vulnerable to power cuts from the national grid in the middle of winter.
- Not suitable for prolonged use outside in wet weather, because the damp atmosphere causes problems with wiring circuitry and electrical components.
- Maintenance and repairs/fault finding is not easily

7.4. Diesel powered forklifts

Diesel powered forklifts are perfect for outdoor operations. The exhaust fumes and diesel particulates escape easily to the atmosphere and do not cause environmental or health and safety issues. Exhaust catalysts and purifiers can also be used to make the machines acceptable for occasional indoor use. Diesel engines are more fuel efficient than LPG powered engines. An average fuel tank of 50 litres diesel will last much longer than an 18 kg bottle of gas used in LPG forklifts. Diesel powered forklifts also have larger torques which makes them better on gradients and more powerful for towing duties. The performance of a diesel truck is usually superior to an electric alternative, with better acceleration and lift speeds. Maintenance and servicing costs of a diesel fork lift are lower than a gas truck. When it comes to disposal, diesel forklifts usually have a higher residual value than LPG or electric machines. Diesel forklifts are available for use at any time of the day or night. The fuel gauge indicates when the diesel tank needs topping up, and this can be done in a matter of minutes (www.bendigomitchell.com, 2012).

Disadvantages

- Diesel powered forklifts are noisier in operation, the exhaust fumes are off-putting to some people, and may trigger smoke alarms inside an enclosed building.
- Their bulkier size means they need more space to operate in.
- The initial purchase price is less than an electric fork lift but usually slightly more than an LPG powered machine.
- Maintenance costs are higher than an electric truck, but less than an LPG truck.

Figure 24: Diesel powered forklift
Source: www.bendigomitchell.com

7.5. LPG powered forklifts

LPG (liquefied petroleum gas) powered forklifts have long been popular. This is due to their competitive pricing and suitability for inside/outside usage and convenience for round the clock working. The engines are usually by-products of car engines, and consequently parts are readily available at keen prices. Compact gas trucks are more manoeuvrable than “yard design” diesel forklifts. LPG powered forklifts are quieter in operation than diesel. Their exhaust fumes are less unpleasant than diesel fumes. The performance characteristics of LPG powered trucks are usually superior to electric and diesel powered equivalents. Travel speeds, rates of acceleration, and lift speeds usually outperform their electric/diesel rivals because of better power to weight ratios and more responsive engines. The service burden of gas trucks is generally less than their electric and diesel forklifts (www.bendigomitchell.com, 2012).

Figure 25: LPG powered forklift
Source: www.bendigomitchell.com

Disadvantages

- Cheapest to buy new
- Maintenance and fuel costs are the highest of the three types.

7.6. Analytical Hierarchy Process (AHP)

The AHP technique will now be used to decide between the three available types of forklifts. Figure 26 below shows the AHP diagram for the different forklifts together with their attributes. The following criterions have been defined:

Fuel – The annual cost of fuel/gas/batteries and availability

Maintenance – The annual maintenance cost

CO_2 Emissions – The amount of CO_2 released into the environment

Noise – The amount of noise made by the forklift (measured in decibels)

Flexibility – Can the forklift be used both indoors and outdoors?

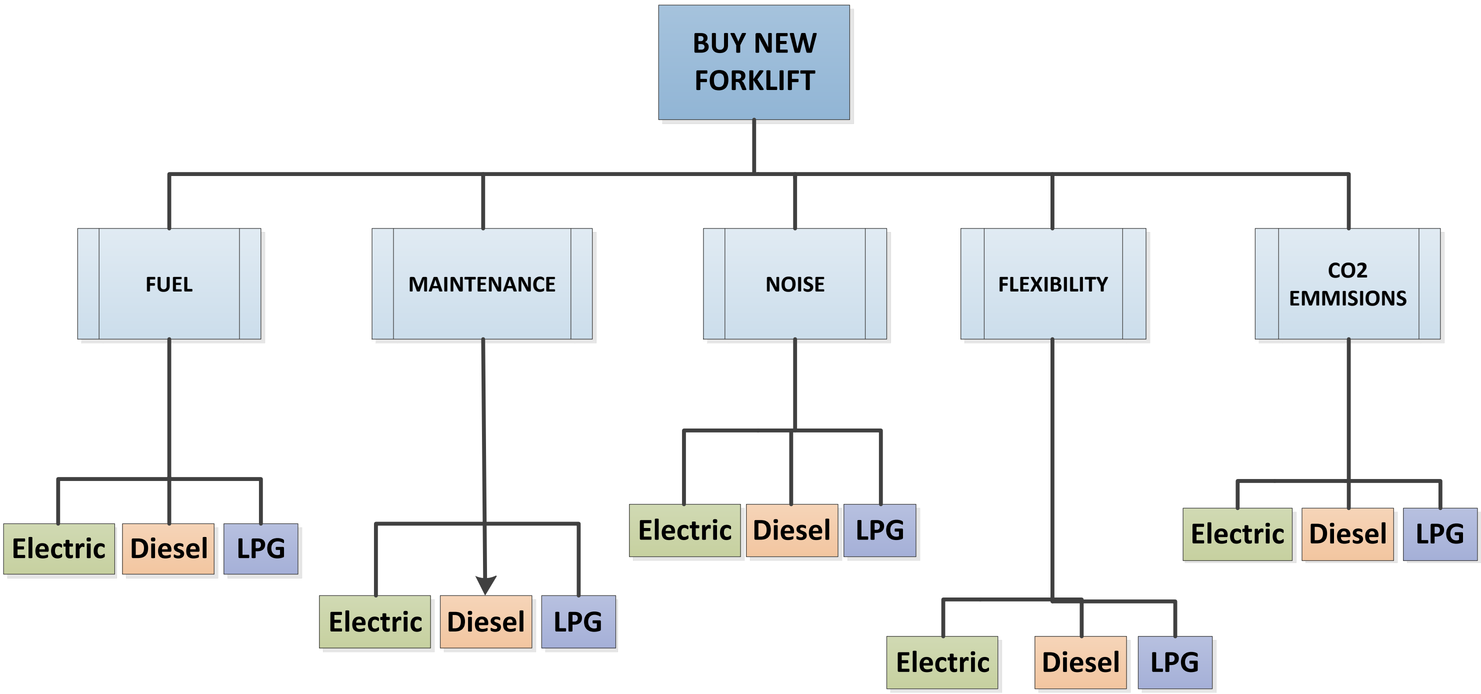


Figure 26: AHP diagram

Table 11 below shows the value scale which will be used to construct and assign vales for the pair wise and intermediate matrix. These matrices are shown in table 12, 13 and 14 below.

VALUE SCALE	
1	Equal
2	Weakly better
3	Strongly better
4	Very strongly better
5	Absolutely better

Table 11: Value scale

	FUEL	MAINTENANCE	NOISE	FLEXIBILITY	CO2 EMISSIONS
FUEL	1	3	5	3	2
MAINTENANCE	0.33	1	4	4	4
NOISE	0.2	0.25	1	2	2
FLEXIBILITY	0.33	0.25	0.5	1	3
CO2 EMISSIONS	0.5	0.25	0.5	0.33	1
SUM	2.3	4.75	11	10.3	12

Table 12: Pair wise comparison matrix (attributes)

						SUM
FUEL	0.42	0.63	2.11	0.63	0.85	4.64
MAINTENANCE	0.14	0.21	1.69	0.84	1.69	4.57
NOISE	0.08	0.05	0.42	0.42	0.85	1.83
FLEXIBILITY	0.14	0.05	0.21	0.21	1.27	1.88
CO2 EMISSIONS	0.21	0.05	0.21	0.07	0.42	0.97

Table 13: Intermediate matrix

FUEL			
	ELECTRIC	DIESEL	LPG
ELECTRIC	1	4	4
DIESEL	0.25	1	4
LPG	0.25	0.25	1
SUM	1.5	5.25	9

				SUM
ELECTRIC	0.67	0.76	0.44	1.87
DIESEL	0.17	0.19	2.67	3.02
LPG	0.17	0.05	0.67	0.88

MAINTENANCE			
	ELECTRIC	DIESEL	LPG
ELECTRIC	1	3	4
DIESEL	0.33	1	3
LPG	0.25	0.33	1
SUM	1.58	4.33	8

				SUM
ELECTRIC	0.63	0.69	0.50	1.32
DIESEL	0.21	0.23	0.38	0.44
LPG	0.16	0.08	0.13	0.23

FLEXIBILITY			
	ELECTRIC	DIESEL	LPG
ELECTRIC	1	0.33333	2
DIESEL	3	1	3
LPG	0.5	0.33333	1
SUM	4.5	1.66667	6

				SUM
ELECTRIC	0.22	0.20	0.33	0.42
DIESEL	0.67	0.60	0.50	1.27
LPG	0.11	0.20	0.17	0.31

CO2 EMISSIONS			
	ELECTRIC	DIESEL	LPG
ELECTRIC	1	5	4
DIESEL	0.2	1	0.33
LPG	0.25	3	1.00
SUM	1.45	9	5.33

				SUM
ELECTRIC	0.69	0.56	0.75	1.25
DIESEL	0.14	0.11	0.06	0.25
LPG	0.17	0.33	0.19	0.51

NOISE			
	ELECTRIC	DIESEL	LPG
ELECTRIC	1	4	2
DIESEL	0.25	1	0.25
LPG	0.5	4	1
SUM	1.75	9	3.25

				SUM
ELECTRIC	0.57	0.44	0.62	1.02
DIESEL	0.14	0.11	0.08	0.25
LPG	0.29	0.44	0.31	0.73

Table 14: Pair wise and intermediate comparison matrix (forklifts)

7.7. AHP Results and conclusion

As seen in table 15 below, the weights for the different types of forklifts were calculated in order to determine which forklift is the best option. The electric forklift proved to be more economical and feasible when considering all the imperative attributes as indicated in the AHP diagram in figure 26 above.

	WEIGHTS
ELECTRIC	**23.4**
DIESEL	**21.9**
LPG	**9.2**

Table 15: Forklift AHP weights

CHAPTER 8: SUMMARY OF RESULTS AND CONCLUSION

8.1. Forklift utilization

The following results were generated for both the 'AS-IS' process and the 'TO-BE' process.

AS-IS process

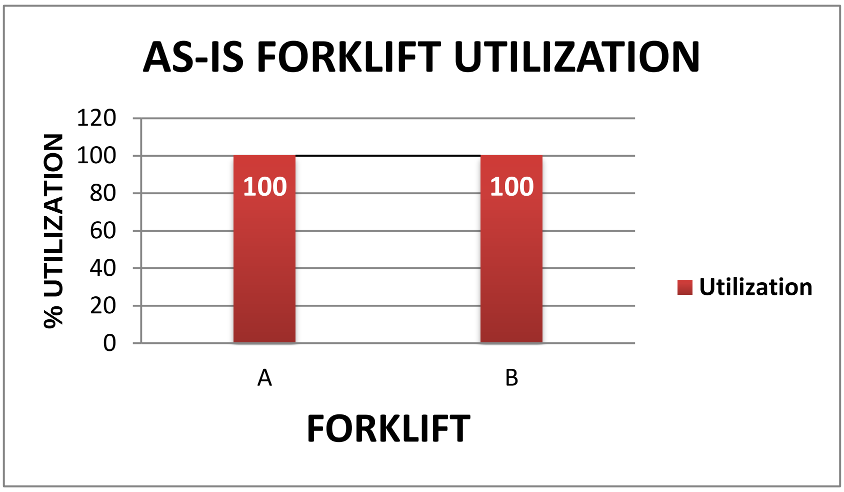


Figure 27: AS-IS forklift utilization

TO-BE process

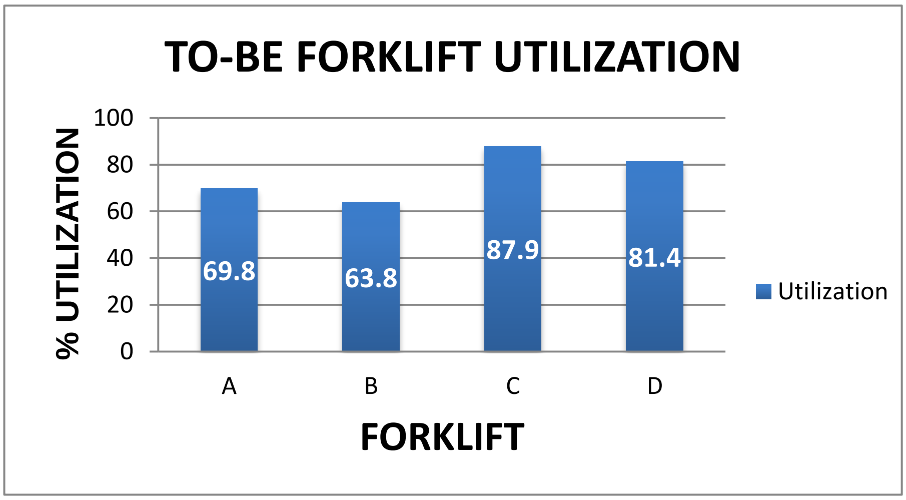


Figure 28: TO-BE forklift utilization

As shown in figure 27 the initial utilization derived from the 'AS-IS' simulation was at full capacity. This means that the current forklifts (labelled A and B) are over utilized. Two more forklifts were then added to the simulation in order to see the effect they would have on the overall utilization. Figure 28 above shows this effect. The utilization is fairy distributed amongst all the forklifts

8.2. Life cycle and cost analysis

Economic service life (ESL)

YEAR	MV	AOC	CAPITAL RECOVERY	AW OF AOC	TOTAL AW
1	149500	R 14 239.97	R 29 700.00	R 2 250.22	R 31 950.22
2	139000	R 15 388.37	R 29 105.66	R 2 431.69	R 31 537.35
3	128500	R 16 661.23	R 28 534.99	R 2 632.83	R 31 167.83
4	118000	R 18 086.09	R 27 987.85	R 2 857.99	R 30 845.84
5	107500	R 19 491.34	R 27 464.01	R 3 080.05	R 30 544.06
6	97000	R 21 229.23	R 26 963.22	R 3 354.68	R 30 317.90
7	86500	R 23 181.61	R 26 485.15	R 3 663.19	R 30 148.35
8	76000	R 25 063.49	R 26 029.44	R 3 960.57	R 29 990.01
9	65500	R 27 368.26	R 25 595.65	R 4 324.78	R 29 920.43
10	0	R 29 798.08	R 28 317.47	R 19 507.66	R 47 825.12

ESL

Table 16: ESL calculations

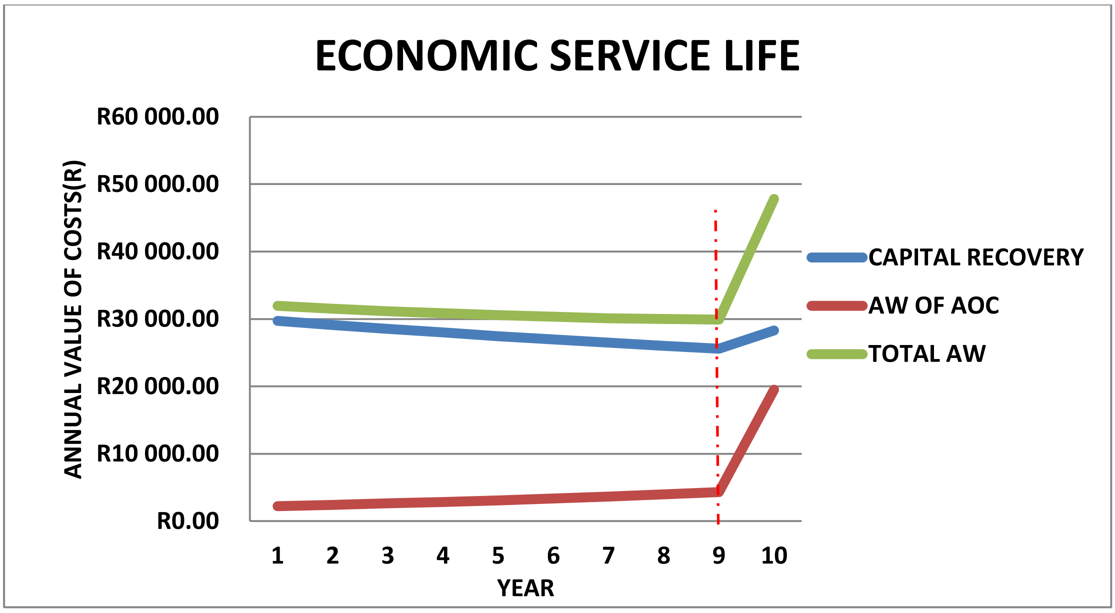


Figure 29: Economic service life

As seen in table 16 above, the economic service life (ESL) was found at year 9. This is where the total annual worth is at its minimum.

The capital recovery curve in figure 29 above is not a true concave shape because the estimated market value changes each year. If the same market were estimated for each year, the curve would appear concave as depicted in figure 7 above. When several total annual worth (AW) values are approximately equally, the curve will be flat over several periods. This indicates that the ESL is relatively insensitive to cost.

Annual operating cost

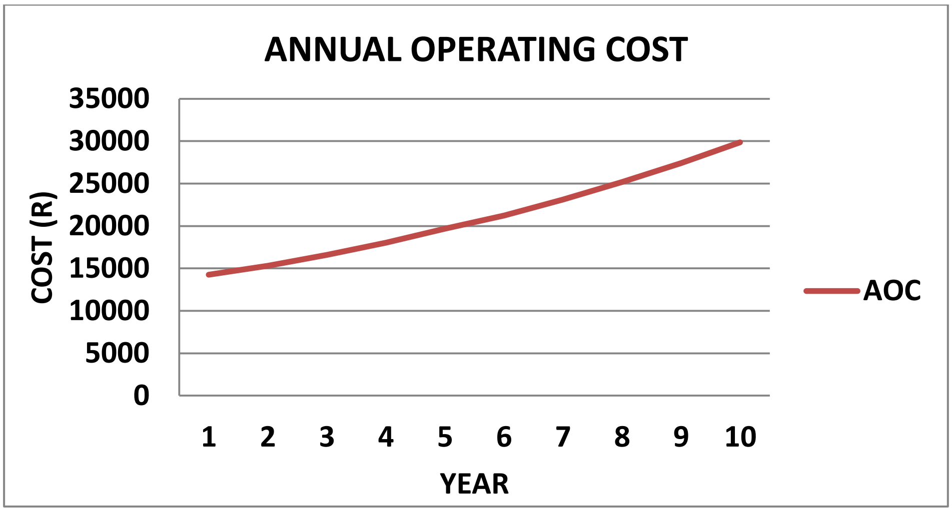


Figure 30: Annual operating cost

Figure 30 above shows the annual operating cost for the first 10 years. It can be seen from the graph that as the years progress, the operating costs tend to increase.

Sensitivity analysis

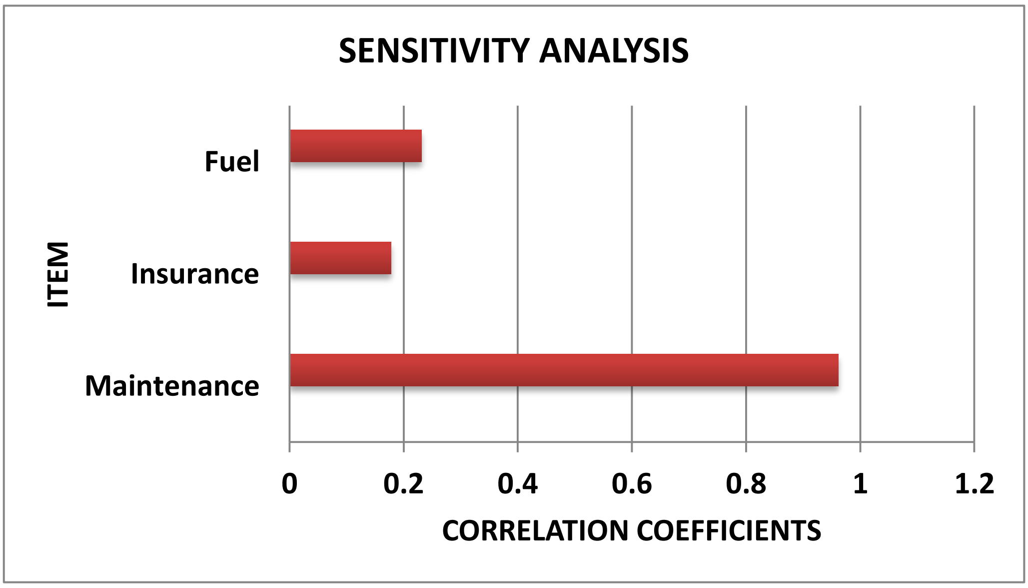


Figure 31: Sensitivity analysis

Figure 31 above shows the graph which was obtained during sensitivity analysis for the uncertain costs associated with the forklift. The graph was obtained by computing the correlation coefficients for each variable item. It can be seen that maintenance is the most sensitive cost for the forklift. It is for this reason that maintenance costs are taken seriously when considering replacing or keeping a current forklift.

8.3. Asset and decision analysis

Analytical hierarchy process (AHP)

	WEIGHTS
ELECTRIC	**23.4**
DIESEL	**21.9**
LPG	**9.2**

Table 17: Forklift AHP weights

As seen in table 17 above, the weights for the different types of forklifts were calculated in order to determine which forklift is the best option. The electric forklift proved to be more economical and feasible when considering all the imperative attributes as indicated in the AHP diagram in figure 26 above.

Forklift cost comparison

As seen in figure 32 below, a saving of 37 509 dollars (R50 012) per annum was recorded when comparing the electric forklift to the diesel forklift. This is achieved through the use of an open source software available on the 'Raymond Handling Solutions' website (http://www.raymondhandlingsolutions.com).

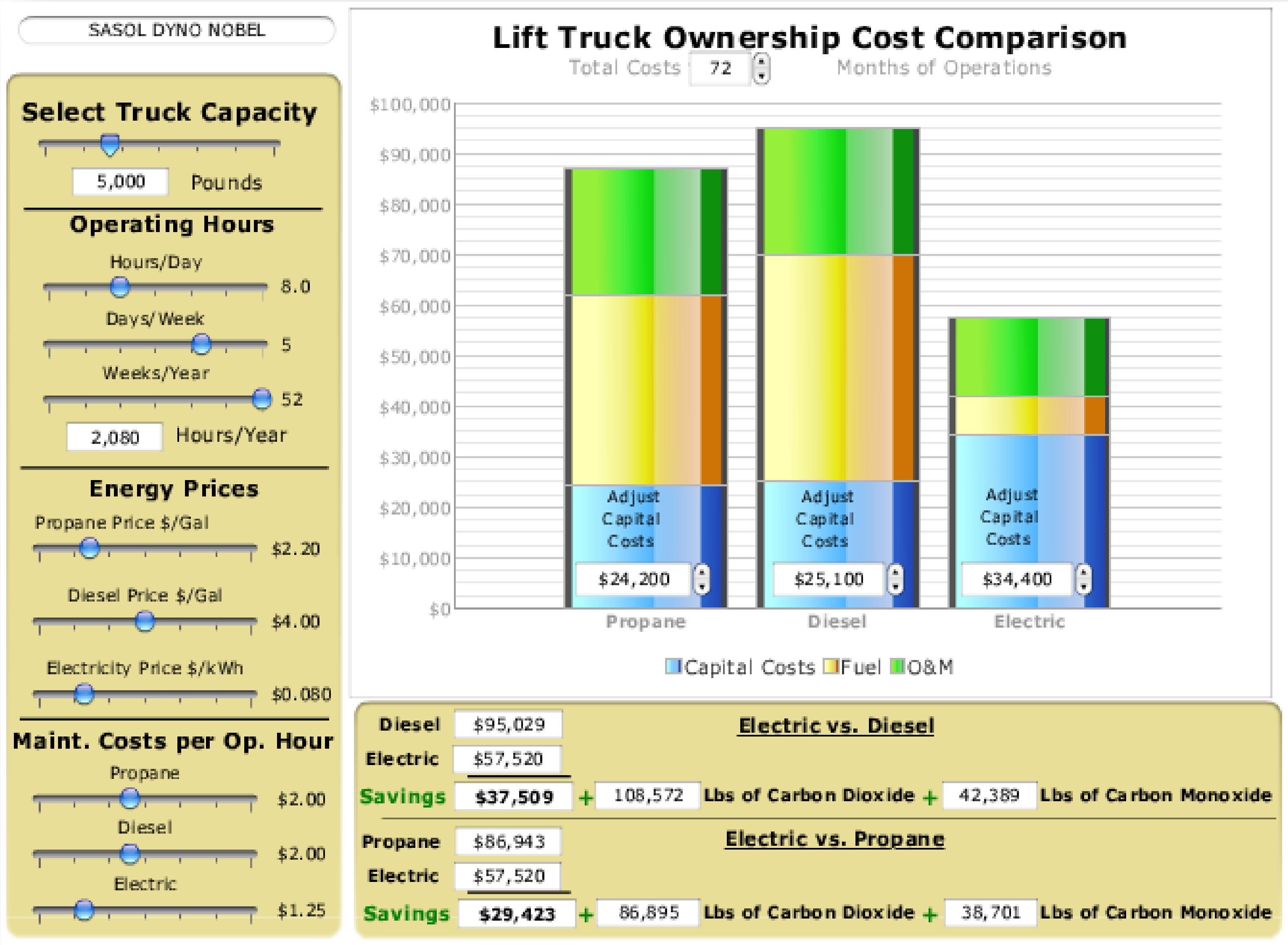


Figure 32: Forklift cost comparison calculator
http://www.raymondhandlingsolutions.com/electric_power_research_institute_epri.html

8.4. Conclusion

The design and analysis of a simulation model made it possible to see and evaluate current forklift utilization. This initial design set a good foundation for data alterations in order to obtain optimal results and make recommendations, which in this case involved the procurement of two extra forklifts. A life cycle model was also designed for the purpose of determining replacement intervals for a forklift. Finally the AHP technique was used to assist in deciding on the most economical forklift, which in this case turned out to be the electric powered one. All the techniques used in this project proved to be reliable in giving desired results. All that is left is for management to implement what has been recommended.

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APPENDIX A: Simulation Results