DURATRAY TRIAL:
REDUCING THE EFFECT OF CARRY BACK AT NEW VAAL COLLIERY

Submitted in Partial Fulfilment of the Requirements

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EXECUTIVE SUMMARY

New Vaal Colliery is one of Anglo American PLC's largest domestic coal producing mines in South Africa. One of the primary deterrents preventing the mine from achieving maximum productivity is the problem of carry-back on certain haul trucks. This problem stems from an evident flaw in the design of the bowl used to transport the overburden material. The design improvements developed by *Duratray* promise to reduce the effect of the carry-back and at the same time allow for improved performance of the haul truck fleet.

This new prototype was tested to ascertain whether it could be considered a viable replacement for the current steel lined haul truck bowls. The purpose of this project was to analyse data from the haul trucks so as to provide the company with a basis on which to make a decision. The study included three major sections. Firstly research was conducted into the validity of the new design, the different statistical methods in which data could be obtained and into the different simulation software packages available. The second phase dealt with the actual analysis and simulation of the current fleet of haul trucks and their utilisation in order to establish a baseline for the remainder of the study. The prototype then underwent the same analysis and simulation in order to determine which alternative had the higher utilisation and performance measures.

Finally a suggestion needed to be made regarding whether it would be sufficiently beneficial for the company to adopt the new prototype design. To do this an Analytical Hierarchy Process was conducted to integrate all aspects of the decision that the company felt to be of importance.

TABLE OF CONTENTS

Page #

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS & ACRONYMS

AATC	Anglo American Thermal Coal
AHP	Analytic Hierarchy Process
BPM	Business Process Modelling
BPR	Business Process Re-Engineering
CI	Consistency Index
CR	Consistency Ratio
GVW	Gross Vehicle Weight
MCDM	Multi-Choice Decision Making
MLA	Machine Learning Algorithm
NVC	New Vaal Colliery
OOS	Object Oriented Simulation
PSA	Parametric Statistical Algorithm
RCI	Random Consistency Index
SDB	Suspended Dump Body

GLOSSARY

Business Process Re-Engineering: The analysis and redesign of workflow within and between organisations. Generally makes use of Business Process Modelling to achieve or substantiate its arguments.

Carry-Back: A thick layer of adhesive sand that builds up on the bowl of a rigid dump truck causing lack of performance and increased downtime

Hypothesis Testing: A method of making decisions about data by making an assumption (null hypothesis) about that data and testing whether the validity of this hypothesis.

Object Oriented Simulation: A method of simulating a process, system or the effects of either of these on its environment by means of creating object that imitate reality and can be controlled to follow a specific logic or procedure.

Open Cast (Strip) Mining: The method of mining whereby the layers of soil, rock and other material is removed from the surface of the Earth until the valuable underlying mineral is exposed.

Overburden: The layers of material, stripped away in open cast mining, that cover the valuable minerals lying beneath it.

CHAPTER 1: INTRODUCTION

1.1 Background to Coal Mining in South Africa

The South African coal mining industry has flourished since coal was discovered in the mid-19th Century. As reported by *The World Coal Association* (2009), South Africa is the 6th largest coal producing country in the world with an annual production of 247Mt, (93% of which being used for electricity generation) behind PR China (2971Mt), USA (919Mt), India (526Mt), Australia (335Mt) and Indonesia (263Mt). The 4 largest coal fields in South Africa account for 86% of the country's total coal reserves; these being: Highveld (31%), Witbank (30%), Ermelo (14%) and Waterberg (11%). (Schmidt, 2008).

Anglo American has been mining in South Africa since 1917 and is one of the top coal producers in South Africa. This division of Anglo American (Thermal Coal) accounts for approximately 24% of all SA production. (Schmidt, 2008) In 2010 *Anglo American Thermal Coal* (AATC) had a total production of 68.1Mt of coal, 36.4Mt (53.5%) of which was produced for the South African power utility Eskom. (Anglo American, 2010a)

1.2 Background to New Vaal Colliery and Carry-Back Problems

New Vaal Colliery (NVC) is one of the mining operations that forms part of AATC a division of Anglo American PLC and is situated South-East of Vereeniging in the Free State Province. The mine, established in the 1980's, makes use of open-cast strip mining methods to produce coal for the nearby Eskom *Lethabo* power station and has enough low-grade coal reserves to supply Eskom until 2030. (Anglo American, 2011) It was also estimated that the mine produced 19.4Mt of coal in 2010 alone, making it one of AATC's largest domestic coal producing mines in the country. (Anglo American, 2010b)

Figure 1 shows the layout of New Vaal Colliery, with the power station situated to the South. The Eastern section is comprised of some 14 ramps that lead to the various sections of the coal face. In a North-Westerly direction lays The Vaal River, the close proximity of the mine to the river is both a blessing and a hindrance.

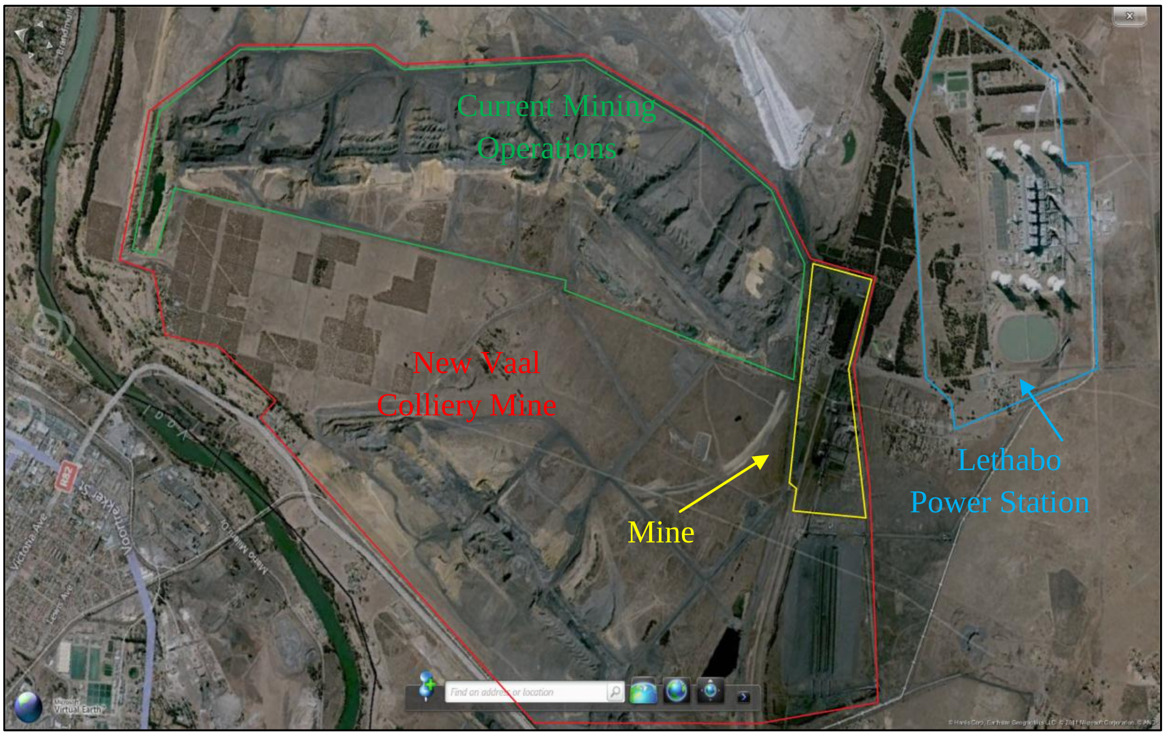


Figure 1: New Vaal Colliery - Overhead View.

The problem of *carry-back* on haul trucks is not something that is new to the mining environment. However, in recent years, significant advances in technology have been made that aim to reduce the effect that this problem has on mining operations.

One of the many hindrances that miners face, when making use of the open-cast strip mining method, is the removal of the *overburden*. This is the layer of soil, rock and other materials that cover the coal seam this is depicted in Figure 2. At NVC this layer is predominantly made up of river sand left behind by the Vaal River thousands of years ago. It is removed with the use of a Komatsu PC1250-8 excavator and CAT 773F rigid dump trucks once the blasting phase has taken place.

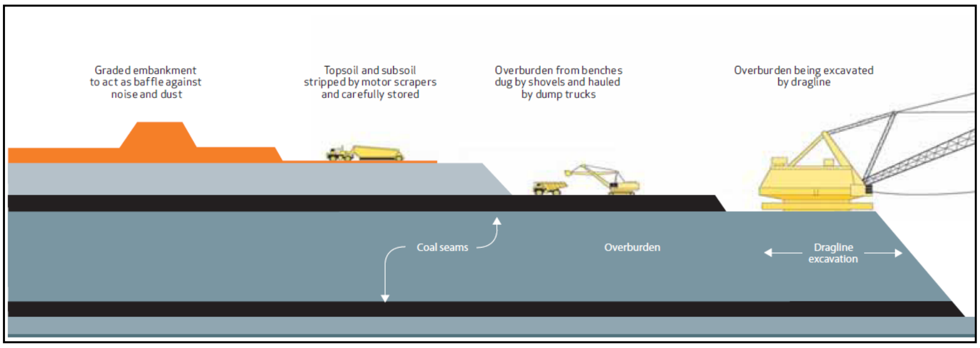


Figure 2: Basic Open Cast/Strip Mining Procedure.

The problem of carry-back stems from the immense weight that is loaded into the bowls of these trucks at one time. The CAT 773F truck is certified to carry a maximum capacity of 53.54t. (Caterpillar, 2011) The reigning trend with ordinary steel lined bowls is that the sand adheres to the bowl under such high loads and can only be removed with the aid of an excavator or other similar equipment. The carry-back, shown in Figure 3, in addition to reducing the amount of material a truck can carry, causes great deal of lost time as frequent removal of carry-back is required during maintenance. In an attempt to reduce the effect that carry-back has on the system, advances in bowl design technology are being developed. These advances are being led by *Duratray International*, and the design implications are discussed further in a later section of this report.

Figure 3: Example of Severe Carry-back Problem.

CHAPTER 2: PROJECT AIM AND DELIVERABLES

2.1 Problem Statement

C.J. Moolman (2000) describes the fact that any open cast (strip) mining operations success depends on the ability to effectively remove the overburden covering the layers of coal. The effect of carry-back deters the mine from achieving this goal as it prevents the hauling trucks from carrying a capacity load and adds to the downtime of the trucks required for the removal of this carry-back.

New Vaal Colliery is especially vulnerable to this problem because the overburden that is removed to uncover the coal is predominantly comprised of river sand. This type of sand makes the trucks significantly more susceptible to the effects of carry-back as it tends to stick to the steel lining in the bowl under high loads. During the rainy season, when the carry-back is at its worst, it can diminish the trucks capacity by as much as 30%. The effect of carry-back also increases the time required for scheduled maintenance considerably and has had a detrimental effect on the overall productivity of the mine.

It has thus been decided that adequate steps need to be taken in an attempt to reduce this problem and ensure that the mine meets its productivity requirements.

2.2 Project Aim

The aim of this study is to analyse the effect of the new equipment (Duratray) with regards to reducing the evident carry-back. The results of this study should conclude whether the Duratray replacement is a better alternative and should give consideration to all aspects that the company would deem important in making such a decision.

2.3 Research Design and Deliverables

The primary deliverable for this study will be a comprehensive document outlining the effect that implementing the *Duratray System* will have on NVC. In order to determine the positive or negative impact that this system will have; a preliminary *AS-IS* study will need to be conducted so that a baseline can be established. This analysis will comprise of an initial time study and simulations to determine the utilisation of the haul trucks along with their performance measures.

Once a baseline is in place, the new Duratray System can be evaluated following the same method, and a decision can be made with regards to the extended implementation of the system. This comprises the *TO-BE* section of the study.

The logical measure that will be used in determining the effect that the system will have is the utilisation of the haul trucks. The utilisation provides a comparative measure on which the separate classes of haul trucks can be critically evaluated. While the utilisation may be the most critical factor for this trial, it cannot be viewed as the only measure the project requires. Other factors such as tyre degradation and the effect of increased loads need to be considered as well.

In addition attention also needs to be paid to the advances that implementing the Duratray system has on the overall productivity of the fleet of trucks. The fundamental measurement made for this purpose is to be the total tonnage of material moved by the fleets.

In conclusion to the study an *Advanced Hierarchy Decision Making Process* (AHP) should be conducted, in conjunction with the company, so as to determine the optimum strategy that the company should assume. This collaborative effort is beneficial due to the integrated nature of the AHP and to ensure that all stakeholders are involved in the process.

2.4 Project Stakeholders

The primary stakeholders of the project from the AATC perspective include: The Asset Optimisation Manager (Danelle Tyler), The Asset Optimisation Professional in Training (Maryke Mouton), the General Engineering Superintendent (Tommie Hawkins), the sectional foremen and truck operators at NVC. Duratray International also has a vested interest in the success of the project as it is their product, and finally the author also has a major interest in the outcome of the project.

2.5 Project Scope

The data analysis and model building sections of this analysis will be conducted and based on the fleet of three (3) CAT 773F haul trucks used to transport the removed overburden. This value chain will serve as the scope of the project in its primary stages.

For the purposes of this trial *Duratray International* has provided the company with a prototype model fitted to one of the CAT 773F haul trucks namely the CAT 773F – 501 haul truck. Trucks 502 and 503 will retain the original bowl design for comparative measures. This haul truck's performance will be measured during the study and compared to that of the existing configuration so that a decision can be made as to whether the new design is a feasible replacement.

2.6 Potential Risks/ Setbacks

In a project of this nature there are many risks that may cause set-backs to the project as a whole. One of the major areas that may result in holding the project up is in determining the simulation software to be used. The ideal situation would see a version of *Talpac* being made available. However, should a licence not be procured in time, the other options of *Simio* and *Arena* can be considered. If this is the case the use of either of these packages may not deliver results that are as accurate as the tailored solutions may be.

Another potential risk that may develop during the execution of this project is the acquisition of all the required data. It may occur that on the day set aside to visit the mine one or more of the trucks happen to be under maintenance or unable to perform due to certain conditions. Should this occur, it would become necessary to arrange another opportunity when the required trucks are operational and then collect the data at that later time.

CHAPTER 3: RESEARCH

3.1 Literature Review

3.1.1 Simulation Methods

In a survey conducted by Hlupic (2000) on the academic and industrial users of simulation modelling, it was determined that over 55.5% of industrial users of simulation models use only one software tool. This indicates that it is very important to ensure that the chosen simulation package is adequate for the environment of its intended use.

There are numerous simulation software packages on the market. Some of the bigger names in simulation include: *Arena*, *Simio*, *Witness*, *Simul8*, and *Flexsim*, all of which are essentially *Object-Oriented Simulation* (OOS) packages. According to Joines & Roberts (1997) an OOS can be developed for any system of interacting objects over any period of time. This type of simulation logic is ideal for use on a mine for a few reasons. Firstly all the haul trucks and excavators and all other pieces of machinery can be viewed as objects. This allows the user to manipulate the software in such a way as to mimic the real life interactions between objects and in so doing draw valuable information from the system. Secondly the advancement of time allows the user to evaluate the utility, reliability and effectiveness of the objects over a period of time.

3.1.1.1 Talpac

Many software developers have produced simulation software specifically for use in the mining environment. One of the leading offerings is one called Talpac. It has been designed and developed by *Runge Limited*, a company that specialises in mining consultancy.

Talpac provides the user with the ability to determine the productivity of haul truck fleets and the costs incurred by these fleets using a discounted cash flow analysis. These advantages provide the user with an excellent tool in the process of equipment selection. (Runge Limited, 2009)

While Talpac is tailored for use with haul truck fleets, and calculating their overall productivity, it is not the only aspect in which it is useful. The software is also useful in calculating the best practical loading techniques and in this sense can help serve the company long after this trial has been completed.

3.1.1.2 Simio

Simio Simulation Software also follows the approach of using an object oriented modelling method to solve complex problems. The aspect that sets Simio apart from other rival simulation programs is that it was designed from the very beginning to be part of the object oriented simulation ideal. (Simio, 2010a)

Another aspect that sets Simio apart from its competitors is that the software actually allows the user to build and save their own objects. This is particularly useful when there is a complex system that needs to be optimised in that individual objects can be modelled separately and then made to interact with each other. These objects can be anything from machines on a factory floor to a truck working on a mine.

The Simio package offers solutions that are also particularly adapted for mining environments. These applications include solutions pertaining to the material handling of an open cast mining operation, the conveyor systems used in underground mines and the testing of suggested solutions. The software also provides the user with an ability to gauge performance based on throughput and test feasibility of certain solutions.(Simio, 2010b)

3.1.1.3 Arena

Developed by *Rockwell Automation*, the Arena Simulation package is used in various ways in various industries. The program is designed to be extremely flexible by allowing the user to entirely sculpt the business process being modelled. (Rockwell Automation, 2011a)

Arena users are able to customise these solutions by virtue of the fact that every process can be modelled separately and can define parameters for each individual step of the process. It is for these reasons that Arena is well suited to projects in the manufacturing, supply chain, logistics and distribution environments. (Rockwell Automation, 2011b)

Again the software follows an OOS paradigm allowing each truck to be modelled as an object thus allowing data from the simulation to be measured.

Figure 4: Simulation Software Packages.

3.1.2 Business Process Modelling Applied to a Mining Environment

Business Process Modelling (BPM), while being difficult to define, is a technique used to find value in any system of interacting processes. Eriksson and Penker (2000), reveal that there are several reasons why people in industry would use business models, including: Helping the user understand the business, being a basis for creating suitable information systems and making improvements to the business structure.

In order to integrate all the business processes effectively and efficiently, it is necessary to investigate and document all existing processes so that the processes can be fully understood. (Trakman et al., 1997) This encompasses the As-Is section of the study. Once this task has been performed, the modeller is able to evaluate proposed solutions or scenarios, which is the To-Be section of the study.

While this study was not performed with the idea for it to be used in a mining environment, it is not unreasonable to assume that applying the same logic to a mining problem would yield beneficial results. Substantiating the argument behind this assumption is the fact that in all the literature reviewed for this subject, in some way, there was a simulation conducted firstly to acquire data for the As-Is study and then to test the proposed solutions and/or scenarios as part of the To-Be study. (Trkman, et al., 1997; Hlupic & Robinson, 1998; Hlupic, 2003)

Additionally according to van Rensburg (2009) the purpose of Business Process Re-engineering (BPR) is to provide greater value to any organisation through the progressive use of business process strategies. The steps used in preparing the organisation for change are:

- Define Scope
- Do Case for Action
- Define the AS-IS model
- Develop the TO-BE Model
- Develop the Business Case

These five steps are the best-practice framework used to develop and implement a change in any organisation. The definition and measurement of the current processes employed and subsequent comparison to similar measures of a conceptual future model are the driving force behind this study and are used by the author extensively throughout.

3.1.3 Data Mining and Statistical Methods

3.1.3.1 Data Mining

Data mining techniques are a relatively new means of transforming raw data into usable knowledge. The necessity we have for the analysis of data, however, is not new. From as early as the sixth century BC, in Ancient China, the concepts of averages and grouping were used. The Ancient Greeks (Plato and Aristotle) also developed statistical tools that helped the leaders at the time govern their countries. (Nisbet, Elder, & Miner, 2009) Statistics, as it came to be known, was again further advanced in the late nineteenth century, predominantly by biologists such as Sir Frances Galton, to include the concepts of regression and correlation. This along with the Bayesian approach to considering the effects of probability and inference testing led largely to what we know the science of statistics to be today.

The first generation of statistical analysis, according to Nisbet et al, (2009) followed a predominantly Aristotelian approach, that is, to break everything down into its smallest components and analyse them individually. This had its advantages in that it gave one an intimate understanding of the process at hand and it allowed for the relatively simple solution of complex problems. However, it soon became apparent that this approach did not allow for the analysis of the nonlinear relationships present in large data sets of the real world. Thus people turned towards the Platonic view. This included a more holistic view of the problem to be solved rather than attempting to solve each individual part of the problem. Followers of this school of thought would prefer to look at the practical significance of the final outcome, rather than the statistical output. For example, in medicine, there is a greater importance for the correct diagnosis of a disease than making the error of misdiagnosing a harmless condition as life threatening. These so called “alpha” and “beta” errors (Montgomery & Runger, 2007) would lead the traditional (Aristotelian) statisticians to introduce the concept of the Confidence Level.

As highlighted by Nisbet et al. (2009) the analysis of highly nonlinear relationships soon became of great importance in the quest for immediate increases in revenue. The development of these techniques formed a third generation of statistical thinking. It involved a compromise between the Aristotelian and Platonic methods, and was based on two parallel paths. The first was used a cause and effect approach, it looked at expressing a nonlinear function directly and defining weights to the inputs, combining their effects and producing an output. This is analogous to how the human brain works, and over time complex patterns could be recognised in the input variables or data. On the other hand, another methodology was concerned with expressing the outputs through following a set of rules or conditions that the inputs were subjected to. This separated the inputs without having to express the relationship directly. These *decision-trees*, as they have come to be known, were very useful for the analysis of nonlinear events.

This progression of statistical thinking has allowed us to come up with increasingly innovative means of expressing the behaviour of data. The ability of an analyser to express the relationship between inputs and outputs is of utmost importance if one is to correctly predict the outcome of an event, process or system. It is for this reason that data mining has become such a powerful tool. Data mining differs from statistical modelling in that it uses *Machine Learning Algorithms* (MLA's) to detect faint patterns or relationships in an otherwise noisy set of data. Statistical modelling methods, on the other hand, uses P*arametric Statistical Algorithms* (PSA's) to predict an outcome based on predictor variables. Figure 5 shows the role that data mining plays in the process of knowledge discovery.

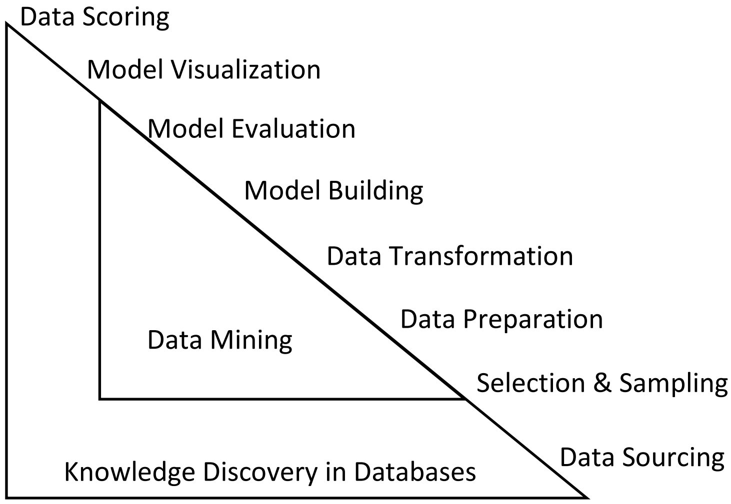


Figure 5: The Relationship Between Data Mining and Knowledge Discovery. Source: **(Nisbet, Elder, & Miner, 2009)**

The data mining activities as described by Hand et al. (2001) include the following processes:
Exploratory Data Analysis: Allows the analyst to view the data set in terms of "summarised statistical parameters," and gives one the ability to get a "feel" for any patterns or trends that may present themselves.

Descriptive Modelling: This process forms "higher-level views" of the data set. It may include activities such as: determining overall probability distributions (*density estimations*), descriptions of the relationships between variables (*dependency modelling*) or the segmentation of the data (*cluster analysis*) where the algorithms attempt to find natural groups amongst the data based on any one particular variable

Predictive Modelling: Classification and Regression: This process generally involves building models where one variable is able to be predicted based on the values of the inputs to the model. Classification is often used in the case of discrete variables whereas regression is more often used in cases where continuous variables are prevalent in the model.

Discovering Patterns and Rules: This process can involve many different activities, from finding combinations of events that occur together frequently to finding groupings of various parameters or variables in a data set. These analyses can then be used to determine rules that can be used to associate the data within the data set.

Retrieval by Content: This final process starts off initially with a known pattern and follows the goal to find patterns of a comparable nature in the new data set. It is mostly used with text or image data sets and very seldom is it used for sets that comprise of variable numeric data.

These processes provide a stable framework on which to base almost any data analysis project or operation. The key to success is to keep in mind that data mining is part art and part science. The artistic side lies in the understanding of the business and what will be regarded as a successful project. This leads one to defining the goals and objectives for the study. The scientific aspects, on which data mining is based, rest on understanding the data itself. Nisbet et al. (2009) describes some of the activities that help an analyst understand the data, these include: data acquisition, data integration, data description, and data quality assessment.

3.1.3.2 XLSTAT

This piece of software is an "add-in" for Microsoft Excel that provides the user with a wide variety of tools to be used in the analysis of various sets of data. It has found applications from a broad sample of users including: *Merryl Lynch*, *Proctor and Gamble*, *Unilever*, *Price Waterhouse Coopers* and many others. (XLSTAT, 2011)

XLSTAT is dependent on Microsoft Excel for the input data, however the computations used to provide the output of the various tools is completely autonomous. One of the many tools offered by this piece of software is its ability to provide descriptive statistics for any set of data. This includes being able to fit a suitable distribution to a data set. As described earlier one of the keys to increased performance is the ability of an analyser to correctly describe the relationships present in the data.

The XLSTAT add-in function of Microsoft Excel contains a function that allows the user to fit distributions to the set of data. This is done by a process known as hypothesis testing. The data is selected and is fitted to a "proposed" distribution (eg. The Normal or Exponential Distributions) the parameters required for these distributions are then calculated. Using these values the data undergoes the hypothesis test based on the Chi-squared test and the Kolmogorov-Smirnov test. These two tests use hypothesis testing to determine whether the data fits into the "proposed" distribution.

Chi-Squared Test:

This test is used to determine if there is a variance between the observed values of a data set and the predicted values of the proposed distribution, the parameters of which are drawn from the data set itself. As with any hypothesis testing procedure, the first step is to develop the *null hypothesis*. In this case the null hypothesis will always be: "The situation that the data set does follow the proposed distribution with the calculated parameters." The alternative hypothesis in this case would be: "the situation where the data set does not follow the proposed distribution," (Maben, 2002)

According to Montgomery and Runger (2007) the procedure requires that a random sample be taken from the population, of unknown distribution, of size *n*. The formula used for the Chi-Squared test is:

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E}$$

Where O_i is the observed frequency in each category, E_i is the expected frequency in the corresponding category, and χ^2 is Chi-Squared and the values can be calculated and used for the hypothesis test. If it can be proved that the population follows the proposed distribution, χ^2 will follow a Chi-Squared distribution with $k - p - 1$ degrees of freedom. Where p is the number of parameters that the proposed distribution. (eg. Normal Distribution: $p = 2$) The hypothesis would be rejected if the value of $\chi^2 > \chi^2_{\alpha,\ k\text{-}p\text{-}1}$. It is reasonable to presume for this that the approximation of the Chi-Squared distribution would improve as n increases.

Kolmogorov-Smirnov Test (KS-Test):

Much like the Chi-Squared test, the KS test makes use of hypothesis testing to determine the distribution of a set of data. However it does offer two advantages over the Chi-Squared test: (Lilliefors, 1967) Firstly it can be used with very small sample sizes, and often is more powerful than the Chi-Squared test with samples of any size.

The procedure begins with a sample of N observations. The analyst would then determine:

$$D = max_{\bar{x}}|F^{*}(X) - S_N(X)|$$

Where $S_N(X)$ is the sample cumulative distribution function and $F^{*}(X)$ is the cumulative distribution function of the proposed distribution described during the definition of the hypothesis test. Using the table in Appendix A, if the value of D is larger than the critical value in the table, the hypothesis can be rejected.

The table shown in Appendix A is comprised specifically for a Normal Distribution by making use of Monte Carlo calculations. The user would find the critical value by take looking down the column specifying the level of significance required (for a 95% confidence interval, the level of significance is 0.05) and across the row specified by the sample size.

Descriptive Statistics are also given as a basic indication of the behaviour of the data.

These techniques will be employed by the author in an attempt to provide the most descriptive parameters that provide full detail for how the CAT 773F trucks operate on the New Vaal mine. Time studies will be conducted along with other readily available information already attained by employees on the mine and will subsequently be integrated and assessed using this framework and guidelines. Once the analysis of each variable is complete the data can be used to provide input to the simulation model which will in turn be used to judge the success or failure of the trial.

As stated previously the XLSTAT add-in function performs these tests automatically relieving the user of a lot of the work required to perform these tests. Both tests will be used by the author to determine the distributions that are best fitted to the data attained throughout this trial.

3.1.3 Analytic Hierarchy Decision Making Process

The Analytic Hierarchy Decision Making Process (AHP) was developed by Thomas L. Saaty (Triantaphyllou & Mann, 1995) in 1977. Saaty (2008) puts forth the idea that all human beings are essentially decision makers:

> *"Everything we do consciously or unconsciously is the result of some decision. The information we gather is to help us understand occurrences, in order to develop good judgements to make decisions about these occurrences… If we only make decisions intuitively, we are inclined to believe that all kinds of information are useful and the larger the quantity, the better. But that is not true."*

Saaty extends this idea by making reference to Darwin and how experts had missed the significance of what he had done. Somehow "*Darwin, who knew less, understood more."*(Saaty, 2008) This forms the basis upon which the Analytic Hierarchy Process was built. It ensures that the decision you are making is based on concise information that was gathered for the purpose of making such a decision.

The AHP can be broken down into four steps (Saaty, 2008):

- Define the problem and determine the required knowledge to be attained from the decision.
- Start structuring the hierarchy with the goal of the decision, then the objectives, through to the criteria on which subsequent elements depend and finally to the alternative options that the decision maker has.
- Construct pairwise comparisons between each element in an upper level to every element in the level below it.
- Using these comparisons develop weights for the priorities of elements in the levels below. Doing this for every element gives a weighted value for each lower-level element developing a global priority. Continuing with this then gives priorities to the alternatives in the bottom most level.

Generally AHP problems will include three levels: The goal of the decision, the criteria on which alternatives are assessed, and finally the alternatives themselves. In order for the pairwise comparisons to be made there needs to be a scale on which numeric indicators give the extent to which one element is more, or less, important than the element it is being compared to. Table 1 details the acceptable standard, put forth by Saaty (2008), upon which two elements may be compared.

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Activities Contribute equally to the objective.
2	Weak of Slight	
3	Moderate	Experience and Judgement slightly favour one activity over another.
4	Moderate Plus	
5	Strong	Experience and Judgement strongly favour one activity over another.
6	Strong Plus	
7	Very Strong (Demonstrated)	An activity is favoured very strongly over another. Dominance is demonstrated in practice.
8	Very, very Strong	
9	Extreme Importance	Evidence favouring one activity over another is of the highest possible order of affirmation.

Table 1: Table of Relative Importance's. Source: **(Saaty, 2008)**

Should one feel as though this system does not give adequate detail to compare two elements then a decimal point may be used to provide this extra detail. (i.e. 1.1-1.9) Once each criterion has been compared to every other criterion, using this importance system, the results can be tabulated in a matrix with each entry being the comparison between elements defined in the row to those defined in the column. The reason behind doing this is to acquire qualitative information from the decision maker and present it in a quantitative manner through these relative importance comparisons. Table 2, adopted from Triantaphyllou and Mann (1995) provides a generic example of how these results can be inserted into a matrix.

	Criterion				
	C_1	C_2	C_3	…	C_N
C_1	c_{11}	c_{12}	c_{13}	…	c_{1N}
C_2	c_{21}	c_{22}	c_{23}	…	c_{2N}
C_3	c_{31}	c_{32}	c_{33}	…	c_{3N}
⋮	⋮	⋮	⋮	⋮	⋮
C_N	c_{N1}	c_{N2}	c_{N3}	…	c_{NN}

Table 2: Example of a Pairwise Comparison Matrix for the Criteria of a Decision.

Note: should any comparison entry (c_{ij}) be a whole number defined in Table 2 then its transpose number (c_{ji}) will be the reciprocal of that value. For example suppose that entry c_{ij}= 9 then c_{ji}= 1/9. Additionally each element when compared with itself should always carry an equal level of importance, i.e. c_{ii} = 1 for all values of i.

Once the Criteria Comparison Matrix has been defined, the priority vector needs to be established. Saaty (2008) explains that to do this the *Right Principal Eigenvector* needs to be determined. This is a vector with N values (N being the number of criteria used to evaluate the alternatives) each corresponding to the geometric mean (the N-th root of the product of all elements in the row) of each row in the matrix and then normalised by dividing the value by the sum of all elements in each row. (Triantaphyllou & Mann, 1995) This is where AHP has an advantage over other Multi-Criteria Decision Making (MCDM) Processes in that it allows for criteria that are not measured in the same units to be compared to each other. One of the weaknesses with AHP is that this process allows for slightly irregular pairwise comparisons. To test whether the comparisons are consistent, the following relation needs to hold true for any combination of comparisons: $c_{ij} = c_{ik}.c_{kj}$.

This reality, however, in this situation is a rare occurrence. In order to determine when a judgement matrix is adequately consistent the *Consistency Ratio* (CR) was developed. The CR is calculated as follows: Firstly the *Consistency Index* (CI) is determined by adding the columns of the judgement matrix and multiplying this vector by the priority vector calculated previously. This calculation gives the decision maker an estimation of the maximum eigenvalue. (λ_{max}) CI is then calculated to be:

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

Next the CR value is obtained by dividing the CI value by the *Random Consistency Index* (RCI) given in Table 3. If the resulting value of CR is less that 10% the consistency of the pairwise comparisons is considered to be adequately consistent. (Triantaphyllou & Mann, 1995) However, should the matrix be of size 2x2 it is not necessary to calculate the CR as it would result in a situation where the CI would be divided by zero. They are thus considered to be consistent as is.

Random Consistency Index									
n	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Table 3: RCI values for different Values of n. Source: **(Triantaphyllou & Mann, 1995)**

Once the criteria have each been compared to each other the decision maker will proceed down to the next level defined in the hierarchy. In most situations that an AHP is used this will be the alternative solutions that are being considered. Each alternative now needs to be considered with regard to each criterion. Using the same scale as before, alternatives $A_1 \dots A_M$ are evaluated according to the criteria defined in Table 2. Table 4 shows how this would be done for comparing the alternatives with respect to just one criterion.

Criteria 1 (C_1)				
	A_1	A_2	A_3	Priority Vector
A_1	a_{11}	a_{12}	a_{13}	v_1
A_2	a_{21}	a_{22}	a_{23}	v_2
A_3	a_{31}	a_{32}	a_{33}	v_3

Table 4: Alternatives Pairwise Comparison for Criteria 1.

Again, a priority vector is calculated for each of these matrices, as with the CR value to ensure that consistent comparisons have been made. After all of these pairwise comparisons are made and matrices established, the synthesis step can begin. All the priority vectors of the alternatives pairwise comparisons become the columns of the *Decision Matrix*. If there are M alternatives and N criteria on which they are judged then there are M judgement matrices (size MxM) and one judgement matrix of NxN.

Given the Decision Matrix and the priority vector of the NxN matrix each alternative is assigned a value based on the following equation:

$$A_{AHP}^{i} = \sum_{j-1}^{N} b_{ij} w_j \ for\ i = 1, 2, 3 \dots M$$

With b_{ij} being the elements of the decision matrix and w_j being those of the priority vector for the criteria matrix, each alternative will have a unique AHP value which will for part of a final priority vector. (Size Mx1) The largest value in this vector will correspond to the best alternative solution, and dictates which decision should be made.

3.2 Product Research

3.2.1 Duratray International

Duratray International is a specialist company, operating out of Victoria, Australia. They design, develop and supply an exclusive "Suspended Dump Body" (SDB) for haul trucks operating on mines all over the world. "The Duratray SDB unique concept relies on the flexibility of a rubber floor which is suspended above a steel frame by elastomeric ropes." (Electra Mining Africa, 2011) Figure 6 illustrates a basic depiction of the products superior design.

Duratray International has the ability to manufacture ten SDB's each month, ranging in size from 36 tonnes to 360 tonnes. (Hall, 2009) The company claims the following advantages for their product: (Duratray International, 2010)

- The Best Lifecycle Cost for the Mining Industry.
- Low Maintenance.
- Higher Volumetric Capacities.
- Lighter in Weight.
- Superior Payload.
- Reduces Carry-back.

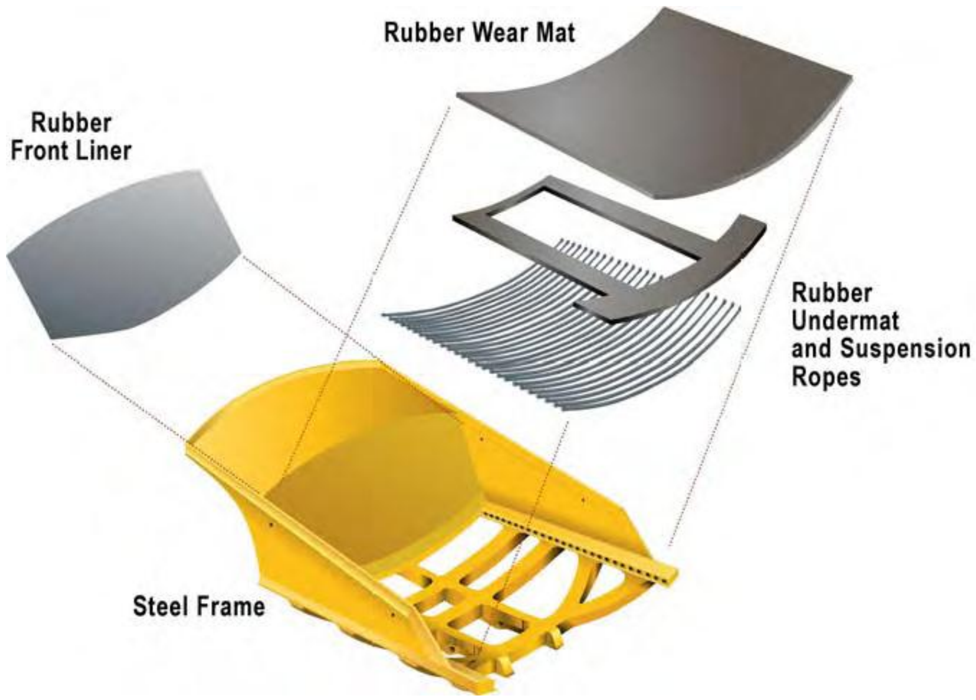


Figure 6: Design of the Duratray SDB. (Exploded View)

3.2.1.1 General Design Features

The design of the Duratray SDB for the CAT 773F trucks include Duratray's flexible wear mat. This is fixed to the front and sides of the frame and suspended on their adjustable elastomeric transverse rope system. The suspension-ropes are made from polyester fibres purpose built for the required load factor, and are protected by a 3mm thick abrasion-resistant rubber lining. The frames themselves are made from high tensile steel.

3.2.1.2 Site-Specific Design Features

The proposed SDB would have a volumetric capacity of approximately 38,9m³. This results in a rough payload of 58 tonnes (based on a density of 1.70 tonne/ m³). This is within the Gross Vehicle Weight (GVW) limits for the CAT773F truck.

The rubber mat is 70mm thick in the front and middle sections increasing to 95mm for the rear section. This makes the SDB suitable for transporting overburden and sand however, they would not be suitable for the transport of burning coal.

3.2.1.3 Pricing

The table in Appendix B shows the pricing structure for one Duratray bowl. The manufacture of the steel frame and assembly takes place in Australia and is then shipped to South Africa. It shows the total cost for the venture. Customs, port and haulage costs are detailed as well. The exchange rate used for all pricing is 1AUD = 6.65ZAR and 1USD = 7.70ZAR.

It is for these reasons that the company have decided to consider this innovative product as a potential replacement for their current truck bowls, which at the moment are made of high tensile steel and develop large amounts of carry-back.

CHAPTER 4: DATA ANALYSIS AND PREPARATION

The task of analysing and preparing the data was the first step to determine whether the Duratray is a viable replacement for the current steel CAT 773F bowls. As discussed previously the most important task in data mining/analysis is to develop goals and objectives for the analysis. In order to do this an understanding of the business and a determination of what uses the analysis will serve is needed.

In this case the analysis is required to serve as an input to the simulation model, thus it is necessary for the data not only to include descriptive statistics, but also to outline certain relationships or patterns that exist between the active operational aspects and parameters. Upon investigation of the sequence of operations employed in the overburden removal section of the mine, it was determined that the first pieces of data that needed to be gathered was the time taken by the trucks to be loaded, unloaded and travel from the filling point to the dumping site. It is imperative that data be gathered from both trucks, those using the Duratray prototype and those using the standard steel bowls so that a comparison could be made. Additionally it was seen as being important to measure the load that was carried by each truck during each cycle. Figure 7 illustrates the loading of a CAT 773 haul truck.

Figure 7: Loading of CAT 773 – 502 in Overburden Removal Process.

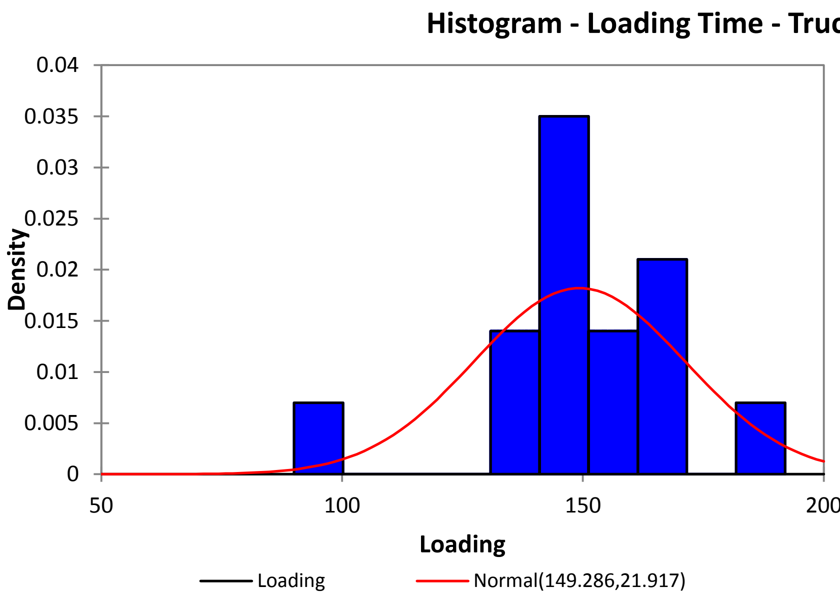
Time studies were conducted on the 16th of August 2011 and were taken on a sample of both truck types (i.e. the prototype with the Duratray fitted and the ordinary steel bowl trucks). The times were recorded under Truck 501 or Truck 502/3. The data that was gathered during the time studies is shown in Table 5. The table separates the process of overburden removal into five phases: Loading time, travelling time to dump site (full), dumping time, and finally travelling to filling location (empty). All phases were measured in seconds allowing for easy calculations to be performed. These were tallied up to give an overall time at the end of each cycle. Finally the “load” column details the amount carried during each cycle.

The travelling times indicated in Table 5 (Full Travel and Empty Travel) were measured over a distance of 1km. Using a simple speed time distance calculation, the speed at which the trucks travelled at whilst full and whilst empty could be ascertained. The distributions that were fitted to each of these can be seen in Table 5.

As the data mining process explained previously dictates, the first action that should be conducted is to view a set of descriptive statistical parameters. Using the Microsoft Excel add-in *XLSTAT* and the Loading Time variable from Truck 501 as an example, various descriptive statistics were calculated and plotted. Amongst these are the sample mean, standard deviation, maximum, minimum, skewness and the plotted histogram. These descriptive statistics for the Loading Time on truck 501 are shown in Figure 8. The histogram includes both the plotted frequencies and the theoretical distribution that could be used to describe the data set. From this plot it is reasonable to assume that the loading time on Truck 501 follows a Normal Distribution with a mean of 146.26 seconds and a standard deviation of 21.917 seconds. The same statistics for each variable were calculated and are presented in Appendix C along with those for Truck502/3.

501					
Loading Time	Full Travel	Dumping Time	Empty Travel	Cycle Time	Load
191	236	18	184	629	46.56
171	238	38	141	588	70.95
146	196	58	196	596	62.75
96	226	73	198	593	72.46
131	219	32	201	583	51.53
152	209	37	169	567	45.71
147	197	31	158	533	63.73
141	205	37	196	579	39.45
153	202	30	216	601	62.74
144	219	36	173	572	64.04
147	226	30	204	607	76.78
167	211	32	236	646	42.73
166	183	36	207	592	61.62
138	190	34	158	520	18.44
502/3					
Loading Time	Full Travel	Dumping Time	Empty Travel	Cycle Time	Load
103	174	29	227	533	43.72
79	242	33	230	584	42.62
111	230	35	238	614	36.09
85	237	33	249	604	42.90
84	202	33	217	536	45.87
97	188	33	169	487	37.76
143	198	33	183	557	34.56
102	199	64	171	536	49.55
121	188	40	154	503	36.87

Table 5: Results of Time Study Conducted on 16 August 2011.



Statistic	Data
Mean	149.286
Standard Deviation	21.917
Maximum	191.000
Minimum	96.000
Skewness	-0.451

Figure 8: Descriptive Statistics for the Loading Time on Truck 501.

Table 6 gives an overview of the summary statistics detailing which distribution best fits each variable along with the parameters for each distribution. The distributions were fitted to each variable by a combination of the Chi-Squared and the Kolmogorov-Smirnov tests. This table gives the reader a clear indication of how each variable in the process behaves over a period of time.

Fitted Distributions			
Variable	**Distribution**	**Parameters**	
501			
Loading Time	Normal	Mean	149.29
		Standard Deviation	21.92
Full Travel	Unifrom	Minimum	4.20
		Maximum	5.46
Dumping Time	Normal	Mean	37.29
		Standard Deviation	13.28
Empty Travel	Normal	Mean	5.41
		Standard Deviation	0.78
Load	Normal	Mean	58.22
		Standard Deviation	13.215
502/3			
Loading Time	Uniform	Minimum	79
		Maximum	143
Full Travel	Normal	Mean	4.90
		Standard Deviation	0.56
Dumping Time	Poisson	Lambda	37
Empty Travel	Unifrom	Minimum	4.02
		Maximum	6.49
Load	Normal	Mean	40.34
		Standard Deviation	4.815

Table 6: Distributions Fitted to Defined Variables.

This analysis will provide the primary input into the simulation model built using the Simio Simulation Software package. However, the above table would appear to indicate that the truck fitted with the Duratray SDB is carrying loads that are heavier on average by almost 20 tons. This could be a cause for concern because the trucks are only designed to carry up to a certain weight. The problem that lies in overloading the trucks is that the tyres are placed under much higher strain, thus causing an increase in tyre degradation. It was therefore deemed necessary to investigate the impact that overloading the truck has on tyre life and the effect that this has on the downtime of the trucks.

The CAT 773F require six 24.00R35 tyres, two are fitted to the front axle and four to the rear. These are sourced from tyre manufacturers *Bridgestone*, *Michelin or Goodyear*. The tyres are inspected for tyre wear and to ensure that they are operating at the correct pressures on a regular basis. This inspection is done during the maintenance times at which the entire mine is on shutdown, thus this downtime on the trucks is not taken into account. The downtime that is necessary to build into the simulation is that incurred when the tyres undergo a failure or need to be changed.

Appendix D provides the details of the reports written during a tyre inspection. These details include an average time that it takes to wear down one mm of tread on the tyre. The effect of these was also taken into consideration when the analysis on the tyre degradation was conducted.

The data that was required, to give an adequate representation of how the increased loads related to the breakdowns that the trucks experienced during the trial, was summarised in Table 7 and labelled as Truck Availability. The data was collected on a weekly basis and has been presented as such for each of the nine weeks of the trial

Week Ending	10-Aug	17-Aug	24-Aug	31-Aug	06-Sep	13-Sep	20-Sep	27-Sep	04-Oct	Average
501	75.07%	96.82%	87.79%	98.53%	98.22%	90.65%	92.08%	94.83%	90.78%	91.64%
502/3	99.59%	98.40%	91.02%	88.78%	84.14%	84.77%	89.96%	95.38%	92.67%	91.63%

Table 7: Percentage Availability of Trucks During Trial Period.

While this availability statistic does include other various breakdowns experienced by the trucks (not just due to tyre wear) it is still included in the data analysis. This is done so that, when used in the simulation, the elements that rely on this data are mimicking reality as accurately as possible. Additionally the data on the downtime incurred by both types of trucks was recorded for the period this data is detailed in Table 8.

Week Ending	10-Aug	17-Aug	24-Aug	31-Aug	06-Sep	13-Sep	20-Sep	27-Sep	04-Oct	Total
501	36.38	5.34	20.51	2.47	2.99	15.71	13.3	8.59	13.52	118.81
502/3	0.6	2.68	15.09	18.85	26.65	25.59	16.87	7.67	10.91	124.91

Table 8: Actual Unproductive Hours of Trucks During Trial Period.

NVC operates for 24 hours every day of the week so as to get achieve maximum productivity. This translates into 168 hours of time available for the trucks to use each week or 1512 hours of available time for the duration of the trial. Using the average percentage of available time in Table 7, the actual time that each truck was productive for was calculated. These details are given in Table 9. Along with these figures for each truck, the number of failures that occur each week (failure per week) was calculated by dividing the total productive hours by the hours of downtime that each truck sustained. The hours between failure was then (hours per failure) was then determined by dividing the total hours available each week by the number of failures each week.

	Hours Used	Failures/Week	Hours between Failure	Failure Time
501	1385.61	11.6624	14.4052	1.091
502/3	1385.51	11.0921	15.1459	1.091

Table 9: Summary of Hours Between Failure and Length of Each Failure.

The *Failure Time* in Table 9 indicates the average length of time it took to repair the breakdowns as they occurred. This figure gives an estimation of the time that each truck was unproductive for each time a breakdown was experienced. It was calculated by dividing the average hours between each failure by the average number of hours of downtime experienced each week.

CHAPTER 5: SIMULATION MODEL

5.1 Simio Design Edition Background

Once the required data has been gathered and formulated in such a way that it becomes more than just data, it becomes useful information. This information is used, as planned, in the designing and building of a simulation model. The software package that was decided upon was the Simio Software Solution. Reasons for choosing this package include the allowance for flexible modelling approaches and the fact that the full version is freely available with only minor limitations. In addition to this Simio offers a three-dimensional modelling environment for the user to work in, which provides for a very lifelike representation of reality. One of the most convenient offerings of the software is that it has the ability to conduct “experiments”. This is particularly useful for this project in that the data for both trucks can be programmed simultaneously and then the same variables can be drawn as results are compared almost immediately without having to analyse the data further.

Simio offers a standard library of “parts” that can be used in countless ways for almost any application that the user can think of. Each of these parts is called an “Object” and can be used to: Create, Process, Transport or even Destroy the entities that are used to mimic the real world processes being modelled. The objects in Simio can be one of five basic types:(Simio LLC, 2010)

- **Fixed**: fixed to a point in the system
- **Link**: makes a pathway between two or more fixed objects on which entities can travel
- **Node**: can be used to define an intersection of links, or can be used with a fixed object to define points of entry and exit.
- **Entity**: a “dynamic” object that is created and destroyed, and moves within a network of links, fixed objects and transporters.
- **Transporter**: similar to an entity, but can pick up other entities and transport them to different Nodes or Fixed Objects.

Figure 9 shows a screen shot of a blank Simio project modelling environment, note the standard library on the left of the screen and the facility, processes and data tabs just above the modelling environment.

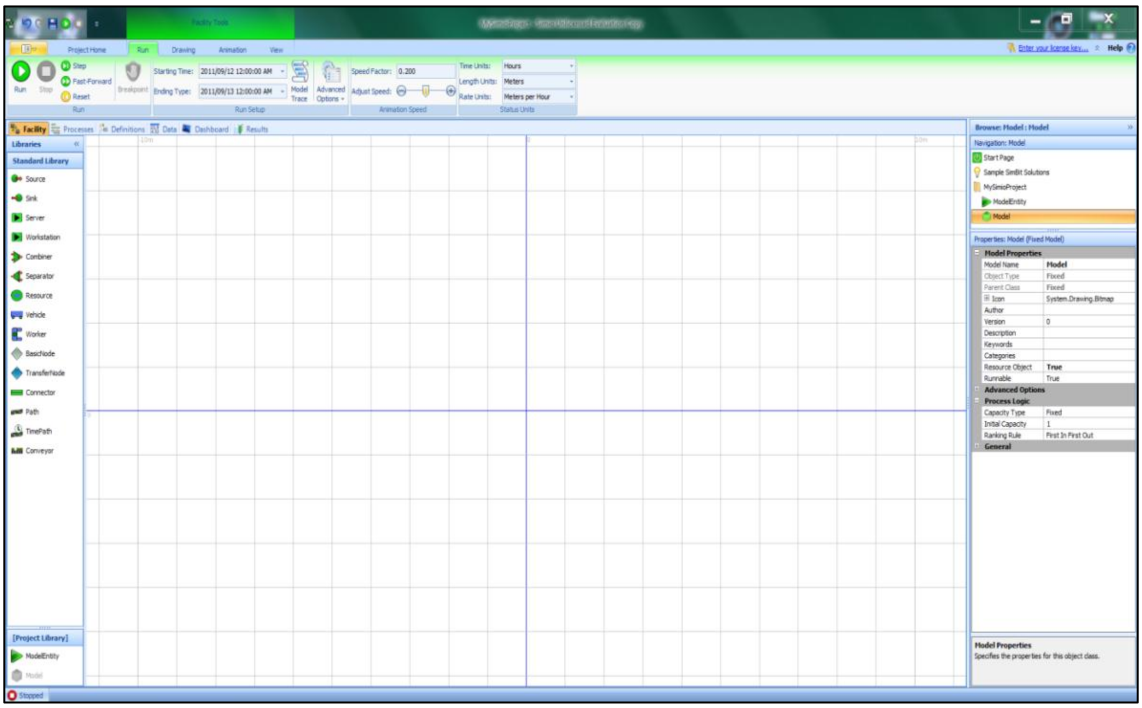


Figure 9: Screenshot of a Blank Simio Project.

Simio also offers the ability to the user to customise each object used in the model. This goes beyond the mere ability to define travelling, processing or transferring times. What the software allows the user to do is to create a “sub-type” of any object in the standard library and then modify the logic embedded into the standard object. This provides the flexibility that some modellers might desire in special circumstances. In addition to this Simio has a general process function that gives the user the ability to define custom logic for some object to follow without drastically altering the object. This can be anything from routing logic for an intersection to assigning new values to certain variables at different points in the simulation.

In addition to these advanced simulation modelling techniques, Simio also gives the user the ability to develop and use data models on which the simulation can run. Much like the logic used in designing information systems, this function requires the definition of data tables, but also gives the user the ability to link certain tables to each other by means of keys. This again gives a further degree of flexibility for the modeller to manipulate the software so that the perfect simulation model can be developed.

5.2 Simulation Design

The first aspect of the model that needed to be constructed was the layout of the mining environment. This was accomplished with the use of satellite pictures taken of the mine. These pictures were then pieced together to obtain an overhead view of the areas involved in this study. With this image sized to scale in Simio, the roads that are drawn are thus also drawn to scale, and in turn eliminate the need to adjust the speed of the trucks based on a scale.

In reality the area that the trucks work in changes constantly. Modelling a dynamic environment such as this can be a very challenging endeavour. For this simulation the outcome that needs to be achieved is a comparison of which truck has the better performance and can produce the most output. It was thus decided that a dynamically changing working environment was not required. Instead should a static environment be used, the different trucks could be compared based on the same conditions just with the different parameters attained in the data analysis and preparation sections. Figure 10, gives an overview of the working area of the mine. It highlights the loading, dumping and repairing areas modelled in the simulation.

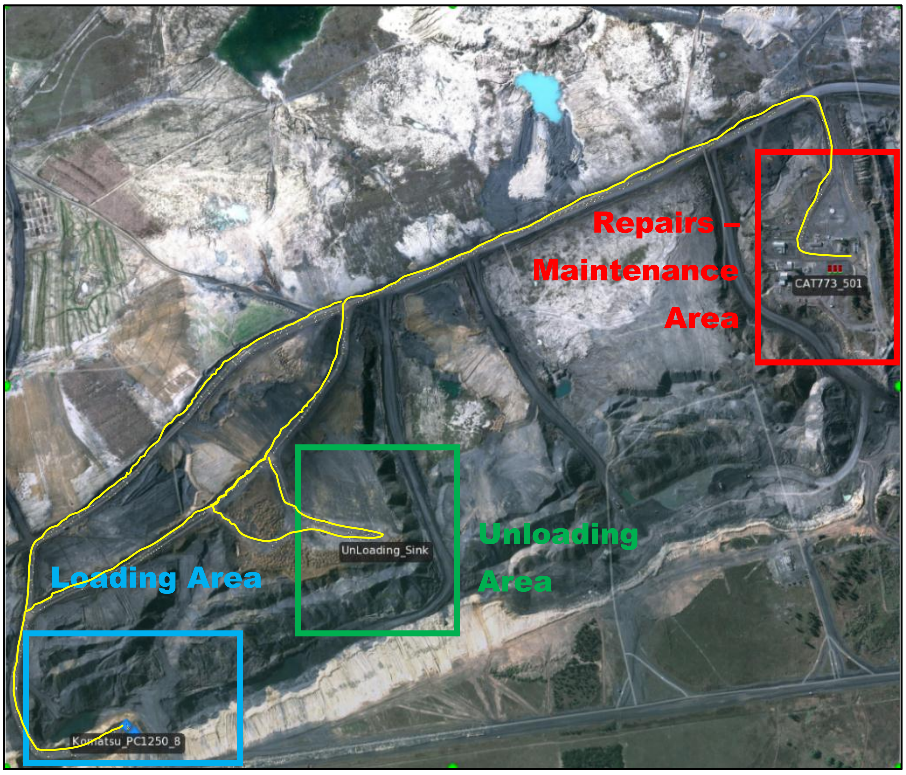


Figure 10: Simulating Environment with NVC Mine Map Superimposed.

The next section that needed to be looked at and developed was the logic behind how the model would be driven. In Simio the driving force behind any model are the *entities* that are created and destroyed. In this situation the primary focus of the simulation are the truck objects carrying the sand. Thus it was decided that the sand being transported should be the driving force in the model and then the trucks could be modelled as transporters for this "product." Using these objects as such allowed the author to include in the entity, a property that assigns to each entity a "load." This keeps track of the amount of sand carried by each truck and can be fixed to follow the distribution formulated in the data analysis.

In addition to this it was decided that a *fixed resource* would be used to model the Komatsu PC1250-8 excavator that loads the trucks. The loading would be done based on the calculated loading times, and the transporters would then move along the *link* objects, to the dumping site. The travelling logic would be done according to the speed that the transporters move when full and then when empty. Finally dumping the sand is done based on the dumping time distributions already established. This process is done solely by the trucks and does not require the aid of any other resources.

The natural areas that can be seen in the overhead view of the mine, are the loading, unloading and repair/ maintenance areas. These are the areas at which the "processing" of the sand takes place and as such constitute the primary focal points for the simulation. Screenshots of these three areas are shown in Figures 11, 12 and 13 to give a better understanding of how the model is laid out.

Figure 11: 3D and 2D View of Simulated Loading Area.

Figure 12: 3D and 2D View of Simulated Unloading Area.

Figure 13: 3D and 2D View of Simulated Repair shop and Maintenance Area.

Each of the three areas had requirements for different types of processes and processing capabilities. As in reality the trucks will begin every shift parked in a section reserved for them near the repair shop (maintenance area). To model this section in the simulation all that was required was a *Basic Node*. This node represents the parking area as well as the repair area and is connected to the other section by means of a bidirectional pathways (link). This is different from all the other links in that the others will only allow objects to move along the link in one direction.

The network of links from the repair shop section to the loading and unloading section can be seen in Figure 10 as yellow lines.

The loading area required objects which created entities (source), those that process them (server), the fixed resource for the Komatsu PC1250-8 and the links for the trucks to pass through. A source was used to create three entities at the beginning of any run. These move immediately to the server from where they are processed by the server. In addition to these initial entities the source was programmed to produce one more entity every time an entity was picked up by a truck.

In Simio, the *Server* has built into it an object referred to as a *transfer node*. This node dictates where the entity must be transferred to (Destination Node), how it should get there (By Sequence, Shortest Path etc.) and whether it should ride on a transporter or not. For this case it was deemed necessary for the entity to ride on one of three transporters, seized from a list containing the three trucks in question. The node also specified the method in which the trucks should be reserved. In this case the truck closest to the node was reserved for the next pick up.

The links to and from the loading area were designed such that there could only be one truck in the loading bay at a time, all others wait in a waiting area (modelled by a basic node and connected to the transfer node by a link with capacity for a single object). The links leading away from the transfer node include a loop whereby any vehicle that fails, whilst on the way to pick up a new load, can turn around and head to the repair shop without having to pick up another load.

Once loading of the trucks has taken place the trucks moved along the links towards the entity's defined Destination Node. In this case the destination was the Unloading Section modelled by an object called a *Sink*. This object essentially destroys the entity in such a way that it could be seen as leaving the system. Before the entities got destroyed, a variable, counting the tonnage assigned to that load (entity), was updated. This kept track of the amount of material processed by the trucks during the run.

Once the basic set up of the networks and objects was completed, the trucks themselves needed to be modelled. This was done with the aid of the Transporter object in Simio, however, custom logic needed to be designed for when the object experienced a failure or breakdown so that it dropped off the load (if carrying one) and then proceeded to the repair shop for repairs.

5.3 Custom Transporter Logic

The transporter object available in the standard library in Simio did not possess the required logic to accurately represent the CAT773F trucks used at NVC. Upon failure the standard transporters will simply stop what they are doing and wait to be repaired. These failures can occur either on a *Time Between Failures* or on a *Count Between Failures* basis and the expressions for each could be specified in the command prompt in Simio.

In order to customise the transporter object it is necessary to create a *sub-type* of the object, so that the internal processes can be altered to fit the requirements of this situation. The processes used by all objects in Simio are driven by tokens that run through and follow the intended logic when each process is executed. The changes that were made to the sub-typed object's processes are discussed below:

- **On Failed Process**: This process is executed when a failure occurs. It halts the "Failure Occurrence Logic" Process wherein the actual failure occurs. This is done to ensure that the object will only recover once certain logic has been followed. There is then a decision step that determines whether the transporter is carrying any riders (entities) at the time of failure. If there are riders on the transporter then it must carry on with what it is doing without stopping (forcing it to unload, the rider will be dealt with in a concurrent process), however, if there are no riders on board then the transporter must be told to move to the node where the repair will take place (SetNode Step). Another Decide step is used to check whether the transporter is parked and will un-park it if it is. Once the process reaches this point the token executing it will stop and wait for the event fired when the transporter reaching the repair shop at which point it will reassign values to necessary variables and resume the Failure Occurrence Logic. The logic is shown in Figure 14 below.

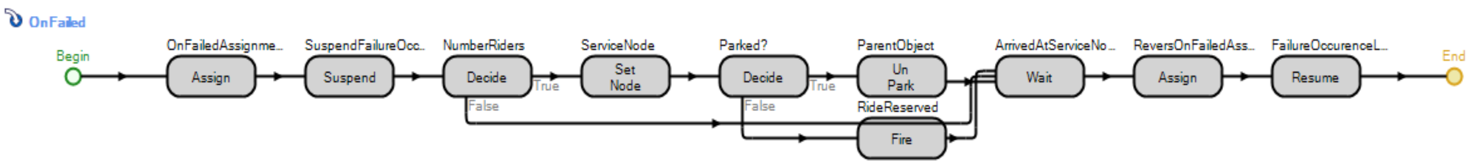


Figure 14: On Failed Process.

- **On Repaired Process**: The only change that needed to be made to this process was to include a release step. This will release the transporter once it has been repaired and make it available to accept requests from entities at the loading server. The process is detailed in Figure 15 below.

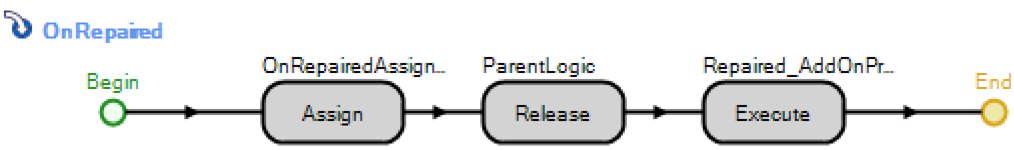


Figure 15: On Repaired Process.

- **On Rider Loading and On Rider Loaded Process**: The alterations that were included in this process are to allow the transporter to seize an additional resource while loading. This is necessary as the Komatsu PC1250-8 is used during loading. Firstly a property needs to be created for the transporter whereby the user can specify a resource. This property is then referenced in the Seize and Release steps shown in Figure 16. The release is shown in the On Rider Loaded Process because the secondary resource is only relieved of work once the truck has been loaded.

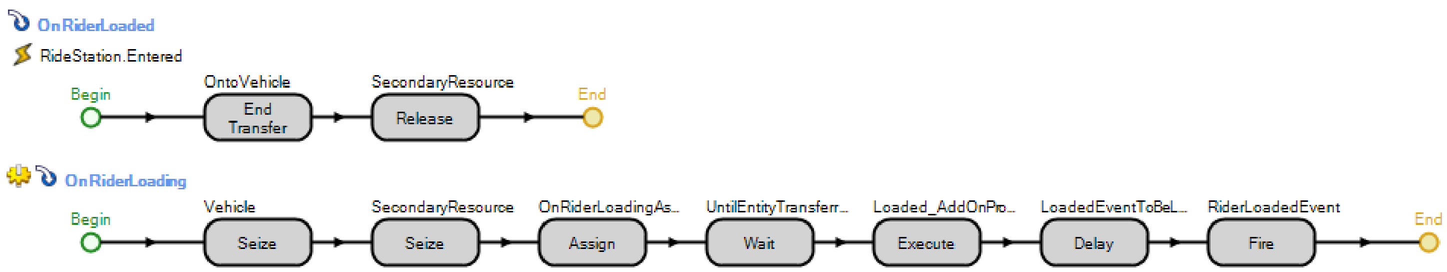


Figure 16: Secondary Resource Seize and Release Process.

- **On Visiting Node Process**: This process is complicated and too large to show completely in this section, thus only the sections that were altered are shown in Figure 17 the full process is shown in Appendix E. The first Decide step, indicated in blue, checks to see whether the current node that the transporter is visiting is the repair shop node, if it is it will park at the node and fire the event *Arrived At Service Node*. If it is not then the transporter will continue with the logic of dropping off a rider with every node that it visits. If then the transporter finds that it cannot pick up a new rider nor can it select another drop off point, it will proceed to the last decide step (indicated in red on Figure 17.) where it will check to see that there are no riders and that a failure is active. Should this be the case the transporter will set its destination to the repair shop, if not it will continue with the process as it would before.

  In addition to this routing logic, there are also two assign steps (green) used, one after the Drop-off step and one after the Pick-up step. These are used to change the speed at which the transporter moves when it is empty and when it is loaded. Building this into the simulation allows for further flexibility to be attained and in turn creates a model that is closer to reality.

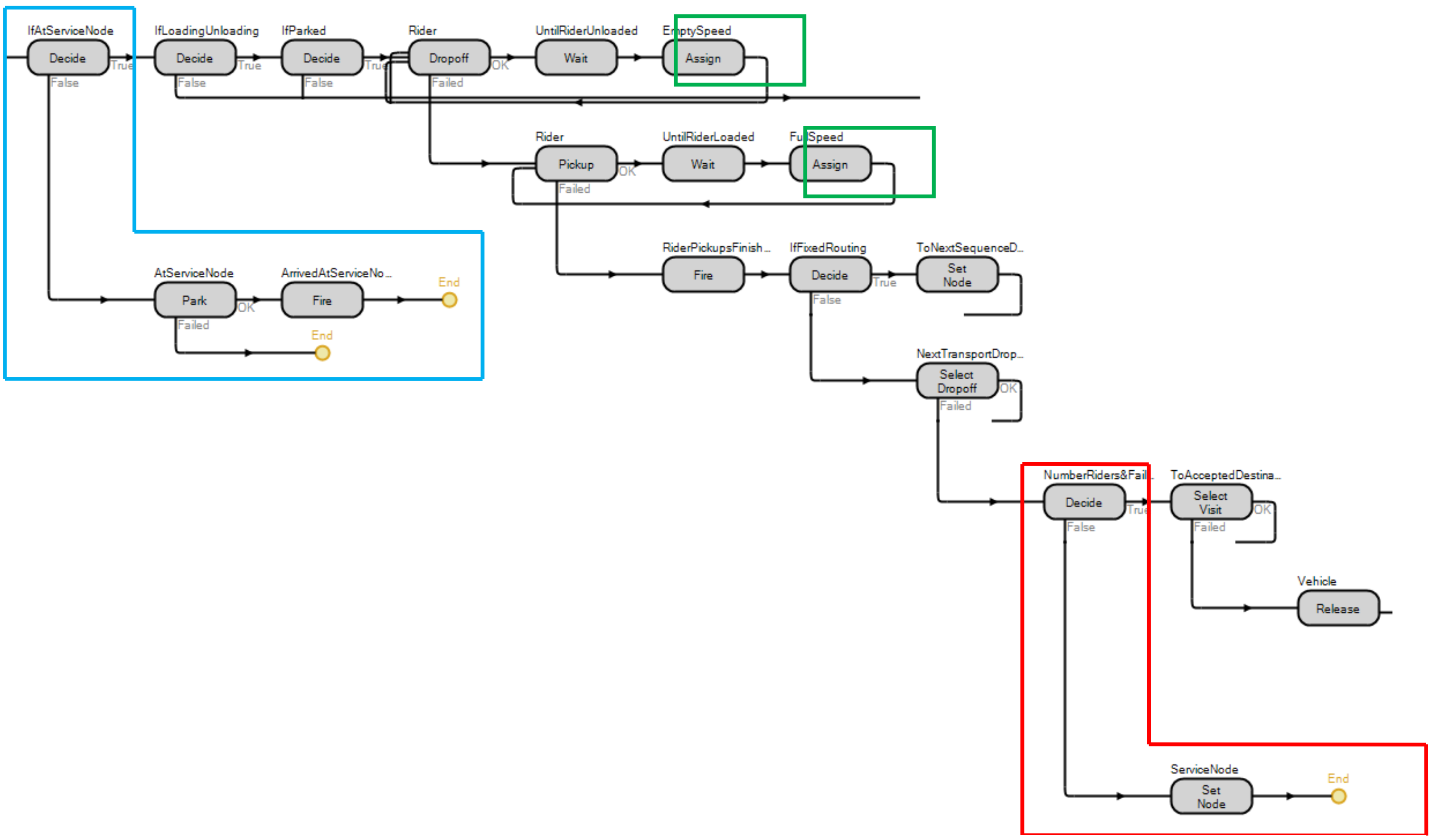


Figure 17: On Visiting Node Process.

5.4 Model Process Logic

In addition to the custom process logic required for the transporter, there is also custom logic required for the main model. While these processes are far less complicated than the transporter logic it is still imperative that they are implemented correctly in order for the simulation to run as accurately as possible.

The first process that was included was to update a *state variable*, within the transporter, to define the repair shop node as a number that can be referred to at any point throughout the simulation. This is used in the On Visiting Node process described previously to check whether the node being visited is the repair shop node. However, the logic can only be implemented in the model itself. The process starts with a step used to search for the numerical ID of the repair shop node, the value returned is then assigned to a temporary variable. Each transporter is then searched for and that temporary variable is then saved into the state variable "ServiceNodeID" within the transporter itself. The logic is run every time a new run begins and is shown in Figure 18.

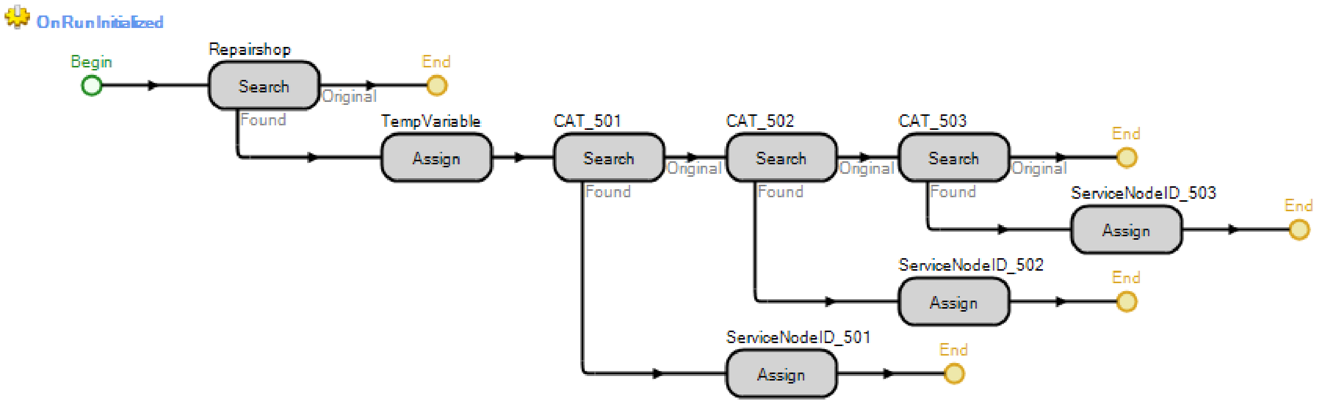


Figure 18: On Run Initialised Process.

The other process that runs in the model itself is a simple process that uses an assign step to update a variable that keeps track of how much sand is transported by the trucks throughout the run. It simple adds the number saved into each entity when it is created and provides a final Load Carried figure at the end of each run. This process is shown in Figure 19 and is run every time an entity is unloaded from the transporter and transferred into the sink.

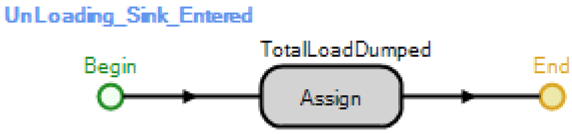


Figure 19: Total Load Carried Update Process.

5.5 Run Parameters

The trucks, at NVC, operate for 24 hours a day, in two shifts of twelve hours. The changeover in between each shift is scheduled to be 15 minutes. This theoretical downtime is programmed into the model by defining the shifts in the standard working day. Simio will follow the defined working time and will cause all resources and objects to stop working during the defined downtime.

The model was run for the period of 28 days. This was deemed to be a long enough trial period to accurately estimate the full impact that implementing the Duratray SDB will have.

Once the simulation was run for the defined period of time, a report was developed that indicated all the information necessary to move forward with the trial.

CHAPTER 6: FINDINGS

6.1 As-Is/Current Scenario

6.1.1 Simulation Parameters

The *As-Is* scenario as defined in the project scope pertains to the situation in which the trucks operate with the steel bowls that come as standard with the CAT 773F trucks. This is the situation where the carry back is a prevalent problem that is having a detrimental effect on the productivity of the trucks.

In order to develop a baseline, against which comparisons can be made, the simulation model needed to run according to this current scenario. To do this certain parameters needed to be entered into the model. The parameters are based largely on the data gathered during the data analysis (Table 7) and were entered into Simio using the expression building function. The parameters and the way they were entered are detailed in Table 10. The functions listed in the Simio Expressions column are written as they would be in Simio. The Object – Category column specifies the object associated with each parameter and the category that it falls under in the properties panel in the simulation builder.

Current Scenario			
Parameter	Simio Expression	Units	Object - Category
Loading Time	Math.Abs(Random.Uniform(79,143))	sec	CAT773 - Transport Logic
Unloading Time	Random.Poisson(37)	sec	CAT773 - Transport Logic
Initial Desired Speed	Math.Abs(Random.Uniform(4.02,6.49)	m/s	CAT773 - Travel Logic
Empty Travel Speed	Math.Abs(Random.Uniform(4.02,6.49)	m/s	CAT773 - Travel Logic
Full Travel Speed	Math.Abs(Random.Normal(4.90,0.56))	m/s	CAT773 - Travel Logic
Initial Node	Repairshop	-	CAT773 - Routing Logic
Secondary Loading Resource	Komatsu_PC1250_8	-	CAT773 - Process Logic
Failure Type	Calender Time Based	-	CAT773 - Reliability Logic
Uptime Between Failure	Random.Exponential(15.14)	hrs	CAT773 - Reliability Logic
Time to Repair	Random.Exponential(1.091)	hrs	CAT773 - Reliability Logic
Service Node	Repairshop	-	CAT773 - Reliability Logic
Maximum No. in System	1	-	CAT773 - Population
Load Carried	Math.Abs(Random.Normal(40.34,4.815))	tons	RiverSand - Process Logic
Entity Destination	Input@Unloading_sink	-	Output@Loading_Server - Routing Logic
Ride on Transporter	TRUE	-	Output@Loading_Server - Transport Logic
Transporter Type	From List	-	Output@Loading_Server - Transport Logic
Transporter List Name	Trucks	-	Output@Loading_Server - Transport Logic
Reservation Method	Reserve Closest	-	Output@Loading_Server - Transport Logic
Selection Goal	Largest Value	-	Output@Loading_Server - Transport Logic
Selection Expression	Candidate.Transporter.RideCapacityRemaining	-	Output@Loading_Server - Transport Logic

Table 10: Parameters for As-Is Scenario Simulation.

6.1.2 Simulation Output

There were several output statistics that the simulation model provided. These have been laid out in Table 11. The first figure that was extracted was the total amount of sand transported by the trucks. This was an important statistic because it provided the primary baseline against which the Duratray SDB was assessed. The second statistic given in the table is the Scheduled Utilisation of the trucks. This relates to the percentage of time during which the trucks were being used to transport sand. These two statistics form the primary outputs that the model was designed to relate.

Output Statistics	
Total Sand Moved	266 568.94
CAT 501 - Utilisation	89.81%
CAT 502 - Utilisation	91.41%
CAT 503 - Utilisation	91.12%
Average Utilisation	90.78%

Table 11: Output Statistics for Current Scenario Simulation.

In addition to these statistics the other details that the simulation produced concerned the failures that the trucks experienced over the simulated period. Table 12 shows the total time that each truck was in a "failed state" along with the number of times that each truck underwent a failure. This information was useful when it came to estimating the cost incurred by NVC when a failure occurred and again the results of this simulation were used as a baseline to compare the effect that the SDB had on the system.

Failures		
CAT 501	Failed Time	68.48
	No of Failures	46.00
CAT 502	Failed Time	57.74
	No of Failures	49.00
CAT 503	Failed Time	59.67
	No of Failures	46.00
Average	Failed Time	61.96
	No of Failures	47.00

Table 12: Failure Results from Current Scenario Simulation.

6.2 To-Be/Future Scenario

6.2.1 Simulation Parameters

Duratray (Future) Scenario			
Parameter	Simio Expression	Units	Object - Category
Loading Time	Math.Abs(Random.Normal(149.29,21.92))	sec	CAT773 - Transport Logic
Unloading Time	Math.Abs(Random.Normal(37.29,13.28))	sec	CAT773 - Transport Logic
Initial Desired Speed	Math.Abs(Random.Uniform(4.20,5.46))	m/s	CAT773 - Travel Logic
Empty Travel Speed	Math.Abs(Random.Uniform(4.20,5.46))	m/s	CAT773 - Travel Logic
Full Travel Speed	Math.Abs(Random.Normal(5.41,0.78))	m/s	CAT773 - Travel Logic
Initial Node	Repairshop	-	CAT773 - Routing Logic
Secondary Loading Resource	Komatsu_PC1250_8	-	CAT773 - Process Logic
Failure Type	Calender Time Based	-	CAT773 - Reliability Logic
Uptime Between Failure	Random.Exponential(14.40)	hrs	CAT773 - Reliability Logic
Time to Repair	Random.Exponential(1.091)	hrs	CAT773 - Reliability Logic
Service Node	Repairshop	-	CAT773 - Reliability Logic
Maximum No. in System	1	-	CAT773 - Population
Load Carried	Math.Abs(Random.Normal(58.22,13.215))	tons	RiverSand - Process Logic
Entity Destination	Input@Unloading_sink	-	Output@Loading_Server - Routing Logic
Ride on Transporter	TRUE	-	Output@Loading_Server - Transport Logic
Transporter Type	From List	-	Output@Loading_Server - Transport Logic
Transporter List Name	Trucks	-	Output@Loading_Server - Transport Logic
Reservation Method	Reserve Closest	-	Output@Loading_Server - Transport Logic
Selection Goal	Largest Value	-	Output@Loading_Server - Transport Logic
Selection Expression	Candidate.Transporter.RideCapacityRemaining	-	Output@Loading_Server - Transport Logic

Table 13: Parameters for To-Be Scenario Simulation.

The *To-Be* simulation deals with the behaviour of the trucks if they all were to be fitted with the Duratray SDB. Much like Table 11, Table 14 illustrates the parameters used in specifying the exact manner in which the logic should be followed in the simulation. The distributions used once again are those determined in the data analysis chapter.

For this scenario all of the data that had been gathered from the truck fitted with the SDB was associated with all three of the trucks in the simulation. By doing this the results delivered reflected what the reality would be should the company decide to implement the new Duratray SDB.

Once again the Functions expressed in the Simio Expression column are written in the nomenclature used in the simulation software and the Object – Category column specifies where exactly each expression needs to be entered.

It should be noted that certain aspects in both the As-Is and the To-Be simulation are the same. Things like the Service Node, Secondary Loading Resource and Reservation Method were the same because the objects and/or logic to which they are associated are the same in both cases.

6.2.2 Simulation Output

In order for this part of the trial to be comparable to the established baseline the same statistics need to be extracted from the results of this simulation as the ones previously extracted from the As-Is section of the study. These results are shown in Table 14, and once again detail the amount of sand carried by all trucks during the 28 day simulation and the utilisation of the trucks during the same period.

Output Statistics	
Total Sand Moved	369 924.77
CAT 501 - Utilisation	89.54%
CAT 502 - Utilisation	91.83%
CAT 503 - Utilisation	88.49%
Average Utilisation	89.95%

Table 14: Output Statistics for the Future Scenario Simulation.

As before the resulting statistics for the failures of the trucks were also extracted from the simulation so that further comparisons could be made. Much like the As-Is simulation results Table 15 provides the details of the failures. Namely: the total time that the trucks spent in a failed state and the number of failures that each truck experienced.

Failures		
CAT 501	Failed Time	70.30
	No of Failures	46.00
CAT 502	Failed Time	54.88
	No of Failures	38.00
CAT 503	Failed Time	77.33
	No of Failures	54.00
Average	Failed Time	67.50
	No of Failures	46.00

Table 15: Failure Results from Future Scenario Simulation.

It should be noted that the results referred to, especially the Total Sand Moved, may not represent reality exactly. These discrepancies are suspected to be due to the fact that the distances covered in the simulation don't necessarily reflect those always travelled by each truck at all times. However, this is not believed to invalidate the results because the results were drawn with the purpose of making comparisons. Thus the fact that both scenarios were subject to the same conditions within the simulation the results can still be compared and conclusions may still be drawn from the resultant data.

6.3 Interpretation of Findings

The purpose behind developing an As-Is and To-Be study is so that a benchmark can be laid and then a similar set of findings can be compared to that benchmark. In this case the simulation results showed that the total amount of sand moved by the fleet of trucks drastically increased when using the Duratray SDB. The results showed a 103 355.83 ton (38.77%) increase in sand moved over a 28 day period. This dramatic increase is believable because of the considerably higher loads that are being carried by the SDB's in comparison to the original steel bowls.

This radical change, however, did come at somewhat of a cost. The average scheduled utilisation of the trucks in the To-Be scenario (89.95%) was somewhat lower than that for trucks in the As-Is scenario (90.78%). This decrease in utilisation gives credence to the established idea that trucks operating with the SDB are more susceptible to tyre wear, hydraulic failure and other such related maintenance issues as a direct result of carrying heavier payloads.

The data shown in Tables 12 and 15, backed up this argument by detailing the actual time spent by each truck in a failed state. While the average number of failures was much the same in both scenarios, the average time spent in a failed state was considerably higher for trucks using the SDB. This gave a clear indication that while the SDB may provide higher capacities and transport more sand than the original steel bowl design does, there are certain setbacks that prevent the immediate decision to change to the Duratray design.

The question that now needs to be answered is whether or not the evident setbacks are enough to prevent the company from implementing the use of the Duratray SDB on the remaining trucks in the fleet.

CHAPTER 7: ANALYTIC HIERARCHY PROCESS (AHP)

As defined in Chapter 3 the first step in an analytic hierarchy process is to develop a clear and concise "goal" for the decision making process. In this case it was very easy to define this goal because it could be directly related to the question asked at the end of the previous chapter: "do the setbacks prevent the company from implementing the Duratray SDB." Or to put it more simply, should the company implement the Duratray SDB or retain the original steel bowls on the CAT 773F trucks.

7.1 Criteria Development Phase

The first step that needs to be undertaken is to define the criteria on which the decision is to be based. The following sections give a brief but clear definition of what each of the criteria entailed and how the alternatives were to be assessed for each criterion.

7.1.1 Carry – Back

The problem of carry – back, as already suggested, is regarded as a major problem faced by NVC. It was the reason for this study being conducted and as such is one of the most important criteria upon which each alternative needs to be assessed.

The alternatives will be assessed according to how much carry – back is developed should it be implemented.

7.1.2 Cost

This criterion determines the extent to which cost plays a role in the decision making. It is safe to assume that the company would rather choose the alternative that will cost them less. However, this becomes complicated when the cost of maintaining the status quo (steel bowls) is, for all intents and purposes, nothing. While this may be the immediate reality, the point needs to be made that the constant maintenance required due to the removal of the carry – back will eventually add up.

Additionally there is also the opportunity cost associated with retaining the steel bowls. Due to their inability to transport as much sand as the Duratray SDB's, the alternatives will also need to be evaluated with the idea that there is an opportunity cost involved as well.

7.1.3 Failure Rate (Maintenance)

Maintenance of equipment and the regularity with which this must be done will perhaps play a slightly less important role in the decision making process but it is still a criteria for consideration when making such a decision.

The failure rates generated in the simulation models for each alternative proved to be useful because they provided a quantitative basis on which the comparisons could be made.

7.1.4 Truck Scheduled Utilisation

Truck utilisation, again perhaps not one of the most imperative criteria involved in the decision making process, but still a necessary measure on which a comparison can be made. It is closely linked to the failure rate and maintenance criteria, but has a slight difference in that it includes delays caused by other influences not just the trucks themselves.

7.1.5 Total Sand Moved (Throughput)

This quantitative selection criteria is one of the more important criteria used to assess the viability of the Duratray SDB. The alternatives will be evaluated according to the throughput developed in the simulation model. This criterion assesses the alternatives based on the quantitative productivity achievable by each alternative.

7.2 Alternatives

The statement made in the development of the decision goal made for a simple definition of the alternatives to be considered. On the one side there was the option of implementing the Duratray on all of the CAT 773F trucks, and on the other there was that of retaining the situation as it is at the moment and keep the steel bowls on the trucks.

7.3 Pairwise Comparison Phase

As soon as the goals, criteria and alternatives were defined, the next step was to make comparisons. Firstly the pairwise comparisons between the different criteria needed to be made. It was imperative that this was done objectively and in line with the goals of the decision. The Consistency Ratio provided an indication as to whether this has been achieved.

7.3.1 Criteria to Criteria Comparisons

Listed below are the comparisons between the different criteria (the first one mentioned in each comparison was the criteria preferred and the value in brackets is the importance rating given to that criteria).

Carry – Back to Cost: (3)

It was decided that the Carry-back criterion should carry a higher weight than that of the Cost criterion. This is because the driving force behind this study was to reduce the carry-back on all trucks. However, the Cost criterion still was thought to have some importance in the decision making process. Thus it was decided that a comparison rating of three be assigned to the Carry-back criterion over the Cost criterion.

Carry – Back to Throughput: (3)

In a similar sense of logic the Carry-back criterion was deemed to carry the same weighting over the Throughput criterion. Once again, with the primary focus of the study on reducing carry-back, the comparison should naturally be weighted towards this criterion. The importance rating of three was decided upon because there is a moderate importance of carry-back over throughput.

Carry – Back to Maintenance: (6)

The Carry-back criterion was decided to have a much higher rating when compared to maintenance. This is due, again, to the fact that the primary purpose of the study was to reduce carry-back. Additionally, should the carry-back of the trucks be reduced, it is reasonable to assume the amount of time spent on maintenance of the trucks will also be reduced.

Carry – Back to Utilisation: (6)

Similarly to the maintenance criterion comparison, the comparison between the carry-back and utilisation criteria was decided to carry a weighting of six. Again the idea of reducing carry-back leading to increased utilisation came to the fore and it was decided that the carry-back should carry the higher weighting when comparing these criteria.

Cost to Throughput: (3)

When considering the criteria of Costs involved in implementing the alternatives and the Throughput acquired as a result of implementing them, it was decided that the Costs should carry a higher importance rating. With this in mind the throughput of the trucks under the alternative scenarios was also decided to have a fairly large influence on the decision made. Thus the importance rating of three was decided upon in favour of the Cost criterion.

Cost to Utilisation: (3)

The major costs incurred in the implementation of the each alternative, was seen to be of greater importance in the trial than the increased utilisation achieved by the trucks. It was thus decided to give the Cost criterion an importance rating of three over the Utilisation achieved by each truck.

Throughput to Maintenance: (3)

The throughput that would be achieved by the trucks in both scenarios, when viewed in relation to the maintenance necessary to keep the trucks in operation under both alternatives, was seen to be of greater importance. It was thus decided to give the Throughput criterion a higher importance rating when making the comparison to Maintenance.

Throughput to Utilisation: (5)

By the same token as the comparison with the Maintenance criterion, the comparison between Throughput and Utilisation weighed relatively heavily on the throughput side. It was adjudged that the value gained through increased throughput would ultimately play a bigger role in the system than making a concerted effort to improve scheduled truck utilisation would.

Maintenance to Cost: (2)

When the comparison was made between the Maintenance and Cost criteria, it was decided that the influence that the role of maintenance of the trucks would play a slightly more important role than that of the costs of implementation. Since one of the indirect aims of the trial is to reduce the amount of maintenance required by the fleet, it was deemed understandable for reasonable investments to be made in the execution of this aim. It was for this reason that Maintenance was given an importance rating of two over the Cost criterion.

Utilisation to Maintenance: (4)

The Utilisation achieved through the implementation of either alternative was deemed to be of greater importance to the company when compared with Maintenance. While the reduction maintenance was seen as an indirect aim of the trial, the increased scheduled utilisation of the trucks was deemed to be of more importance to the company when making a selection between the alternatives.

As the comparisons were made, the values were recorded into the Criteria Comparison Matrix, (constructed according to the guidelines set out in Chapter 3) this can be seen in Table 17. The calculated priority vector is also included in the table, for use in the synthesis step.

Criteria - Criteria Comparisons

	Carry - Back	Cost	Throughput	Maintenance	Utilisation	Priority Vector
Carry - Back	1.00	1.00	5.00	6.00	6.00	0.15
Cost	1.00	1.00	2.00	0.50	3.00	0.17
Througput	0.20	0.50	1.00	3.00	5.00	0.11
Maintenance	0.17	2.00	0.33	1.00	0.25	0.13
Utilisation	0.17	0.33	0.20	4.00	1.00	0.09

Table 16: Criteria Comparison Matrix.

To check the consistency of the Criteria Comparison Matrix the Consistency Index and subsequent Consistency Ratio were calculated to be:

$$CI = 0.11430$$
$$CR = 10.82\%$$

This CR of 10.82% was deemed to be consistent enough to accept this matrix and continue with the process.

7.3.2 Alternatives Comparisons

According to the literature researched, the next step in the Analytic Hierarchy Process is to compare each of the alternatives based on each of the criteria in turn. Seeing as though the results of these comparisons were a set of 2x2 matrices, it was not necessary to calculate the Consistency Ratios for each one. In the details of each comparison below, Alternative One is the alternative relating to maintaining the status quo and Alternative Two is that of implementing the new Duratray SDB.

Carry – Back:

With the primary aim of the trial to reduce the amount of carry-back retained by the trucks, the alternatives needed to be evaluated relatively strictly when it came to comparing them. Should the SDB be implemented, the problem of carry-back would be almost completely eliminated. However, should alternative one be chosen, the problem would still exist in its entirety. It was for this reason that, using the scale for intensity of importance, Alternative One was given a rating of nine against Alternative Two. Table 17, shows the effect of this and provides the priority vector for this criterion as well.

Carry - Back

	Alternative One	Alternative Two	Priority Vector
Alternative One	1.00	0.11	0.33
Alternative Two	9.00	1.00	3.00

Table 17: Carry-back - Alternative Comparison Matrix.

Cost:

The costs involved with implementing each of the individual alternatives could, for the most part, be physically quantified. However, as mentioned previously, the missed opportunity cost that would be incurred should Alternative One be chosen would require much more research and in such a case an appropriate estimation of the relationship between the alternatives would suffice.

Appendix B shows the total costs incurred with purchasing and procuring one SDB to be slightly more than R 2 million, or just over R6 million should the remaining trucks also be fitted with SDB’s. With this in mind it was decided that an importance rating of six should be given to Alternative One. The reasoning behind this rating is that the direct costs involved with Alternative One are negligible in comparison to the capital investment required for Alternative Two. However, due to the lost opportunity cost, it would seem unreasonable to give Alternative One a rating of nine over Alternative Two. Table 18 shows the matrix for this comparison of alternatives with regard to the Cost criterion.

Cost

	Alternative One	Alternative Two	Priority Vector
Alternative One	1.00	6.00	2.45
Alternative Two	0.17	1.00	0.41

Table 18: Cost - Alternative Comparison Matrix.

Throughput:

Using the quantified outputs from the simulation models, the difference between the two alternatives could be completely objective when it came to evaluating with regards to throughput. It was revealed, through the simulations, that Alternative Two would produce 38.77% more throughput than Alternative One would.

It was based on this overwhelming increase in throughput that it was decided to give Alternative Two a rating of six over Alternative One. This is reflected in Table 19.

Throughput			
	Alternative One	Alternative Two	Priority Vector
Alternative One	1.00	0.17	0.41
Alternative Two	6.00	1.00	2.45

Table 19: Throughput - Alternative Comparison Matrix.

Maintenance:

As with the Throughput criterion, the maintenance comparisons, could be assessed based on objective results from the simulation. The number of failures experienced by trucks should Alternative One be adopted, was only one more than what it would be should Alternative Two be chosen. This difference is minimal, however still needs to be expressed. Thus Alternative Two was given a rating of two over Alternative One for the Maintenance criterion.

Maintenance			
	Alternative One	Alternative Two	Priority Vector
Alternative One	1.00	0.50	0.71
Alternative Two	2.00	1.00	1.41

Table 20: Maintenance - Alternative Comparison Matrix.

Utilisation:

The utilisation of the trucks, as shown in the simulation, differs very slightly. Alternative One achieved a scheduled utilisation of 90.78% whereas Alternative Two only achieved 89.95%. With the difference being 0.83% there is very little to judge between the two. Therefore, it was decided that an importance rating of two would be sufficient to differentiate between the alternatives.

Utilisation			
	Alternative One	Alternative Two	Priority Vector
Alternative One	1.00	2.00	1.41
Alternative Two	0.50	1.00	0.71

Table 21: Utilisation - Alternative Comparison Matrix.

7.4 Synthesis Phase

The synthesis step in the Analytical Hierarchy Process is the accumulation of all comparisons made between the criteria and the alternatives themselves. The Decision Matrix is constructed first by constructing a matrix of all the priority vectors resulting from the alternative comparisons. This matrix represents the evaluations between the alternatives based on all the criteria. Table 22 shows the construction and detail of the Decision Matrix.

The next step in the synthesis step of the AHP is to determine the criteria priority vector. The priority vector was calculated when the Criteria Comparison Matrix was developed and can be seen in Table 16.

Once the Decision Matrix and the Criteria Priority Vector are known, an AHP rating can be calculated with the equation:

$$A_{AHP}^{i} = \sum_{j-1}^{N} b_{ij} w_j \ for \ i = 1, 2, 3 \ldots M$$

Decision Matrix

	Carry-back	Cost	Throughput	Maintenance	Utilisation
Alternative One	0.33	2.45	0.41	0.71	1.41
Alternative Two	3.00	0.41	2.45	1.41	0.71

Table 22: Decision Matrix.

With the b_{ij} being every element of the Decision Matrix, and w_j being those of the criteria Priority Matrix, the equation becomes nothing more than a matrix multiplication of the two.

7.5 Results Phase

This matrix multiplication resulted in the calculation of two values, each pertaining to one alternative. The final values were calculated to be:

- Alternative One: 0.727256
- Alternative Two: 1.03848

As detailed in Chapter 3, it is the alternative associated with the largest value that should be the desired course of action taken or decision made. In this case the final AHP value for Alternative Two is clearly larger than that of Alternative One.

It was thus concluded that the benefits of implementing the Duratray Suspended Dump Body outweigh the effects that would come as a result of not implementing it.

CHAPTER 8: CONCLUSION

Anglo American Thermal Coal, being one of the largest coal mining companies in South Africa and indeed the world, strive to achieve excellence in every aspect of their professional operations and commitments. This is no different at New Vaal Colliery. In order for this perpetual pursuit of perfection to provide sustainable improvements to problems, in the existing systems used, need to be identified. One such problem identified at New Vaal Colliery was the continual removal of carry-back required for the fleet of CAT 773F rigid dump trucks.

When addressing the problem of carry back, it was determined that the only way to completely eliminate the problem was to change the bowl design of the trucks. Duratray International, a company specialising in a unique bowl design technology that removes carry-back (called the Suspended Dump Body), was contacted and a prototype was bought to South Africa so that testing could be done to determine whether the SDB would be a worthwhile investment for the company.

Before testing could commence, a plan needed to be developed to ensure the success of the trial. The plan that was developed was based on a strategy used in business process engineering; whereby an initial study would be conducted to determine a baseline or benchmark against which the performance of selected ideas and solutions could be evaluated. This initial study, it was decided, would be conducted based on the current bowl design that has the problem of developing large amounts of carry-back. The details that would be required from the study included the utilisation of the trucks under certain conditions as well as the performance of the trucks, measured by the amount of material that they can haul.

Were this trial to be based on a data analysis alone, it would be subject to conditions that may not necessarily affect both the prototype and the original bowl design. It was thus decided that in order for objective and consistent results to be obtained a simulation model would be built. The inputs for the simulation would be drawn directly from the data analysis of the two bowl types and the results would be combined with other contributing factors to make a final decision as to whether the prototype would be suitable.

Prior to commencement of the trial research was conducted into different methods of analysing data, different simulations and different decision making techniques. The research gave an understanding of what type of problems could be faced in these three phases of the trial and how to overcome them. Once the research was completed, it was decided that basic data mining techniques and procedures would be followed for the data analysis phase, Simio Simulation Software would be used to model the trucks and their operating logic and the Analytic Hierarchy Process would be used to integrate all aspects in making the final decision of whether the SDB should be implemented or not.

The data analysis first comprised of gathering data. This was done by: conducting time studies, (to gain an insight into the parameters constraining the physical process of overburden removal) conducting load studies (to determine the capacity loads of the trucks) and collecting downtime reports (so as to develop an idea of how much time the prototypes and original designs spend in an unproductive state). The data analysis section comprised primarily of filtering the data and fitting each category to a statistical distribution that adequately describes its behaviour.

Moving into the simulation phase involved firstly building a simulation model that accurately mimics reality. The simulation package (Simio) used allowed for the custom logic, necessary to imitate the unique processes followed by the CAT 773F trucks, to be built and executed. The results of the simulations showed that, while the prototype SDB does provide significantly more throughput (38.77%) than that of the original design, the scheduled truck utilisation was lower than that provided by the original bowl design. When the results were studied further it was found that this was as a result of longer downtimes incurred by the truck using the prototype SDB. The question that then needed to be answered was whether or not this increased throughput justified the increased downtime.

At this point it was deemed necessary not only to make the trade-off between the throughput and the utilisation, but also to include in the decision the effects of: increased maintenance, costs incurred by implementing one alternative or the other and of course the alternative's ability to eliminate the problem of carry-back.

In order to integrate all of these criteria, an Analytic Hierarchy Process was conducted. By giving each criterion a specific weighting compared to each of the other criteria and then evaluating the alternatives according to each criteria, a final objective decision can be made with regards to which alternative should be adopted. The results of this process showed that the Duratray Suspended Dump Body should be adopted by the fleet of CAT 773F rigid dump trucks used in the overburden removal process at New Vaal Colliery.

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Appendix A

Table of Critical Values for the Kolmogorov-Smirnov Test

(Lilliefors, 1967)

TABLE 1. TABLE OF CRITICAL VALUES OF D

The values of D given in the table are critical values associated with selected values of N. Any value of D which is greater than or equal to the tabulated value is significant at the indicated level of significance. These values were obtained as a result of Monte Carlo calculations, using 1,000 or more samples for each value of N.

Sample Size N	Level of Significance for $D = \text{Max}\ \lvert F^*(X) - S_N(X) \rvert$				
	.20	.15	.10	.05	.01
4	.300	.319	.352	.381	.417
5	.285	.299	.315	.337	.405
6	.265	.277	.294	.319	.364
7	.247	.258	.276	.300	.348
8	.233	.244	.261	.285	.331
9	.223	.233	.249	.271	.311
10	.215	.224	.239	.258	.294
11	.206	.217	.230	.249	.284
12	.199	.212	.223	.242	.275
13	.190	.202	.214	.234	.268
14	.183	.194	.207	.227	.261
15	.177	.187	.201	.220	.257
16	.173	.182	.195	.213	.250
17	.169	.177	.189	.206	.245
18	.166	.173	.184	.200	.239
19	.163	.169	.179	.195	.235
20	.160	.166	.174	.190	.231
25	.149	.153	.165	.180	.203
30	.131	.136	.144	.161	.187
Over 30	$\frac{.736}{\sqrt{N}}$	$\frac{.768}{\sqrt{N}}$	$\frac{.805}{\sqrt{N}}$	$\frac{.886}{\sqrt{N}}$	$\frac{1.031}{\sqrt{N}}$

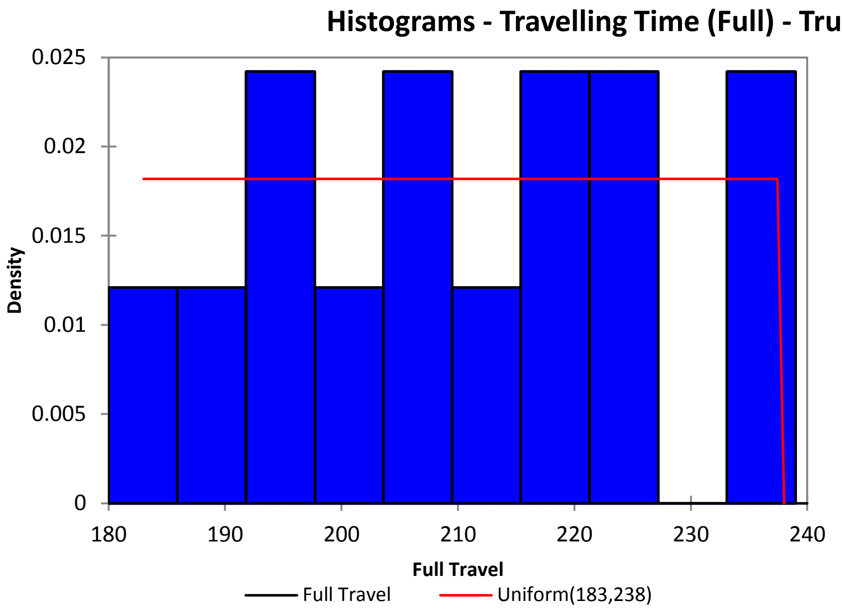
Appendix B

Detailed Cost Structure for the Duratray SDB

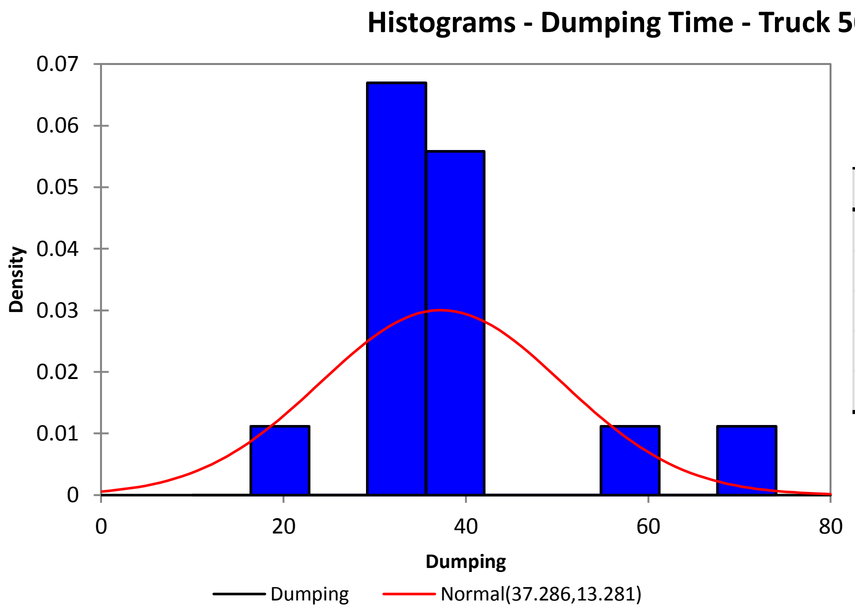
Duratray Trial Costs				
Exchange Rate		ZAR/USD1.00	R	7.70
		ZAR/AUD1.00	R	6.65
Merchandise		AUD	ZAR	
SDB CAT773 Bowl Only		$ 180 000.00	R	1 197 000.00
Pick-Up Charges		AUD	ZAR	
Inland Haulage - ExNaval Base		$ 3 899.70	R	25 933.01
Origin Charges		$ 850.00	R	5 652.50
Sub-Total		$ 4 749.70	$	31 585.51
Ocean Freight Charges (Fremantle-Durban)		USD	ZAR	
Ocean Freight + BAF + CAF		$ 28 050.00	R	215 985.00
BAF		$ 590.00	R	4 543.00
CAF		$ 1 002.40	R	7 718.48
Sub-Total		$ 29 642.40	R	228 246.48
Total - Overseas Billing		$ 33 744.41	R	259 831.99
SARS/Customs Charges	Rate	USD	ZAR	
Customs Duty	20%		R	239 400.00
Customs VAT	14%		R	217 854.00
Sub-Total			R	457 254.00
South Africa Port Charges - Durban		USD	ZAR	
Terminal Handling Fee			R	2 127.00
Cargo Dues			R	4 056.13
Container Cleaning			R	150.00
Delivery and Service Order Fee			R	760.00
Merchant Haulage Fee			R	630.00
Origin Cargo Description			R	462.00
Cargo Redirect			R	865.00
Degroup and Release Fee			R	261.00
Special Attendance			R	1 500.00
Sub-Total			R	10 811.13
SA Haulage Charges - Durban to Vaal		USD	ZAR	
SDB CAT773			R	61 600.00
Cargo Transfer - Container to Vehicle			R	7 500.00
Sub-Total			R	69 100.00
SA Local Charges		USD	ZAR	
Documentation			R	550.00
CAF			R	2 598.32
Agency Fee			R	4 383.48
Finance Fee			R	8 843.39
Sub-Total			R	16 375.20
Total SA Local and Customs Charges		$ 71 888.35	R	553 540.33
		USD	ZAR	
Total Charges from Ex-Works Perth		$ 105 632.77	R	813 372.31
Total Cost to Company			R	2 010 372.31

Appendix C

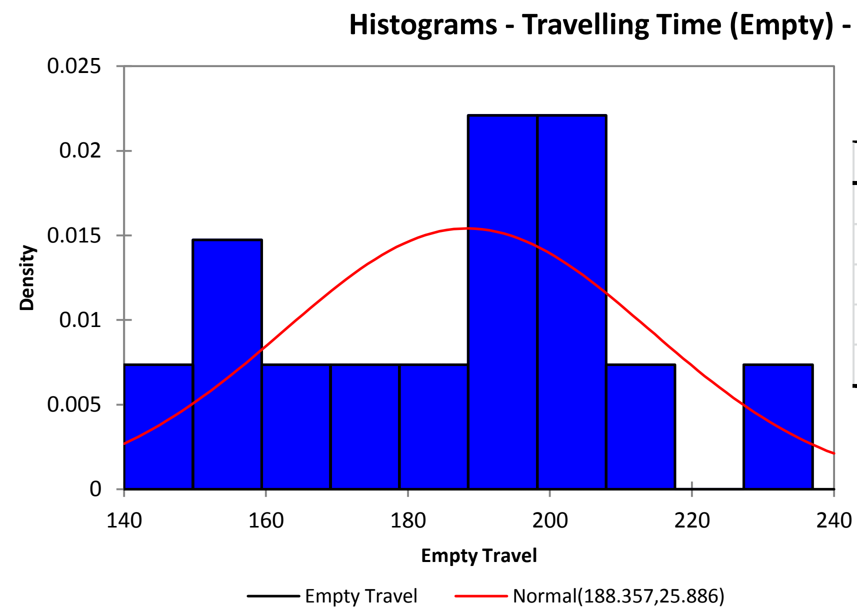
Descriptive Statistics for Remaining Variables



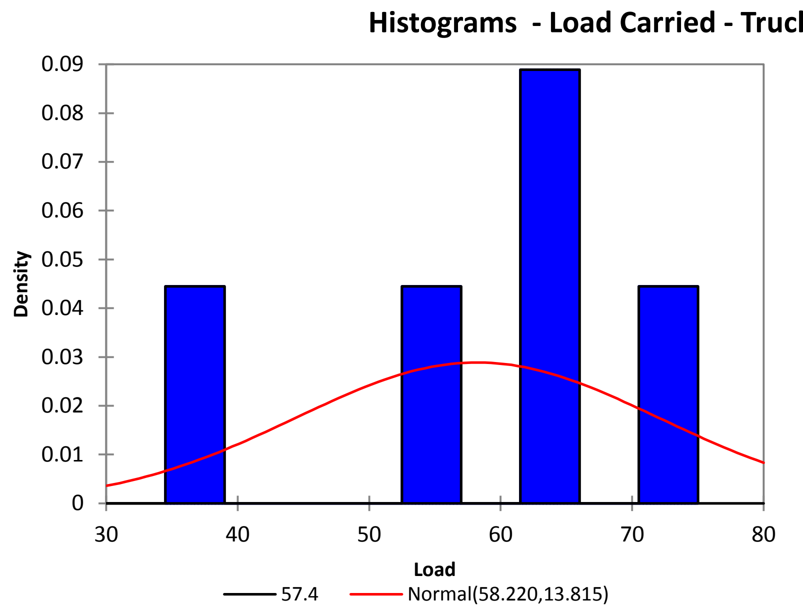
Statistic	Data
Mean	211.214
Standard Deviation	16.867
Minimum	183.000
Maximum	238.000
Skewness	0.036



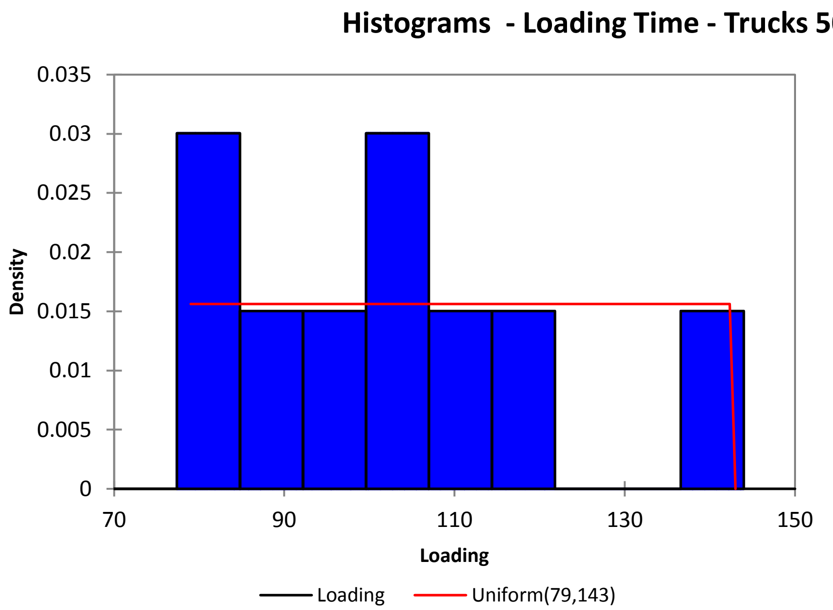
Statistic	Data
Mean	37.286
Standard Deviation	13.281
Minimum	18.000
Maximum	73.000
Skewness	1.400



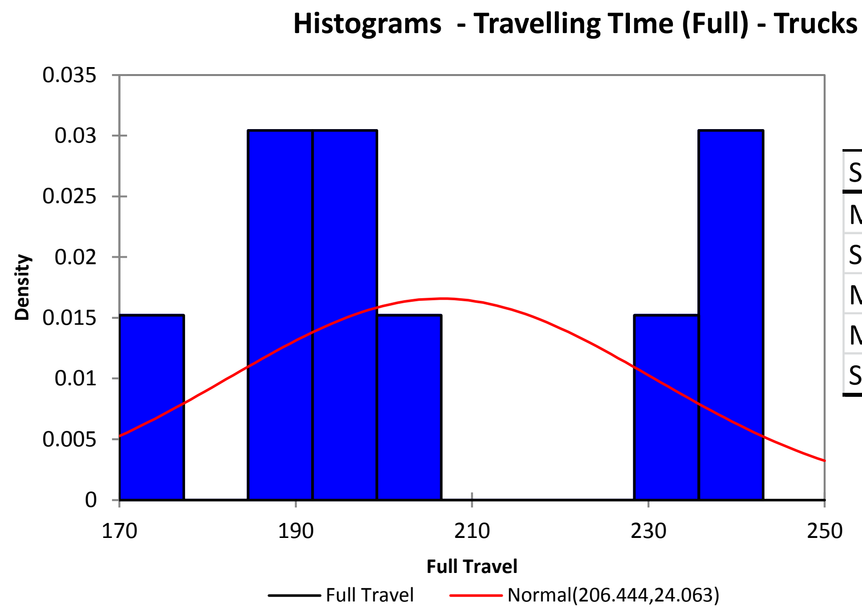
Statistic	Data
Mean	188.357
Standard Deviation	25.886
Minimum	141.000
Maximum	236.000
Skewness	-0.122



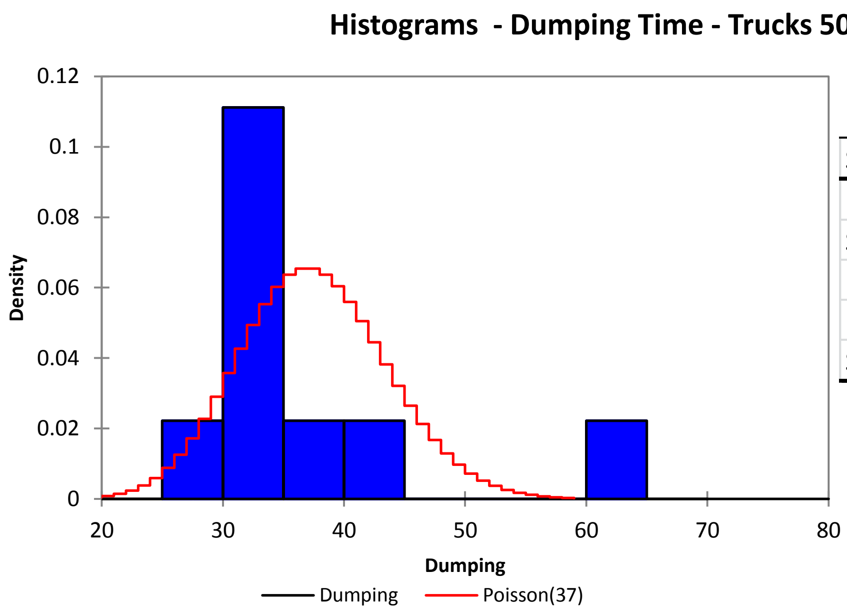
Statistic	Data
Mean	58.220
Standard Deviation	13.815
Minimum	37.300
Maximum	74.000
Skewness	-0.382



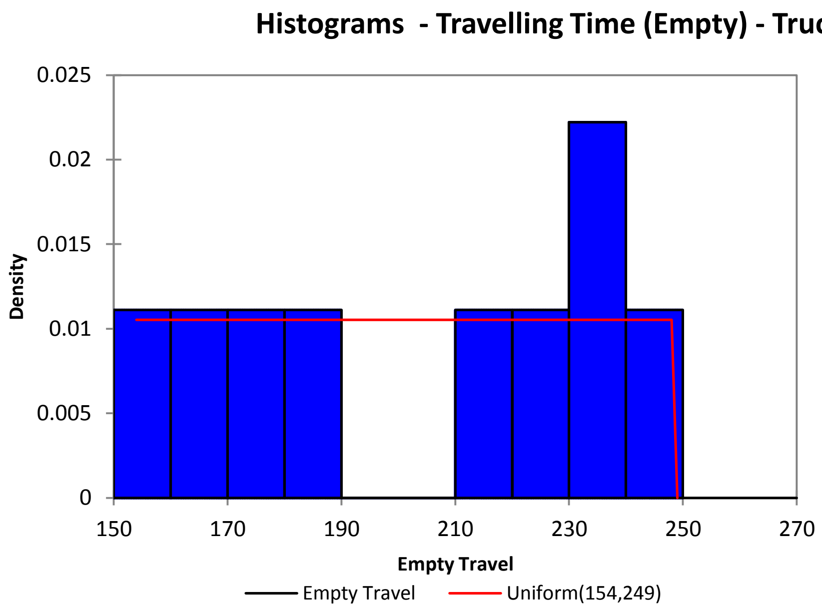
Statistic	Data
Mean	102.778
Standard Deviation	20.266
Minimum	79.000
Maximum	143.000
Skewness	0.611



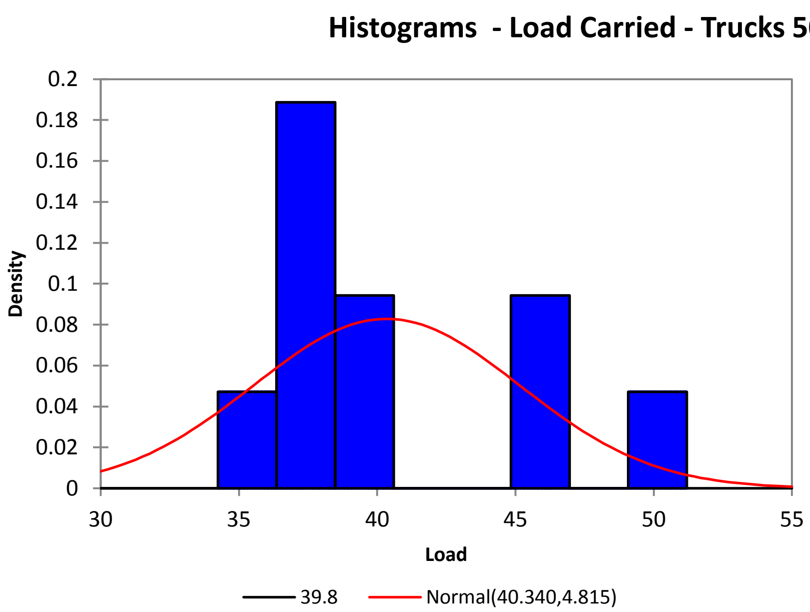
Statistic	Data
Mean	206.444
Standard Deviation	24.063
Minimum	174.000
Maximum	242.000
Skewness	0.309



Statistic	Data
Mean	37.000
Standard Deviation	10.524
Minimum	29.000
Maximum	64.000
Skewness	1.864



Statistic	Data
Mean	204.222
Standard Deviation	35.017
Minimum	154.000
Maximum	249.000
Skewness	-0.148



Statistic	Data
Mean	40.340
Standard Deviation	4.815
Minimum	35.600
Maximum	50.200
Skewness	0.871

Appendix D

Detailed Tyre Degradation Tables

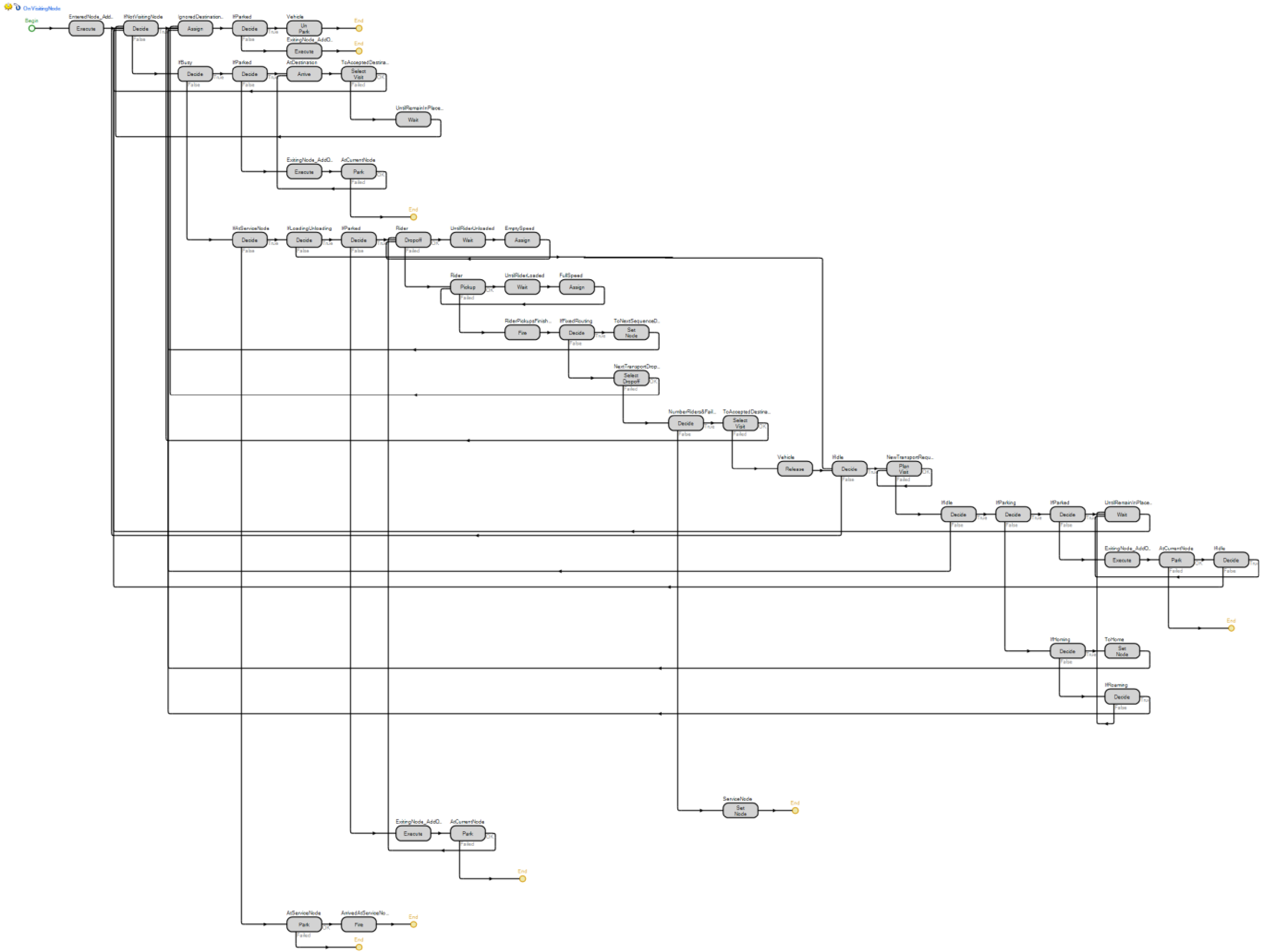
Truck 501					
Wheel Pos	Tyre Make	Tyre Size	Tread Pattern	Hours Used	Hrs/mm
LF	Michelin	24.00R35	XDT	4679	259.9
RF	Michelin	24.00R35	XDT	4679	334.2
RRO	Michelin	24.00R35	XDT	5906	281.2
RRI	Michelin	24.00R35	XDT	5906	246.1
LRI	Michelin	24.00R35	XDT	11118	195.1
LRO	Michelin	24.00R35	XDT	11118	252.7

Truck 502					
Wheel Pos	Tyre Make	Tyre Size	Tread Pattern	Hours Used	Hrs/mm
LF	Bridgestone	24.00R35	VRLS	1488	248
RF	Bridgestone	24.00R35	VRLS	1488	297.6
RRO	Michelin	24.00R35	XDT	6889	382.7
RRI	Michelin	24.00R35	XDT	6889	275.6
LRI	Michelin	24.00R35	XDT	8233	265.6
LRO	Michelin	24.00R35	XDT	146	49

Truck 503					
Wheel Pos	Tyre Make	Tyre Size	Tread Pattern	Hours Used	Hrs/mm
LF	Bridgestone	24.00R35	VRLS	1793	163
RF	Bridgestone	24.00R35	VRLS	1793	224.1
RRO	Michelin	24.00R35	XDT	10375	225.5
RRI	Michelin	24.00R35	XDT	10375	216.1
LRI	Michelin	24.00R35	XDT	9248	215.1
LRO	Michelin	24.00R35	XDT	10375	259.4

Appendix E

On Visiting Node Process



OnVisitingNode
Begin
Execute
Decide
Assign
Park
Arrive
Select Visit
Wait
Dropoff
Pickup
Fire
Set Node
Release
Plan Visit
End