SIMULATION MODELLING OF AN INVENTORY SYSTEM WITH FLUCTUATING DEMAND AND PRICE

BY

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*"Whatever the mind
of man can
conceive and believe,
it can achieve."*

~ Napoleon Hill

EXECUTIVE SUMMARY

Sufficient inventory management is critical in the procurement, storage and usage of product. Thus it is important to find and implement the most suitable inventory system for operating a business at full potential. The aim of the project was to improve the current tyre procurement department of SAA in terms of efficiency and effectiveness by reducing cost and implementing a system that increases visibility in the department. This was achieved through the implementation of an information system and ordering policy model which illustrates a probability to decrease overall cost with 26% annually.

This report introduces the project environment and main problem areas encountered at SAA's Operational Procurement and Fleet Department (OPF). OPF is in charge of managing all vehicles excluding aircraft at SAA. However the department lacks a suitable inventory system for the procurement and storage of various vehicle tyres. Further problems are the uncertainty regarding demand, price and tyre lifetimes which result in ineffective management and inventory policies. The problem environment is also suitable for literature improvement as most research models fail to enclose the totality of the current situation at OPF.

An in depth literature review outlines research on the subject of inventory management. Theory concerning inventory management is highlighted and the main types of models applicable to the project are chosen. Various ordering policy models are reviewed and evaluated and gaps in the knowledge base are identified. Simulation modelling as a tool for inventory management is also discussed and models created for this purpose is analysed. The use of information system design in inventory management is investigated and evaluated against the current OPF setting. The literature review concludes with a technique selection where the most applicable Industrial Engineering tools are selected in analysing and solving the applicable problems.

Following the review, data analysis was conducted to define the current state of OPF and to find any shortcomings. It was found that the data provided is not sufficient to ensure a perfect solution for OPF. Included in the data analysis are cost calculations, demand and price distributions as well as a full scale business process breakdown. To conclude the data analysis phase, an as-is simulation model was created to analyse the current state of tyre procurement and to set a margin for future system implementation. It was found that 90% of the simulation results correlate with the actual data received from OPF.

To address the problem at hand this report focuses on different inventory policy solution alternatives. This includes an EOQ model with backorders, a predetermined fixed order quantity model, a fixed time period model as well as a derivative of a two-period dynamic programming model by Fabian et al (1958). Testing of the models entailed the design of a simulation model that encompasses all of the solution alternatives. The simulation model is validated and verified in depth to give accurate results regarding the solution models.

Simulation of these models shows that the Fabian et al (1958) model decreases total overall inventory costs by 46%. Various design criteria was also used in evaluating the models and shows that the Fabian et al (1958) model has an

overall design criteria score of 74%, making it the best model out of the ones tested. With this model OPF can save up to R 400 000.00 on tyre procurement annually, however this solution does increase the quantity of shortages.

To eliminate the high shortage quantity created by the Fabian model, alterations were made to include the use of a maximum shortage quantity that is allowed per tyre type. This solution decreases the shortage quantity of the original model by 73%. In turn this decreases the time spent on processing and filing orders as well as the risk of shortages occurring during delivery lead times. In total, the altered model decreases the total cost of OPF by 26% or R 319 359 annually.

The solution model is implemented with the incorporation of an information system consisting of a database as well as a software program. This information system aims to replace the OPF manual system as well as to increase visibility in the department.

In conclusion, the project report encompasses the following:

a. problem investigation,
b. literature review,
c. data analysis,
d. solution alternative design,
e. model validation,
f. simulation model development,
g. testing and results,
h. information system design and implementation.

According to the literature review, space still exists for research involving inventory control whereas the solution development aims to contribute to the knowledge base. Data analysis shows that OPF was in dire need of a new inventory management system which is solved through the development of a mathematical solution model and information system. As shown by the simulation model, OPF is currently spending over R 1 000 000 on tyre procurement annually which include more than a 100 shortages each year. As stated above, the derivative of the Fabian et al (1958) model with maximum shortage level will attempt to reduce the cost by 26% and the shortage quantity by 25%.

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GLOSSARY

SAA	SOUTH AFRICAN AIRWAYS (SOC) LTD
OPF	OPERATIONAL PROCUREMENT AND FLEET DEPARTMENT
PPPFA	PREFERENTIAL PROCUREMENT POLICY FRAMEWORK ACT
EOQ	ECONOMIC ORDER QUANTITY
(s, Q)	REORDER POINT, REORDER QUANTITY INVENTORY POLICY MODEL
(r, Q)	CONTINUOUS REVIEW POLICY
(s, S)	ORDER-UP-TO POLICY
(R, S)	PERIODIC REVIEW POLICY
RFQ	REQUEST FOR QUOTE
DOA	DELEGATION OF AUTHORITY
GRV	GOODS RECEIVED VERIFICATION
PO	PURCHASE ORDER
IVR	INVOICE VERIFICATION RECEIPT
FOA	FUNCTIONAL OPERATING AREA
ERD	ENTITY RELATIONSHIP DIAGRAM
WBS	WORK BREAKDOWN STRUCTURE
SQL	SEQUENTIAL QUERY LANGUAGE
GUI	GRAPHICAL USER INTERFACE

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Sufficient inventory management is critical in the procurement, storage and usage of product. Thus it is important to find and implement the most suitable inventory system for operating a business at full potential. Unfortunately several presently used inventory models do not consider the uncertain environment involved when modelling supply chains. This project investigates the inventory management systems at South African Airways (SOC) Ltd's Operational Procurement and Fleet department.

1.1.1 SOUTH AFRICAN AIRWAYS (SOC) LTD. (SAA)

The production section of South African Airways (SOC) Ltd. (SAA), previously known as South African Airways Technical, is the most advanced aircraft overhaul, repair and maintenance company in Africa and serves local as well as international airlines. The main operations are done at OR Tambo International Airport in Johannesburg, however SAA also provides service to customers in Durban, Lanseria as well as Cape Town and is seeking to expand to international markets, emphasizing other African airlines.

The mission of SAA is to provide world-class service to customers, internally and externally for the purpose of delivering sustainable profits and increasing market shares. The company strives to grow into an organization with global reach and is focussing on improvement programs involving all aspects of the supply chain.

SAA has a personnel base of over 2600 employees of which two thirds are maintenance related staff. Other areas of expertise include Engineering, Quality Assurance, Supply Chain Management, Human Resources and Finance. SAA has been FAA certified since the 1990's and has served local and international airlines for over seventy years. The company consist out of a diverse number of departments which contribute to the world class service provided by SAA.

In addition to the above mentioned services, SAA performs specialized services to customers which include quality assurance, procurement, technical information, logistics, maintenance planning and training for all the required components as well as the effective management of aircraft maintenance.

1.1.2 OPERATIONAL PROCUREMENT AND FLEET DEPARTMENT (OPF)

The project presented focuses on the Operational Procurement and Fleet Department (OPF) of SAA which is in charge of ground fleet management. The department lacks a suitable inventory management system for the procurement and storage of vehicle tyres. At present procurement is triggered when the need for new tyres arise. The need is satisfied only after a number of quotes are received and the order is authorized by SAA. The procurement manager makes a final decision with a comparison on the 80/20 principle as per the PPPFA (80% on price, 20% on BEE (Black Economic Empowerment). The SAA vehicle fleet consists of several vehicle types ranging from small motor vehicles to tugs responsible for towing aircraft. According to the department manager, these vehicles travel on harsh surfaces and operate in changing environments that have a significant effect on the lifecycle of the tyres. The challenge of procurement arises due to this instability in tyre usage rates and lifecycles. The need to replace tyres has become a fuzzy, uncertain situation where constant review and strategic action is needed.

1.2 PROBLEM INVESTIGATION

The Operational Procurement and Fleet Department (OPF) has no inventory management system in place for the procurement and storage of tyres and at present orders are only placed as a demand arises. No planning exists in terms of future procurement systems and the complete process is executed manually. This manual approach takes up a great amount of time and is not managed well. No detailed records of purchase information exist and suppliers are chosen according to the lowest price and PPPFA standards at the time a purchase needs to be made. Evidently the department lacks visibility between procurement processes. Forecasting and future requirement planning is non-existent with no effort to reduce inventory cost and shortages.

The main problem arises as a result of the constant pressure and uncertainty regarding inventory management. Tyre prices are influenced by other factors such as the international rubber price and supply which fluctuate daily. The difference in tyre life in the department creates pronounced fluctuation in the monthly tyre demand, causing difficulties when making decisions on the quantity of tyres to be procured. The cause of variable tyre usage is the different surfaces vehicles operate on that increase wear and lessens the product lifetimes. The manner of usage also creates problems; this relates to the personnel range conducting different methods of tyre usage – sometimes tyres are looked after well, whereas some tyres are treated with no respect.

The procurement manager is thus continuously upheld by tyre-related problems and is not able to focus on all the aspects of the department. Tyres are only sourced when needed and can cause other departments to come to a standstill due to the lack of functioning vehicles. This problem is increased due to the authorization process that essentially needs to occur before tyres can be ordered and delivered. Authorization requires two procurement managers to sign off on a quoting request; when shortages constantly occur this process becomes a bottleneck in the OPF system. This uncertainty in demand and price increases the difficulty to procure tyres in the current setting. Forecasting and future requirements planning is non-existent with no effort to attempt and reduce inventory cost and shortages. There are no known trends to prepare the department for any sudden increase in demand and since the order is required immediately, no planning regarding sourcing at low price intervals is considered.

The procurement system functions manually and although the rest of SAA has state of the art technology implemented for inventory management, this department affects the optimality of the entire company due to the lack of proper inventory control. SAA is in the process of implementing this inventory control system in all of the company; however it is a time consuming process that will take years to complete - OPF is in dire need of a proper inventory management system now. At present, all transactions are done manually and the financing department updates the books and ledgers by hand each time a transaction is made. There is thus no visibility between the two departments and this causes money to be lost in terms of time. Errors occur as data is handwritten and the manual transfers cause confusion as well as non-alignment in finance information.

In conclusion, SAA itself is struggling to keep head above water and is constantly on the edge of bankruptcy. The company has become solely dependent on government subsidies as the company structure is continuously creating financial dilemmas. By improving the processes in OPF and creating a system which reduces procurement cost, the whole of SAA will be able to feel the relieved pressure on the financial system.

1.3 PROJECT AIM AND SCOPE

The project goal is to improve the current tyre procurement department in terms of efficiency and effectiveness by means of cost reduction and the implementation of a system that increases visibility in the department. The problem solution is required to integrate an electronic system to replace the manual processes of OPF. Furthermore the solution should assist the OPF manager in tyre procurement and management by means of reducing cost and setting up a planning horizon in terms of procurement.

The project aims to develop and implement an inventory ordering policy model for OPF. The implemented model will attempt to reduce the overall cost of OPF by determining when and how much product to source from the desired suppliers. This solution will also reduce the uncertain environment at OPF and improve the overall management of tyre procurement. Metrics to be considered in the problem solving process include cost, process visibility, procurement policy, model responsiveness and model reliability.

The following objectives need to be met to achieve the goal of the project:

a. in depth research on previous and current implemented ordering policy models,
b. problem and data analysis,
c. develop and test a derived ordering policy model,
d. simulate the OPF system with the new ordering policy,
e. analyse and interpret the simulation and model results,
f. implement the model in the form of a database and software program.

The ordering policy model is developed on previously researched models and contributes to the current research base. This model is extensively tested and validated both mathematically as well as with simulation modelling techniques. Furthermore the model will be implemented at OPF in the form of a database and a simple software program. It is important to understand OPF and the processes used to formulate a suitable solution. Thus it will be necessary to have a complete understanding of the department before formulating the ordering policy model to ensure that the correct information is addressed in the model.

The project scope only includes the OPF at the OR Tambo International Airport branch and will not include the fleet management of SAA in Durban, Cape Town and Lanseria.

1.4 PROJECT APPROACH AND DELIVERABLES

1.4.1 LITERATURE STUDY

The literature study contains research on various ordering policy models currently used and developed by industry. The study addresses the most appropriate models that relate to the project environment and the constraints inherent to the OPF system. The research is the basis for the development of a solution model. Simulation modelling as well as information system design is investigated to determine the most appropriate model testing, validation and implementation techniques.

1.4.2 PROBLEM ANALYSIS

The problem analysis phase is a continuous process from the very beginning of the project up to the Design phase. Key milestones in this phase include a clear and definite problem statement, an As-Is situation simulation model with results and interpretation of the current system results, various constraints in the system and the project environment, analysis of the necessary metrics to assess and final technique and tool selection.

1.4.3 INFORMATION MANAGEMENT

Deliverables in the Information Management phase include the gathering of relevant and usable data and information from OPF, analysis of information using appropriate techniques and tools, finding trends and consistencies in the information and interpreting the information and trends.

1.4.4 SOLUTION DESIGN

The first step in designing an appropriate inventory ordering policy model is to determine the constraints and the critical factors that need to be addressed in the model. To recognize the performance metrics of the company is of the utmost importance to develop a suitable and valid model. Following this step is the development of decision variables and objective functions to understand what the model will analyse and what it should achieve. Only after these issues have been addressed can the model be developed and created. Model development will be done with Operations Research techniques and various statistical methods. At this stage dynamic programming seems to be a probable approach. Finally the phase concludes with an in depth validation of the model created.

1.4.5 SIMULATION AND TESTING

To test the practical relevance of the mathematical model, a simulation model was created to test the model against real life situations. Verification and validation of the simulation model is of the utmost importance and various experiments were run to ensure the model reacts in accordance with practical results. Finally the simulation results are interpreted and any inconsistencies re-evaluated and tested.

1.4.6 IMPLEMENT SOLUTION

The project concludes with the implementation of the solution model at OPF. This is with the creation of a database for managing all the fleet vehicles and any relevant transactions. The mathematical model will also be a user-friendly design of a simple computer program that can be linked to the database to determine when, where and how much product should be procured.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

The literature review focuses on different aspects of inventory management. First, inventory control is investigated and includes research on a number of widely used inventory control policies and the reason for its use. Derivatives on general ordering policies are discussed as these models incorporate a broader spectrum of variables and assumptions. The importance and use of simulation modelling in inventory management and investigation is discussed and evaluated along with the need for information systems in effective and efficient management of supply chains. Various methods and tools are considered and by means of comparative analysis the most suitable solutions are chosen to address the project aim.

2.2 INVENTORY CONTROL AND ORDER POLICIES

Inventory control is a critical part of supply chain management. Extensive research has been conducted regarding inventory systems and policies and a wide range of models have been developed to address the different problems and situations faced by supply chain managers. This section focuses on various inventory ordering policies that are currently in use and have been researched over time.

Inventory order policy is described by BusinessDictionary.com as "rules to when an inventory replenishment order is to be issued, such as when the stock falls to a certain level or to zero." According to Holton (2005) ordering policies determine the frequency for delivery orders of an organization. The policy has major influences on the inventory carrying level and the number of transactions an organization should support (Holton, 2005).

Inventory represents between 45% and 90% of all business expenses (Connecticut Licensing Info Center, 2009). Inventory is important to ensure companies have the correct product on hand to avoid backlogs as well as lost-sales, to provide proper accounting of inventory and to prevent spoilage or theft. Furthermore, inventory control involves the care, disposition and procurement of materials since different companies carry different types of inventory. The focus of this literature review is on finished goods purchased inventory. Connecticut Licensing Info Center (2009) explains the three major inventory control approaches that are used in any type of organization. The chosen system will ultimately depend on the operation type and the level of product stored.

The Eyeball System is used by the majority of small businesses and involves the key manager to visually conduct an inventory inspection. If any goods seem to be out of stock, an order is placed. This type of system is unreliable since a stock-out incurs great amounts of shortage cost. The Reverse Stock system gives a more systematic approach to inventory control. This system involves keeping safety stock to reduce stock-outs. When the safety stock level is reached, a new order is placed. Well-designed reverse stock systems ensure that the new order arrives just as the last of the remaining stock is used. The Perpetual Inventory System can consist out of manual, card-orientated or computer-operated systems. This approach uses an automatically triggered order that is generated by a programmed instruction once the inventory level drops below a predetermined amount. The aim of the perpetual inventory approach is to tally the currency as well as the unit use of various products. The data generated by this approach is necessary to reduce stock-outs and to maintain constant sale evaluations (Connecticut Licensing Info Center, 2009).

2.3 GENERAL ORDER POLICY CLASSIFICATION

Inventory models in its most basic form are classified into probabilistic and deterministic models. Probabilistic models include situations where some or all of the decision variables are uncertain, however they can be modelled with statistical distributions. Deterministic models have known parameters that do not change according to a known distribution and include systems which normally have fixed variables. According to (Bijvank, 2009), it is reasonable to assume a deterministic model when the future period demand can be forecasted with considerable accuracy.

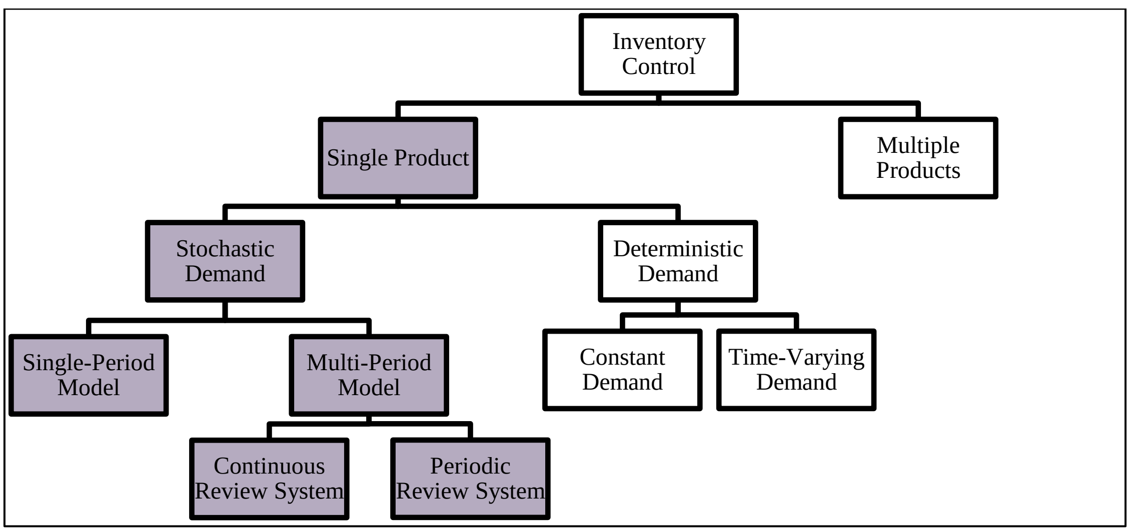

FIGURE 1: CLASSIFICATION OF INVENTORY SYSTEMS

Furthermore, systems can be classified as single- or multi-period models and will be explained in sections 2.3.1 and 2.3.2. The literature contains research on various inventory policy model approaches under the previously explained situations. These approaches include variables regarding the number of products modelled, lead times, demand classes, demand distribution types as well as the number of customers and suppliers in the system. This paper will only consider probabilistic inventory policy models and focus on systems with uncertain demand or price.

2.3.1 SINGLE PERIOD MODELS

When products with limited selling periods are considered, no decisions are to be made regarding the time an order needs to be placed, however only the order size needs to be determined. These models are termed single-period models and are only useful for a single time period (Bijvank, 2009).

Single period inventory models are useful in identifying the order size given a perishable product or a single opportunity to buy product. The single order size is determined by balancing the cost of over- and under-compensating demand. These models are very useful in areas such as overbooking airline seats, ordering fashion items (seasonable demand) and all one-time order systems (Chase et al, 2011). In these problems a decision maker determines the quantity to be ordered and the value of the product. The basic equations used in these models include a quantity and value variable describing the product being purchased as well as a cost function (Winston, 2004). When the cost function is to be minimized the optimal solution becomes:

$$E(q) = \sum_{d} p(d)c(d,q) \quad (1)$$

Where $p(d) = Probability\ of\ a\ discrete\ random\ variable\ being\ equal\ to\ the\ value\ of\ a\ product$

$p(d) = P(\boldsymbol{D} = d)$

$E(q) = Expected\ cost\ if\ q\ is\ chosen$

$q = quantity\ variable$

$d = value\ of\ product\ assumed\ by$

$\boldsymbol{D} = integer - valued\ discrete\ random\ variable$

$c(d,q) = cost\ function\ dependent\ on\ q\ and\ d$

An example of a single period model is given by Peijun (2010) where an inventory problem is analysed with uncertain demand characterized with a probability distribution. The problem is based on one time decisions of a product with a short life cycle and the factor of regret. These decisions determine the state and nature of the demand that should be considered for each order quantity.

The classic newsvendor problem is a good example of a single period decision model. The newsvendor problem uses continuous demand that can be either deterministic or probabilistic. The newsvendor problem has a fixed sequence of events that need to occur to be classified as this type of model. The sequence involves deciding on the order size and knowing with what probability the demand of units occur. The cost of over- and under stocking is of the utmost importance in this problem (Winston, 2004). The main drawback of the newsvendor problem is the lack of modelling setup costs, this can be critical in determining the optimal solution.

2.3.2 MULTI-PERIOD MODELS

Chase et al (2011) explains that multi-period models are designed with the objective to ensure that product is available on an on-going basis throughout a certain time period. Thus inventory control is conducted more than once to ensure products are always available. Two types of multi-period inventory models exist, namely periodic review models and continuous review models.

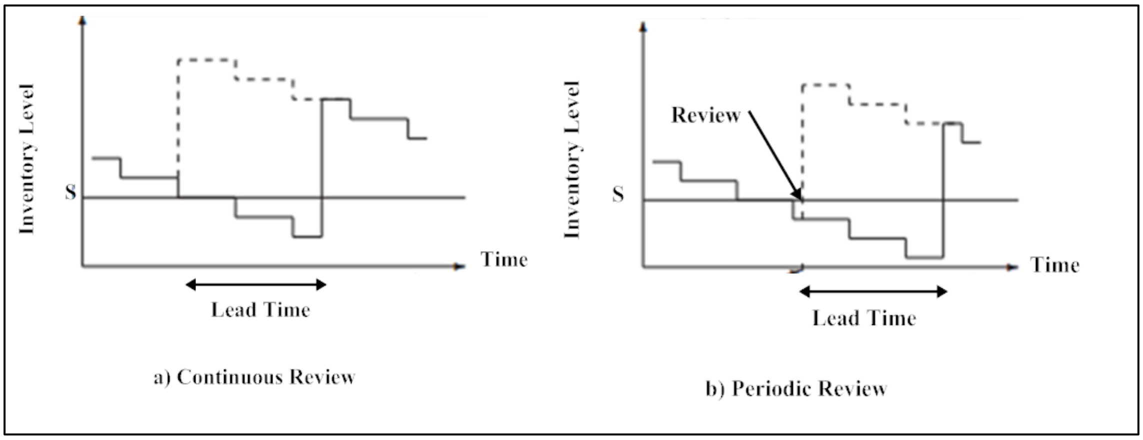

FIGURE 2: THE ON-HAND INVENTORY LEVEL (SOLID LINE) AND INVENTORY POSITION (DASHED LINE) FOR THE REPLENISHMENT POLICIES WHIT A FIXED ORDER SIZE UNDER (1) CONTINUOUS AND (2) PERIODIC REVIEW CONDITIONS (BOJVINK, 2009).

PERIODIC REVIEW MODEL

Periodic review models focus on reviewing the current inventory level at certain time periods. If the on-hand inventory is too low, the required quantity of product is ordered to bring the stock level up to a predetermined level. A widely used periodic review policy is the (R, S) policy as explained by Winston (2004). This approach uses the concept of on-order inventory levels that is explained as the sum of on-hand inventory and inventory that is on order. The (R, S) model is described as follows: every R units of time the on-hand level of inventory is reviewed and an order is placed to bring the stock up to a predetermined level S. (R, S) policies incur higher holding costs than a cost-minimizing continuous review model such as the (r, Q) policy, however this method is more easily administered and the order placement times can be predicted with certainty.

The calculations for the basic (R, S) model are not given in this review, only the value of S that will minimize the expected holding and shortage cost is given as follows:

$$P(\boldsymbol{D_{L+R}} \geq S) = \frac{Rh}{Rh + c_{LS}} \tag{2}$$

Where $R = time\ between\ reviews$

$\boldsymbol{D_{L+R}} = demand\ during\ a\ time\ interval\ of\ length\ L + R$

$L = lead\ time\ for\ every\ order$

$h = cost\ of\ holding\ one\ item\ in\ inventory\ for\ one\ year$

$c_{LS} = cost\ incurred\ for\ every\ lost\ sale$

A model that has uncertain demand and lead time that uses the periodic review system is the model described by Jin-Song and Hui (2009) which follows the models developed by Quyang et al (2001) which incorporates mixed inventory models with fluctuating demand. This model uses minimum and maximum demand levels to disregard the use of demand distributions in a fuzzy environment. Another example of a periodic review model was developed by Frank et al (1991) where different demand classes are used with demands being either certain or unknown. The demands are classified as deterministic as well as stochastic and needs to be fully satisfied (Frank et al, 1991).

CONTINUOUS REVIEW POLICIES

Continuous review policy models involve systems where every item is tracked and the inventory is updated when an item is used or removed. Well known continuous review policy models include the (r, Q) and (s, S) models derived from the basic EOQ model first developed by Harris (1913). This basic model was developed with deterministic demand and will not be considered in this study. The improved version considers a system with non-zero lead time and random demand that can be backlogged. The (r, Q) policy involves quantity Q to be ordered as soon as the inventory level reaches a low of r. This policy is also known as a two-bin policy. The (s, S) policy places an order when the inventory level drops below the aggregate level s. The order size will be sufficient to raise the inventory level to S when zero lead time is assumed. The order size is thus not fixed and is dependent on the value of inventory once the order is placed. Advantages of continuous review policies are the real-time updates of inventory levels that are permitted. This makes it easier to determine when products are to be replenished. However a disadvantage arises due to the cost of implementation such as bar-coding software and computer systems.

2.4 DERIVATIVES OF BASIC MODELS

2.4.1 MODELS ALLOWING BACKORDERS

According to (Bijvank, 2009), inventory models that allow backorders have received most of the attention regarding inventory literature. The main reason for this is that order-up-to policies have proven optimal results for backorder models using periodic reviews (Scarf, 1960). The main indicator of inventory status in a backorder model is the inventory position. This position is increased with the placement of orders and decreased when a demand for product occurs.

Continuous review models for the backorder problem have not been researched fully and not much is known about the optimal policies regarding these models (Bijvank, 2009). It is concluded that most of the research done on continuous backorder models has been performed on the (s, Q) ordering policy. Here the model was improved to include different demand and lead times but it is found that the optimal value of s and Q is still difficult to find. Near optimal reorder points have been found by using several approximation procedures (not covered in this study). Bijvank (2009) suggests that future research should be conducted on the investigation of optimal replenishment policies since there are hardly any comparisons between the periodic- and continuous review models with backorders.

Although little is known about continuous review models with backorders, periodic review models have well known optimal results. Most of the models which include backorders in this setting assume to have no fixed order cost and the consequence is that orders are placed periodically to minimize the inventory holding and shortage cost (Bijvank, 2009). The result of this is that orders are placed more regularly than in a fixed order cost system. These models also assume that lead time is an integral multiple of the review period, which is not common in practical systems. Models with fixed order cost are hard to come by and little research has been done regarding these systems.

Another model that regards backorders is developed from the basic EOQ model. This model uses the normal EOQ formulae for a case of uncertain demand, but calculates a new reorder point and order quantity to satisfy all demand eventually (Winston, 2004). Fixed purchase costs are incurred and the average number of backorders is assumed to be small in comparison to the on-hand inventory level. This assumption is deemed reasonable as shortages normally make out a small percentage of production or sales.

The solution for this EOQ model is as follows:

$$Q = \left(\frac{2KE(\boldsymbol{D})}{h}\right)^{0.5} \quad (3)$$

$$P(\boldsymbol{X} \geq r) = \frac{hQ}{c_B E(\boldsymbol{D})} \quad (4)$$

Where $Q = Economic\ Order\ Quantity$

$r = Reorder\ Point$

$\boldsymbol{D} = Random\ variable\ for\ annual\ demand\ where\ E(D) is\ the\ mean$

$c_B = shortage\ cost\ incurred\ per\ unit$

$h = holding\ cost\ per\ unit\ per\ year$

$K = cost\ to\ place\ an\ order$

$\boldsymbol{X} = Demand\ during\ lead\ time$

Kumaran et al (2009) developed a model that considers a continuous and periodic review approach of which a proportion of the demand is backordered. The remaining demand is lost during the period where the stock-out occurs and is considered under a fuzzy environment. The fuzziness is introduced by imprecise cost components that are vague to a certain extent. The article by Bazaraa et al (1973) considers both deterministic and stochastic demand classes where several single supplier systems are evaluated. These models consider situations where a fraction of the demand is backordered and the other fraction is lost as also explained by Kumaran et al (2009). For each of the cases a mathematical model that represents the average annual operating cost is explained. Pan and Hsiao (2001) developed a model with negotiable back-orders as well as a model with variable lead time.

2.4.2 SINGLE PRODUCT MODELS

Single product models put emphasis on inventory systems where only one product is sourced or produced as suggested by Tang and Wang (2007), where the model is based on Hybrid Intelligent Algorithm (HIA) credibility theory for the determination of pricing and inventory decisions for a single product. The uncertainty of this environment includes the market demand, unit price, salvage value and shortage cost. Another example is the optimal stock allocation model created by Francis et al (2002) for a capacitated supply system.

The research involves one product that is demanded by several customers where the allocation of stock is a key decision variable that arises from different backorder costs for all customer types. The basis of the model indicates that ignoring inventory allocation can have a negative effect on efficient inventory management. Federgruen and Heching (1991) takes a single item periodic review model and tries to determine the pricing and replenishment strategies simultaneously in a system with uncertain demand. The demand for each period is independent; however the distributions are dependent on the product price according to universal stochastic demand functions. Stock-outs are backlogged for both finite and infinite horizon periods and aims to maximize the total discounted profit. Furthermore Flynn and Garstka (1990) consider a periodic review model in a stationary environment with stochastic demand. In this model orders can be scheduled for any set period, however the inventory levels are determined every T periods through an audit. Another contemplation for a single product model considers deterministic demands and was developed by Golabi (1985). The product price is distributed by a known function and a decision must be made regarding the amount of product that must be ordered in each period. The model aims to minimize the total cost while still satisfying all of the demand.

Fabian et al (1958) developed a model that considers the fluctuation in market price to determine when and how much raw material to purchase. A dynamic programming model is created with the assumption that the current price, on-hand inventory and inventory costs are available at present. The fluctuating demand and price are estimated by normal distributions. The model was tested on a real life case study to ensure its feasibility. The analytical model presents a great difficulty to solve and thus the authors include a surrogate model that combines the original analytical model with simple decision rules for the evaluation of the problem.

2.4.3 MULTIPLE-SUPPLIER MODELS

In the following models, the decision maker sources from a number of suppliers (identical or different). Minner (2002) gives a review on multiple-supplier inventory models in managing supply chains. Two cases are explained where deterministic lead times are considered. The first case uses a periodic review to determine the policy for inventory management. This is an optimal replenishment policy with multiple suppliers, different lead times and purchase prices. In general this is a very complex model and can be simplified by using no more than two suppliers and excluding setup costs. Due to the complexity, the calculations for this model are excluded. The second case uses continuous review policies and is a $(S1, S2, Q1, Q2)$ policy. This model is used in environments with negligible or zero setup costs. Fluctuating demand that is Poisson distributed is used and a one-for-one ordering policy will be appropriate for two supply mode extensions. Stochastic lead times are used with multiple suppliers with random lead times as the model aims to reduce the effective lead times of orders.

Another model explained by Minner (2002) is based on a continuous review policy derived from the basic (s, S) model. This model determines the optimal reorder point and number of suppliers needed. This is a multi-stage inventory model also referred to as multi-echelon inventory systems (explained below) where multiple suppliers and retailers co-exist. Lastly Minner (2002) focuses on reverse logistics models that have become popular due to increased competitiveness and environmental consciousness of customers and suppliers. Reverse logistics describes the return, maintenance and reverse flow of products in a supply chain. This is a relatively new concept and few models address this problem in their computations. These models share various features with multiple supplier models in the way that a product return relates to a second mode of supply

Next, systems with two modes of supply are considered such as the ones developed by Moinzadeh and Nahmias (1988) where continuous reviews approach of a single product is considered. The system models a single product with different order types where lead time, holding-, stock-out- and ordering costs are built into the model. The demand can be both discrete and continuous and reordering takes place due to on-hand inventory. In general this is a modification of the basic (r, Q) ordering policy but with two supplier options. Another multi-period model with two suppliers was developed by Bagchi and Sudararaghavan (2013) where a global and local supplier is involved. The objective here was to minimize the upper cost limit with known variance and mean but with uncertain distribution. In an inventory system with emergency orders as explained by Moinzadeh and Schmidt (1991) the buyer sources from two different suppliers where one has a shorter lead time than the other. The demand and fixed ordering costs are low in relation to the high inventory holding costs. This model uses a one-for-one ordering policy and uses information on the age of outstanding orders to calculate the optimal levels. The demand is variable and Poisson distributed. This model can be viewed as an $(S - 1, S)$ inventory model.

Arda, Y. and Hennet, J. (2006) analyses an enterprise network from the perspective of a manufacturer that receives customer orders. The aim is to minimize the sum of the average holding- and stock out cost. The manufacturer has several supplier options with random lead times and the demand for product is also uncertain. The basis of the model is a queuing network with a base-stock inventory policy used by the manufacturer. The important economic value of ordering from different suppliers when considering random demand and shortage cost is shown through numerical applications.

A development on the previous models can be found in Glock (2011) where the number of suppliers is increased. This model considers a single buyer with any number of heterogeneous suppliers. Decision variables include supplier selection and order size with an objective to minimize the sourcing costs. The solution to the problem is done in two stages with the result showing a reduced number of supplier combinations after tested for optimality. The model can also help to determine the total cost of alternative sourcing agreements as well as provide assistance in finding a situation where a product can be distributed and produced at the lowest total cost. Hum et al (2005) Uses several vendors to source material and aims to minimize the average inventory levels. This model relates to the classical staggering problem. The model is derived from a model later revisited by Boctor et al (2012) where inventory replenishment of multiple items are supplied by external vendors but the demand stays constant. These multiple items share a limited storage space and resources. Ordering and inventory holding costs are considered and assumed to be known and constant. The idea is to determine the time length of fundamental cycles and item replenishment periods while also minimizing the storage space and resource requirements.

Newsvendor problems are also improved to solve the problem of multi-supplier systems as stated by Dada et al (2003). The uncertainty regarding this model is the unreliability of the suppliers. The decision functions include decisions regarding whether or not an order is placed with a supplier and how much to order from each supplier. This model considers the trade-off between cost and reliability of a supply chain and the impact thereof on customer service levels.

Lastly multi-echelon systems are considered. Ganeshan (1999) describes a model where the optimal inventory policy for this type of system is determined. Previous research regarding multi-echelon systems has various shortcomings and this model tries to address these shortcomings. The main advantage of this model is that it relaxes the restrictions associated with demand and lead time distributions. Assumptions include constant unit price of a single product being evaluated. This model uses a distribution system with one central warehouse and various identical suppliers and the demand is given as stochastic and Poisson distributed. This model is a variation of the classical (s, Q) inventory policy with multiple suppliers.

2.4.4 FUTURE RESEARCH AREAS

Although inventory models have been researched extensively there are still dark spots and unknown territory to explore. Silver (2008) published an article where he summarizes what research is outstanding to fill the gap between inventory theory and practice. His paper suggests a variety of research and techniques to be of help to breach this gap.

Firstly Silver (2008) suggests that more attention should be devoted to the formulation of accurate models and solutions instead of focusing on optimal solutions for interesting mathematical problems which may be concluded as unrealistic. To accomplish this, more attention should be given to heuristic methods. Thus far steady state conditions are the focus of inventory models since these approaches are more analytically traceable however the shortening of product lifespans have made these models less relevant. Silver (2008) thus encourages researchers to focus more on transient systems. Improvements in decision consistency are also needed and Silver (2008) suggests that diagnostic tools can be helpful in this regard as stated by Saipe (1979). It is important to consider the effects of aggregate consequences rather than the performance of individual products as companies want to see results overall and not on a small scale. Grossman (1991) points out that there exists a need for more easily understood procedures and implementation aids to support companies in the implementation and understanding of inventory processes. Models that show beneficial results should be researched and improved further to discover better and more user friendly practices.

Silver (1981 and 2008) introduces various research gaps:

a. Statistical Assumptions in Inventory Management.
   Most inventory models assume particular demand distributions, that the distribution parameters are known and that the system is stationary. These assumptions can sometimes be incorrectly derived and can have significant effects on the model accuracy.
b. Intermittent Demand.
   A great amount of models assume relatively smooth demand patterns. These assumptions can be inaccurate when dealing with erratic demand patterns. When intermittent demands are faced, managers tend to increase safety stock but without appropriate research and calculation. Having appropriate means of determining control parameter values would be useful.

c. Coordinated Control under Probabilistic Demand

Controlling item groups can be advantageous to achieve discounts and setup cost. The models that include these types of parameters are difficult to use and formulate and thus simpler methods are needed.

d. Coordination Decisions

Product line depth, vendor selection, transportation options and price all have significant effects on inventory control and the current literature addresses these parameters only meekly. Other areas that need to be addressed include contracts, incentives and multiple stocking points.

e. Impact of e-business opportunities.

f. Dynamic realistic representation of commonality impact of components.

g. Postponement opportunities.

2.5 SIMULATION MODELLING IN INVENTORY CONTROL

2.5.1 SIMULATION MODELLING BACKGROUND AND OVERVIEW

Maria (1997) describes the simulation of a system as the operation of a model of the system that can be reconfigured and experimented with. The main reason to use simulation modelling is to reduce the cost associated with impractical implementation in the real system. In simulation, the system can be studied and properties of the actual system can be inferred. The use of simulation is to alter a system or test a new system and reduce the chance of failure before the system is implemented. Simulations are very useful to determine where the problem lies in an actual system or to determine the best design of a proposed system.

There are various different software packages available for use in simulation modelling. Some of these packages are extremely expensive however they provide more features than free and inexpensive software. The question is what the software will be applied to and the complexity of the problem to be solved. Two main simulation package types are those that include simulation languages or application-oriented simulation. Simulation languages offer more flexibility but require a lot more skill and training, whereas application-based software is less flexible but offers an easy to use user platform. Table 1 gives an overview of the different software on the market.

Simulation Languages	**Application- Oriented**
Arena	COMMET 111
AweSim	SIMIO
SimTalk	FACTOR
SLX	QUEST
Simscript	SIMPROCESS
Micro Saint	
Any Logic	

TABLE 1: SIMULATION SOFTWARE

In operations research, simulation modelling is one of the most frequently used techniques for problem solving (Maria, 1997). Benefits of simulation modelling include:

a. Observing the behaviour of the system over long time periods.
b. Test the feasibility of hypotheses regarding the system.
c. Study the effects of policies in a company.
d. Use experiments with unknown situations.
e. Identify parameters that are the driving force of performance.
f. Identify and eliminate bottlenecks.
g. Analyse different system configurations.

2.5.2 SIMULATION MODEL RESEARCH

Andric et al. (2005) states in an article that modern inventory management approaches make use of mathematical models and informational systems. This paper models an inventory control process by using coloured petri nets. The model was created with MS Excel and the results show a significant improvement in the system. A study by Gbolagade, et al (2012) is based on the role of simulation modelling for conducting scientific experiments on inventory control. The programming language used in this model was Turbo Pascal due to its capability and flexibility. The paper concludes that simulation modelling should be considered as an important tool in industry since it promotes automation and problem solution without the uncertainty of implementing without knowledge. It further suggests that stock control should be implemented and used by all companies to minimize operating costs as inventory control ensures efficient and effective asset utilization.

A manual by the National Research University (2011) aims at studying the effect of inventory management on the overall supply chain networks by using simulation modelling. This model is derived from the well-known "distribution game" which simulates the work of a supply chain. This new model uses an object-orientated approach to design a model to correspond with the decomposition of a supply chain structure. The model was developed with the use of AnyLogic, a powerful and up and coming simulation modelling software which uses Java programming language. An article by Drake and Marley (2010) states that inventory management is a critical area in operations management. This article demonstrates the use of a model created with Crystal Ball to indicate how a periodic review system can reduce the number of stock-outs in a system. "Simulation models enable a priori managing and analysing variety of possible results and implication of selected inventory policies," (Marcikic and Radovanov, 2006). The model presented makes use of Monte Carlo simulation to integrate dynamic quantitative analysis and theoretical, qualitative inventory concepts. Monte Carlo simulations are interested in what-if scenarios and thus various alternatives can be modelled with this technique.

Pope (1981) describes in an article that the sole purpose of simulation is to apply theories and techniques from various study fields in order to isolate decision making. The model created here is the Inventory Management Simulation (IMS) model, designed to alleviate the problem of decision making. The software is of an interactive nature and is easy to use. IMS is effectively a student learning software and can be used by managers to make simple inventory decisions. A Monte Carlo simulation created by Zabawa and Mielczarek (2007) describes the model of supply chain and the implementation using general purpose tools and simulation packages. MS Excel is used to store the necessary formulas and extended software was used to calculate parameters to minimize the inventory cost.

Lastly Kopytov and Muravjovs (2011) describe a two-level single-product inventory control system model for the controlling of wholesales in a warehouse. ExtendSim 8 was used to create the simulation model. The study resulted in the following suggestions as why to use simulation modelling:

a. It provides clarity of results,
b. it gives the possibility of finding the optimum solution of an inventory problem when the calculations of an analytical model are difficult,
c. it gives the user the ability to control necessary parameters and
d. the models can be used to examine stock dynamics.

2.6 SYSTEMS DESIGN IN INVENTORY CONTROL

2.6.1 INTRODUCTION AND BACKGROUND

Inventory management information systems are databases used for administering and storing the information required for efficient inventory product management. There are many inventory management systems currently available such as enterprise resource planning (ERP) and material resource planning (MRP) systems. Possibly the most well-known ERP system on the market is SAP. However this system takes years to implement and is very expensive.

Furthermore information systems can be seen as an integrated set of components responsible for the collection, storage and processing of data. This data is further translated into the information, knowledge and finally usable digital product (Britannica, 2013). Information systems are relied on for operation management as well as interaction with customers and suppliers. Currently for organizations to be competitive in the workplace, it is vital for a business to incorporate an all-inclusive information system to reach potential customers, process financial accounts and manage human resources.

2.6.2 IMPORTANCE OF INFORMATION SYSTEMS IN INVENTORY MANAGEMENT

According to (Information Systems Within Organizations, 2007), information systems can facilitate inventory policies, management and control. Information systems for inventory management usage are able to track product into, out of and between inventories, creating high visibility in a system. In the case of bar codes, product numbers allow management to track product movement through an inventory information system. Another advantage of inventory information systems is the easy calculation of stock and re-order levels as well as re-order quantities in accordance to past information.

Information systems become essential when management encounters that the same information is used in multiple areas and the manual handling of this information becomes redundant. This also includes that changes in one area of information requires the same changes to occur in various other areas. Information systems are also necessary in situations where a large amount of data is used and becomes unmanageable. In the case where information needs to be tracked and assessed throughout an organization, information systems become essential for successful handling and maintaining inventory. When information needs to be available instantly and without effort, information systems are required.

2.6.3 ADVANTAGES AND DISADVANTAGES OF INFORMATION SYSTEM USAGE

Information management systems have a number of advantages over conventional systems. It is important to weigh advantages and disadvantages of the implementation of an information system in an organization before a decision is made, as advantages may transform into a disadvantage if implemented and incorporated incorrectly. Sqa.org.za (2013) translated system features into the following advantages:

a. Reduce information redundancy.
b. Increase information consistency as well as reduce the number of data errors.
c. Greater application information integrity and independence.
d. Improved overall information security.
e. Improved user access through query languages.
f. Reduced data multiplication, storage and retrieval costs.

In contrast to the advantages, information systems may also have a number of limitations:

a. Development and design of information systems are complex, difficult and time-consuming.
b. High initial capital costs can be incurred.
c. Damage and problems of an information system affects virtually the system as a whole and no application goes unscathed.
d. Information systems require training of users as well as programmers.
e. The conversion from a manual file to a database may incur high conversion costs and will be time consuming.

2.6.4 DATABASE CATEGORIES

Information systems can be divided into different categories, this review will evaluate desktop, server as well as web-enabled databases (Chapple, 2013).

Desktop databases are relatively inexpensive and are used primarily in businesses changing from a manual system to a relatively easily implemented information system. These systems hardly require any programming skills and have interactive user-friendly interfaces. Desktop databases allow development and design to be done by the user and do not require the expertise of an outside consultation company.

Server databases accommodate situations where heavy-duty systems are required. The database software is generally expensive and requires capital for development and integration procedures. Server based information systems require design and development to be done by specialized companies or individuals, as the whole process is completed through extensive data programming.

Lastly, web-enabled databases enable the user to have access to web interaction. Both desktop and server databases can be implemented to enable internet interaction and use. Companies can ensure immediate connection and integration with other companies or branch through an internet connection. This type of database eliminates the use of a server; however this may reduce the credibility and security across the system.

2.6.5 MICROSOFT ACCESS AS AN INFORMATION SYSTEM

The most widely used desktop database available on the market is MS Access. This software is readily available and comes included with a Microsoft Office Professional license. MS Access is a flexible database development software and is user-friendly with easy to use interfaces. About.com describes MS Access as a powerful database engine that is integrateable with other MS Office software. MS Access uses intuitive Graphical User Interface (GUI) and is the industry standard to information system design. MS Access offers online training and a good support system for users. A special feature to the product is the voice recognition technology that allows the user to input information by spoken commands.

A great advantage to MS Access is that it can integrate with SQL based database software and be used as a front end to the software. MS Access offers many advantages when purchased as part of a MS Office package. The software integrates with other MS Office packages such as MS Excel to simplify and facilitate data transfers and spread sheet connectivity.

2.7 CONCLUDING REMARKS

Various model types have been considered and developed over the past years. All areas of inventory control have been addressed however none of the discussed models include situations that resemble the situation at SAA. The various components regarding backlogging, multiple-suppliers and uncertain demand and price are all addressed individually with no comprehensive all inclusive models.

This review discusses inventory modelling and reflects on the literature gaps and future research topics. Only probabilistic models are considered with a clear distinction between single- and multi-period review policies. Emphasis is placed on models that concern only one product, models with backorders and multi-supplier systems. These models are discussed and reviewed and the shortcomings are highlighted.

The review looks at simulation modelling as a tool for inventory management and finds that simulation modelling is useful in analysing and testing systems that have yet to be implemented, at a lower cost. By using simulation models, various parameters can be changed to evaluate the changes in the system. Various advantages are also discussed.

Lastly, information system design in inventory management is evaluated. It is found that information systems have various advantages over manual filing systems and the different software categories are highlighted. It should also be noted that when implemented incorrectly, an information system can cause more harm than good.

It is clear that there are numerous gaps and shortcomings when inventory modelling is concerned and further research needs to be done to optimize inventory replenishment in the future.

2.8 TECHNIQUE SELECTION

All of the information from the review was used in the selection of appropriate Industrial Engineering techniques. For the final solution an inventory model was derived from one of the researched mathematical models that has the most suitable correlation to the data from SAA. The mathematical model is a periodic review model since this is easily implemented and can be used as an alternative to the monthly inspections. The model incorporates operations research through dynamic programming. Business process analysis and various logistic calculations were incorporated in the data analysis phase and puts into perspective the performance metrics and problem areas the project focuses on.

Various Operations Management tools are used to evaluate the data and to decide on the most appropriate method to implement the solution. Business process analysis and various logistic calculations were incorporated in the data analysis phase and puts into perspective the performance metrics and problem areas the project focuses on. Plant Simulation is a powerful simulation software program that uses SimTalk as simulation language and is used for simulation modelling operations. This software provides the user with the freedom of using the simulation language simultaneously with the application-oriented side of the program, thus allowing the user to create an extensive model that will incorporate all the necessary systems and parameters accurately.

Information system design is used to develop a database to eliminate the manual processes. Section 8.2.4 compares the different database software readily available and Chapter 8 discusses the design and development of a system that will be implemented at OPF. MS Access is ultimately chosen as the most appropriate software to be used for the development of an information system for OPF. The information system aims to increase visibility and efficiency in the department. To ensure solution and model credibility, a number of validation techniques were chosen and incorporated in the design and evaluation of the project solutions. A sensitivity analysis as well as a practical interpretation of the solution model are included in the project document and increases the validity of the solution. Figure 3 provides an outline to the method used to formulate a proper solution to the problems at OPF.

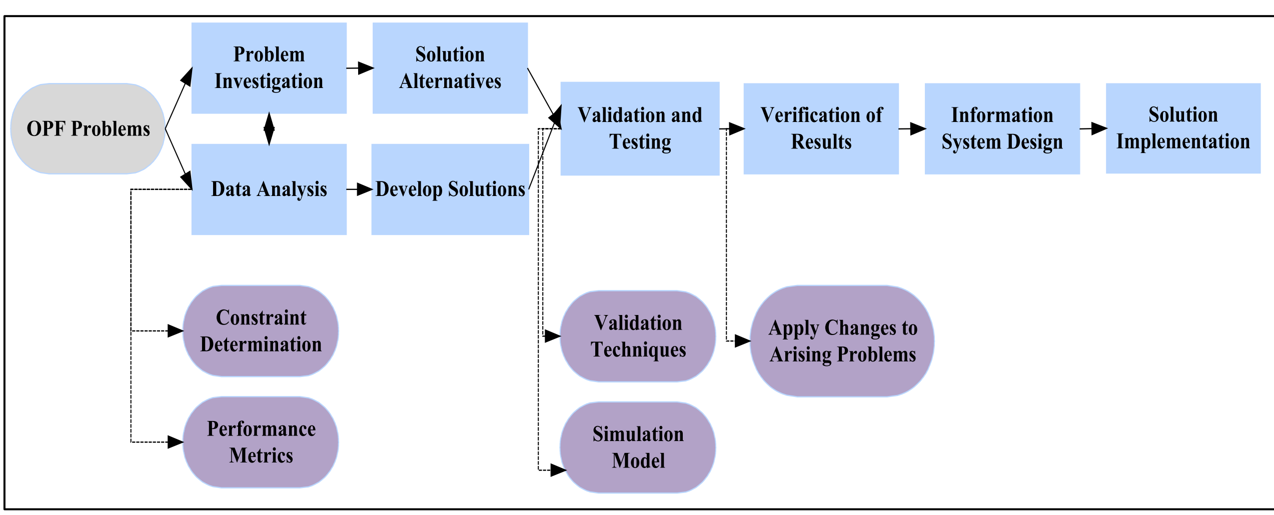

FIGURE 3: PROBLEM SOLVING METHODOLOGY

CHAPTER 3: DATA ANALYSIS

3.1 INTRODUCTION

Data analysis is an important tool to evaluate and investigate the current state of an organization. Efficient problem solving is impossible without proper knowledge of the inner workings and metrics of a company. This data analysis concentrates on the information OPF uses for the procurement of tyres.

3.1 INVENTORY ANALYSIS

3.1.1 PRODUCT TYPE

The product under consideration is tyres procured by the Operational Procurement and Fleet Department. Eleven vehicle types are considered which operate in changing environments under various circumstances. Many of the vehicles operate on rough surfaces with high wear that is harmful to the tyres and result in shorter and variable life times. Furthermore, these eleven vehicle types use thirty different tyre sizes. A summary of the vehicles and tyre types are given below in Table 2.

Vehicle Type	Quantity	Tyre Size	Average Tyre Life	Environment*
Toyota Avanza	35	185x65x14	2 sets per year	4
Toyota Quantum	12	195x14	2 sets per year	5
1.4 Polo Sedan	4	185x65x14	1 set per year	2
Toyota Conquest	12	165x13	1 set per year	3
½ Ton LDV	20	155x13	2 sets per year	4
1 ton LDV	40	195x14 & 195x15	2 sets per year	4
Other	200	Mixed	1 set every 2 years	2
Forklifts (1,5 ton , 3 ton, 12 ton)	80	65x10, 500x8, 815x15, 900x20, 1000x20, 1100x20	1 set every 2 years	3
Tugs	8	385x26, 1200x24, 1400x25, 1600x25	1 set per year	5
7 ton Truck	2	1000x20	2 sets per year	4
10 ton Truck	1	1100x20	3 sets per year	5

TABLE 2: VEHICLE SUMMARY

* The environmental factor indicates the surface the vehicles operate on. 5 = High wear and crude driving, 1 = Tar roads and normal driving conditions.

Normally Dunlop tyres are bought since these tyres have longer lifetimes and give better performance; however low-priced tyres are strongly considered due to the high wear and misuse of the tyres. The “Other” group refer to vehicles that are almost at the end of their life time or vehicles with low kilometres that are soon to be replaced to standardize to the other vehicle types.

3.1.2 INVENTORY TYPE

The tyres kept in inventory are classified as finished goods ordered on a made-to-stock basis. These tyres can also be classified as market pull product since inventory is kept to satisfy a demand and not to influence the demand. It is necessary in these circumstances to have a tried and tested ordering policy to ensure the company operates at its full potential while still considering the variability in demand, lead times and availability of product.

3.1.3 INVENTORY COST

INVENTORY HOLDING COST

According to (Coyle et al, 2008) holding cost consists out of the following areas:

a. Capital Cost
b. Storage Space Cost
c. Inventory Service Cost
d. Inventory Risk Cost

OPF has the following holding cost related to tyres. The holding cost only consists out of storage cost and cost not covered by insurance. The insurance cost of tyres is not paid by OPF and thus it is not included in the calculations.

Cost Element	**Quantity**	**Total in Rand**
Capital tied up in inventory	182 tyres currently in inventory	R198 920.00
Storage Space Cost	32m^2 @ R1350 / m^2	R43 000.00 / month
Storage Space Percentage of Holding Cost	Dependent on the amount in inventory	R43 000/R198 920 = 21% of purchase price per tyre per month
Insurance Percentage of Holding Cost	Insurance is paid for losses exceeding R5000 per tyre	(R56 143.54/12)/R198 920 = 2,3% per tyre per month

TABLE 3: HOLDING COST CALCULATIONS

ORDERING COST

The cost associated with placing an order only includes costs internal to SAA since there is no delivery or ordering cost demanded by the supplier. The ordering costs are summarized in Table 4.

Cost Element	**Person Involved**	**Quantity**	**Total in Rand**
Enquiry Cost		**RFQ, Paperwork and Phone Calls**	
	Purchasing Researcher	R22000 / 160h / month	1.5h / month = R206.25
Delivery Cost	None		
Order Preparation	Purchasing Researcher	R22000 / 160h / month	0.5h / month = R68.75
	Management	R30 000 / 160h / month	1h / month = R187.50
Stock Inspection	Administrative Officer	R18 000 / 160h / month	1h / month = R112.50
Payment Processing	Administrative Officer	R18 000 / 160h / month	1h / month = R112.50
	Management	R30 000 / 160h / month	1h / month = R187.50

Total Ordering Cost	R875.00 / month

TABLE 4: ORDERING COST CALCULATIONS

Data analysis show that on average OPF makes two orders a month. Thus the ordering cost per order becomes:

Number of Orders	27 orders in 15 months	2 orders / month
Cost per Order	R875 / 2 orders	R468.11 / order

TABLE 5: FINAL ORDER COST CALCULATION

The above cost per order has been validated against OPF's original purchasing data and has been proved to be correct. According to OPF managers, this information will be used as a basis to explain the reason of high cost incurred on monthly tyre purchases.

SHORTAGE COST

In the case of shortages, OPF does not have any cost associated with lost opportunities or lost sales since the tyres are used on their own fleet. OPF also explained that even though a vehicle cannot operate, a 100% service level is still met due to the amount of extra vehicles available. It was found however that when a stock out occurs, an emergency order is placed to replenish inventory. Thus shortage cost can be associated with the cost of making an emergency order.

When considering order costs, the cost to place an order was around R468 per order. This was based on an average of three products being enquired and ordered at one stage. When an emergency order occurs, there is no inspection cost associated and only one product is ordered; thus the shortage cost becomes:

$$Shortage\ Cost = \frac{cost\ per\ order\ with\ an\ average\ of\ three\ products}{three\ products} = \frac{R468 - R112.50}{3} = R118.5 \quad \mathbf{5}$$

3.2 PROCESS ANALYSIS

In order to evaluate the ordering process more clearly, a business process map was created for better visibility of what is happening at OPF. The business process map follows all the steps in tyre procurement currently used at OPF. Little of the process can be re-engineered since it is linked with different sectors of SAA, however by computerizing the process on the side of OPF the process as a whole can be improved. This improvement will reduce order cycle times due to better visibility and will eliminate the manual processes completely. OPF will thus be able to see the entire stock amount without any physical inspection and the system will automatically calculate the orders to be made. RFQ's will be able to be set up quickly and an overall better flow of information will be possible.

OPF is one of the few departments at SAA that is not integrated with the SAP system of SAA. The products procured by OPF are not listed as stock items on the SAA accounting system and thus there is no sufficient management of these products. When considering the procurement of tyres at OPF it is necessary to know the exact process that is followed and the logic behind it.

3.2.1 BUSINESS PROCESS MAP

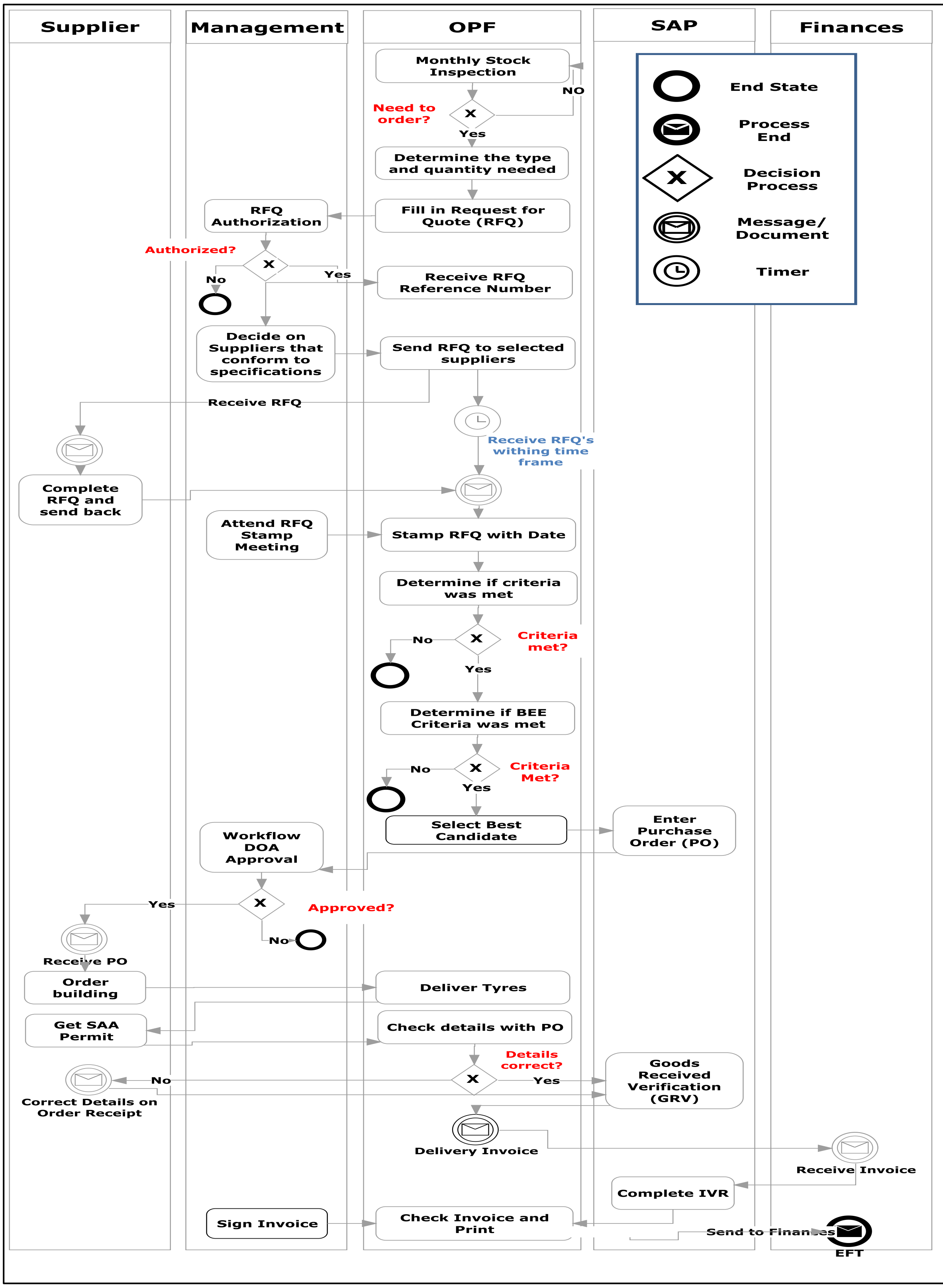

FIGURE 4: OPF TYRE PROCUREMENT PROCESS MAP

Meetings and interviews at OPF concluded that tyres are procured as a need occurs and relatively no ordering policies are adhered to. Products are procured on the basis of lowest price and B-BBEEE standards and lead times are relatively short in relation to the demand. All products are bought on credit which is paid within 30 days and quotations from three to seven suppliers are received each time an order needs to be made. OPF has limited storage area for the tyres, however currently only a small portion of the space is used.

Tyres do not have a specific storage lifetime and all unnecessary stock can be stored for a number of years without perishing. This is one of the reasons why OPF has not implemented a proper system, since a shortage can be filled within a short period of time and tyres that are not needed can be stored without further problems.

3.3 ORDERING PROCESS FUNCTIONS

3.3.1 SUPPLIERS

OPF does not have any fixed contracts with suppliers as this will cause a supplier to freely increase prices as they please and causes that prices are not on a competitive level. When ordering tyres, OPF enquires from an average of seven suppliers. The suppliers are chosen on grounds of lead time, quality and dependability. For privacy reasons, the different suppliers will not be listed in this report.

3.3.2 DELIVERY LEAD TIMES

Delivery lead times for all of the suppliers are relatively short and constant. There is no data available on the lead times for different suppliers and thus the triangular distribution is used to approximate the lead times. This distribution is typically used for describing a population where the information is limited and where there exists a known relationship between parameters (Boost.org, 2000). The triangular distribution uses an educated guess with a set minimum and maximum and a modal value. Table 6 gives the approximation of the lead time distribution:

Day Parameter	**Number of Days**
Minimum Days of Lead Time	0.5 day
Maximum Days of Lead Time	5 days
Most likely Days of Lead Time	2 days

TABLE 6: LEAD TIME PARAMETERS

3.3.3 BBEE CLASSIFICATION AND FUNCTIONALITY

SAA must comply with the government BEE standards for preference points claimed in terms of the preferential procurement regulations that was issued in 2011. These regulations state that the following rules must be applied to all purchases up to a R1 000 000 to award preference points to purchase prices and B-BBEEE status levels of contribution. Along with the price and B-BBEEE status level goods will be evaluated on functionality of predetermined norms that include reliability, quality and viability of suppliers. SAA evaluates all suppliers on the basis of an 80/20 or a 90/10 preference point system which is calculated in Table 7.

80/20 Preference Point System	90/10 Preference Point System
$$P_s = 80\left(1 - \frac{(P_t - P_{min})}{P_{min}}\right)$$ 6	$$\boldsymbol{P_s = 90\left(1 - \frac{(P_t - P_{min})}{P_{min}}\right)}$$ 7

TABLE 7: B-BEEE PREFERENCE POINT CALCULATIONS

Where P_s = *Points scored for comparative price of bid under consideration*

P_t = *Comparative price of bid under consideration*

P_{min} = *Comparative price of lowest acceptable bid*

B-BBEEE points are allocated to suppliers with the following weights:

Status Level	Points (90/10)	Points (80/20)
1	10	20
2	9	18
3	8	16
4	5	12
5	4	8
6	3	6
7	2	4
8	1	2

TABLE 8: B-BBEEE POINT ALLOCATION

By using the above preference point system, SAA has awarded the following points to their most used suppliers:

Supplier	A	B	C	D	E	F	G
Status Level	12	16	6	12	12	16	6

TABLE 9: SUPPLIER PREFERENCE POINTS

SAA bases the functionality on criteria that include product specification, lead time and the quality of products. Product specification is measured by the percentage resemblance to the originally expected product. Lead time relates to the responsiveness of each supplier and the quality of product speaks for itself. The following weights are given to the predetermined functionality criteria:

Criteria	Weight
Specification	60%
Lead Time	20%
Quality of Product	20%

TABLE 10: FUNCTIONALITY CRITERIA

3.4 PURCHASE DATA ANALYSIS

3.4.1 2012 PURCHASE DATA

FIGURE 5: OFP TYRE PURCHASE DATA 2012-2013

3.4.2 DEMAND AND PRICE DATA

ESTIMATION OF DEMAND AND PRICE

Demand and price data for one year was evaluated. It was however found that data for one year is not sufficient since some tyre types are only purchased once or twice a year. This made it very difficult to estimate the distributions and monthly demand and price. It was suggested that OPF gather as much information on purchases in the coming months to ensure the final solution will incorporate as much useful data as possible to eliminate errors. Even though the information is little, all tyre information was estimated to be normal distributed as there are no trends or seasonal aspects involved in the usage of tyres. With the information on hand, the means and standard deviations of each tyre type was calculated and a sample of 100 observations was used to construct histograms to ensure the data was approximately normal distributed. Furthermore, the Kurtosis and Skewness of the data was calculated as this is a more reliable tool for statistical approximation than the use of histograms. The Kurtosis of data is defined by Montgomery (2007) as a measure of the degree to which a unimodal distribution is peaked. Skewness can be defined as the asymmetry showed by a distribution. The closer the Kurtosis and Skewness is to zero, the more likely the data is normally distributed.

STATISTICAL DEMAND AND PRICE DATA

Appendix A shows the results of the Kurtosis and Skewness tests conducted on the price and demand data. The results show that approximately 90% of the price and 60% of the demand data was found to be normal or approximately normal distributed. The data that was found to be extremely skew and have a Kurtosis far from zero is due to the lack of sufficient information for those tyre types. Most of these tyres are only procured once or twice a year and thus has a very low demand.

CHAPTER 4: SOLUTION DEVELOPMENT

To address the problems at OPF, it is clear that a different policy is needed for the procurement of tyres. This chapter looks at a number of alternative solutions that might be viable for implementation at OPF. The derivative of a model by Fabian et al (1958) will also be explored. It is important to remember that the development of an ordering policy is not the whole solution for the problem to OPF. The solution models are developed and evaluated against cost and technical criteria but to complete the solution process the model is required to integrate with an information system.

4.1 SOLUTION ASSUMPTIONS AND METRICS

All of the below described solution models will be subject to the following assumptions. The models will be reviewed once a month when inspection takes place. Shortages are met by purchasing an efficient amount to satisfy the monthly demand. All demand must be satisfied and the shortage quantity is purchased at a high price. The models will not incorporate lead time as demand during lead time is assumed to be zero. Even though there are multiple suppliers and products, the model will evaluate each product separately. The supplier will be chosen manually by the company after the models have evaluated the quantity of tyres to purchase. The demand and price distributions are normal distributed but will be formulated as Weibull distributions for the simplicity of calculations.

The probability density function of a Weibull distribution is given by:

$$f(x, b, k) = \left\{ \frac{k}{b} \left(\frac{x}{b} \right)^{k-1} e^{-\left(\frac{x}{b}\right)^{k}} \right\} \; for \; x \geq 0$$

8

.Where *b = The scale parameter.*

k = The shape parameter.

For the Weibull distribution to approximate a normal distribution, a shape parameter of close to $k = 3$ will be used. The scale parameter differs for each of the tyre types and is determined with the following equation where τ denotes the gamma distribution and $E(X)$ is the mean number of tyres bought per month from the normal distribution.

$$b = \frac{E(X)}{\tau(1 + \frac{1}{k})}$$

9

The solution models aim to address, incorporate or improve the relevant performance metrics as set out in the data analysis phase. The main objective is to reduce overall procurement cost by taking the following into consideration:

a. Inventory Cost
b. Shortages during lead time
c. Purchasing cost

Furthermore process visibility is to be increased through demand and price history being incorporated in the decision making process for future procurement. The model should also calculate the effect of price and demand fluctuations on the inventory to be kept. Validating and testing the models should ensure the reliability of the solutions in terms of respectable prediction abilities as well as positive use of historic data to ensure representative results. Lastly, the model should ensure responsive feedback and accuracy regarding procurement. The model is insufficient if it is cost effective and reliable, however lacks timely response.

4.2 SOLUTION ALTERNATIVES

As seen in the Literature Review (Chapter 2) there are various inventory models in use by industry. These models are used for different situations and product types. In this report, four different policies will be tested and validated against each other to find the best fit for OPF. These models are the following:

a. Economic Order Quantity (EOQ) model with backorders allowed
b. Predetermined fixed order quantity replenishment model
c. Derivative of a two-period model by Fabian et al (1958)
d. Fixed time period replenishment model

4.2.1 ECONOMIC ORDER QUANTITY (EOQ) MODEL WITH BACKORDERS

Throughout history and industry, the EOQ models have been very popular and are used in various situations and applications. These models are relatively easy to compute as well as implement and have high success rates. This contributes to the popularity of the models. As explained in section 2.4, there are a number of derivatives to these models.

ASSUMPTIONS

a. Uncertain Demand – The average demand per month will be used.
b. No specific reorder point – evaluated once per month.
c. Tyres will only be ordered when the inventory level drops below two tyres per type when inspected.
d. Price information will be updated in the model monthly.
e. No sales are lost, all sales will be backlogged.
f. A limit is placed on the monthly number of shortages allowed.

While taking the above mentioned assumptions into consideration, the following mathematical equations and parameters were chosen for the EOQ model development.

PARAMETERS

h = *Holding Cost per Period*
q-M =*Maximum Shortages per Period*
q = *Economic Order Quantity*
D = *Average Monthly Demand*

s = *Shortage Cost per Unit Short*

K = *Order Cost*

P = *Cost of Product*

M = *Maximum Number of Shortages Allowed*

Subject to the following calculations:

$$Holding\ Cost\ per\ Year = \left(\frac{M^2h}{2D}\right)\left(\frac{D}{q}\right) = \frac{M^2h}{2q} \tag{10}$$

$$Shortage\ Cost\ per\ Period = \frac{(q-M)^2}{2q} \tag{11}$$

With all of the above cost equations in mind, the total cost can be calculated by minimizing the following equation:

$$TC(q, M) = \frac{M^2h}{2q} + \frac{(q-M)^2}{2q} + \frac{KD}{q} + PD \tag{12}$$

Where q and M are calculated as follows;

$$q = \sqrt{\frac{2KD(h+s)}{hs}} \tag{13}$$

$$M = \sqrt{\frac{2KDs}{h(h+s)}} \tag{14}$$

4.2.2 PREDETERMINED FIXED ORDER QUANTITY REPLENISHMENT MODEL

This fixed order quantity model uses previous demand and purchase information from OPF to determine a fixed quantity to order that stays unchanged throughout. These quantities are determined by taking the average demand per period for each tyre type. This model also allows for backorders and no lead time.

ASSUMPTIONS

a. The average demand per month will be used as order quantity.
b. No specific reorder point – evaluated once per month.
c. Price information will be updated in the model monthly.
d. No sales are lost, all sales will be backlogged.
e. A limit is placed on the monthly number of shortages allowed.

PARAMETERS

h	= *Holding Cost per Period*
q-M	=*Maximum Shortages per Period*
q	= *Predetermined Order Quantity*
D	= *Average Monthly Demand*
s	= *Shortage Cost per Unit Short*
K	= *Order Cost*
P	= *Cost of Product*
M	= *Maximum Number of Shortages Allowed*

Subject to the following calculations:

$$Holding\ Cost\ per\ Period = \left(\frac{M^2h}{2D}\right)\left(\frac{D}{q}\right) = \frac{M^2h}{2q}$$

15

$$Shortage\ Cost\ per\ Period = \frac{(q-M)^2}{2q}$$

16

With all of the above cost equations in mind, the total cost can be calculated by minimizing the following equation:

$$TC(q,M) = \frac{M^2h}{2q} + \frac{(q-M)^2}{2q} + \frac{KD}{q} + PD$$

17

Where q and M are calculated as follows;

$$q = \ Average\ Demand\ per\ Period$$

$$M = \sqrt{\frac{qs}{(h+s)}}$$

18

4.2.3 DERIVATIVE OF A TWO-PERIOD MODEL BY FABIAN ET AL (1958)

This model was developed by Fabian et al (1958) as described in Chapter 2. It considers the fluctuation in market price to determine the quantity of tyres to purchase. This is a dynamic programming model that uses iterative techniques to determine the order quantity with the minimum expected cost. In the time of this model's development, the analytical model proved great difficulty to solve since computer based programming was not yet widely used and available. In the current century, however this model could be programmed in a software language to simplify the evaluation of the model greatly.

A few changes were made to the original model to suit the application better. This includes the incorporation of order costs and a change in the evaluation of shortage costs. This model does not incorporate the purchasing cost of a tyre when bought due to a shortage when calculating the cost of a short unit; however the unit cost of a tyre short is calculated separately from the cost of purchasing a unit due to a shortage. This developed the need for an extra unit in the minimizing equation as will be explained below. This model will be used as the preferred solution and will be verified for optimality against the other specified solution alternatives.

The parameters for this model will be explained in the next section; however the constant input parameters for each tyre type will be given in Appendix C.

CONSTANT INPUT PARAMETERS

$\emptyset(x)$ = *The probability density function for the monthly demand.*

$\acute{y}(p)$ = *The probability density function for the future price.*

$\check{s}$ = *The maximum storage capacity.*

c_1 = *The cost associated with holding one unit of inventory over one period.*

c_2 = *The cost associated with having one unit of inventory short over one period.*

a_1 * = *The shape parameter for a demand weibull distribution.*

a_2 * = *The shape parameter for a price weibull distribution.*

b_1 * = *The scale parameter for a demand weibull distribution.*

b_2 * = *The scale parameter for a price weibull distribution.*

** These parameters are subject to the specific tyre type being evaluated.*

VARIABLES

s = *The starting inventory level at the start of the period.*

P = *The current market price.*

$I(S)$ = *The expected cost of inventory during a period.*

S = *The amount of inventory at the beginning of a month.*

K = *The ordering cost.*

r_1 = *The usage rate during a period assuming the usage is less than the inventory level.*

r_2 = *The usage rate during a period assuming the usage is more than the inventory level.*

C_1 = *The holding cost associated with keeping inventory at a usage rate of* $r1$.

C_2 = *The holding cost associated with keeping inventory at a usage rate of* $r2$.

U = *The shortage cost associated with having insufficient inventory at a usage rate of* $r2$.

X = *The demand during period* 2.

P = *The price during period* 2.

n = *Period*

h = *Quantity of product short*

MINIMIZING FUNCTION

$fn(s,P)$

$= \text{The minimum total cost over n months when the inventory starting level is s and the market price is P}$

$$f_n(s,P) = min_{S\geq s}\{(S-s)P + I(S) + K + P*(h) + \int_0^{\infty}\int_0^{S} f_{n-1}(S-x,p)\emptyset(x)\gamma(p)dxdp + \int_S^{\infty}\int_S^{\infty} f_{n-1}(0,p)\emptyset(x)\gamma(p)dxdp\,\}$$ **19**

Subject to the following Constraints:

$c_1 = 0.023 * P$

$c_2 = 118.5$

$x = \text{random variable derived from a weibull distribution}$

$p = \text{random variable derived from a weibull distribution}$

$h = \begin{Bmatrix} |x-S|\ if\ S > x \\ 0\ if\ S \leq x \end{Bmatrix}$

$s = \begin{Bmatrix} r - S\ if\ S > r \\ 0\ if\ S \leq r \end{Bmatrix}$

$$\emptyset(x) = \left\{ \frac{a_1}{b_1}\left(\frac{x}{b_1}\right)^{a_1-1} e^{-\left(\frac{x}{b_1}\right)^{a_1}} \right\}$$ **20**

$$\gamma(p) = \left\{ \frac{a_2}{b_2}\left(\frac{x}{b_2}\right)^{a_2-1} e^{-\left(\frac{x}{b_2}\right)^{a_2}} \right\}$$ **21**

$r = \begin{Bmatrix} r_1\ if\ S < x \\ r_2 if\ S > x \end{Bmatrix}$

$r_1 = \begin{Bmatrix} x\ if\ S < x \\ 0\ if\ S > x \end{Bmatrix}$

$\boldsymbol{r_2 = \begin{Bmatrix} x\ if\ S < x \\ 0\ if\ S > x \end{Bmatrix}}$

$$\boldsymbol{C_1 = c_1\left(S - \frac{1}{2}r_1\right)}$$ **22**

$$C_2 = \frac{1}{2} c_1 \frac{S^2}{r_2}$$

23

$$U = c_2(r - S)$$

24

$$I(S) = \int_0^S c_1 \left(s - \frac{1}{2} r\right) \emptyset(r) dr + \int_S^\infty \left[\frac{c_1 S^2}{2r} + c_2(r - S)\right] \emptyset(r) dr$$

25

$$K = \begin{Bmatrix} R161\ if\ (S - s) > 0 \\ R0\ if\ (S - s) = 0 \end{Bmatrix}$$

$$s_2 = S - r$$

$$S \geq s_n$$

$$S \leq \dot{\check{s}}$$

$$\{x, S, s_n, r, C_1, C_2, P, p, U\}; \geq 0$$

$$\{x, S, s_n, r\}; integer$$

$$n = 1,2$$

Where

$$f_1(s, P) = (S - s_1) * P + I(S) + K + P * abs(S - x)$$

$$f_1(S - x, p) = x * P + I(S) + K + P * abs(S - x)$$

$$f_1(0, p) = S * P + I(S) + K + P * abs(S - x)$$

ASSUMPTIONS

The holding and shortage costs are determined by the usage rate $r1$ and $r2$ where $r1$ = the usage rate where the starting stock was efficient to meet the monthly demand and $r2$ = the usage rate where the starting stock was insufficient to meet the monthly demand. Figure 6 shows the rate functions.

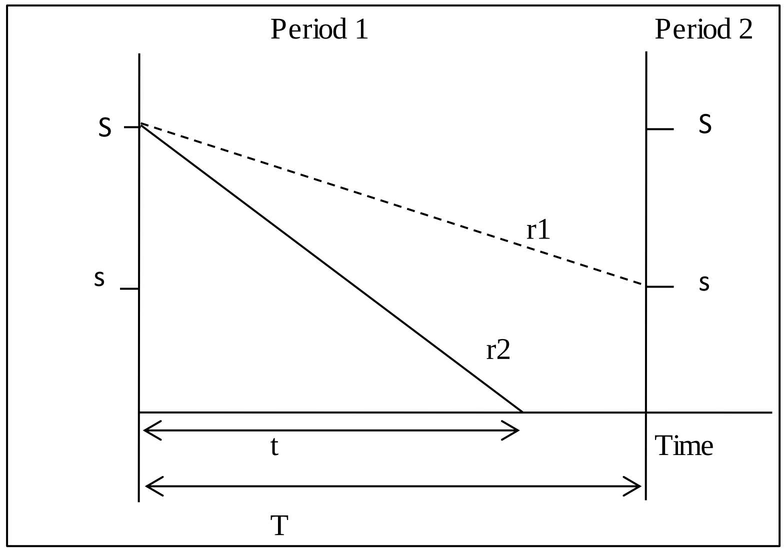

FIGURE 6: GRAPH SHOWING THE RELATIONSHIP BETWEEN DIFFERENT USAGE RATES

If $S \leq r$ then the stock at the end of the period is zero otherwise it is $S - r$. The quantity purchased will be $S - s$ and assuming that tyres are never sold after being purchased then $S \geq s$. The maximum stock level is defined as $\mathring{s}$ so that $S \leq \mathring{s}$. These assumptions can be summarized as $\mathring{s} \geq S \geq s$. Ordering cost is estimated to be R486 per order when an order involves an average of three or more tyre types per order. Thus the model includes an order cost of K=R161 since the model is only valid for one tyre type.

4.2.4 FIXED TIME PERIOD REPLENISHMENT MODEL

The fixed time period model is essentially a one period model following the same logic as the model derivative by Fabian as explained in 4.2.3. The assumptions and input parameters are the same as the previously described model. The only differences come in with the period n, as n can now only be equal to n=1. This model makes purchasing decisions once every month but without including a second period in the decision. The minimizing equation is also different and will be shown below.

MINIMIZING EQUATION

$$f(s,P) = \text{The minimum total cost per month when the inventory starting level is } s \text{ and the market price is } P$$

$$f(s,P) = min_{S \geq s}\{(S-s)P + I(S) + K + P * (h)\}$$

26

Subject to the same constraints as the model in section 4.2.3 with the following exceptions:

$S \geq s$

$\{x, S, s, r, C_1, C_2, P, p, U\}; \geq 0$

$\{x, S, s, r\}; integer$

$n = Non\ existant$

4.3 SOLUTION EVALUATION CRITERIA

To compare the different models developed and discussed above, it is necessary to define criteria against which these models will be analysed. These criteria will be further divided into technical, design, cost and effectiveness components, as described below (Palmius, 2007). This section only explains the evaluation criteria as the solutions will only be evaluated after validation and testing.

4.3.1 TECHNICAL CRITERIA

a. Functionality: This criterion is concerned with user requirements and whether the model adheres to it. Functionality also adheres to model maintenance and whether it is easy to correct errors and to understand the logic behind the solution.
b. Ease of Use: This criterion asks whether the system is designed with the end user in mind. Straightforward implementation and use of solution is important here.
c. Quality: Involves the correct design of the solution with no errors. The solution needs to be clearly defined with no ambiguities. This criterion is also concerned with the conceptual integrity of the design
d. Consistency: Consistency decides if there is a coherent line of reasoning in the solution. Uniform design parameters and assumptions are necessary and the solution should be non-contradictory.
e. Orthogonality: Orthogonality is concerned with the separation of independent functions. Functions that are independent should be modelled and created separately, however dependent functions should be grouped together and function in relation to one another.
f. Propriety: This criterion provides comparison on the solution being proper to the purpose of its design. Each problem or function needs to be defined only once. Solutions should not be redundant but should aid to the comprehensibility of the system.
g. Generality: Generality relates to the flexibility and adaptability of the solution to be used in other industries or situations. When minor changes can be made to accommodate other implementations, the solution will have a high generality score.

4.3.2 COST CRITERIA

a. Holding cost: This criterion compares different solutions on the average cost of keeping inventory in stock over a period of time.

b. Shortage Cost: This criterion compares different solutions on the average cost of tyre shortages over a period of time.
c. Purchase Cost: This criterion compares different solutions on the average cost of purchasing tyres over a period of time.
d. Total Cost: This criterion compares different solutions on the total cost of procuring tyres over a period of time.
e. Order Cost: This criterion compares different solutions on the average cost of ordering tyres over a period of time.

4.3.3 EFFECTIVENESS / EFFICIENCY CRITERIA

a. Performance: Performance decides whether or not the solution performs validly and as designed.
b. Shortages: This criterion compares the quantity of tyre shortages that occur during a period of time.
c. Utilization: This criterion determines the relationship between the quantity of tyres purchased and the quantity of tyres that are demanded.
d. RFQ processing time: This compares the total processing time of RFQ's for every solution.
e. Orders needed: This criterion is concerned with the quantity of orders that need to be made (and thus the time spent on the phone by OPF personnel) during a time period.
f. Quantity Purchased: The quantity purchased determines whether the solution purchases too much or too little product.

4.3.4 PERFORMANCE METRICS

a. Inventory Cost: The cumulative sum of holding, shortage and ordering cost.
b. Reliability: Does the model have respectable prediction abilities, rated by lower shortages and future procurement.
c. Process Visibility: Is previous demand and price information incorporated in the model.
d. Responsiveness: Is the procurement of tyres timely and is the effect of lead time on demand incorporated? Is there accuracy in the quantity purchased per month?

CHAPTER 5: SIMULATION MODEL

5.1 SYSTEM DESCRIPTION

The system modelled represents the ground fleet of South African Airways to evaluate the impact of different inventory management policies on the cost and effectiveness of the fleet operation. The model primarily looks at the procurement of tires in the company and how often product should be purchased to keep costs to a minimum while still incorporating the uncertainty regarding demand and price. The simulation model was created with the software *Technomatix Plant Simulation* developed by Siemens.

The simulation model is used to evaluate the solution models outlined in Chapter 4, this chapter follows the methodology used in creating a suitable and validated simulation model for the environment at OPF. The solution models are also compared to an as-is simulation model to determine the performance of the solution models against current OPF processes. This chapter outlines the flow of the model, the conceptual design, translation of model components as well as the scenarios followed.

5.2 SIMULATION MODEL OBJECTIVES

The simulation model aims to evaluate the impact of various inventory management policies on the procurement of tyres at South African Airways and to determine the minimum cost model to be implemented at South African Airways. The simulation model is also concerned with a model that produces a low failure time and high utilization of tyres and time.

5.3 CONCEPTUAL DESIGN

5.3.1 PROCESS FLOW

The process flow diagram depicts the processes and the logic followed by the simulation model.

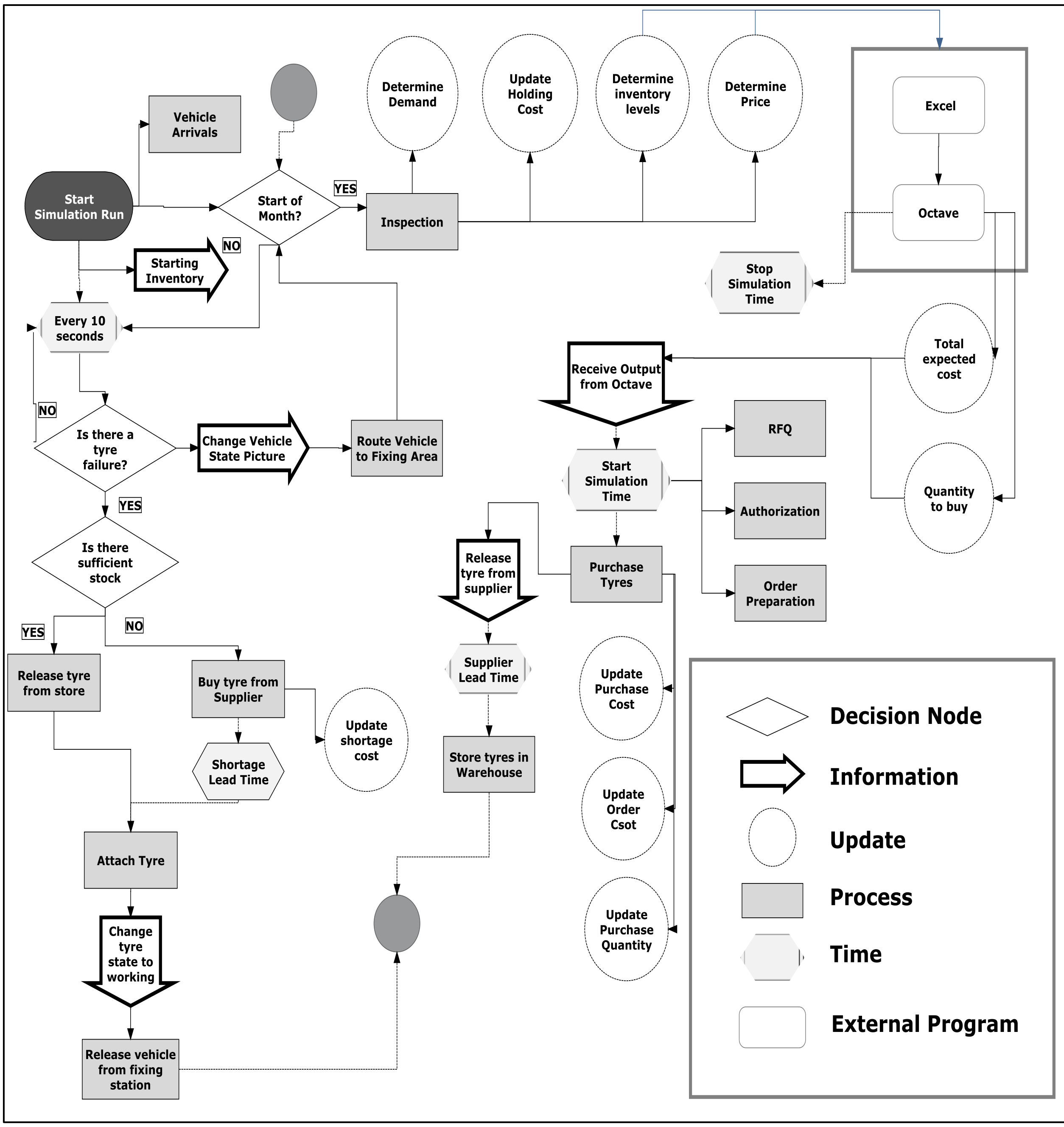

FIGURE 7: SIMULATION MODEL PROCESS FLOW CHART

5.3.2 EVENT DESCRIPTION

SIMULATION INITIALIZATION

At the initialization of the simulation, the model identifies the month and the day to determine whether it is necessary for an inspection. The various component sources are triggered at this point to release all the vehicles into the system. The simulation also triggers the warehouse to be filled with the manually indicated starting inventory levels.

MONTH START

At the start of every month, the simulation triggers an inspection. This inspection determines the quantity of each tyre type that is in stock and the hypothetical price of each tyre type for the month specified. After these variables are determined, the simulation can do one of several actions:

a. In the case of the fixed time period model and the two period model by Fabian et al (1958):
   The inspection triggers a *Microsoft Excel* file to open that in turn opens the file that contains and runs the mathematical model. This is done since the mathematical model is too complex to be programmed in *Technomatix Plant Simulation.* The simulation time stops while the mathematical program is evaluating the information; this process takes approximately fifteen minutes. The program concludes by saving output data (the quantity of tires to be bought and the minimum expected cost) in a *Microsoft Excel* file which in turn is read by the simulation model. The simulation time is started once more. The simulation model responds by purchasing the quantity of tires specified in the *Microsoft Excel* file.
b. In the case of the EOQ and Fixed Quantity model:
   When the EOQ and Fixed Quantity model is tested, the inspection triggers a method that calculates the different order quantities for the average demand and the price during that month. In the case of the Fixed Quantity model, the order quantities are already determined. After these quantities are determined, the model purchases the specified tires.

In the case that tires are purchased, variables for purchase cost, order cost and total quantity purchased are updated. After inspection and before the tires is purchased, the simulation model also updates the holding cost for the previous month. Along with purchasing tires, the simulation triggers the start of RFQ, RFQ authorization and Order Preparation processes. These processes simulate the personnel jobs of calling suppliers for price information and authorizing purchases.

For tires to be imported into the system, the tyre purchase process also triggers the Supplier component to release a tyre into the system. This tyre has a lead time before it is stored in the SAA warehouse.

ONCE PER DAY

Every day simulation runs a method to inspect whether vehicles have failed due to non-functional tires. To determine this, the demand is divided up into the month to determine on which days the vehicle must fail to ensure the correct number of failures occur in a month. When a failure day arrives, the vehicle changes its operational state to failed, and will enter the tyre fixing area. The simulation model detects a vehicle in this area and in turn checks the inventory warehouse for a corresponding tyre type. The following options can happen:

a. A tyre is in stock:
   When a tyre is present in the system, the system will release the tyre from the warehouse to the attach tyre component. The process of changing a tyre takes twenty minutes to complete. The vehicle operational state is afterwards changed to working and the vehicle exits the fixing area. Failure time will be updated as soon as the vehicle exits this area.

b. Out of tyre stock: When a tyre is not present in the system, the simulation will trigger the shortage supply component that will release a tyre into the system. The lead time for a short tyre is five hours. After the tyre arrives at the attach tyre component, the failed vehicle's operational state will be changed to working and it will exit the fixing area. The shortage and purchase cost will be updated accordingly. The vehicle failure time will be updated as soon as the vehicle exits the area.

ONCE PER HOUR

Every hour the simulation updates the variable simulation time, to ensure that any variables using this time will be updated accordingly (Time-Off, Time-Start, Time-failed). This update will also determine whether there are any unnecessary vehicles waiting in the fixing area that are not supposed to have failed. This scenario sometimes happens because the track to the fixing area is triggered when a vehicle enters the operational state of being failed. Unfortunately when a vehicle enters the track, the response is too slow to turn of the enter function immediately and some unwanted vehicles may also enter the fixing area. This causes the fixing area to become unnecessarily crowded and some of the vehicles are not able to leave, since these unnecessary vehicles do not trigger the component to change the tyre, their operational state can never be returned to working. The unnecessary breakdown method is thus triggered to release these unnecessary vehicles from the fixing area.

5.3.3 CONCEPTUAL TRANSLATION

The following components were used in the inventory management simulation model. Certain elements are used solely for special purposes (explained in scenarios).

ENTITIES

Entities can be described as the main actors in a system. Entities are the physical components that request resources, have physical appearance, communicate with the system and its background and offer visibility into the system. Entities move around the system triggering activities and processes.

The simulation model developed uses the following entities:

c. Tyres – each of the various tyre types are modelled as a separate entity that move around in the system.
d. Vehicles – each of the various vehicle types are modelled as tyre obtainers and trigger the necessity for tyre purchases and tyre changes.
e. RFQ – the physical document to request tyre purchases,
f. Viewers – non visible entities that move through the system to trigger methods and events.

ATTRIBUTES

Attributes are inherent qualities or characteristics of a component or entity. These inherent characteristics describe objects giving identity and personage to the component that possesses it. Table 11 describes the different attributes modelled in the simulation model.

Attribute	Description
Vehicle Pictures	Each vehicle has a specific picture to identify it by.
Need Change	When a vehicle has a tyre that needs to be changed, the attribute Need Change is triggered. This attribute can have the values 1 and 0, relating to "true" and "false".
Tyre Pictures	Each tyre has a specific picture to identify it by.
RFQ Pictures	Each RFQ document has a specific picture for identification.
Failed Picture	The vehicles can be either in an operational state of failure or working.

TABLE 11: ATTRIBUTE DESCRIPTIONS

VARIABLES

Storage locations with an identifiable name relating to a specific modelling parameter are referred to as variables. These variables contain information and a specific value that can be changed throughout the simulation run. Variables are used to reference stored values and separates information. Variables can be either dependent or independent, depending on the type of information it contains. The simulation model uses the following variables:

Variable Name	Description
Price	The current market price of each tyre type.
Demand	The demand of each tyre type during a month.
Inventory in stock	The quantity of tires in the warehouse during the simulation.
Simulation Times	The time of the simulation.
Amount Purchased	The quantity of tires already purchased.
Day Number	The number for the day of the week.
Month Number	The number for the month of the year.
Purchase Cost	The cost accumulated for purchasing tires.
Order Cost	The cost accumulated for ordering tires after an inspection.
Holding Cost	The cost accumulated for holding inventory in stock each month.
Shortage Cost	The cost accumulated for having tyre shortages during a month.
Daily Demand	The daily demand for each tyre type.
Demand Days	The days of the month when a tyre fails.
RFQ Quantity	A document produced when a tyre is purchased from the supplier.

TABLE 12: VARIABLE DESCRIPTIONS

OPERATIONAL STATES

The vehicles in the simulation model can have various states of operation, depending on the characteristics of the system. Table 13 describes these states.

Operational State	Description
Failed	A vehicle has a faulty tyre that needs to be changed.
Working	A vehicle is in a working condition.

TABLE 13: STATE DESCRIPTIONS

METHODS

Methods are pieces of programming code that regulates the simulation model in the background. These methods can be triggered by different events in the system and are also able to trigger events, change variables, read attributes, create entities as well as trigger other methods. This section describes how each of these methods operate and how they integrate and interact with the system.

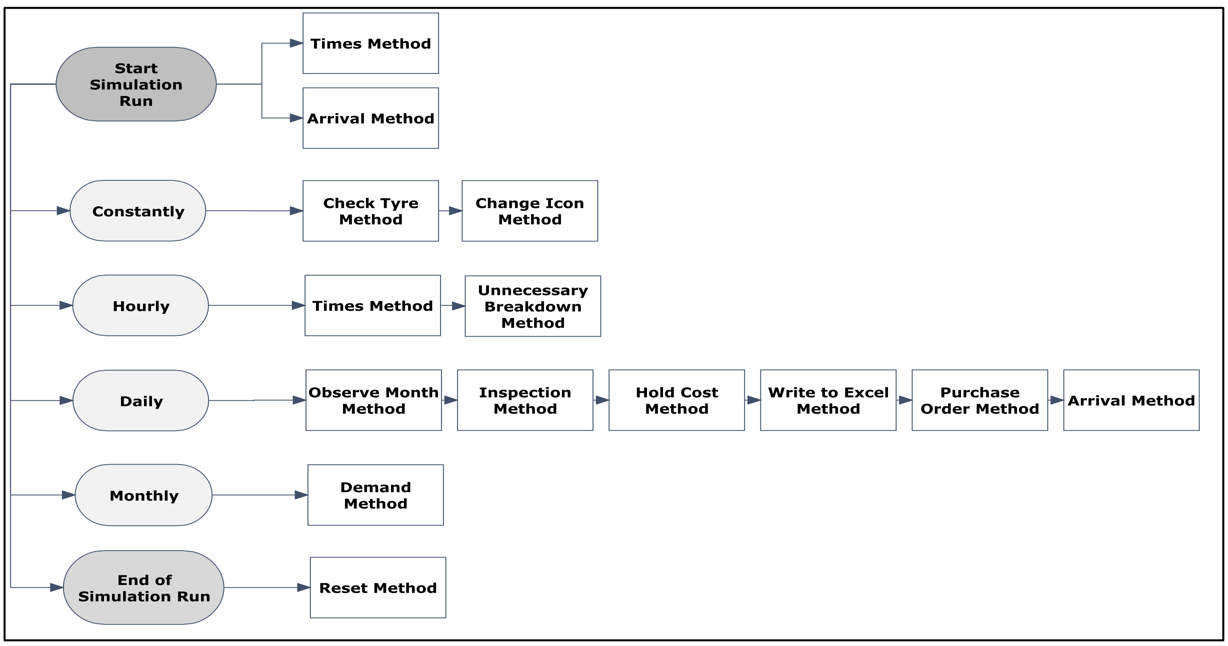

FIGURE 8: METHOD BREAKDOWN

a. Times

This method runs every hour and updates the Simulation Time variable, Month Number and Day Number variables. It also triggers a method called Unnecessary Breakdown.

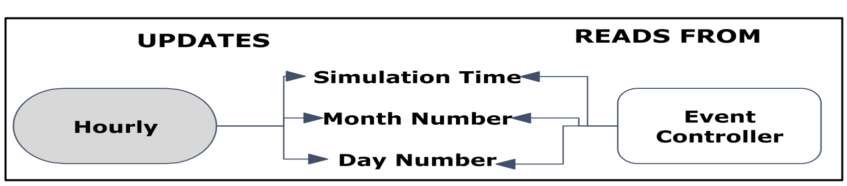

FIGURE 9: TIMES METHOD

b. Arrival

The arrival method is triggered when a tyre enters the warehouse and updates the inventory levels accordingly.

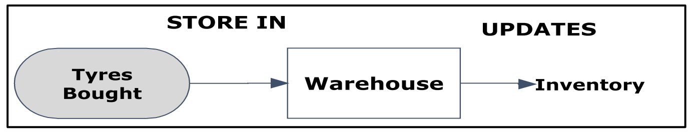

FIGURE 10: ARRIVAL METHOD

c. Change Tyre

The Change Tyre method is situated at the entrance to the track that leads to the fixing area. Every time a vehicle attempts to enter this area, the method reads the variable "Need Change" of the vehicle in question. If the variable states that the vehicle does not need a change, the vehicle will not enter the area and will be routed to a different track. However, when the variable states that a tyre change is needed, the track is opened and the vehicle variable changed to ensure no other vehicles enter the area.

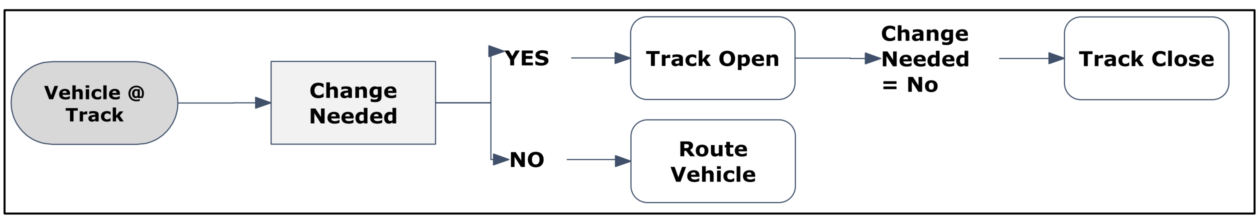

FIGURE 11: CHANGE TYRE METHOD

d. Change Icon

To have a visible view of vehicles that have tyre failures, this method changes the picture of the tyre from working to failed.

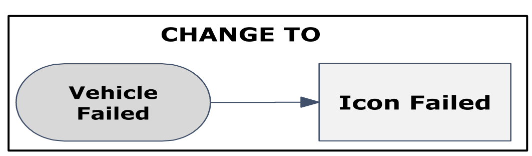

FIGURE 12: CHANGE ICON METHOD

e. Unnecessary Breakdown

When a vehicle fails, the track to the fixing area is opened. After the vehicle enters the area, the track is closed so that no other vehicles can enter. Unfortunately, the system does not always react quickly enough before the track is closed, and other vehicles can enter the area even if they have not failed. This causes the area to become blocked. To reduce this blockage, the Unnecessary Breakdown method checks to see if there are vehicles in the fixing area for which a tyre has not been released. If such a vehicle is found, the model will change the vehicle state to working and release the vehicle from the area.

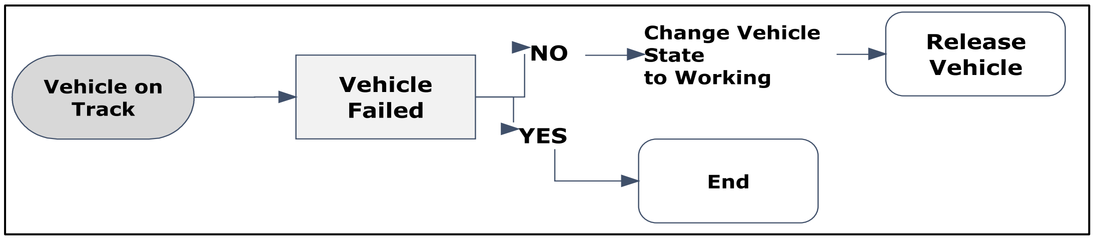

FIGURE 13: UNNECESSARY BREAKDOWN METHOD

f. Observe Month

This method observes changes in the Month Number. When the month number changes, it indicates that the start of the month has arrived and thus the Inspection method is triggered. This method also updates the demand for the new month.

FIGURE 14: OBSERVE MONTH METHOD

g. Inspection

The Inspection methods runs once a month and calculates the inventory in the system at that moment. The method also calculates the price of goods during a month to ensure the relevant costs are calculated accordingly. This method triggers the Hold Cost method which in turn triggers the Octave program to run.

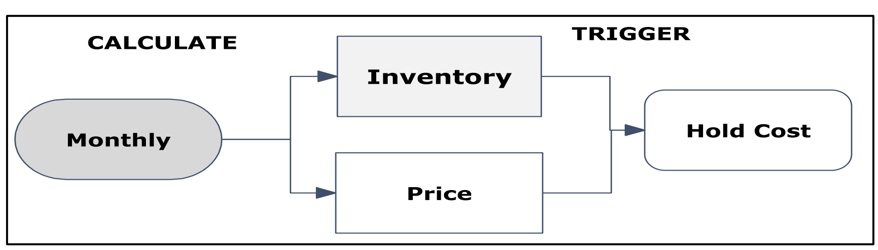

FIGURE 15: INSPECTION METHOD

h. Hold Cost

This method updates the holding cost at the start of each month. It takes into account all of the inventory currently in the system, and adds the months holding cost for these tires to the total holding cost variable.

FIGURE 16: HOLD COST METHOD

i. Write Inventory to Excel

After inspection is done and the holding cost is updated the simulation model triggers an Excel file to open. This file updates according to the current inventory levels and the current market price of each of the tyre types. In turn the file is triggered by a macro to open Octave and to run the mathematical model that calculates the quantity of tires to buy. While Octave is running, the simulation model loops until the program terminates. A trigger tells the model to exit the loop. The method triggers the Purchase Order method to run.

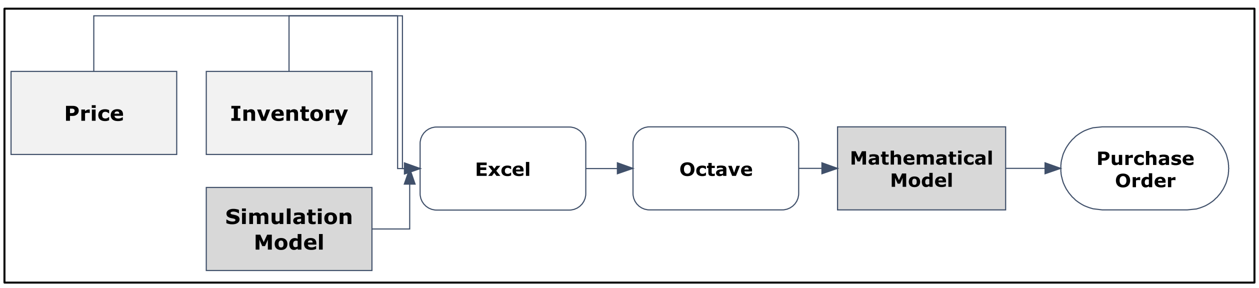

FIGURE 17: WRITE INVENTORY TO EXCEL METHOD

j. Purchase Order

The Purchase Order method is run after inspection and as soon as the Octave model is finished. This method orders the different tires specified by the Octave model and adjusts the various costs and purchase quantities. This method also ensures that when tires are bought, the Supplier component creates the set quantity of tires to be stored in the warehouse.

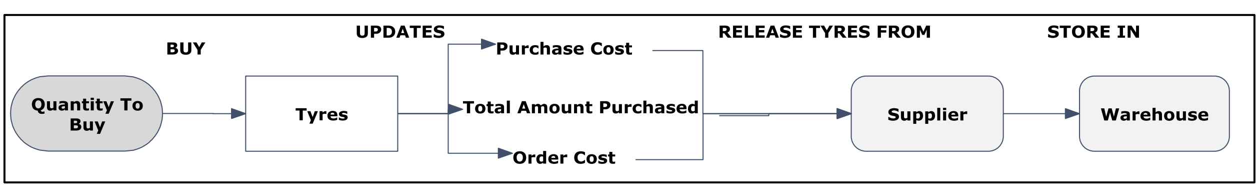

FIGURE 18: PURCHASE ORDER METHOD

k. Demand Method

This method is run every day to see if a failure has occurred. This method divides the monthly demand into days and when a day with a demand is reached, the method triggers all the necessary components (As explained in section 4.4 c). The Method updates the various cost variables and the inventory levels.

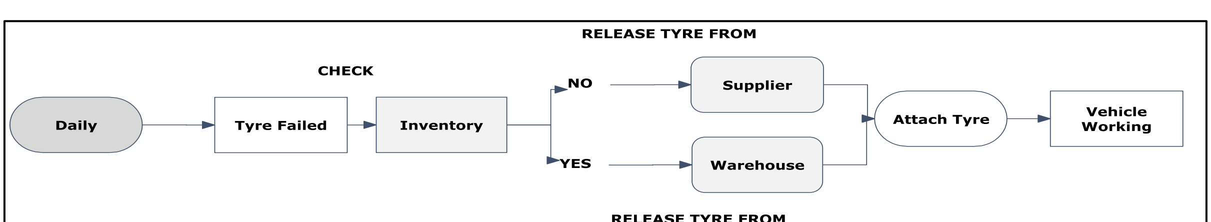

FIGURE 19: DEMAND METHOD

l. Reset

This method is run when the simulation is reset. It changes the following variable back to the starting parameters: Month Number, Simulation Time, Day Number, Starting Inventory, Holding Cost, Purchase Cost, Order Cost, Shortage Cost, Total Amount Purchased, Vehicle State = working.

FILES

Files are resources that hold information from the system. These files can be either tables or files from external programs.

File Type	**Description**
FileLink	A *Microsoft Excel* file that takes the inventory and price from the simulation model as input.
Output	The *Microsoft Excel* file that gives the expected cost and quantity to be bought as output from the mathematical model.
How to Buy	A table that holds the information from the Output file.
Start Model	A table that decides whether or not the model should run the mathematical program.
End Model	A table that determines the need to read the Output file after the completion of the mathematical model.
Tyres in Stock Table	A table holding information on the quantity of tires in the system at the start of the simulation run.
Inventory	A table holding information on the quantity of tires in the system at any point in time.
Vehicle Creation	A table that holds the quantity of vehicles to be created at the start of the simulation.

TABLE 14: FILE DESCRIPTIONS

COMPONENTS

Components describe the objects in the simulation model that process, transform and transport entities throughout the system.

Component	**Description**
Event Controller	Controller of simulation time and date.
File Interface	A component for embedding files in the simulation model to be used external to the model.
Source	A component that creates different entities to be used in the system.
Single Proc	A component that is used to evaluate and process information and entities.
Supplier	A component that creates a tyre when the system purchases product.
Delivery Time	A component that holds the tyre in transition before it is stored in the warehouse.
Shortage Supply	A component that creates a tyre when a shortage occurs.
Delivery Time Short	A component that holds the tyre in transition before it is stored in the warehouse.
RFQ	A component that creates a RFQ when tires are purchased.
RFQ Authorization	A process for authorizing RFQ's.

Order Preparation	A process for preparing orders.
Drain	A component that deletes entities.
Buffer	A component that holds tires before they are attached to failed vehicles.
Attach Tyre	A process for attaching tires to failed vehicles.
Store	The warehouse for storing product.

TABLE 15: COMPONENT DESCRIPTIONS

5.3.4 SCENARIO IDENTIFICATION

a. As-Is Model

This model models the OPF system in its current state. All input variables and information from historical real life data was used in modelling this system. The inspection purchases are controlled with an inventory safety stock of four tyres per tyre type causing the model to purchase the outstanding quantity at the start of each month. This model is not very efficient, hence the objective to improve it, and is used to set the bar for improvement. This model does not include the use of an external mathematical program or the use of *Microsoft Excel* files.

b. Economic Order Quantity (EOQ) model with backorders allowed

In this model, the simulation system determines whether or not the re-order point for each tyre type has been reached during the monthly inspection. When this point is breached, the system calculates the required order quantity based on the average demand and the current market price. For the EOQ model, the re-order point has been set at two tyres, to eliminate any shortages that can occur during supplier lead times. This model does not include the use of an external mathematical program or the use of *Microsoft Excel* files.

c. Predetermined fixed order quantity replenishment model

In the case of a model that has a fixed order quantity, inspection is by-passed and the simulation will always purchase the same quantity of tires every month. This model does not include the use of an external mathematical program or the use of *Microsoft Excel* files.

d. Derivative of a two-period model by Fabian et al (1958)

The two-period model will be run at inspection every month and includes the use of the external *Microsoft Excel* and mathematical files. The mathematical model calculates the required purchase quantities and each month the purchasing decisions are re-evaluated.

e. Fabian model analysed every second month

This is the same as the model described in d., however it differs since the mathematical model re-evaluates purchasing decisions only once every second month.

f. Fixed time period replenishment model

This model uses the first period calculations of the Fabian (1958) model described in d. and only calculates the best order quantity for a single month and does not consider price and demand changes during a second period. This model needs to be re-evaluated monthly and is only concerned with the demand and purchasing decisions on a month to month basis. This model makes use of the external *Microsoft Excel* and mathematical model files.

CHAPTER 6: VALIDATION

6.1 VALIDATION INTRODUCTION

Model validation is concerned with determining the degree to which the model conforms to the real world. Thus model validation determines the accurate representation of the solution against the original system or data. There are various levels for validating models, as discussed by Carley (1996).

a. Face Validation: Determines whether the appearance and animation of a computational model is comparable with the real world.
b. Parameter Validation: Matches model parameters with reality.
c. Process Validation: Determines the correspondence of the modelled process with the real process.
d. Pattern Validation: Compares different results throughout the model with real process results.
e. Point Validation: Uses the behaviour of the model based on a single dependent variable to determine the accuracy against the original system.
f. Distributional Validation: Validates statistical distributions of model parameters with real world parameters. This includes comparing process means, standard deviations and distribution shapes.
g. Value Validation: Matches model results with original results.
h. Theoretical Validation: Defines whether the model is a better predictive indicator than a linear model.

For each of the solutions and the simulation model some or all of the above levels will be evaluated to ensure the models are as close to the original environment as possible. Furthermore validation can be grouped into four main techniques:

a. Grounding: This technique compares the model against the real world in terms of reasonableness of the model. It also determines whether simplifications in the model detract the credibility of the system. This technique ensures that model boundaries and initial parameters are correct and represents the original system.
b. Calibrating: Calibrating is a multi-step and iterative process where different parameters, results and processes are altered and tested against the real world system.
c. Verifying: Verification verifies the model results against that of the real system instead of focusing on the internal workings of the model.
d. Harmonizing: Tests the theoretical adequacy of the model relative to that of a linear model.

This report will make use of grounding, calibrating and verification.

6.2 SIMULATION MODEL VALIDATION

To ensure the simulation model performs according to the real life situation at OPF, various validation techniques were used. The simulation model was validated in terms of the as-is state of OPF, to ensure the bases of the model was modelled correctly.

6.2.1 GROUNDING VALIDATION OF SIMULATION MODEL

The model was validated through grounding by analysing the original purchase data from OPF. As discussed in previous sections, each of the tyre types was evaluated and the parameters for Weibull distributions were determined through the use of software called *StatAssist.* This software compares the original data with various distribution types, and generates parameters for all known distribution types to fit the data. The data was all normal distributed, however the Weibull distribution can be manipulated to fit the normal distribution almost perfectly. Weibull equations are more user friendly than those of the normal distribution, and since this project was concerned with testing the Weibull distribution, this was used. The original inventory levels as specified by OPF were used as starting parameter levels in the simulation model to ensure credibility.

Furthermore the layout and the visible appearance of the model were used to validate whether or not the vehicles and components in the system reacted and behaved as a real transportation system would. The visible appearance gives the operator a better grasp on what exactly the model is doing at any time. A close eye was kept on the happenings of the model throughout the modelling process.

Reasonableness of the process was tested by comparing the layout of the system with that of the original system. The model was designed on the original map of OR Tambo International Airport thus giving it authenticity and original value. Every step followed by the simulation model was also compared to the process map and descriptions given by the personnel of OPF.

6.2.2 CALIBRATING THE SIMULATION MODEL

Calibration was done throughout the design of the simulation model. Hours were spent only watching the model as it did simulation runs to determine where objects and parameters were giving incorrect results. A good understanding of the original process was also needed to determine whether or not the model behaved accordingly. Processing times and demand data were continuously monitored for any outliers or unreasonable parameter results. The process was observed to determine if there were any blockages that occurred at intersections and whether vehicles entered the fixing area illegally. Single objects were also followed as it moved through the model to determine whether it took the correct route and triggered the correct methods and objects at the appropriate time.

6.2.3 VERIFYING THE SIMULATION MODEL

Furthermore the simulation results were compared with the original information from OPF. It is evident that the simulation is generally in line with the original data as there is a 90% correlation between the original and the simulated data. There are only a few tyres that are either over or under purchased, this might be the result of insufficient historic data as explained in previous sections. The results show that the model is a good approximation of the real world and can thus be used for further analysis of the procurement department of SAA. Appendix B shows the complete comparison between the real and the simulated data.

Figure 20 clearly depicts the comparison between the simulated demand data and the average demand according to its parameters. Comparing these results give the modeller the proper indication that the simulation model is behaving according to the real life parameters.

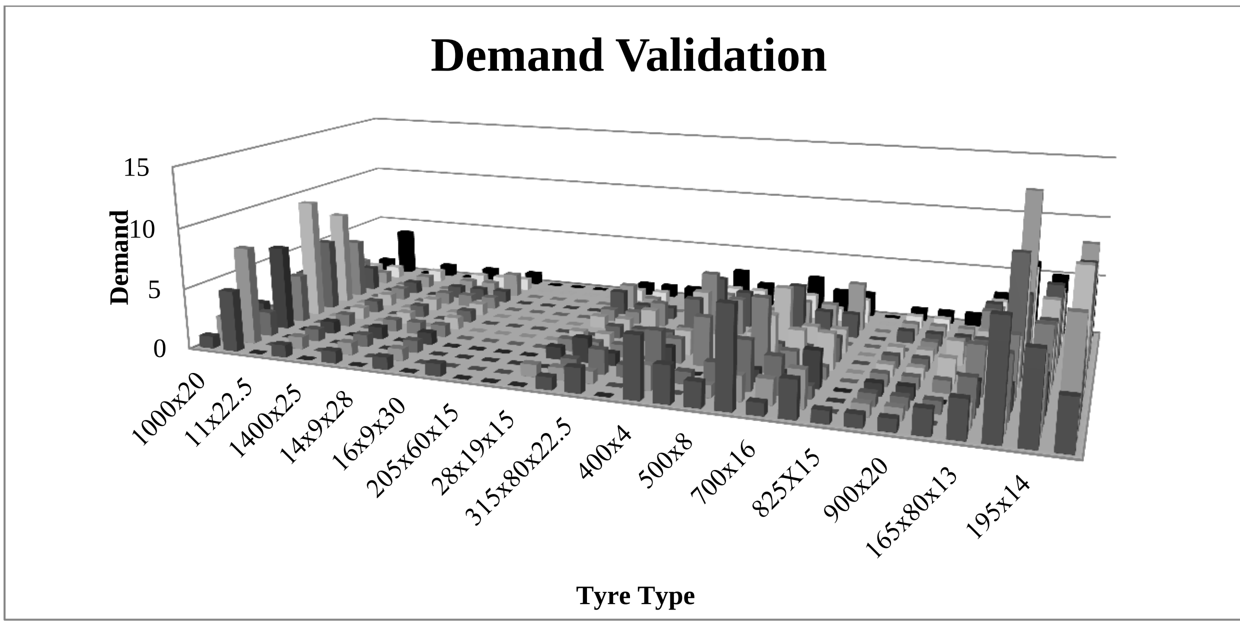

FIGURE 20: DEMAND VALIDATION GRAPH

6.3 MATHEMATICAL SOLUTION MODEL VALIDATION

It is also necessary to validate the mathematical models that were used as solution alternatives, as a faulty mathematical model can never be rectified by a finely validated and verified simulation model. The EOQ and Fixed Order Quantity models are tried and tested models used throughout industry, and thus need not be re-validated in this report. However the derivative of the model by Fabian et al (1958) needs validation as it is not a well-known and tested model. This model is also not used in its pure form, and thus the alterations need to be validated accordingly. Further validation of the model is given by discussing simulation results in Chapter 7.

6.3.1 GROUNDING OF SOLUTION MODEL

The input parameters for the Fabian model is the same as those used for the as-is simulation model; the demand and price distributions are Weibull distributed. The ordering cost and holding cost parameters are based on historical data from OPF and was validated through the results given by the as-is model. Simplifications in this model include the exclusion of lead time. It was determined that the demand during lead time is either zero or very close to it, thus excluding this will not have a great effect on the credibility of the model. This model determines the cost and appropriate purchase quantity, these are the same outputs as most defined and tested inventory policies used in industry, making this model a reasonable counterpart.

6.3.2 CALIBRATING THE SOLUTION MODEL

As previously described, calibration is an iterative process. Various hand computations and computer based computations were done to evaluate and compare the results. The computer based computations were calculated one by one to determine whether or not the results were correct and whether the minimum cost was chosen. Computations done in Excel concluded that the "S" curves conformed to those of the model depicted in Fabian et al (1958), this is further explained in section 6.4.

6.3.3 VERIFYING THE SOLUTION ALTERNATIVES

To ensure the various solution alternatives were used and calculated correctly, hand-computations were done to compare the results of the simulation model with the model results. The following table gives a summary of these results. It is evident that each of the solution alternatives aligns with the simulation model. Thus it can be concluded that the solution alternatives are valid for use.

Solution Alternative	**Model Computational Results**	**Simulation Model Results**	**Conformance of Results**
Fabian Derivative	R 787 843.80	R 761 018.00	**96.5%**
EOQ	R 842 807.42	R 847 378.00	**99.4%**
Fixed Order Quantity	R 1 010 755.80	R 1 021 788.00	**98.9%**

TABLE 16: SOLUTION VERIFICATION

6.4 PRACTICAL MODEL DEVELOPMENT

Separate to the numerical calculation of the mathematical inventory model, a practical model can be used to determine the optimum inventory level for the lowest possible cost under uncertain conditions. This entails a computational development method for the visual representation of the decision function. Separate calculation strategies were used to develop a decision function for the first and second period policies. This practical model allows the user to visually compare the current market price to the starting inventory level. This decision policy is to be evaluated in three steps:

a. Determine the current unit price $P_2(s)$ at the beginning of an evaluation period.
b. Use the current market price to read the optimum starting inventory level (s) from the decision curve.
c. Replenishment should take place up to the determined level of s whenever the current inventory level is lower than s. However when the inventory level exceeds the optimum level of s, no replenishment should take place.

This practical model allows management to quickly determine the optimal inventory level whenever the unit price per tyre is available. To establish the decision curve, various calculations needed to be performed. According to Fabian et al (1958), the first and second period policies are employed by the following equations:

$$P_1(s) = c_2 \int_s^{\infty} \emptyset(x)dx - c_1 s \int_s^{\infty} \left\{\frac{\emptyset(x)}{x}\right\} dx - c_1 \int_0^{s} \emptyset(x)dx$$

27

$$P_2(s) = P_1(s) + \int_0^{s} \left\{ \int_0^{P_1(s-x)} p\gamma(p)dp + \int_{P_1(s-x)}^{\infty} P_1(s-x)\gamma(p)dp \right\} \emptyset(x)\, dx$$

28

For a more detailed description of the practical model one of the products' calculations will be discussed further. The parameters used in these calculations are as outlined in Appendix A.

6.4.1 DECISION FUNCTION CALCULATION FOR PRODUCT 185X65X14

Demand calculations for period one:

x	$\int_s^{\infty} \left\{\frac{\emptyset(x)}{x}\right\} ds$	$\emptyset(x)$	$\emptyset(x)/x$	$\int_s^{\infty} \emptyset(x)dx$	$\int_0^{s} \emptyset(x)dx$
0	0.252291282	0	0	0.998311	0
1	0.232252944	0.020038	0.020038	0.988292	0.020038
2	0.202794723	0.038878	0.019439	0.958834	0.049497
3	0.174595389	0.055439	0.01848	0.911675	0.077696
4	0.148139627	0.068863	0.017216	0.849524	0.104152
5	0.123814725	0.078585	0.015717	0.7758	0.128477
6	0.101895179	0.084366	0.014061	0.694324	0.150396
7	0.082537118	0.086293	0.012328	0.608995	0.169754
8	0.065782202	0.084729	0.010591	0.523484	0.186509
9	0.051569622	0.080253	0.008917	0.440992	0.200722
10	0.039754065	0.073571	0.007357	0.364081	0.212537
11	0.030127171	0.065432	0.005948	0.294579	0.222164
12	0.022439955	0.056556	0.004713	0.233585	0.229851
13	0.016424019	0.047572	0.003659	0.181521	0.235867
14	0.011809902	0.038982	0.002784	0.138244	0.240481
15	0.008341532	0.031143	0.002076	0.103182	0.24395
16	0.005786395	0.024273	0.001517	0.075474	0.246505
17	0.003941572	0.018467	0.001086	0.054104	0.24835
18	0.002636162	0.013721	0.000762	0.03801	0.249655
19	0.001730863	0.009959	0.000524	0.02617	0.251176
20	0.001115561	0.007064	0.000353	0.017658	0.251176

TABLE 17: PERIOD ONE DEMAND CALCULATIONS

Price calculation for first period:

s	$c_2 \int_s^{\infty} \emptyset(x)dx$	$-c_1 s \int_s^{\infty} \left\{\frac{\emptyset(x)}{x}\right\} dx$	$-c_1 \int_0^s \emptyset(x)dx$	P_1
0	118.2999	0	0	118.2999
1	117.1126	-2.73064	-0.23559	114.1464
2	113.6218	-4.76859	-0.58194	108.2713
3	108.0335	-6.15825	-0.91348	100.9618
4	100.6686	-6.96682	-1.22453	92.47723
5	91.93227	-7.27856	-1.51052	83.14318
6	82.27741	-7.188	-1.76823	73.32117
7	72.16586	-6.79283	-1.99583	63.3772
8	62.03281	-6.18731	-2.19282	53.65268
9	52.25761	-5.45682	-2.35992	44.44087
10	43.14356	-4.67396	-2.49884	35.97076
11	34.90766	-3.89632	-2.61202	28.39932
12	27.67984	-3.16597	-2.7024	21.81147
13	21.51021	-2.5103	-2.77313	16.22677
14	16.38188	-1.94392	-2.82738	11.61058
15	12.22702	-1.47109	-2.86816	7.887762
16	8.943657	-1.08851	-2.8982	4.956947
17	6.411319	-0.78781	-2.91989	2.703616
18	4.504194	-0.55789	-2.93524	1.011065
19	3.10116	-0.38665	-2.95312	-0.23861
20	2.092515	-0.26232	-2.95312	-1.12292

TABLE 18: PRICE CALCULATIONS FOR PERIOD ONE

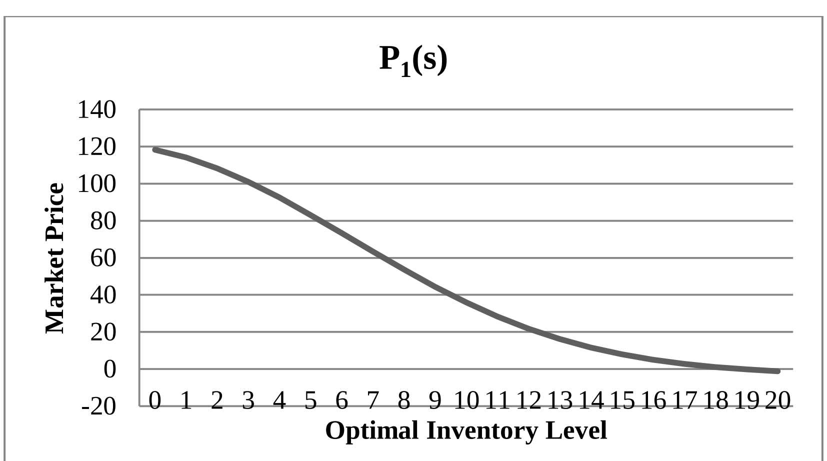

FIGURE 21: FIRST PERIOD ORDERING POLICY

Table 18 is used to plot a decision curve for the first period ordering policy. These values and calculations are furthermore used in formulating the ordering policy for the second period. The second period price per unit calculations are done for an inventory level which ranges between one and twenty units. This allows the user of the decision curve a range of starting inventory levels which can be evaluated. Analysis of demand and holding cost parameters also shows the tendency for product to be at inventory levels higher than twenty becomes very low. For simplicity and readability, only the calculations for a starting inventory level of twenty units are shown.

S	x	$(S - x)$	$\emptyset(x)$	$P_1(S - x)$	$\int_0^{P_1(s-x)} p\gamma(p)\,dp$	$\emptyset(x)\int_0^{P_1(s-x)} p\gamma(p)\,dp$	$\int_{P_1(s-x)}^{\infty} p_1(s - x)\gamma(p)dp$	$\emptyset(x)\int_{P_1(s-x)}^{\infty} p_1(s - x)\gamma(p)dp$
20	0	20	0	1.1217	0	0		
20	1	19	0.020	0.2374	0	0	0.010159	0.000204
20	2	18	0.038	1.0123	9.920E-17	3.86E-18	0.010159	0.000395
20	3	17	0.055	2.7049	8.521E-14	4.72E-15	0.010159	0.000563
20	4	16	0.068	4.9583	2.520E-12	1.74E-13	0.010159	0.0007
20	5	15	0.078	7.8893	6.267E-11	4.93E-12	0.010159	0.000798
20	6	14	0.084	11.612	1.040E-09	8.78E-11	0.010159	0.000857
20	7	13	0.086	16.228	1.177E-08	1.02E-09	0.010159	0.000877
20	8	12	0.084	21.813	7.120E-08	6.03E-09	0.010159	0.000861
20	9	11	0.080	28.401	3.841E-07	3.08E-08	0.010159	0.000815
20	10	10	0.073	35.973	2.227E-06	1.64E-07	0.010157	0.000747
20	11	9	0.065	44.443	9.065E-06	5.93E-07	0.01015	0.000664
20	12	8	0.056	53.655	3.799E-05	2.15E-06	0.010121	0.000572
20	13	7	0.047	63.380	0.0001117	5.32E-06	0.010047	0.000478
20	14	6	0.038	73.324	0.0003133	1.22E-05	0.009846	0.000384
20	15	5	0.031	83.146	0.0007695	2.4E-05	0.009389	0.000292
20	16	4	0.024	92.480	0.0015818	3.84E-05	0.008577	0.000208
20	17	3	0.018	100.96	0.0030399	5.61E-05	0.007119	0.000131
20	18	2	0.013	108.73	0.0048591	6.67E-05	0.0053	7.27E-05
20	19	1	0.009	114.14	0.0070945	7.07E-05	0.003065	3.05E-05
20	20	0	0.007	118.29	0.0090314	6.38E-05	0.001128	7.97E-06

TABLE 19: SECOND PERIOD DEMAND CALCULATIONS

From here on the final $P_2(s)$ values can be determined by calculating parameters for the equation given in section 6.4.

s	$P_1(s)$	$\int_0^{s} \emptyset(x)\int_0^{p_1(s-x)} p\gamma(p)dpdx$	$\int_0^{s} \emptyset(x)\int_{p_1(s-x)-1}^{s} P_1(s - x)\gamma(p)dpdx$	$P_2(s)$
0	118.2999			

1	114.1464	5.4391E-17	1.41393E-17	114.1464
2	108.2713	6.4327E-16	2.9096E-16	108.2713
3	100.9618	3.75615E-15	2.59701E-15	100.9618
4	92.47723	1.4543E-14	1.43052E-14	92.47723
5	83.14318	4.35036E-14	5.70304E-14	83.14318
6	73.32117	1.09108E-13	1.81604E-13	73.32117
7	63.3772	2.41374E-13	4.90562E-13	63.3772
8	53.65268	4.86183E-13	1.17004E-12	53.65268
9	44.44087	9.09964E-13	2.53318E-12	44.44087
10	35.97076	1.60539E-12	5.07603E-12	35.97076
11	28.39932	1.79E-12	9.54856E-12	28.39932
12	21.81147	4.34906E-12	1.70417E-11	21.81147
13	16.22677	6.77068E-12	2.90924E-11	16.22677
14	11.61058	1.0226E-11	4.78084E-11	11.61058
15	7.887762	1.50419E-11	7.60144E-11	7.887762
16	4.956947	2.16171E-11	1.17421E-10	4.956947
17	2.703616	3.04324E-11	1.76818E-10	2.703616
18	1.011065	4.20613E-11	2.60298E-10	1.011065
19	-0.23861	1.16289E-11	3.53866E-10	-0.23861
20	-1.12292	5.71807E-11	3.755E-10	-1.12292

TABLE 20: SECOND PERIOD PRICE CALCULATIONS

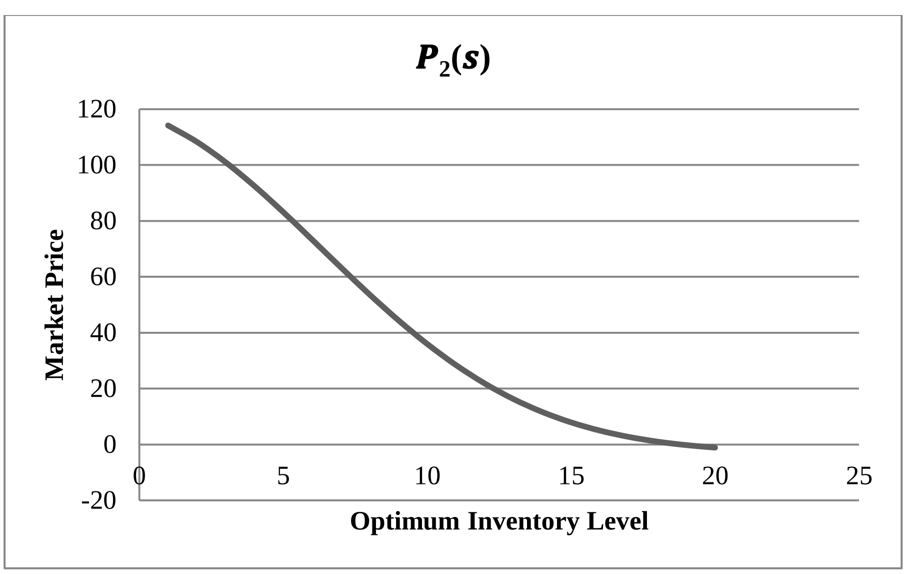

FIGURE 22: SECOND PERIOD ORDERING POLICY

Figure 22 shows the decision curve for the second period ordering policy. Once the unit price per tyre is known, the optimal inventory level for two periods can simply be read from the curve. The calculations of the decision curve resulted in a decision curve with the following equation formula:

$$y = 0.0024x^4 + 0.1016x^3 - 1.4212x^2 - 2.0733x + 117.47 \tag{29}$$

Appendix D shows the decision curves as well as equations for all of the products procured by OPF.

6.4.2 DECISION FUNCTION EVALUATION

The decision functions were analysed and evaluated against pre-set optimal inventories to compare to the mathematical model, Table 21 illustrates the results. Blank spaces in Table 21 determine inventory levels that will never be optimal for a specific tyre type. For some tyres it is also shown that it is never optimal to keep any safety stock as it will be more cost effective to purchase the tyre as the need arises. These tyre types have very low demands and high purchase prices that increase holding cost dramatically.

	Optimal Inventory Level against Rand per Unit										
Inventory Level	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1000x20	193	82	17	-	-	-	-	-	-	3	7
1100x20	113	77	48	25	8	-	-	-	-	-	-
11x22.5	53	-	-	-	-	-	-	-	-	-	-
1200x24	-	-	-	-	-	-	-	-	-	-	-
1400x25	-	-	-	-	-	-	-	-	-	-	-
145x80x10	219	68	-	-	-	-	-	-	-	2	19
14x9x28	0	-	-	-	-	-	-	-	-	-	-
1600x25	-	-	-	-	-	-	-	-	-	-	-
16x9x30	-	-	-	-	-	-	-	-	-	-	-
175x80x14	45	14	-	-	-	-	-	-	-	-	-
205x60x15	0	0	-	-	-	-	-	-	-	-	-
205x65x15	0	0	-	-	-	-	-	-	-	-	-
28x19x15	16	3	-	-	-	-	-	-	-	-	-
300x15	47	16	1	-	-	-	-	-	-	-	-
315x80x22.5	1	-	-	-	-	-	-	-	-	-	-
385x95x25	-	-	-	-	-	-	-	-	-	-	-
400x4	3	1	0	-	-	-	-	-	-	-	-
400x8	3	1	0	-	-	-	-	-	-	-	-
500x8	18	5	-	-	-	-	-	-	-	-	-
650x10	63	15	-	-	-	-	-	-	-	-	-
700x16	4	1	-	-	-	-	-	-	-	-	-

750x6	33	2	-	-	-	-	-	-	-	-	-
825X15	12	-	-	-	-	-	-	-	-	-	-
900x16	0	-	-	-	-	-	-	-	-	-	-
900x20	1	-	-	-	-	-	-	-	-	-	-
155x13	150	52	5	-	-	-	-	-	-	-	-
165x80x13	187	118	68	34	13	0	-	-	-	-	-
185x65x14	117	114	108	101	92	83	73	63	54	45	36
195x14	82	110	110	93	70	47	26	11	1	-	-
195x15	138	112	89	70	53	38	26	16	8	2	-

TABLE 21: EVALUATION OF OPTIMAL INVENTORY LEVEL AGAINST RAND PER UNIT

CHAPTER 7: SOLUTION EVALUATION

7.1 INTRODUCTION

Chapter 7 summarizes and analyses the results of the simulation model for all of the solution alternatives. Results regarding cost, efficiency as well as performance metrics are evaluated and conclusions on the most suitable model for OPF are given. Alterations to the Fabian et al (1958) derivative model are also included. The chapter concludes with a sensitivity analysis of the Fabian et al (1958) derivative model.

7.1 SIMULATION RESULTS

Each of the solution models were simulated for a period of one year with information documented every month. For simplicity the results will be represented per model with the following references:

A. As-Is state model.
B. Derivative of a two-period model by Fabian et al (1958) evaluated every second month.
C. Derivative of a two-period model by Fabian et al (1958).
D. Fixed time period replenishment model.
E. Economic Order Quantity (EOQ) model with backorders allowed.
F. Predetermined fixed order quantity replenishment model.

7.1.1 SUMMARY OF MONTHLY RESULTLS

COST RESULTS (IN RAND)

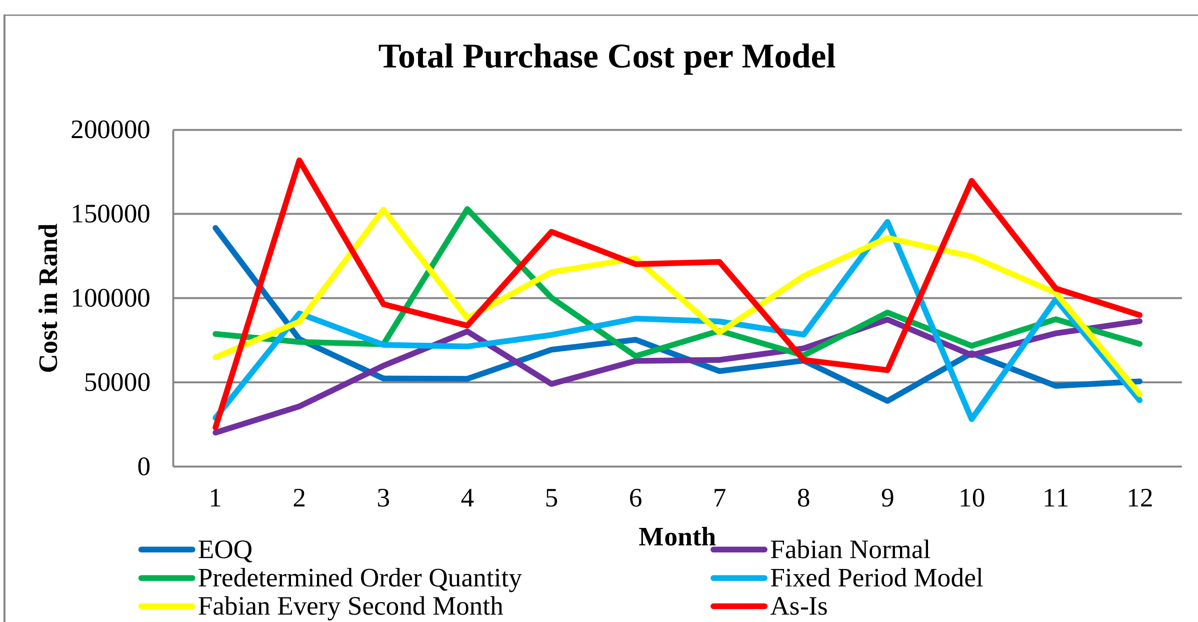

FIGURE 23: PER MODEL PURCHASE COST

Cost Parameter	A	B	C	D	E	F
Shortage Cost	1773	4385	3930	3279	3890	1007
Purchase Cost	289220	145391	57153	64761	85795	117404
Order Cost	936	608	468	468	468	780
Holding Cost	6251	6952	1867	7053	2038	1675
Total Cost	**298180**	**157336**	**63418**	**75561**	**92191**	**120866**

TABLE 22: MONTHLY COST RESULTS

EFFICIENCY RESULTS

Efficiency Parameter	A	B	C	D	E	F
Number of Tyres Purchased	47	56	46	60	124	85
Number of Shortages	15	37	33	28	10	8
Shortage (%)	32	66	72	46	8	10
Orders Made	10	20	13	15	7	6
Utilization (%)	100	88	100	82	40	58
RFQ Processing Time (hours)	17	33	22	25	12	10
RFQ Processing Time (%)	2	4	3	3	2	1

TABLE 23: MONTHLY EFFICIENCY RESULTS

7.1.2 SUMMARY OF YEARLY RESULTS

COST RESULTS (IN RAND)

Cost Parameter	A	B	C	D	E	F
Shortage Cost	21569	28796	47163	39392	49533	17301
Purchase Cost	1087207	1051375	685834	777135	715350	980032
Order Cost	5756	3276	5616	5616	5616	5616
Holding Cost	74435	102849	22405	84940	30838	18839
Total Cost	**1188967**	**1186296**	**761018**	**907083**	**801337**	**1021788**

TABLE 24: YEARLY COST RESULTS

EFFICIENCY RESULTS

Efficiency Parameter	A	B	C	D	E	F
Number of Tyres Purchased	595	621	549	722	589	666
Number of Shortages	182	243	398	332	394	146
Shortages (%)	31	39	73	45	71	23

Orders Made	116	135	156	108	175	79
Utilization (%)	99	95	100	82	100	89
RFQ Processing Time (Hours)	193	225	260	180	292	132
RFQ Processing Time (%)	2	3	3	2	3	2

TABLE 25: YEARLY EFFICIENCY RESULTS

7.2 WEIGH SOLUTIONS AGAINST CRITERIA

This section compares each of the solution alternatives by scoring points regarding the design criteria specified in Chapter 4.3. Each criterion can be scored between 0 and 5. Where a 5 indicates the best possible score and adherence to the criteria. At the end of the section each model will be given an overall score.

7.2.1 TECHNICAL CRITERIA

Criteria	B	C	D	E	F
Functionality	3	3	4	3	2
Ease of Use	3	3	4	5	5
Quality	3	4	4	5	4
Consistency	5	5	5	5	4
Orthogonality	5	5	5	3	2
Propriety	5	5	4	4	3
Generality	4	4	3	3	3

TABLE 26: TECHNICAL CRITERIA EVALUATION

7.2.2 COST CRITERIA

Criteria	B	C	D	E	F
Holding Cost	2	4	3	1	5
Shortage Cost	1	2	3	4	2
Purchase Cost	1	5	3	4	3
Total Cost	1	5	2	4	5
Order Cost	2	4	3	4	2

TABLE 27: COST CRITERIA EVALUATION

7.2.3 EFFICIENCY / EFFECTIVENESS CRITERIA

Criteria	B	C	D	E	F
Shortages	4	1	3	3	5
Utilization	4	5	2	5	2
RFQ Processing Time	3	2	4	1	5
Orders Needed	3	2	4	2	5
Quantity Purchased	3	5	1	4	2

TABLE 28: EFFICIENCY CRITERIA EVALUATION

7.2.4 PERFORMANCE METRICS

Metric	B	C	D	E	F
Inventory Cost	2	5	4	4	4
Reliability	3	2	3	3	5
Process Visibility	5	5	5	2	1
Responsiveness	3	4	3	4	1

TABLE 29: PERFORMANCE METRIC EVALUATION

7.2.5 TOTAL POINT ACCUMULATION

Criteria	B	C	D	E	F
Technical	28	29	29	28	23
Cost	7	19	14	17	17
Efficiency	17	15	1	15	19
Metrics	13	16	15	13	11
Total	**65**	**79**	**72**	**73**	**70**

TABLE 30: EVALUATION POINT ACCUMULATION

7.3 INTERPRETATION OF SIMULATION RESULTS

Only the solution model with the highest point score will be evaluated and interpreted. Reference may however be made to other solution models that score higher than the evaluated model. As seen in Table 31, the derivative of the Fabian et al (1958) model, evaluated every month, scored the highest number of points.

7.431 DERIVATIVE OF A TWO-PERIOD MODEL BY FABIAN ET AL (1958): RESULTS

COST RESULTS

The cost results clearly illustrate that the derivative of a two-period model by Fabian et al (1958) is the most cost effective model. The overall cost is the overall lowest and when compared to the as-is state of OPF, this model lowers cost by 64% or approximately R 427 949 per year. Monthly cost can also be reduced with 21% or approximately R 234 762 when using the Fabian model. This policy also provides the lowest holding and purchase cost yearly. However the downside of this model is the high shortage cost which is 46% higher than that of the as-is model. This creates controversy towards the model - it may be cost effective, however it will require personnel to constantly have to deal with tyre shortages which take time and effort. This model thus requires a trade-off decision between cost and comfort.

EFFICIENCY RESULTS

This model requires the lowest quantity of monthly and yearly tyre purchases. When comparing this to the utilization of tyres, one can clearly understand that this model uses a systematic process concerned with acquiring just the right quantity of tyres to operate the department. In both monthly and yearly cases this model shows a 100% utilization rate; thus using all the tyres bought throughout the month or year. From one perspective, this is good for the company as no excess stock is kept. On the other hand, this method is very risky and does not provide for safety stock being kept and if a countrywide tyre shortage is faced, the company will quickly run into problems. It is important to remember that the monthly results are averaged over the total year, thus, the results tabulated in Table 24 does not indicated whether or not the model purchases tyres for a one period or two period usages.

As stated in the cost results of section 7.3.1, this model increases shortages from 31% to 73% annually. The model gives this output as the cost per unit short at OPF is not exceptionally high. The model objective is also to minimize cost and thus does not take into account the total number of shortages. Due to the high shortage quantity, the number of orders made throughout a period is elevated as well. This explains the high processing times for this model as each order, normal or short, requires an RFQ to be created, authorized and processed. Section 7.5 evaluates the effect of incorporating a maximum number of shortages in the Fabian et al (1958) model.

As this is the most cost effective model, the supplier lead times were additionally calculated as well. Lead time when orders are placed after inspection (normal order placement) accumulated to 39 days and 5 hours over a year. Shortage lead time when stock outs occur (special order placement) accumulated to 32 days and 12 hours. When comparing these results to the total orders made, 6 hours of lead time per tyre is approximated to normal order placements and 2 hours to special order placement lead time per tyre. With any luck the suppliers in real life are just as committed to responsiveness.

PERFORMANCE METRIC RESULTS

It is imperative for the mathematical model to align according to the performance metrics, as these are the criteria against which a company weighs its success. The Fabian et al (1958) derivative model scored the highest point average in the metrics criteria which was 16 out of a possible 20. This already indicates that the model is well on its way to guarantee success at OPF. When considering inventory cost, this model has the second lowest total of R75 184. The reason for this model not having the lowest inventory cost is due to the extremely high shortage quantity that needs to be purchased throughout a year. In terms of respectable prediction abilities, the Fabian model is considered top notch, however the high quantity of shortages creates a paradox which in turn lowers the overall score for reliability. Section 7.4 evaluates the addition of a maximum shortage quantity for the purpose of increasing overall reliability of the model.

The process visibility of this model is exceptional. Not only is previous demand and price data used for the ordering calculations, the historic data is first analysed, evaluated and translated into a set distribution. This distribution has the ability to be updated constantly without affecting the overall ability and structure of the model. Responsiveness considers the timely ordering and delivery of goods; this Fabian model procures goods within a minimum lead time zone and ensures all demand will be met during a month at the lowest possible cost. Responsiveness will also be increased in the evaluation of the model with a maximum shortage quantity.

Overall this model scores 80% for performance metrics. The only lack in performance is due to the high shortages obtained by the model. As the model was not originally designed to reduce shortages, it fares exceptional in all other categories.

DESIGN CRITERIA RESULTS

The derivative of the Fabian et al (1958) model proved to be the top model on design criteria analysis. Considering the initial objectives of this project, "to improve the current tyre procurement department in terms of efficiency and effectiveness by means of cost reduction," (section 1.2), the Fabian model comes closest to achieving this due to its cost effectiveness.

Criteria	Score
Technical	83%
Cost	76%
Efficiency	60%
Metrics	80%
Total	**75%**

TABLE 31: DERIVATIVE OF A TWO-PERIOD MODEL DESIGN CRITERIA RESUTLS

7.4 MATHEMATICAL MODEL SENSITIVITY ANALYSIS

To investigate the sensitivity and the relationship between the output of the expected cost and the level of starting inventory, output from the mathematical model with regards to expected cost and inventory starting levels were compared. This sensitivity analysis was conducted through hand computed calculations. Each of the product types' Weibull and inventory parameters were used to calculate the expected cost against a predetermined inventory starting level.

This investigation shows a tendency of increasing cost as the inventory level rises. Certain types of tyres however show a high cost at low inventory levels with a steep drop as inventory reaches between 1 and 3. Following this drop is a slow increasing trend. This increase in the starting inventory level is due to the high build-up of holding cost of unused product. Another phenomenon occurs with 185x65x14 and 195x14 tyres; in the case of these tyres, the holding cost and procurement price of the product is fairly equal. Thus the expected cost against increasing inventory fluctuates immensely. With only a single inventory increase, the expected cost might increase or decrease with a few thousand Rands.

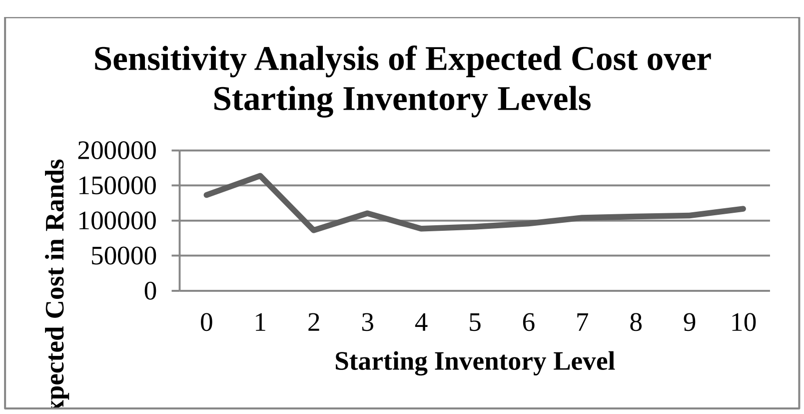

FIGURE 24: SUMMARY SENSITIVITY ANALYSIS OF EXPECTED COST OVER STARTING INVENTORY LEVELS

Figure 24 summarises the accumulated effect of the products on overall cost. Appendix E contains detailed graphs on the exact effect the inventory level has on each product cost. In essence it should be noted that the starting inventory level of tyres at OPF will significantly affect the total expected cost of monthly tyre procurement, whether or not a purely numerical or practical approach to the Fabian derivative model is incorporated.

When compared to already interpreted results, one can clearly understand why the Fabian et al (1958) derivative model tends to keep inventory at low levels. The lowest overall cost is achieved with an average inventory level of two products per tyre. Having an average lower than this increases the cost due to shortages and it incurs higher purchasing cost. When comparing the sensitivity analysis results to the simulation model results, it might seem that there exists controversy; however one must remember that not all of the tyre types have the most optimal price at such low inventories and due to high demand and price fluctuations, shortages occur more likely.

7.5 INCORPORATING A MAXIMUM SHORTAGE QUANTITY TO THE DERIVATIVE OF THE FABIAN ET AL (1959) MODEL

Due to the high shortages incurred by the Fabian et al (1958) derivative model, it was deemed vital to incorporate alterations into the solution. Meetings and interviews with the OPF management concluded that a maximum of three shortages will be allowed per tyre type per month. As twenty out of the thirty tyre types have average demands of one or lower a small chance exist that these tyres will run short, further reducing the total number of shortages. Table 32 summarizes the results for varying maximum shortage quantities to determine whether or not the maximum set by OPF still reduces the overall procurement cost.

Maximum Shortage Allowed	Total Cost per Month	Monthly Shortages
2	R 75 528.91	4
3	R 74 134.09	7
4	R 72 817.46	16
5	R 67 330.76	24

TABLE 32: COMPARISON OF MAXIMUM SHORTAGE QUANTITIES

To incorporate this maximum shortage quantity into the Fabian et al (1958) derivative model, an extra constraint is to be added to the computational equations of the model. This constraint ensures that the optimal cost parameters include shortages of lower than three for each tyre type.

$$M \leq 3 \; where \; M = Maximum \; Shortage \; Quantity \; Allowed$$

Compared to the Fabian et al (1958) model derivative discussed in section 7.3, the model with a maximum number of shortages of three per tyre offers a good alternative to having an unlimited shortage quantity. This option may not offer the lowest cost model, however shortages are reduced by 75%. This percentage translates to 131 hours of order preparation time. The incorporation of such a maximum shortage quantity still reduces the overall cost of OPF by 26% or R 319 359 annually.

Model	Shortages	Total Cost	Cost Comparison
Fabian et al (1958)	398	R 761 018	87%
Fabian et al (1959) with maximum shortage	79	R 869 608	

TABLE 33: COMPARISON OF RESULTS BETWEEN A MODEL WITH UNLIMITED SHORTAGES AND A MODEL WITH A MAXIMUM SHORTAGE QUANTITY

Working with a shortage lead time of 2 hours and a normal supplier lead time of 6 hours, the new overall delivery times for the altered model were calculated. The same number of orders is made in a year, with only the shortage quantity being less. Using these parameters the overall shortage lead time accumulates to 7 days and the normal supplier lead times to 39 days. Overall this decreases lead time by approximately 25 days or 35%. This dramatically reduces the occurrence of shortages during lead time periods.

The reduced shortages and lead times immensely increase the responsiveness and reliability of the model. Ensuring a 90% overall performance metric score. In terms of efficiency, the shortage and RFQ processing times are reduced significantly. Shortage cost is also reduced by 70%, however holding cost increases dramatically to level the trade-off.

Evidently the advantages of incorporating a maximum shortage level far override the negatives. This alteration of the Fabian et al (1958) derivative model is thus deemed the most suitable and optimal model for OPF. This model ensures high responsiveness and reliability, increased visibility in the system and a great reduction in management being tied up in unnecessary order processing and shortage related problems. The model ensures the main objective of the project is met by reducing overall cost dramatically. High utilization rates are achieved to ensure little or no inventory stays unused, while still accommodating for stock-out risks.

CHAPTER 8: INFORMATION SYSTEM DESIGN AND IMPLEMENTATION

8.1 INTRODUCTION

To implement the mathematical model at OPF as well as to replace the manual procurement system, an information system was designed which also increases visibility in the department. This information system, implemented as a database, reduces overall inspection time as well as order and purchase preparation times. This chapter outlines the process of designing a suitable and sensible information system to improve the current procurement system at OPF. Various user and system requirements are translated into functional elements to incorporate the core elements of the information system.

8.2 DESIGN METHODOLOGY

The design approach is based on the Systems Development Life-Cycle Policy created by the U.S House of Representatives (1999). This methodology consists of seven main phases:

a. Project Definition Phase
b. User Requirements Phase
c. System/Data Requirements Definition Phase
d. Analysis and Design Phase
e. System Build/ Prototype Phase
f. Implementation and Training Phase
g. Sustain Phase

The sustain phase is not included in this report as the project concludes with the implementation of the system.

8.2.1 PROJECT DEFINITION

The project definition phase includes the development of an objective, scope and system users. A work breakdown structure (WBS) was developed to ensure all activities are completed and included in the development. Furthermore different software and platform alternatives are compared in order to choose the most suitable software applicable to OPF.

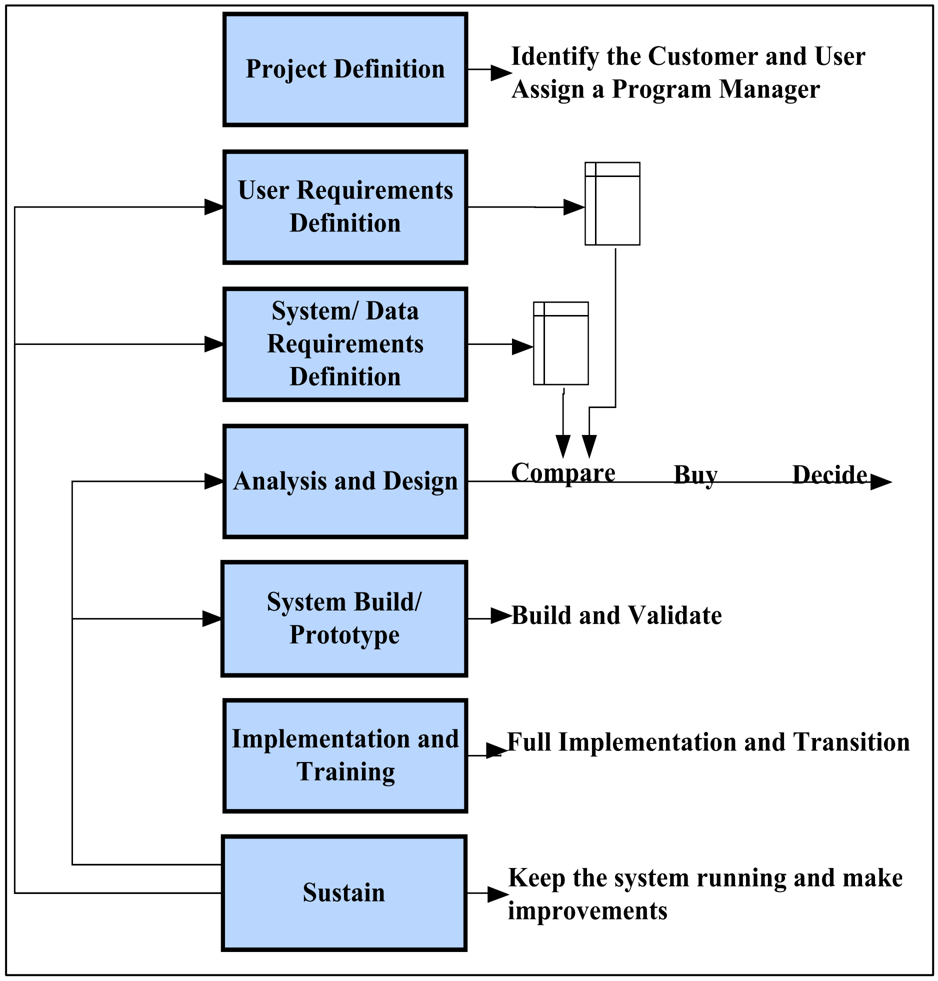

FIGURE 25: SYSTEMS DEVELOPMENT LIFE-CYCLE APPROACH

8.2.2 DEFINITION STATEMENT AND SCOPE

The information system was designed to increase visibility in OPF between different departments and products. The information system will incorporate the mathematical model solution (Chapter 4, 7) and serves as an interface for information required by the model. The information system contains input data to the model and uses output information from the model. The information system incorporates only vehicles from the OPF system at OR Tambo international airport.

Detailed payment and acquisition reports will not be included in the information system, as SAA requires OPF to enter this information directly into the SAP database. The system users only include the management of OPF who is responsible for the procurement of tyres and the management of the ground fleet.

8.2.3 WORK BREAKDOWN STRUCTURE

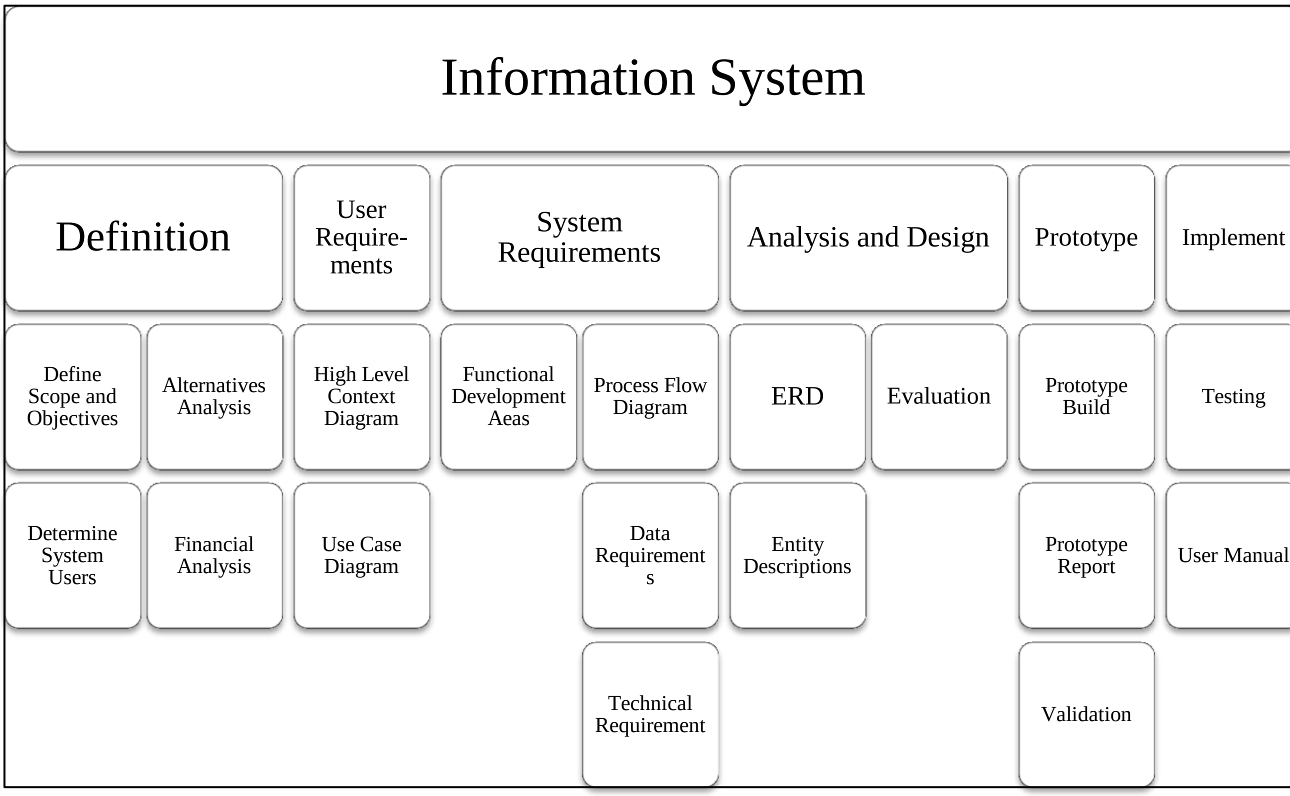

FIGURE 26: INFORMATION SYSTEM WORK BREAKDOWN STRUCTURE

It is important to develop a working WBS to ensure all aspects are considered and completed before testing and implementation of the information system occurs. The WBS sets out a logical flow of activities with set milestones and phases to be completed as the procedure continues.

8.2.4 ALTERNATIVES ANALYSIS

Before creating the database, the most suitable software was to be chosen. There are hundreds of database software on the market and a comparison was needed to determine the best fit for OPF. There exist mainly three types of database interfaces: desktop, server and web-enabled. In this comparison, desktop and server databases will be compared against pre-determined criteria. Web-enabled databases are excluded as such a database still requires either a desktop or server platform to be used.

Database type comparison:

Criteria	Desktop Database	Server Database
User Related	Most suitable for single users	Multi-user interfaces
Web Interaction	May offer web solutions	Offers web integration
Cost	Inexpensive	Expensive
Ease of Use	User friendly	Heavy duty, powerful performance

Flexibility	Limited Flexibility	Highly flexible
Database Size	Limited data storage capability	Scalable – easy increase in database storage capability

TABLE 34: SERVER AND DESKTOP DATABASE COMPARISON

In addition to the information system platforms, various software alternatives exist in each category. According to Chapple (2013), the following desktop and server-based software are the best on the market: MS Access, Filemaker Pro, Alpha Five, Paradox, MS SQL Server, Oracle Personal Edition and IBM DB2.

Desktop database comparison:

MS Access	Filemaker Pro	Alpha Five	Paradox
Tight integration with other MS Office products	Popular with Macintosh users	Targeted at database beginners	Integration with other database software
Good online support	Intuitive, user-friendly	User friendly, ease of use	Not as user friendly as other software
Great front end	Integration compatibility with MS Office	Only available directly from manufacturer	Need to buy entire WordPerfect Office Suite to use
Can be used as a stand-alone product		Great for web development	
R2000	R3000	R2000	R5000

TABLE 35: DESKTOP DATABASE SOFTWARE COMPARISON

Server database comparison:

MS SQL Server	Oracle Personal Edition	IBM DB2
Free for personal use	High capabilities	XML Support
Easy to use and understand	Less user friendly	Designed with developers in mind
Expensive enterprise licence	Difficult to implement	
	High volumes and capacity	
R20000	R5600	R8000

TABLE 36: SERVER DATABASE SOFTWARE COMPARISON

MS Access was ultimately chosen as the best database software to be used. The developer is familiar with the software and no SQL language training is required. OPF also has an MS Access licence and thus no initial cost will be incurred. MS Access is easy to understand, user-friendly and easy to implement. The software is able to integrate with MS Excel to ensure integration with the mathematical model. Previously created Excel spread sheets has the ability to be read into MS Access, thus reducing the quantity of initial information transfers.

8.3 USER REQUIREMENTS DEFINITION

In the development of any system or product, user requirements are of the utmost importance to ensure a usable and feasible end product. No matter how practical and technologically advanced a product might be, if the user does not want it – it is ultimately useless. The user requirements phase starts at a high level investigation into the needs and requirements of OPF and the users involved in the information system. A high-level context diagram translate main requirements into system functions whereas the Functional Operating Area analysis digs deeper into the per activity requirements of the users. To conclude, the phase describes each of the user requirements as a requirements document.

CONCEPT OF OPERATIONS

The context diagram denotes the high-level interactions of the user with the system. The information system is essentially divided into four main categories that describe the main functions the database will provide. Essentially OPF wants to input information for vehicles and tyres. These categories are further broken down into vehicle maintenance and tyre purchases. The concept of operations looks at the core of the information system and the purpose for its development.

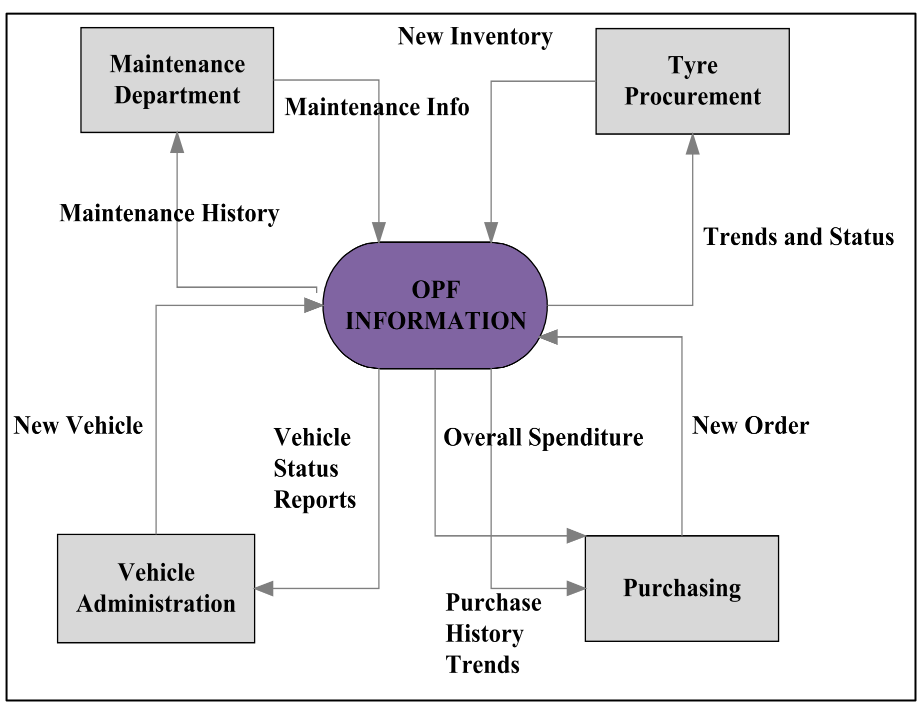

FIGURE 27: INFORMATION SYSTEM DESIGN CONTEXT DIAGRAM

FUNCTIONAL OPERATING AREAS

According to The House of Representatives (1999) the core business processes can be divided into major groupings called Functional Operating Areas (FOA). The processes within each of these FOA's are candidates for becoming the system functional requirements. By identifying the functional requirements, one can begin to identify the related technology areas early in the development process.

To determine and evaluate the FOA's and functional requirements, a Use Case diagram was developed to provide the main activities performed by the external system users. OPF has the following FOA categories:

a. Vehicle Operations
b. Tyre Operations
c. Maintenance Operations
d. Purchasing
e. Ordering
f. Deliveries
g. Procurement Model

Three main actors to the system were also identified:

a. Vehicle Management
b. Tyre Procurement Management
c. Finances

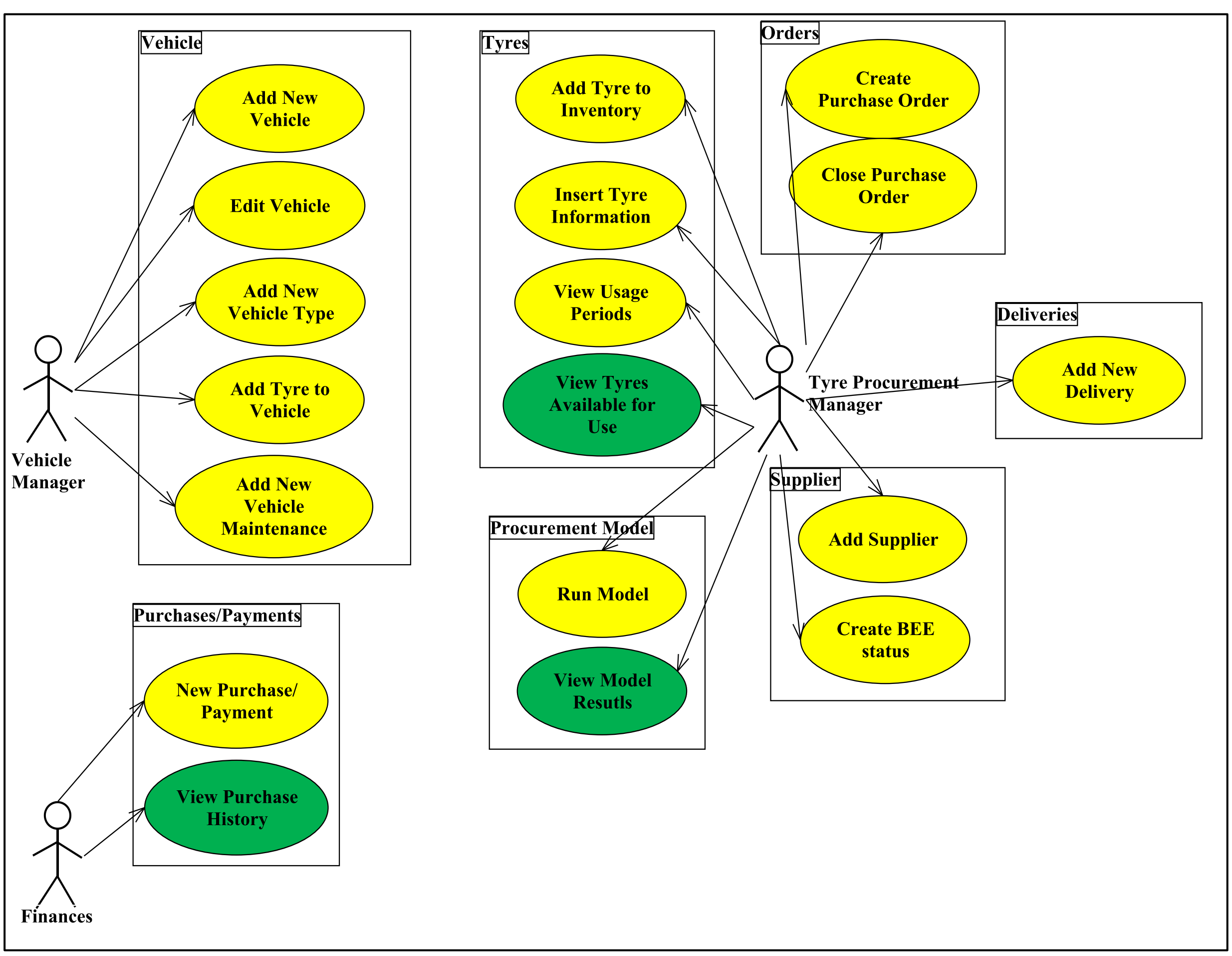

FIGURE 28: INFORMATION SYSTEM DESIGN USE CASE DIAGRAM

The Use Case diagram depicts the activities each of the system actors want to perform as well as high-level feedback expected from the system. Each of the FOA categories can now be translated into a list of activities outlined in the user requirements document.

USER REQUIREMENTS

Requirement	**Description**
User login	User logs in as a specific database user with appropriate parameters.
Add to inventory	The user inserts information for a new tyre purchased. Each tyre is identifiable with an identification number.
Delete inventory	The user needs to be able to remove any information of product not in inventory anymore.
View inventory	The user needs to be able to view the entire inventory available.
Add vehicle	The user needs to be able to insert information regarding a new vehicle in the department.
View vehicle information	The user needs to be able to view all the necessary information regarding a single vehicle in the system.
Delete vehicle Information	When a vehicle is sold or not in use, the user must be able to delete the relevant information and records.
View vehicle market value	It is necessary for the user to view information regarding the value of a vehicle in the system.
View tyre cost centre purchases	The user needs to be able to view and interpret purchase information allocated to each of the cost centres in the system.
Create new order	A new order can be created by a user.
View and edit orders	The user needs to be able to view and change information for all or a single order.
Add tyres to orders	The user needs to be able to insert information on the product that needs to be ordered. An order must be capable to take information for more than one product type.
Add tyre fit to vehicle	It must be possible for a user to link the information of a specific tyre to a specific vehicle when a tyre of a vehicle is changed.
View vehicle fits	The user must be able to view all the tyres in inventory that are fitted to a specific vehicle.
View tyre usage	The user must be able to view the period a tyre was fitted to a vehicle.
Add new purchase	A new purchase can be entered by the user.
Close an order	It must be possible for a user to close an order that has been fulfilled.
View purchases	The user needs to be able to view all purchase information for a certain period of time.
View individual purchase	It is necessary for a user to be able to view the information regarding a single

information	purchase.
View demand trend	A user must be able to view and interpret a trend in tyre demand data.
View price trend	A user must be able to view and interpret a trend in tyre price data.
Add delivery	A new delivery can be added by a user.
View delivery history	It must be possible for a user to view previous delivery information.
Add vehicle maintenance	A user must be able to add new information regarding vehicle maintenance.
Update vehicle status	The status of a vehicle must be updateable by the user.
View tyre use availability	The user must be able to determine how much product is available for use.
Edit and close vehicle maintenance	The user must be able to edit and close maintenance records for certain vehicles.
View Inventory	Inventory information must be viewable by users.
Run procurement model	The user needs to be able to activate the mathematical procurement model from within the information system.
View procurement model results	The user needs to be able to view and interpret the results of the procurement model.
Edit or add procurement model parameters	It is necessary for the user to be able to edit of add parameters relating to the procurement model and related tyres.

TABLE 37: INFORMATION SYSTEM DESIGN USER REQUIREMENTS

8.4 SYSTEM REQUIREMENTS DEFINITION

The system requirements translate the user requirements into the functional abilities of the information system. The user requirements require the system to be able to perform certain tasks. Furthermore the system requirements include automation and non-functional activities.

Requirement	Description
Integrates with MS Excel	The information system will be able to interact and exchange information from MS Access to and from MS Excel
MS Excel integrates with OCTAVE	The MS Excel information will be able to interact and exchange information with OCTAVE*.
Automated update if one feature is changed	The information system will be able to link information and to update the relevant data if a feature is changed.
User friendly	The information system needs to be user friendly and understandable for non-computer trained users.
Security	The information system should offer a secure platform for OPF to manage information.
User Identification	The information should be able to recognise specific users and act accordingly.
Opens new forms with buttons	The information system should incorporate buttons for the transfer and

	switching between information.
Prompts for save	The information system should ensure that all data entered is saved before navigating to other information.
Reporting	The information system must be able to create reports with the relevant information required by the user.
No duplicates	The information system should ensure that no information is duplicated.

TABLE 38: INFORMATION SYSTEM DESIGN SYSTEM REQUIREMENTS

* OCTAVE will be explained in section *Model Design*.

8.5 SYSTEM DESIGN

The system design phase translates the user and system requirements as well as the project definition into operational activities and system capabilities. The system is summarized by the use of an Entity Relationship diagram (ERD) which incorporates all the information required and used by the system as well as the user. Each of the entities in the ERD are expanded and described. This phase concludes with the incorporation of the mathematical procurement model into the system.

SYSTEM DESIGN

The Entity Relationship diagram (ERD) divides the system into eight modules described by fifteen entities or tables. Each of these tables interacts with each other through a relationship. An entity can be related to another with one of the following relationships:

a. One-to-Many: In this relationship, one entity can be related to one or many instances of another entity.
b. One-to-One: In this relationship, one entity can be related to only one instance of another entity.

These relationships enable the system to store and read information across the system and enables modules to interact with one another.

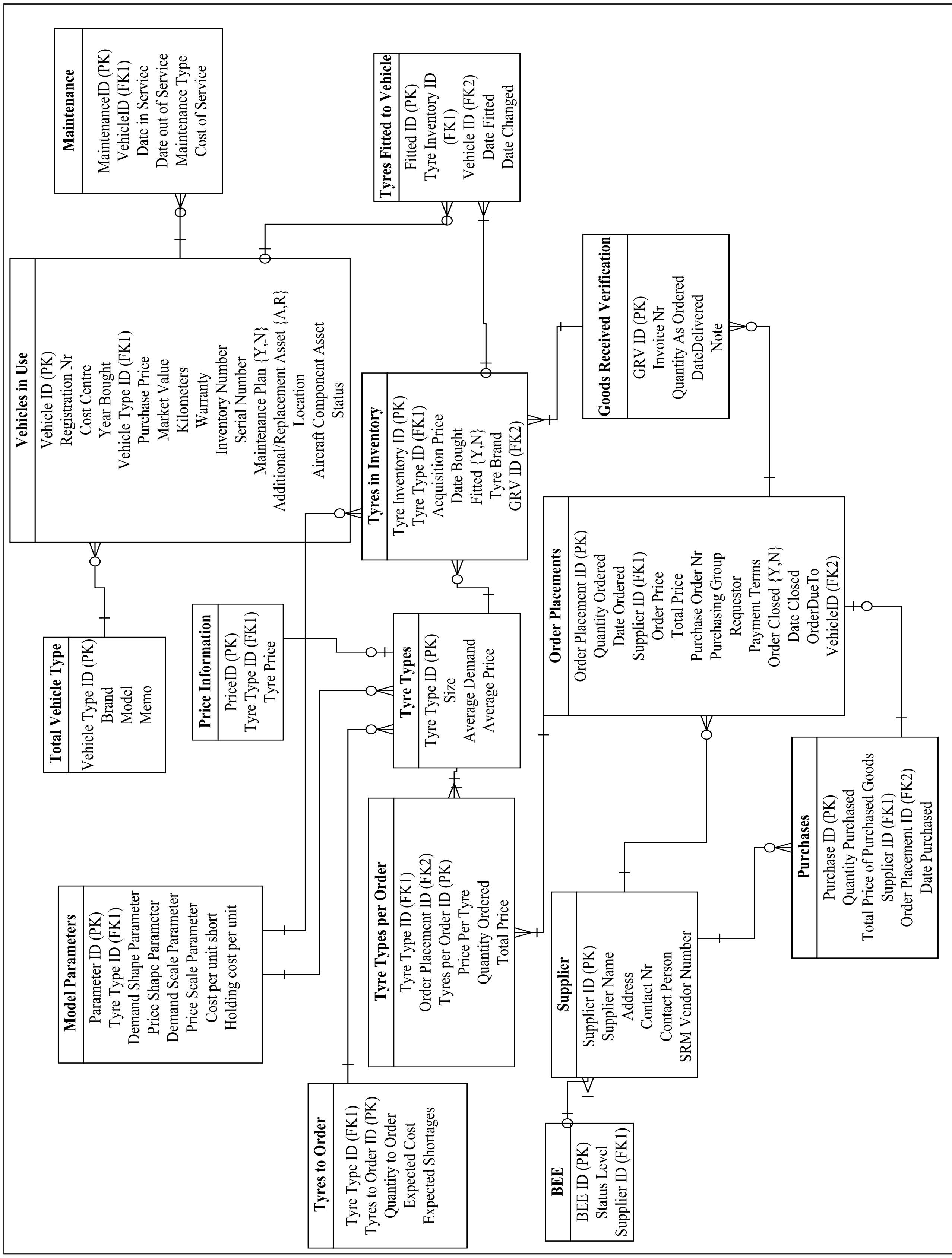

FIGURE 29: OPF INFORMATION SYSTEM ENTITY RELATIONSHIP DIAGRAM

MODULES

For optimal functionality and logical flow, the information system is categorised into eight modules. Each of these modules relate to a functional area of the database. In other words, a module can be seen as a system related to the supra-information system, which in turn exists out of several sub-systems and smaller functional areas. Figure 30 summarizes the different modules to be used.

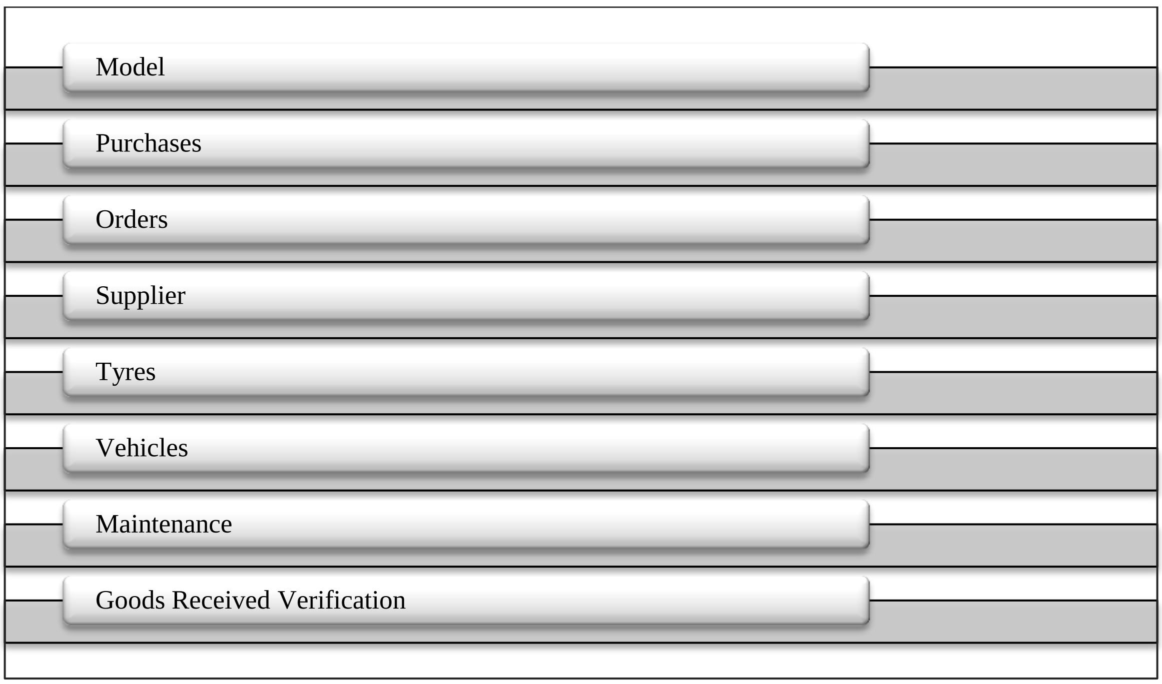

FIGURE 30: OPF INFORMATION SYSTEM MODULE DESIGN

TABLES

Table 40 describes each of the tables used in the ERD. Tables relate to the information held by all different entities and can be seen as a sub-system of the modules discussed above. This information identifies an entity instance and is used to develop reports and information trends.

Table Name	**Description**
Model parameter	Holds information on Weibull and parameter information used by the procurement model.
Tyres to order	Holds information on the results given by the procurement model.
BEE	Holds information on supplier BEE status and level.
Supplier	Holds information per supplier such as supplier name, address and SRM Vendor Number.
Purchases	Holds all information required to make a purchase.
Order Placements	Holds all information necessary to set an order.
Goods Received Verification	Holds all information regarding tyre deliveries.

Tyres fitted to Vehicle	Holds all information of tyres fitted to vehicles.
Tyres in Inventory	Holds all inventory information.
Tyre Types	Holds information on each of the different tyre types.
Tyre Types per Order	Holds information regarding all tyres in one order.
Vehicles in Use	Holds information on all vehicles at OPF.
Maintenance	Holds information on all maintenance done on vehicles.
Vehicle Types	Holds information on each of the different vehicle types at OPF.
Price Information	Stores historic information on tyre prices to be used by the procurement model.

TABLE 39: OPF INFORMATION SYSTEM DESIGN TABLES

REPORTS

Furthermore the information system is broken down into reports. Reports summarize main data, specified by the user, which relate to module instances. Reports are also useful in linking information across tables and modules. Table 40 describes the reports that will be available in the OPF database.

Report Name	**Description**
Model Results	Detailed results on the quantity of tyres to procure as evaluated by the mathematical model.
Closed Orders	Detailed information on the quantity of fulfilled orders during a specified period.
Open Orders	Detailed information on the quantity of yet to be fulfilled orders during a specified period.
Purchase History	Information on purchases acquired during a specified period of time.
Purchases per Cost Centre	Information regarding purchases made by each separate cost centre.
Purchases per Tyre type	Information on purchases regarding each type of tyre.
Shortages per Period	Detailed information explaining the quantity of shortages that occurred during a specified period.
Purchases per Supplier	Information on purchases made to separate suppliers.
Supplier Information	Detailed information on each of the suppliers OPF purchases from.
Total Maintenance History	Information on all previous maintenance activities performed on a vehicle.
Tyre Usage per Period	Information on the period a tyre was fitted to a certain vehicle.
Tyres in Stock	Inventory information on the quantity of tyres currently in possession by OPF that are not fitted to vehicles.
Tyres Fitted to Vehicles	Information on all tyres in inventory currently fitted to a specific vehicle.
All Tyres in Inventory	Inventory information on the quantity of tyres currently in possession by OPF.
Tyres Fitted per Cost Centre	Information on tyres fitted to vehicles in a specified cost centre.
Vehicles per Cost Centre	Vehicle information pertaining to information on a certain cost centre.
Vehicles per Brand	Vehicle information categorised by the vehicle make and brand.

TABLE 40: OPF INFORMATION SYSTEM DESIGN REPORT DESCRIPTIONS

MODEL DESIGN

The mathematical model integrates with the information system through a software program containing the logic behind the model. The software used to program the model is OCTAVE, a powerful numerical calculation software that is easy to use and implement. OCTAVE was chosen as it is an open product and provides the basic built in functions to aid in the calculation of integrals and differentials. Appendix E contains the programming code used.

Unfortunately OCTAVE cannot directly integrate with MS Access, and thus MS Excel was used as a linkage between the software. The MS Excel files imports information directly from MS Access containing data on the mathematical model parameters. OCTAVE reads the information and as an output provides MS Excel with results. In conclusion MS Excel exports the results back into the OPF database to be used by the information system user.

8.6 IMPLEMENTATION AND TRAINING

VALIDATION AND VERIFICATION

To ensure validity and credibility of the system, the necessary validation and verification techniques were used. Verifying the information system involved hands-on testing from the OPF users to determine whether or not the information entered were followed through to each of the different modules where it needed to be accessed and available. Input from different users was double checked to see if the databases matched and where errors occurred. The relationships between tables were evaluated by attempting to manipulate the system and creating double entries where only one is allowed.

IMPLEMENTATION PLAN

The final information system, incorporating the mathematical model, was implemented at OPF by means of a compact disk (CD) application. The CD contains all the relevant files and folders needed to run and use the information system. A detailed user manual containing all the relevant information on the system was written and included in the CD package. Meetings and information transfers were done to transpose the manual system onto the computer-based information system. OPF is now able to enter information quickly and efficiently and have access to historical records and procurement policies.

The information system successfully increases visibility between processes at OPF as tyres can be directly linked to vehicles. Vehicles are also directly linked to cost centres and all transactions can be traced back to the purchaser and the exact inventory which was purchased. The incorporation of the mathematical procurement model allows the OPF management to make hands-on, calculated procurement decisions, with the risk of procurement already evaluated.

OPF is to further test the information system, to provide feedback for future improvements. Within the next two years, the information system will accumulate sufficient data for an even more accurate procurement policy. This will also allow the department to implement demand and price forecasting to ensure accurate information is provided to the system.

CHAPTER 9: CONCLUSION

It is apparent that OPF requires an all-inclusive inventory system which promotes the procurement of tyres and furthermore increases efficiency and visibility in the department. A large amount of problems exist in the department that necessitates attention and the range of the project is impeccably Industrial Engineering related. Additionally a gap exists in modern research and investigations around inventory policies can contribute to the literature base.

When considering the data analysis it is crystal clear that OPF has various problems and is not addressing them. There is no sufficient inventory management system in place and this project is the first to address the involvement of inventory costs in the decision making when procuring products. The analysis concludes that there is insufficient data for accurate solutions to be formulated and various assumptions were made. The as-is simulation model confirms that there are various problems since OPF spends more than R1 000 000 annually on tyre procurement alone. This high cost is largely due to shortages occurring outside of inspection periods.

To address the problem at hand this report focused on different inventory policy solution alternatives. This includes an EOQ model with backorders, a predetermined fixed order quantity model, a fixed time period model as well as a derivative of a two-period dynamic programming model by Fabian et al (1958). Simulation of this model show that the Fabian et al (1958) model decreases total overall inventory costs by 46% and has an overall design criteria score of 74%, making it the best model out of the ones tested. With this model OPF can save up to R 400 000.00 on tyre procurement annually, however this solution does increase the quantity of shortages.

To eliminate the high shortage quantity created by the Fabian model, alterations were made to include the use of a maximum shortage quantity that is allowed per tyre type. This solution decreases the shortage quantity of the original model by 73%. In turn this decreases the time spent on processing and filing orders as well as the risk of shortages occurring during delivery lead times. In total, the altered model decreases the total cost of OPF by 26% or R 319 359 annually.

The solution model is implemented with the incorporation of an information system consisting of a database as well as a software program. This information system aims to replace the OPF manual system as well as to increase visibility in the department.

According to the literature review, space still exists for research involving inventory control whereas the solution development aims to contribute to the knowledge base. Data analysis shows that OPF was in dire need of a new inventory management system which is solved through the development of a mathematical solution model and information system. As shown by the simulation model, OPF is currently spending over R 1 000 000 on tyre procurement annually which include more than a 100 shortages each year. As stated above, the derivative of the Fabian et al (1958) model with maximum shortage level will attempt to reduce the cost by 26% and the shortage quantity by 25%.

The problem solution is well on its way to produce enhanced inventory management, cost reduction and system visibility at OPF.

CHAPTER 10: REFERENCES

1. Andric, B., et al. (2005) *Modelling Inventory Control Process Using Colored Petri Nets*, paper presented at The 7th Balkan Conference on Operational Research, Romania, Constanta: University of Belgrade.

2. Arda, Y. and Hennet, J. (2006) *Inventory Control in a Multi-Supplier System*. International Journal of Production Economics, 104 (2), p.249-259.

3. Bagchi, S. and Sudararaghavan, P. (2013) *Multi-Period Sourcing Strategy Under Demand and Supply Uncertainty With Two Suppliers*. [online] Available at: http://www.pomsmeetings.org/ConfProceedings/025/FullPapers/FullPaper_files/025-0871.pdf [Accessed: 26 Mar 2013].

4. Bazaraa, M. et al. (1973) *Inventory Models with a Mixture of Backorders and Lost Sales*. Naval Research Logistics, 20 (2), p.255-263.

5. Bijvank, M. (2009) *Service Inventory Management Solution Techniques for Inventory Systems without Backorder*s. Ph.D. University of VRIJE.

6. Boctor F.F. and Bolduc M.C. (2012) *The inventory replenishment planning and staggering problem revisited*. *CIRRELT*, Working paper.

7. Boost.org (2000) *Triangular Distribution - 1.38.0*. [online] Available at: http://www.boost.org/doc/libs/1_38_0/libs/math/doc/sf_and_dist/html/math_toolkit/dist/dist_ref/dists/triangular_dist.html [Accessed: 1 May 2013].

8. Businessdictionary.com (n.d.) *What is order policy? Definition and Meaning*. [online] Available at: http://www.businessdictionary.com/definition/order-policy.html [Accessed: 27 Mar 2013].

9. Carley, K. 1996. Validating Computational Models. [report] Carnegie Mellon University.

10. Chapple, M. 2013. Choosing a Database for Your Organization. *About.com*.

11. Connecticut Licensing Info Center (2009) *SCORE - Inventory Control.* [online] Available at: http://www.ct-clic.com/newsletters/customer-files/inventory0602.pdf [Accessed: 27 Mar 2013].

12. Dada, M. et al. (2003) *A Newsvendor Model with Unreliable Suppliers*. [Report] . University of Illinois at Urbana: Krannert Graduate School of Management.

13. Drake, M. and Marley, K. (2010) *A Simulation to Illustrate Periodic-Review Inventory Control Policies.* Spreadsheets in Education (iJSiE), 4 (2).

14. Encyclopedia Britannica. 2013. *information system*. [online] Available at: http://www.britannica.com/EBchecked/topic/287895/information-system [Accessed: 17 Sep 2013]

15. Fabian, T. et al. (1958) *Purchasing Raw Material on a Fluctuating Market*. Operations Research, 7 (1), p.104-122.

16. Federgruen, A. and Heching, A. (1999) *Combined Pricing and Inventory Control under Uncertainty*. Operations Research, 47 (3), p.454-475. Available at: http://0-www.jstor.org.innopac.up.ac.za/stable/223116 [Accessed: 7 March 2013].

17. Flynn, J. and Garstka, S. (1990) *A Dynamic Inventory Model with Periodic Auditing*. Operations Research, 38 (6), p.1089-1103. Available at: http://0-www.jstor.org.innopac.up.ac.za/stable/170974 [Accessed: 7 March 2013].

18. Francis, D. et al. (2002) *Optimal Stock Allocation for a Capacitated Supply System*. Management Science, 48 (11), p.1468-1501.

19. Frank, K. et al. (1999) *Optimal Policies for Inventory Systems with Priority Demand Classes*. [report] Ann Arbor: University of Michigan

20. Ganeshan, R. (1999) *Managing supply chain inventories: A multiple retailer, one warehouse, multiple supplier model.* International Journal of Production Economics, 59 (3), p.341-354.

21. Gbolagade, K., et al. (2012) *Computer Simulation for Inventory Control.* Scholarly Journal of Mathematics and Computer Science, 1 (1), p.1-5.

22. Glock, C. (2011) *A Multiple-vendor Single-buyer Integrated Inventory Model with a Variable Number of Vendors*. Computers and Industrial Engineering, 60 (1), p.173-182.

23. Golabi, K. (1985) *Optimal Inventory Policies when Ordering Prices are Random.* Operations Research, 33 (3), p.575-588. Available at: http://0-www.jstor.org.innopac.up.ac.za/stable/170559 [Accessed: 7 March 2013].

24. Grossman, T.A.. (1999) *Why Spreadsheets Should Be in OR/MS Practitioners' Tool Kits*. OR/MS Today 26(2), 20-21

25. Harris, F. (1913) *How Many Parts to Make at Once. Factory*, The Magazine of Management, 10:135–136, 1913.

26. Holton, J. (2005) *Order Policy Analysis and Recommendations*. [online] Available at: http://www.symphonyconsult.com/whitepapers/Orderpolicy.pdf [Accessed: 27 Mar 2013].

27. Hum, S. et al. (2005) *Staggering Periodic Replenishment in Multivendor JIT Environments*. Operations Research, 53 (4), p.689-710.

28. Information Systems Within Organizations. 2007. [report] Prentice Hall.

29. Jacobs, F. R., Chase, R. B., & Jacobs, F. R. (2010). *Operations and Supply Chain Management.* New York, McGraw-Hill Irwin.

30. Jin-Song, H. and Hui, Z. (2009) *A Minimax Distribution Free Procedure for Fuzzy Mixed Periodic Review Inventory Model"*, paper presented at Intelligent Computation Technology and Automation, 2009. ICICTA '09. Second International Conference on , 10-11 October. p.vol 2. pp. 637-640.

31. Kopytov, E. and Muravjovs, A. (2011) *Simulation of Inventory Control System for Supply Chain "Producer-Wholesaler-Client" in Extendsim Environment*, paper presented at 25th European Conference on Modelling and Simulation, Transport and Telecommunication Institute.

32. Kumaran, M. and Vijayan, T. (2008) *Inventory Models with a Mixture of Backorders and Lost Sales Under Fuzzy Cost* .European Journal of Operational Research, 189 (1), p.105-119.

33. Marcikic, A. and Radovanov, B. (2006) *Simulation in Inventory Management.* [report] Siberia: Faculty of Economics Subotica University of Novi Sad

34. Minner, S. (2002) *Multiple-supplier Inventory Models in Supply Chain Management: A Review*. Int. J. Production Economics, 81 p.265-279.

35. Maria, A. (1997) *Introduction to Modelling and Simulation.* Winter Simulation Conference, Binghamton.

36. Moinzadeh, K. and Nahmias, S. (1988) *A Continuous Review Model For An Inventory System With Two Supply Modes*. Management Science, 34 (6), p.761-773.

37. Moinzadeh, K. and Schmidt, P. (1991) *An (S-1, S) Inventory System with Emergency Orders*. Operations Research, 39 p.308-321.

38. Montgomery, D. and Runger, G. (2007) *Applied Statistics and Probability for Engineers*. Hoboken, NJ: Wiley.

39. National Research University – Higher School of Economics (2011*) Designing Simulation Models for Inventory Management Analysis in Supply Chains*. [online] Available at: http://www.xjtek.com/upload/books/Maxim%20Rojkov.pdf [Accessed: 14 May 2013].

40. Ouyang, L.Y. and Chang, H.C. (2001) *The Variable Lead Time Stochastic Inventory Model with a Fuzzy Backorder Rate*. Journal of the Operations Research Society of Japan, 44(1), p.19-33.

41. Palmius, J. 2007. "Criteria for Measuring and Comparing Information Systems", paper presented at 30th Information Systems Research Seminar, Scandinavia, Mid Sweden University.

42. Pan, J. and Hsiao, Y. (2001) *Inventory Models with Back-order Discounts and Variable Lead Time*. International Journal of Systems Science, 32 (7), p.925-929.

43. Peijun, G. (2010) *Research on Pricing-Inventory Models for New Products under Uncertainty*, paper presented at Service Systems and Service Management (ICSSSM), 2010 7th International Conference on, 28-30 June. p.1-5.

44. Pope, J. (1981) *An Inventory Management Simulation*. Journal of Experiential Learning and Simulation, 3 (4), p.: 261-269. Available at: http://sbaweb.wayne.edu/~absel/bkl/.%5Cjels%5C3-3n.pdf.

45. (2011) *Preference Points Claim Form in Terms of the Preferential Procurement Regulations*. Preferential Procurement Policy Framework Act, SBD 6.1

46. Saipe, A. (1979) *Diagnosing Production-inventory Systems using Variance Analysis*. INFOR 17(1), 42-51.

47. Scarf, H. (1960) *The Optimality of (s, S) Policies in the Dynamic Inventory Problem*. In K.J. Arrow, S. Karlin, and P. Suppes, editors, Mathematical Methods in the Social Sciences, chapter 13. Stanford, Calif.: Stanford University Press.

48. Silver, E.A. (2008) *Inventory Management: A Tutorial, Canadian Publications, Practical Applications, and Suggestions for Future Research.* Information Systems and Operational Research, 46, p.15–28.

49. Silver, E.A. (1974) *Operations Research in Inventory Management: A Review and Critique*. Operations Research, 29(4) p.628-645.

50. Sqa.org.uk. 2013. *Advantages and Limitations*. [online] Available at: http://www.sqa.org.uk/e-learning/MDBS01CD/page_04.htm [Accessed: 17 Sep 2013].

51. Tang, X. and Wang, L. (2007*) Research on Pricing-Inventory Models for New Products under Uncertainty*, paper presented at Management Science and Engineering, 2007. ICMSE 2007. International Conference on, 20-22 Aug. Chengdu: Chengdu Neusoft Inst. of Inf., p.1133-1138.

52. U.S House of Representatives. 1999. *Systems Development Life-cycle Policy*. [report] Washington D.C: U.S House of Representatives.

53. Winston, W. (2004*) Introduction to Probability Models*. 4th ed. Belmont: Brooks/Cole Cengage Learning, Chapter 4.

54. Zabawa, J. and Mielczarek, B. (2007) *Tools of Monte Carlo Simulation in Inventory Management Problems.* paper presented at s 21st European Conference on Modelling and Simulation, Wrocław: Wroclaw University of Technology.

CHAPTER 11: APPENDICES

APPENDIX A – SKEWNESS AND KURTOSIS RESULTS

DEMAND

Tyre	Average	StDev	Skewness		Kurtosis	
1000x20	1	0.728431	0.96671683	NORMAL	-0.3487762	NEAR NORMAL
1100x20	4	3.953339	2.3924087	SKEW	5.82007222	UNEFFICIENT DATA
11x22.5	0	0.989172	3.56526521	SKEW	13.0519084	UNEFFICIENT DATA
1200x24	1	0.2	-0.4335027	NORMAL	-1.6818613	NEAR NORMAL
1400x25	0	0.2	3.87298335	SKEW	15	UNEFFICIENT DATA
145x80x10	1	0.185577	0.32453671	NORMAL	-2.2405303	UNEFFICIENT DATA
14x9x28	0	0.4	1.67208193	SKEW	0.8974359	NEAR NORMAL
1600x25	1	0.319438	-0.4464599	NORMAL	-0.8140364	NEAR NORMAL
16x9x30	0	0.132781	0.21276158	NORMAL	-2.4444444	UNEFFICIENT DATA
175x80x14	0	0.3	3.87298335	SKEW	15	UNEFFICIENT DATA
205x60x15	0	0.3	3.87298335	SKEW	15	UNEFFICIENT DATA
205x65x15	0	0.2	-1.1147213	SKEW	-2.3333333	UNEFFICIENT DATA
28x19x15	1	0.723627	1.1763539	SKEW	-0.7342657	NORMAL
300x15	1	0.5	3.87298335	SKEW	15	UNEFFICIENT DATA
315x80x22.5	1	0.451541	1.77120184	SKEW	2.35946971	UNEFFICIENT DATA
385x95x25	0	0.3	-3.8729833	SKEW	15	UNEFFICIENT DATA
400x4	3	1.42361	0.22254369	NORMAL	-1.7004049	NEAR NORMAL
400x8	2	1.58575	-0.1489609	NORMAL	-2.3076923	UNEFFICIENT DATA
500x8	1	0.970086	1.14328791	SKEW	-0.2386914	NORMAL
650x10	3	2.126552	1.24039442	SKEW	-0.002789	NORMAL
700x16	2	1	-1.1147213	SKEW	-2.3333333	UNEFFICIENT DATA
750x6	2	0.983192	1.14355168	SKEW	-0.0268911	NORMAL
825X15	0	0.5	3.87298335	SKEW	15	UNEFFICIENT DATA
900x16	1	0.04714	0.78822698	NORMAL	-1.6153846	NEAR NORMAL
900x20	1	0.282843	-0.2043551	NORMAL	-1.8990187	NEAR NORMAL
155x13	1.00	0.62361	-0.1489609	NORMAL	-2.3076923	UNEFFICIENT DATA
165x80x13	3.00	0.499632	-0.3864583	NORMAL	-1.5383997	NEAR NORMAL
185x65x14	6.00	6.715173	3.19903504	SKEW	10.987838	UNEFFICIENT DATA
195x14	5.00	1.569147	-0.107885	NORMAL	2.83911809	UNEFFICIENT DATA
195x15	5.00	2.995582	0.38198587	NORMAL	-0.6000001	NORMAL

TABLE 41: DEMAND SKEWNESS AND KURTOSIS RESULTS

PRICE

Tyre	Average	StDev	Skewness		Kurtosis	
1000x20	3407.714	295.8135	0.19445277	NORMAL	-1.0504363	NEAR NORMAL
1100x20	3041.974	616.0871	1.04703951	SKEW	1.27720944	NEAR NORMAL
11x22.5	2946.143	306.3231	0.31482328	NORMAL	-1.8783254	NEAR NORMAL
1200x24	5119.519	1562.195	0.78789255	NORMAL	-0.9386175	NORMAL
1400x25	12335.2	909.9258	-0.4074781	NORMAL	-2.9749682	UNEFFICIENT DATA
145x80x10	406.4286	28.74945	1.15859452	SKEW	1.2608834	NEAR NORMAL
14x9x28	1737.667	1331.296	1.97965835	SKEW	3.92952931	UNEFFICIENT DATA
1600x25	17892.14	2985.554	1.62461147	SKEW	2.75781408	UNEFFICIENT DATA
16x9x30	6025	310.4717	-0.9006596	NORMAL	1.06502707	NEAR NORMAL
175x80x14	419	75	-1.1417584	SKEW	2.68553022	UNEFFICIENT DATA
205x60x15	1034	100	-1.1855305	SKEW	2.62692423	UNEFFICIENT DATA
205x65x15	578	50	-1.9381883	SKEW	3.81404959	UNEFFICIENT DATA
28x19x15	998.3333	188.5618	2	SKEW	4	UNEFFICIENT DATA
300x15	272.5	87.5	0	NORMAL	-6	UNEFFICIENT DATA
315x80x22.5	3571.571	441.6417	1.13278047	SKEW	0.03446723	NORMAL
385x95x25	11300	300	0	NORMAL	-6	UNEFFICIENT DATA
400x4	188.6667	6.649979	1.00495344	SKEW	0.05647137	NORMAL
400x8	165	42.62237	0.2079848	NORMAL	-4.3768939	UNEFFICIENT DATA
500x8	596.6667	51.8545	1.31581682	SKEW	1.030931	NEAR NORMAL
650x10	779	30.69202	-1.0482941	SKEW	0.91933943	NORMAL
700x16	261.6667	200.3469	0.03217262	NORMAL	-5.8145397	NEAR NORMAL
750x6	1453.444	260.2572	-0.0175643	NORMAL	-0.6480658	NORMAL
825X15	1825.333	96.36851	0.300876	NORMAL	-4.2715992	UNEFFICIENT DATA
900x16	1928.5	517.6005	0.83344188	NORMAL	-0.2314819	NORMAL
900x20	2744.286	646.5181	-0.7188743	NORMAL	-1.2346439	NEAR NORMAL
155x13	277.5	22.5	-0.3703703	NORMAL	-3.9012345	UNEFFICIENT DATA
165x80x13	425.5	109.1066	2.13827906	SKEW	4.96452658	UNEFFICIENT DATA
185x65x14	511.1818	102.0613	1.3819439	SKEW	1.53879271	NEAR NORMAL
195x14	734.2	100.8036	-0.267632	NORMAL	1.17631723	NEAR NORMAL
195x15	839.2667	184.8345	1.55008404	SKEW	3.92866724	UNEFFICIENT DATA

TABLE 42: PRICE SKEWNESS AND CURTOSIS RESULTS

APPENDIX B – COMPARISON RESULTS OF AS-IS SIMULATION MODEL

Tyre	Real Quantity	Average Simulated	Difference
1000x20	8	12.4	4.4
1100x20	56	55.2	0.8
11x22.5	6	12	6
1200x24	22	13	9
1400x25	2	8.8	6.8
145x80x10	18	11	7
14x9x28	3	8.2	5.2
1600x25	8	14.5	6.5
16x9x30	5	11.2	6.2
175x80x14	4	11.1	7.1
205x60x15	4	9.3	5.3
205x65x15	6	10	4
28x19x15	12	13.2	1.2
300x15	15	14	1
315x80x22.5	14	14.6	0.6
385x95x25	2	12.2	10.2
400x4	30	24.8	5.2
400x8	34	9.4	24.6
500x8	14	21.2	7.2
650x10	33	33.8	0.8
700x16	26	19.2	6.8
750x6	30	19.4	10.6
825X15	4	13.7	9.7
900x16	7	15.3	8.3
900x20	10	13.3	3.3
155x13	10	14.6	4.6
165x80x13	50	34.6	15.4
185x65x14	160	58.1	101.9
195x14	75	41.9	33.1
195x15	81	44.9	36.1
Purchase Cost	R 977 299.02	R 1 087 206.8	R 109 907.78

TABLE 43: COMPARISON RESULTS OF AS-IS SIMULATION MODEL

APPENDIX C – INPUT PARAMETERS FOR FABIAN MODEL

	Weibull Distribution Parameters				Inventory Parameters	
Tyre Type	**a1**	**a2**	**b1**	**b2**	**c1**	**c2**
1000x20	1	14.318	1.2	3535.6	0.023 *P	118.5
1100x20	1.5874	5.9338	5.5947	3277.2	0.023 *P	118.5
11x22.5	1.4648	10.971	0.99274	3080.5	0.023 *P	118.5
1200x24	3	2.4297	1.1	5846.6	0.023 *P	118.5
1400x25	1.5	13.59	0.2	12801	0.023 *P	118.5
145x80x10	5	17.299	1.1	416.05	0.023 *P	118.5
14x9x28	1.5	2	0.2	2139.3	0.023 *P	118.5
1600x25	2.3673	7.2685	1.234	19080	0.023 *P	118.5
16x9x30	1.5	23.628	0.2	6152.7	0.023 *P	118.5
175x80x14	2	5.3352	0.6	463.28	0.023 *P	118.5
205x60x15	2	6.314	0.3	1054.6	0.023 *P	118.5
205x65x15	2	7.0212	0.3	612.33	0.023 *P	118.5
28x19x15	2	6.012	0.5	1064.8	0.023 *P	118.5
300x15	2	3.5464	0.6	292.29	0.023 *P	118.5
315x80x22.5	2	10.905	0.4	3771.5	0.023 *P	118.5
385x95x25	2	26.531	0.5	11478	0.023 *P	118.5
400x4	2	34.003	0.4	192.11	0.023 *P	118.5
400x8	2	4.3274	0.4	180.3	0.023 *P	118.5
500x8	2	13.931	0.5	617.79	0.023 *P	118.5
650x10	2	29.767	0.7	794.8	0.023 *P	118.5
700x16	2	1.5814	0.4	287.88	0.023 *P	118.5
750x6	2	6.788	0.6	1555.2	0.023 *P	118.5
825X15	2	22.045	0.5	1879.4	0.023 *P	118.5
900x16	2	3.6676	0.3	2156.1	0.023 *P	118.5
900x20	2	4.4473	0.4	3062.8	0.023 *P	118.5
155x13	3.271	15.36	1.2347	283.71	0.023 *P	118.5
165x80x13	4	3.7799	3	487.07	0.023 *P	118.5
185x65x14	1.4928	5.9675	9.9451	558.17	0.023 *P	118.5
195x14	3.679	8.6282	5.6864	779.44	0.023 *P	118.5
195x15	2.0575	6.3621	5.6708	939.29	0.023 *P	118.5

TABLE 44: INPUT PARAMETERS FOR FABIAN ET AL (1958) DERIVATIVE MODEL

APPENDIX D – DECISION FUNCTIONS FOR PRACTICAL MODEL

The following practical decision curves were developed for product procurement as an alternative to numerical inventory management.

1000x20

$$y = -0.0025x5 + 0.1465x4 - 3.1763x3 + 31.778x2 - 140.25x + 193.31$$

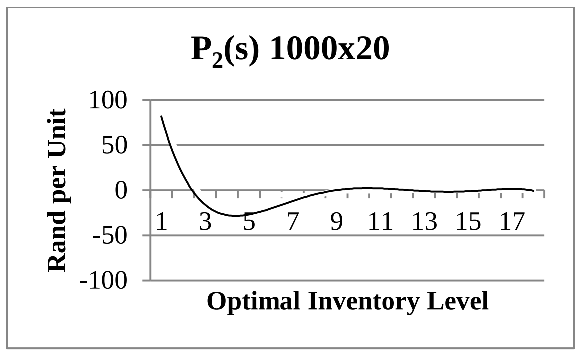

FIGURE 31: P2(S) 1000X20

1100x20

$$y = 0.0036x4 - 0.2047x3 + 4.3034x2 - 40.375x + 113.1$$

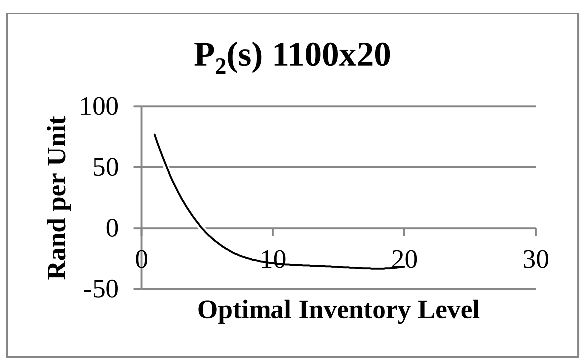

FIGURE 32: P2(S) 1100X20

11x22.5

$$y = 0.0001x6 - 0.0101x5 + 0.2768x4 - 3.7847x3 + 26.796x2 - 91.359x + 52.743$$

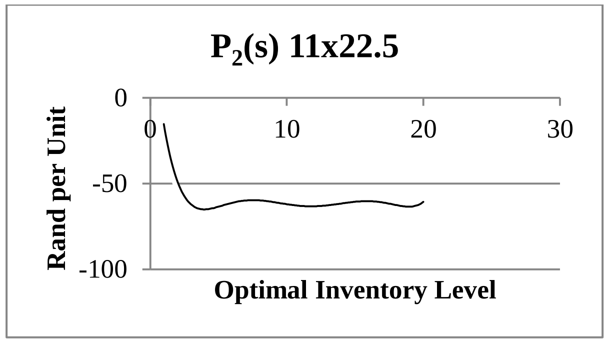

FIGURE 33: P2(S) 11X22.5

1200x24

$$y = 0.0002x6 - 0.0162x5 + 0.4398x4 - 5.9197x3 + 40.987x2 - 135.11x - 29.41$$

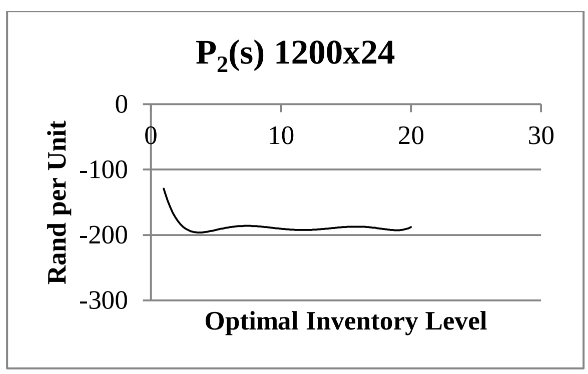

FIGURE 34: P2(S) 1200X24

1400x25

$$y = 5E - 08x6 - 3E - 06x5 + 9E - 05x4 - 0.0013x3 + 0.0087x2 - 0.0287x - 0.0656$$

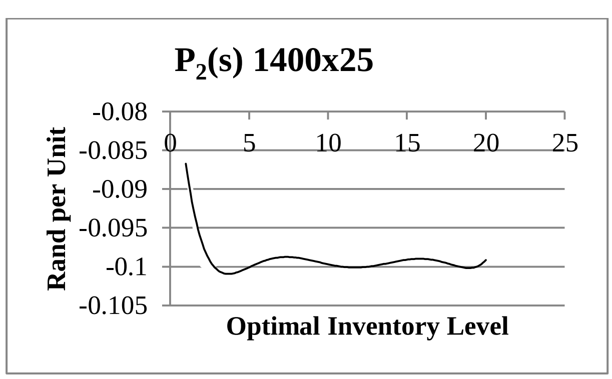

FIGURE 35: P2(S) 1400X25

145x80x10

$$y = 0.0004x6 - 0.0247x5 + 0.6698x4 - 9.0075x3 + 62.276x2 - 204.84x + 218.82$$

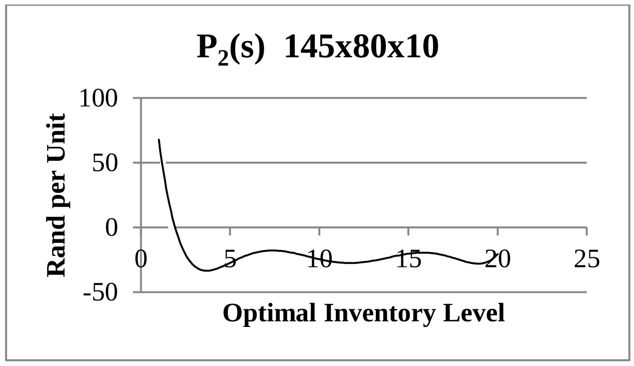

FIGURE 36: P2(S) 145X80X10

14x9x28

$$y = 5E - 08x6 - 4E - 06x5 + 1E - 04x4 - 0.0013x3 + 0.0088x2 - 0.0289x + 0.0201$$

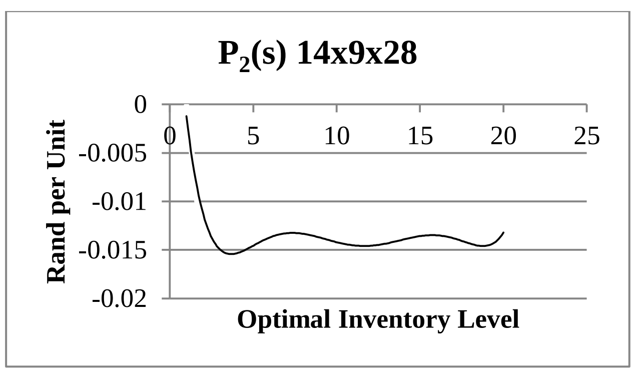

FIGURE 37: P2(S) 14X9X28

1600x25

$$y = 0.0003x6 - 0.0185x5 + 0.4991x4 - 6.6464x3 + 45.299x2 - 145.71x - 367.94$$

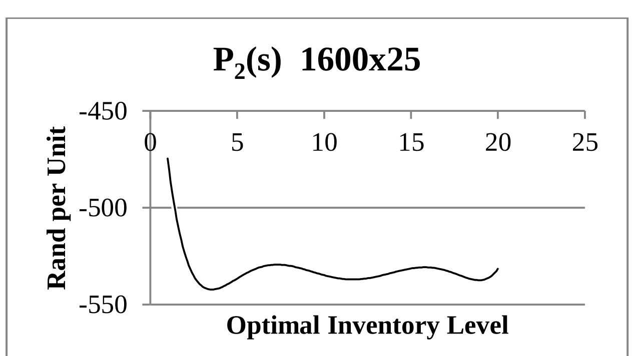

FIGURE 38: P2(S) 1600X25

16x9x30

$$y = 5E - 08x6 - 3E - 06x5 + 9E - 05x4 - 0.0013x3 + 0.0087x2 - 0.0287x - 0.0147$$

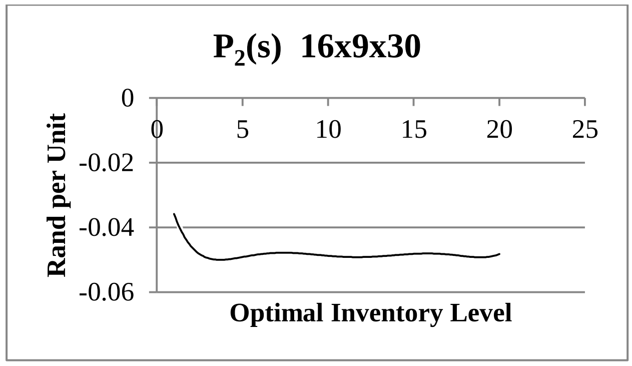

FIGURE 39: P2(S) 16X9X30

175x80x14

$$y = 7E - 05x6 - 0.0051x5 + 0.1387x4 - 1.8657x3 + 12.9x2 - 42.434x + 45.19$$

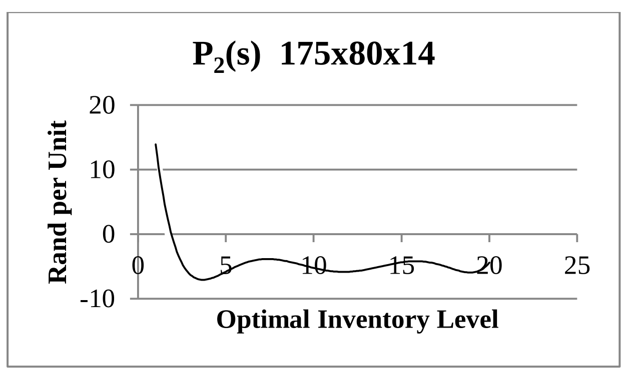

FIGURE 40: P2(S) 175X80X14

205x60x15

$$y = 7E - 08x6 - 5E - 06x5 + 0.0001x4 - 0.0018x3 + 0.0124x2 - 0.0408x + 0.0364$$

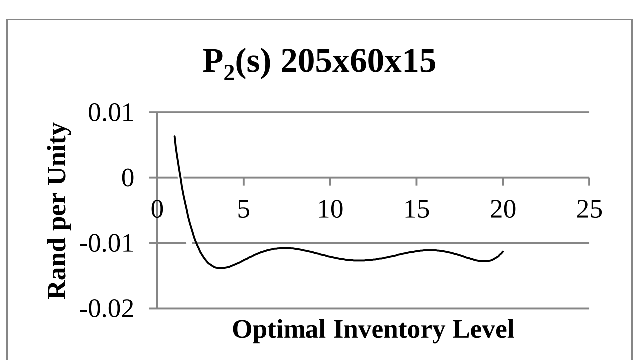

FIGURE 41: P2(S) 205X60X15

205x65x15

$$y = 7E-08x6 - 5E-06x5 + 0.0001x4 - 0.0018x3 + 0.0124x2 - 0.0408x + 0.0416$$

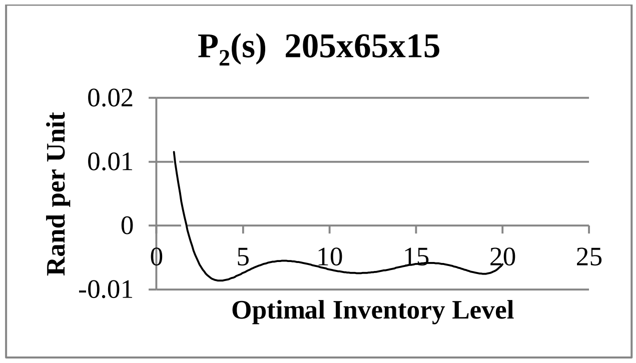

FIGURE 42: P2(S) 205X65X15

28x19x15

$$y = 3E-05x6 - 0.0022x5 + 0.0588x4 - 0.791x3 + 5.4688x2 - 17.988x + 16.224$$

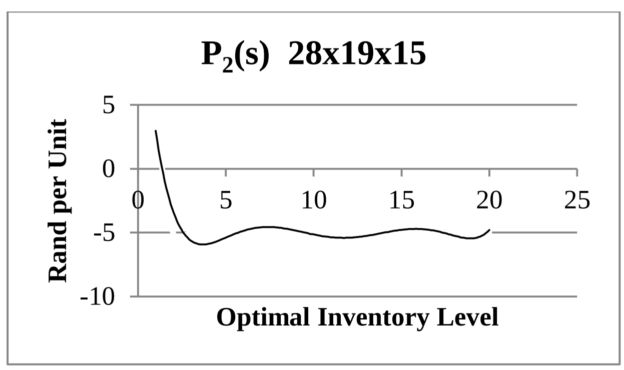

FIGURE 43: P2(S) 28X19X15

300x15

$$y = 7E-05x6 - 0.0051x5 + 0.1389x4 - 1.8675x3 + 12.909x2 - 42.453x + 46.95$$

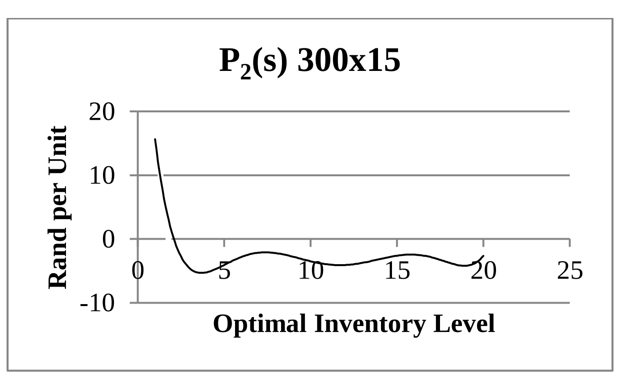

FIGURE 44: P2(S) 300X15

315x80x22.5

$$y = 5E - 06x6 - 0.0004x5 + 0.0097x4 - 0.1303x3 + 0.9006x2 - 2.9623x + 0.5295$$

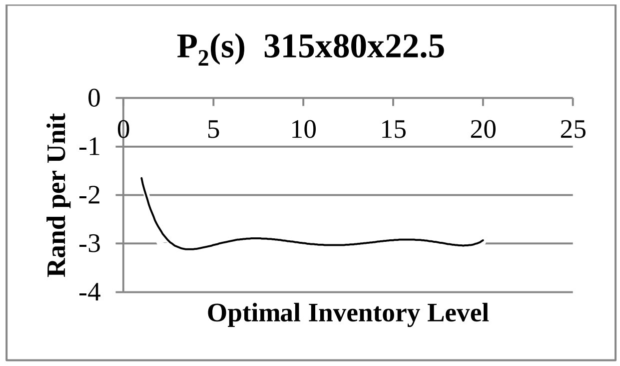

FIGURE 45: P2(S) 315X80X22.5

385x95x25

$$y = 3E - 05x6 - 0.0022x5 + 0.0588x4 - 0.791x3 + 5.4689x2 - 17.988x - 35.853$$

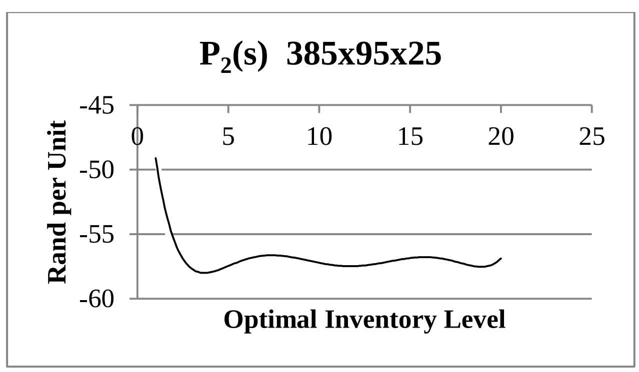

FIGURE 46: P2(S) 385X95X25

400x4

$$y = 5E - 06x6 - 0.0004x5 + 0.0097x4 - 0.1303x3 + 0.9006x2 - 2.9623x + 3.3458$$

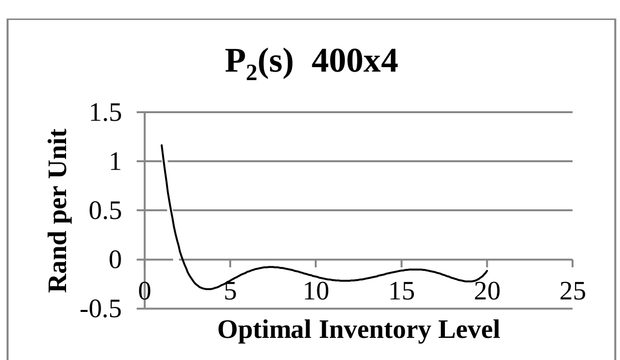

FIGURE 47: P2(S) 400X4

400x8

$$y = 5E - 06x6 - 0.0004x5 + 0.01x4 - 0.1332x3 + 0.9156x2 - 2.9952x + 3.3878$$

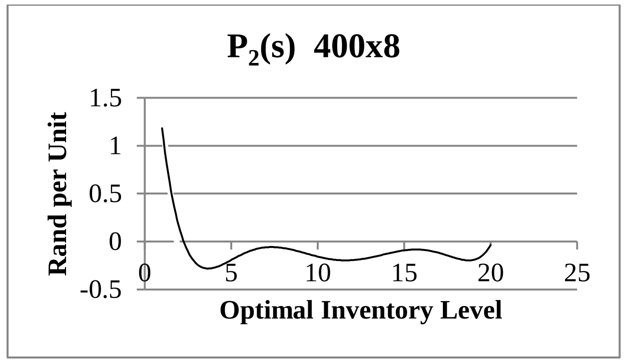

FIGURE 48: P2(S) 400X8

500x8

$$y = 3E - 05x6 - 0.0022x5 + 0.0588x4 - 0.791x3 + 5.4688x2 - 17.988x + 18.254$$

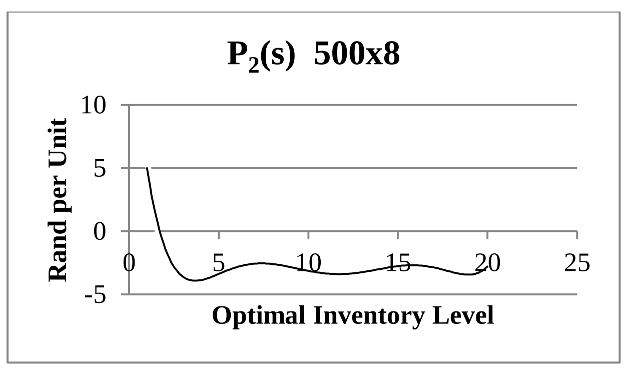

FIGURE 49: P2(S) 500X8

650x10

$$y = 0.0001x6 - 0.0079x5 + 0.2138x4 - 2.8764x3 + 19.898x2 - 65.507x + 63.289$$

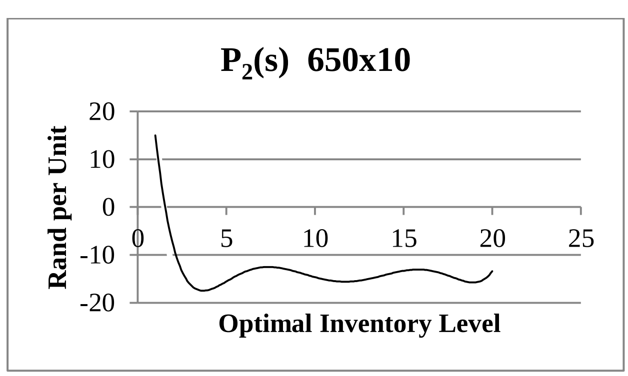

FIGURE 50: P2(S) 650X10

700x16

$$y = 1E-05x6 - 0.0007x5 + 0.0164x4 - 0.1998x3 + 1.2506x2 - 3.7292x + 3.8072$$

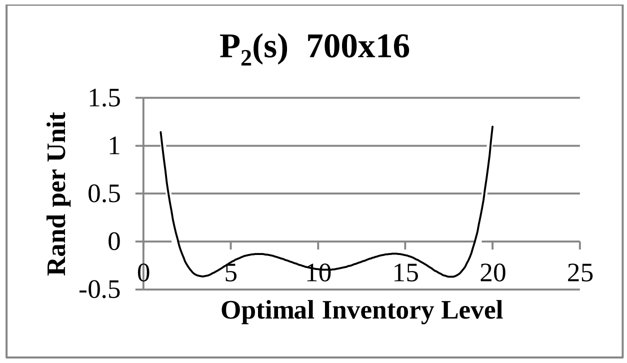

FIGURE 51: P2(S) 700X16

750x6

$$y = 7E-05x6 - 0.0051x5 + 0.1387x4 - 1.8658x3 + 12.9x2 - 42.435x + 32.86$$

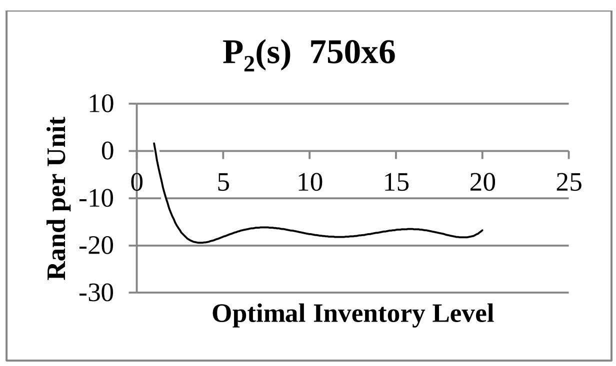

FIGURE 52: P2(S) 750X6

825X15

$$y = 3E-05x6 - 0.0022x5 + 0.0588x4 - 0.791x3 + 5.4688x2 - 17.988x + 12.043$$

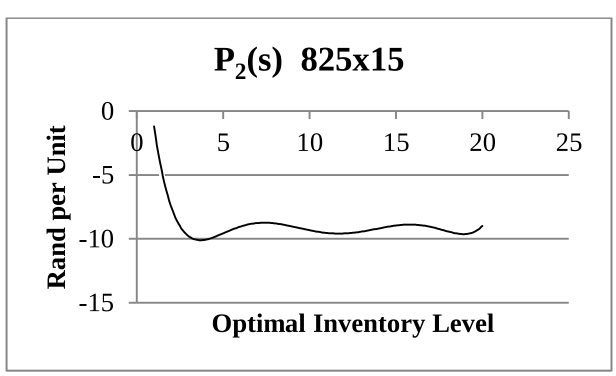

FIGURE 53: P2(S) 825X15

900x16

$$y = 7E-08x6 - 5E-06x5 + 0.0001x4 - 0.0018x3 + 0.0124x2 - 0.0408x + 0.0261$$

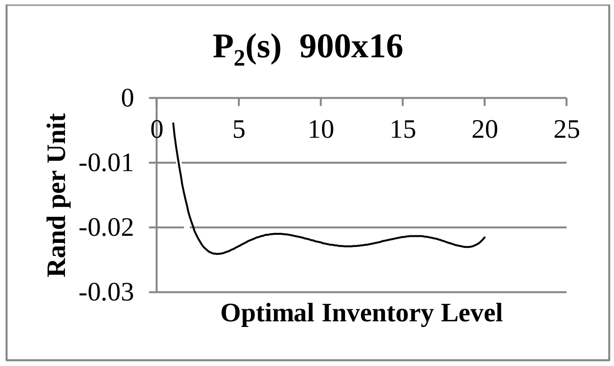

FIGURE 54: P2(S) 900X16

900x20

$$y = 5E-06x6 - 0.0004x5 + 0.0097x4 - 0.1303x3 + 0.9006x2 - 2.9623x + 1.2182$$

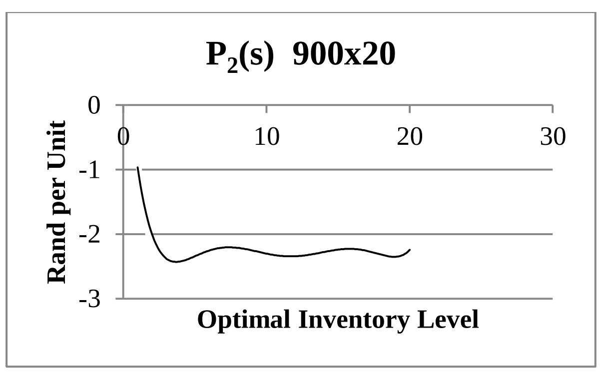

FIGURE 55: P2(S) 900X20

155x13

$$y = 0.0002x6 - 0.0155x5 + 0.4226x4 - 5.7159x3 + 39.842x2 - 132.68x + 150.24$$

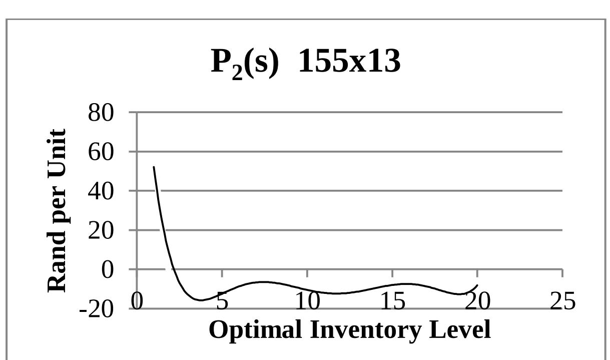

FIGURE 56: P2(S) 155X13

165x80x13

$$y = -0.0004x5 + 0.0317x4 - 0.9225x3 + 12.685x2 - 81.542x + 187.34$$

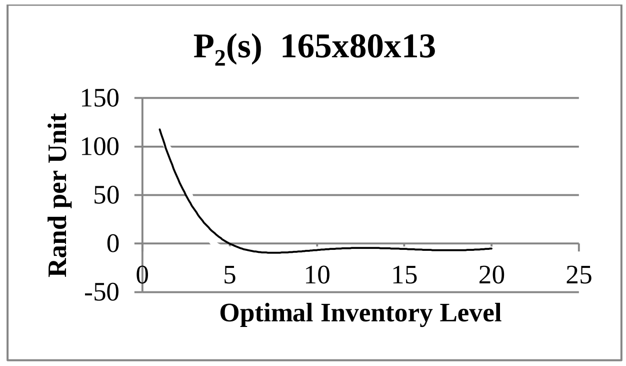

FIGURE 57: P2(S) 165X80X13

185x65x14

$$y = -0.002x4 + 0.1016x3 - 1.4212x2 - 2.0733x + 117.47$$

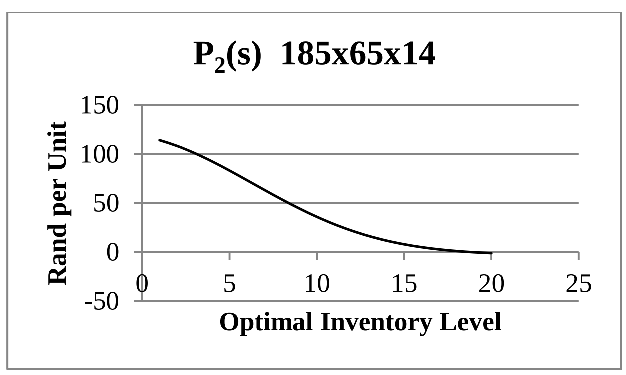

FIGURE 58: P2(S) 185X65X14

195x14

$$y = -0.0001x6 + 0.0078x5 - 0.236x4 + 3.4362x3 - 23.277x2 + 48.295x + 82.19$$

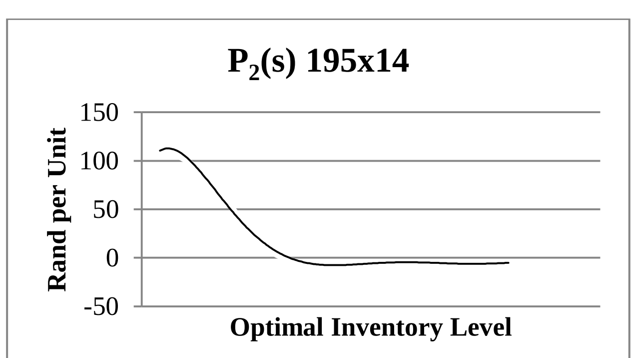

FIGURE 59: P2(S) 195X14

195x15

$$y = -0.0343x3 + 1.7101x2 - 27.766x + 138.42$$

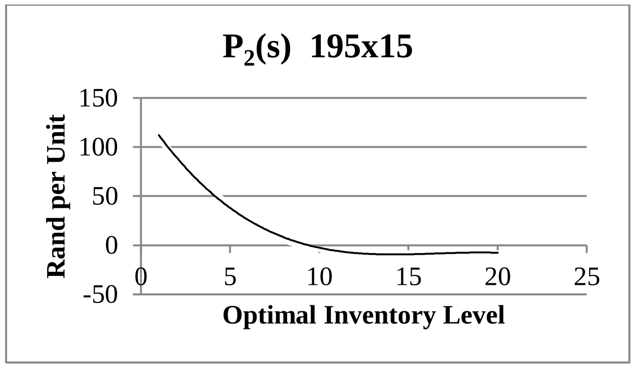

FIGURE 60: P2(S) 195X15

APPENDIX E – OCTAVE PROGRAMMING CODE

```
%Mathematical Inventory Model: Tyre Type - XXX
% Input:

% y = pdf of demand
% z = pdf of price
% f = minimizing function
% I = inventory cost

inv=4;                              %starting inventory
a1=1;                               % shape parameter for demand
a2=14;                              % shape parameter for price
b1=1.2;                             % scale parameter for demand
b2=1535;                            %scale parameter for price

% Program:

Pbegin = norminv(rand(),3407.71,295.81);        % Current Market Price
x = ceil(wblinv(rand(),b1,a1));                 % "Guess" for period demand
p = wblinv(rand(),b2,a2);                       % "Guess" for next period price

short = 118.5;                                  %shortage cost
fnew=3000000;                                   %minimum cost at a certain inventory level
sold=0;                                         %certain inventory level with minimum cost
nold=0;                                         %previous period with minimum cost
hold=0.023*Pbegin;                              %previous period holding cost
fm=0;                                           %ending minimum cost

for i=inv:50
   snew=i;

          y= @(x) (a1/b1)*((x/b1).^(a1-1)).*exp(-((x/b1).^a1));
          z= @(p) (a2/b2)*((p/b2).^(a2-1)).*exp(-((p/b2).^a2));

                    if x<snew;
                      r1=x;
                      r2=0;
                      C1= @(x) hold*(snew-0.5*x);
```

```
        C2=0;
        C2S=0;
        t=0;
            t1=0;
            q= @(x) C1(x).*y(x);        % holding cost for r1
            q1 = quad(q,0,snew);      %integral of q

       else r1=0;
r2=x;
             C1=0;
             C2= @(x) 0.5*hold*(snew^2)/x;
             C2S= @(x) short*(x-snew);
             q=0;
            q1=0;
            t= @(x) (C2(x)+C2S(x)).*y(x);     % hold and short cost for r2
            t1 = quad(t,snew,inf);              % integral of t
             end

 I = q1 + t1;                                      %inventory cost
```

<u>% MINIMIZING FUNCTIONS</u>

```
       f1 = (snew-inv)*Pbegin + I;
       h1 = @(p,x) (-(0.5)*x.*p+I).*y(x).*z(p) ;
       h2 = @(p,x) ((0.5)*(snew)*p+I).*z(p).*y(x);

       j1 = dblquad(h1 ,0,inf,0,snew);
       j2 = dblquad(h2,0,inf,snew,inf);

       f2 = (0.5)*(f1 + j1 + j2);

            if f1 < f2
                fm=f1;
                n=1;
                else fm=f2;
                n=2;
            end
```

```
        if fm<fnew;
            fnew=fm;
            nold=n;
            sold=snew;
        end
end
```

APPENDIX F – SENSITIVITY ANALYSIS RESULTS

SENSITIVITY ANALYSIS RESULTS FOR VARIOUS TYRE TYPES

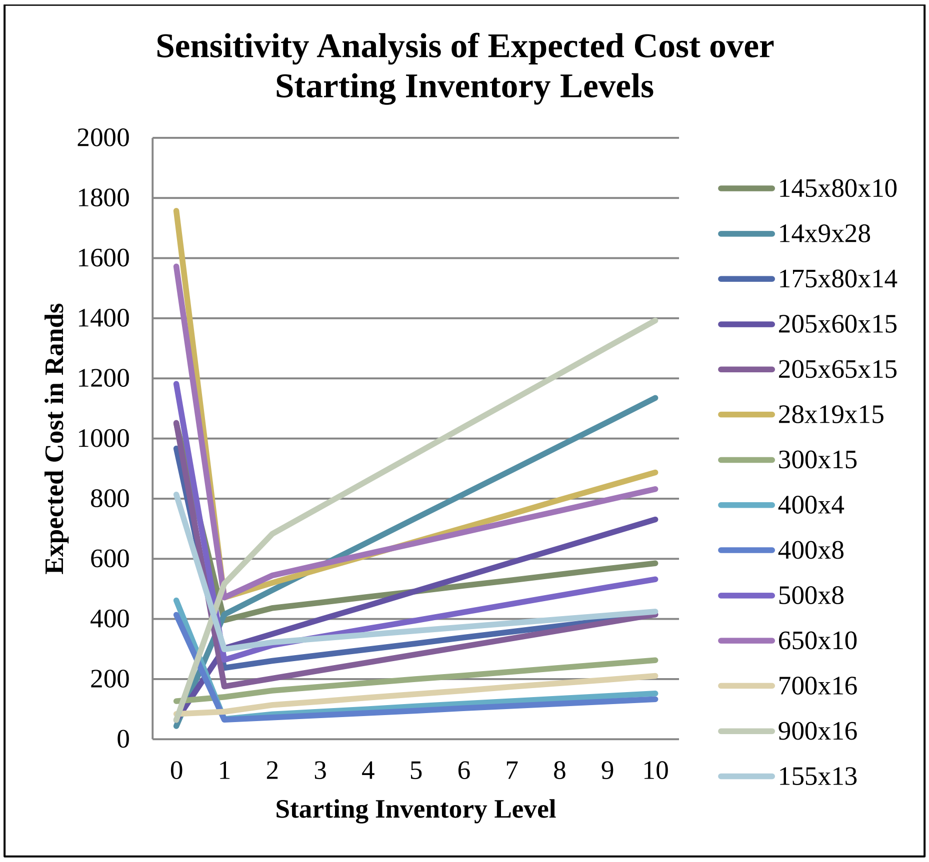

FIGURE 61: SENSITIVITY ANALYSIS RESULTS OF SELECTED TYRE TYPES (1)

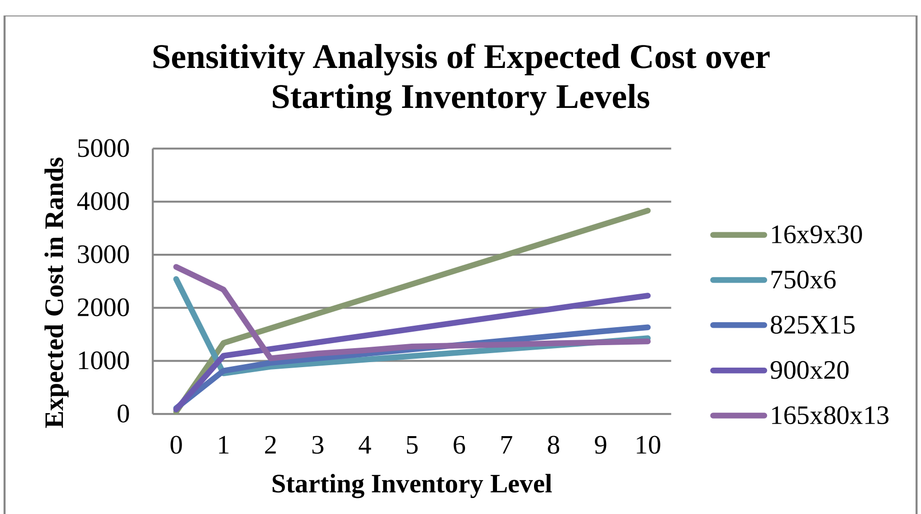

FIGURE 62: SENSITIVITY ANALYSIS RESULTS OF SELECTED TYRE TYPES (2)

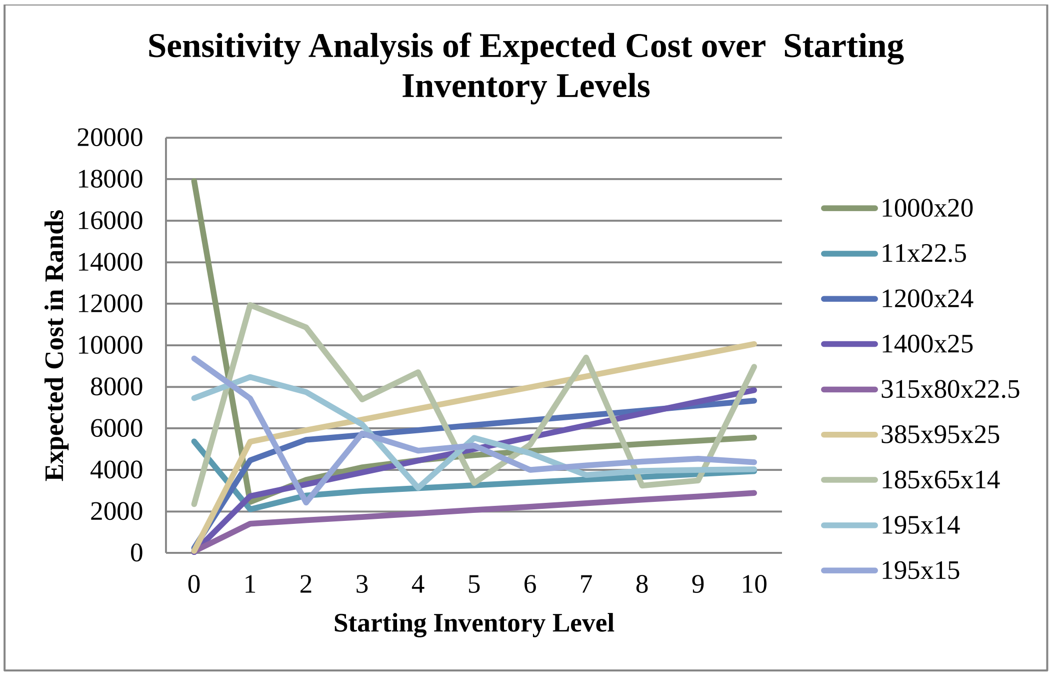

FIGURE 63: SENSITIVITY ANALYSIS RESULTS OF SELECTED TYRE TYPES (3)

APPENDIX G – SPONSORSHIP FORM

Department of Industrial & Systems Engineering
Final Year Projects
Identification and Responsibility of Project Sponsors

All Final Year Projects are published by the University of Pretoria on *UPSpace* and thus freely available on the Internet. These publications portray the quality of education at the University and have the potential of exposing sensitive company information. It is important that both students and company representatives or sponsors are aware of such implications.

Key responsibilities of Project Sponsors:

A project sponsor is the key contact person within the company. This person should thus be able to provide the best guidance to the student on the project. The sponsor is also very likely to gain from the success of the project. The project sponsor has the following important responsibilities:

1. Confirm his/her role as project sponsor, duly authorised by the company. Multiple sponsors can be appointed, but this is not advised. The duly completed form will considered as acceptance of sponsor role.
2. Review and approve the Project Proposal, ensuring that it clearly defines the problem to be investigated by the student and that the project aim, scope, deliverables and approach is acceptable from the company's perspective.
3. Review the Final Project Report (delivered during the second semester), ensuring that information is accurate and that the solution addresses the problems and/or design requirements of the defined project.
4. Acknowledges the intended publication of the Project Report on UP Space.
5. Ensures that any sensitive, confidential information or intellectual property of the company is not disclosed in the Final Project Report.

Project Sponsor Details:

Company:	South African Airways (SOC) Ltd.
Project Description:	Inventory Management System
Student Name:	Liezl Koornhof
Student number:	10113101
Student Signature:	Koornhof
Sponsor Name:	Bertus Stein
Designation:	Senior Manager – Operational Purchasing.
E-mail:	bertussteyn@flysaa.com
Tel No:	011-9783525.
Cell No:	073 5682768.
Fax No:	
Sponsor Signature:	