A maintenance strategy for a network of automated fluid management systems

Dissertation submitted in partial fulfilment of the requirements for the degree Master of Engineering in Development and Management at the Potchefstroom Campus of the North-West University, South Africa.

by

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November 2012

ACKNOWLEDGEMENTS

I would like to thank professor Harry Wichers, my supervisor, for consistently helping and motivating me to complete the research. The focus provided by professor Wichers drove me to complete the research and in doing so, shaped my character going forward in life.

To my wife Nikki, my son Joshua and my daughter Adison, I thank you for being the support which carried me over the finish line. I thank you for all the time you have sown into my life during this research process and I trust that this tree will bear great fruit for you to enjoy in the future. Thank you for all the cups of coffee and all the hugs in times when I needed them most.

Finally I would like to thank my Lord in Heaven. Your wisdom, strength and guidance helped me when the load was too heavy to bear and I did not know what to do. Your love gave me perseverance to complete the research and Your Spirit gave me the words when I had none. I am ever thankful for Your help and I feel mightily small when I am in Your hands.

ABSTRACT

The current economic climate in South Africa requires organisations to optimise available resources – human and otherwise – to successfully sustain business operations. This is especially true for the growing SMME sector in South Africa.

Organisations utilising hydrocarbon based products for input products into their respective process - specifically fuels and lubricants – face an even greater challenge in optimising resource usage as fuel and lubricant prices have increased substantially over the last decade. Automated and advanced technological solutions to properly and effectively manage these fuel and lubricant resources must be employed within organisations. This is critical as fuel and lubricants can constitute a large part of the annual expenditure within an organisation. Such organisations can include:

- Mining operations
- Transport operations
- Agricultural operations
- Maritime operations

Newcom Fluid Management has developed a Fuel & Fluid Management Solution which consists of an electronic control system and various other elements to assist organisations in managing these fuel and lubricant resources. The Newcom FMS makes use of physical hardware on the client's site as well as an internet based software system to control, monitor and report on all fuel and lubricant usages. There is also a large human resource element behind the system which continuously maintains these remote systems such that clients can enjoy the availability of fuels and lubricants when desired.

The Newcom FMS must be properly maintained and resources optimised to allow Newcom to not only make a profit, but to stay competitive in the market place by providing clients with a sustainable and available solution. Therefore a properly researched maintenance management strategy must be developed for Newcom and the Newcom FMS solution to ensure that not only the client's resources are optimised, but also Newcom's resources in order to maintain the Newcom FMS.

The aim of this research was to:

- Research the theory behind maintenance management;
- Identify and develop a sustainable maintenance strategy for the Newcom FMS solution taking into account the success factors as required by Newcom;
- Test the experimental strategy and the current maintenance program at current Newcom clients and capture data on the two strategies employed;
- Analyse and compare the experimental data to determine the effectiveness of the experimental maintenance strategy versus the corrective strategy;
- Provide the experimental maintenance strategy "product" to Newcom along with the data obtained in the experiment as well as the recommendations on the way forward with the data obtained from the experiment serving as inputs.

The parameters which were measured in the experiment were:

- System availability;
- Strategy expenditure and
- Resources usage.

The parameters were selected by Newcom as being the most pertinent to their current operational environment. Achieving success in these areas would effectively increase the probability of a successful maintenance management strategy for Newcom.

The experimental data was captured for the period the experiment was executed for. This data was analysed, the results were interpreted and recommendations were made on the experiment.

A report with the findings was presented to Newcom to demonstrate the impact of the newly developed experimental strategy implemented at current client operations. Recommendations of proposed future actions to be taken were also provided to Newcom which included areas of improvement within the newly developed maintenance strategy.

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KEYWORDS

fluid management, fluid management system, maintenance system, reliability, maintenance, maintenance management, reliability centered maintenance (RCM), system, systems engineering.

ABBREVIATIONS

CM	-	Corrective Maintenance
CMMS	-	Computerized Maintenance Management System
CS	-	Corrective Maintenance Strategy
DMS	-	Data Management Software or System
DPM	-	Depot Management or On-Site Control System
EMS/ES	-	Experimental Maintenance Strategy
FDat	-	Failure Database
FFBD	-	Functional Flow Block Diagram
FMS	-	Fluid or Fuel Management System
I.S.	-	Intrinsically Safe
LCC	-	Life Cycle Cost
LMS	-	Level Management System
MB/D	-	Million Barrels per Day
MSI	-	Maintenance Significant Items
MTBF	-	Mean Time Before Failure
Newcom	-	Newcom Fluid Management (Pty) Ltd
PM	-	Preventative Maintenance
RCA	-	Root Cause Analysis
RCM	-	Reliability Centered Maintenance
RF	-	Relative Frequency
RFID	-	Radio Frequency Identification
RSA	-	Republic of South Africa
SE	-	Systems Engineering
SMS	-	Short Message Service

SoS	-	System-of-Systems
T2N	-	Tank-to-Nozzle
VIM	-	Vehicle Information Module

1 INTRODUCTION

1.1 Background

Common sense dictates that if a living organism does not grow, such organism is in the process of dying. So too must business organisations continue to grow and sustain their operations successfully in order to live or survive. The world financial recession which was suffered throughout the 2008/2009 period (RSA Reserve Bank, 2008/2009) dealt a devastating blow to the world economy and in turn the business environment in South Africa.

Over the past five years, it was estimated that in South Africa alone 440 000 businesses had to close down (Adcorp Holdings, 2012). The negative impact from the recession has put enormous pressure onto existing organisations to maintain profitable operations in difficult economic times. Organisations must strive to either improve production and/or implement savings in whichever way possible to sustain a successful business in the current economic environment (RSA Reserve Bank, 2008/2009).

According to Fabrycky and Blanchard (2006:3) a system can be defined as "an assemblage or combination of elements or parts forming a complex or unitary whole". Considering this definition, a business can be considered a system with various elements working together for a unitary goal. A system is composed of components which are the operating parts and consist of inputs, a process and outputs (Blanchard and Fabrycky, 2006:3).

A business system needs inputs in order for the process to produce outputs which organisations can then market at a profit (Blanchard and Fabrycky, 2006:3). Organisations which use hydrocarbon products as a process input – diesel fuels and lubricants – face a very complex challenge in these current economic times where this hydrocarbon inputs are becoming increasingly expensive and scarce (OPEC Report, 2011:26). The criticality of the situation is further compounded by the current economic environment which forces organisations to continuously optimise business processes.

The current world demand for Brent crude oil is estimated at 88.14 mb/d (OPEC Report, 2011:26). The OPEC Monthly Oil Market Report for August 2011 specifies that the largest derivate of Brent Crude Oil currently being demanded by the world is Diesel Fuel, Gasoline and Lubricant products. These products constitute 42% of the total world demand for Brent crude oil (OPEC Report, 2011:26). The demand for Brent crude oil has increased over the recent decades and this has led to an increase in the price of Brent crude oil – refer to figure 1.

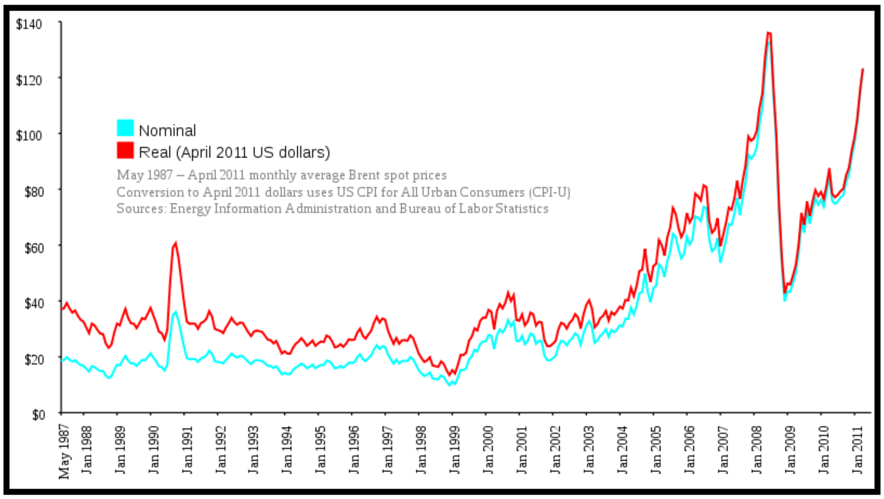

Figure 1: Monthly average Brent spot prices from May 1987 – April 2011 (wikipedia/Brent_Crude, July 2011)

As with all natural resources, Brent crude oil is a finite commodity (http://en.wikipedia.org/wiki/Petroleum, September 2012) and this natural resources will become increasingly scarce in the future. The logical implication of this statement is that crude oil products will only become more expensive in the future.

Organisations that require diesel fuels and lubricants as process inputs need to embark on a uniquely challenging quest for sustainable and profitable business operations. This unique challenge is due to the fact that not only do these organisations face the difficult economic times in South Africa (RSA Reserve Bank, 2008/2009), but these organisations also have to plan and react to an input commodity (Brent crude oil products) which is being depleted at a rate of 88.14 mb/d and which will only become more expensive in the future as the world reserves are depleted.

South Africa's demand for diesel fuel, petroleum and lubricants is currently calculated at 21 896 million liters per year (SAPIA, 2011:32). The various business sectors in South Africa consume the following diesel fuels on an annual basis:

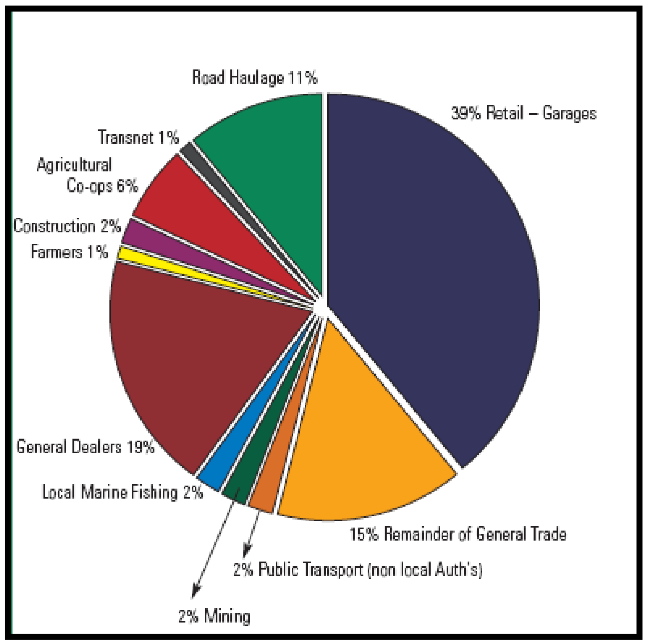

Figure 2: Diesel Usage in South Africa by Sector (Impact on Air Quality Report, 2008:24)

Considering the graph in figure 2, the following organisation types are identified as large users of fuel and lubricants:

- Road Transport – Road Haulage;
- Agriculture – Agriculture Co-Ops and Farming;
- Construction – Construction;
- Marine – Marine and Fishing;
- Mining – Mining;
- Public Transport – Public Transport and

- Industrial Activities (Generators, Engines, Equipment, etc.) – General Dealers.

From the data obtained in figure 2 and the information obtained from the SAPIA report (SAPIA, 2011:32 and Impact on Air Quality Report, 2008:24), table 1 is created and displays the volumes of diesel fuels and lubricants being used by the various industries in South Africa annually:

Table 1: Hydrocarbon Consumption per Market Sector

	Total Share	Mining	Transport	Agriculture	Construction
Market Size	43%	2%	32%	7%	2%
Description	Total RSA Usage				
Diesel	9757	195.14	3122.24	682.99	195.14
Fuel Oil	470	9.4	150.4	32.9	9.4

NOTE: All data shown in millions of liters.

From figure 2 and table 1, it can be seen that there is an estimated 43% or 10 227 million liters of diesel fuel, petroleum and lubricants consumed by organisations who can consider these fuel and lubricants as a process input. It would therefore be strongly advisable to develop and put in place mechanisms to manage the usage of these hydrocarbon resources by these organisations.

The current market conditions in South Africa – considering the recession aftermath - necessitate organisations to optimise production by any means possible due to a global downturn in economic activities (RSA Reserve Bank, 2008/2009). By better utilizing and managing an organisation’s resources, it means an organisation can achieve optimum levels of production and sustain operations successfully. The optimisation of fuel and lubricant usage by an organisation can lead to a potential source where organisations can either save on operational expenditure and/or optimise production.

In conclusion, organisations that use fuel and lubricants as a process input must manage these scarce input commodities with dedicated multi-discipline systems (human processes, electronic control system, process re-engineering, etc.). By properly managing these resources, the probability for profitability for an organisation is increased dramatically. Also, by properly managing fuels and lubricants, production can be improved due to the improved availability of fuels and lubricants.

1.2 Newcom FMS Overview

Newcom Fluid Management is a privately owned company based in Vanderbijlpark, Gauteng, South Africa. In a personal interview conducted by the author, HD van Huyssteen, director of Newcom, said the company's core focus is to be a technology developing company. Newcom specializes in the development of electronic products and systems for the industrial market sector in South Africa. (Van Huyssteen, personal communication, Feb 2011).

The Newcom Fluid Management Solution (FMS) is an integrated system solution, developed and manufactured by Newcom, which provides a total wet stock management solution for a client organisation that utilizes hydrocarbon resources as a process input. (Newcom_FMS, 2012:4). Wet stock management consists of the management of fluids from the moment of on-site reception by a client; monitoring of fluids in storage tanks to the eventual dispensing of that fluid to a user or operator. (Newcom_FMS, 2012:4)

The FMS system consists of several sub-systems working together in different geographical locations to provide a client with all the relevant information regarding the client organisation's fluid usages. The main fluids currently being managed by Newcom consist of hydrocarbon fuels and lubricants (Van Huyssteen, personal communication, Feb 2011).

The FMS solution, deployed at client organisations, is a multi-dimensional solution. This means the system comprises of sub-systems which are made up of software elements, electronic hardware elements and human elements. The FMS consists of the following sub-systems (Newcom_FMS, 2012:4):

- On-Site Control System or Depot Management System (DPM);
- Central Data Management System (DMS);

- Newcom System and
- Client System (Client Organisation)

See Annexure B for a detailed description of a typical FMS solution and a functional description of the different system elements. The typical FMS solution can be summarised as follow:

- The DPM captures operational data of onsite operations concerning fluid usage and storage;
- The DPM also performs control functions on the refueling infrastructure to only allow fuel and lubricants to authorised users;
- The DMS communicates with all the DPM points and collects all the data from the DPM points;
- The DMS stores the data in a central database, processes the data and presents the data to a client via an internet based interface as well as through specialised reporting mechanisms such as SMS;
- Newcom installs and commissions all the systems;
- Newcom jointly operates and maintains the systems for clients; and
- The Client uses the system.

Figure 3 displays the FMS System of Systems concept together with the interfaces between the different sub-systems. Refer to section 2.7.1 for information on a SoS.

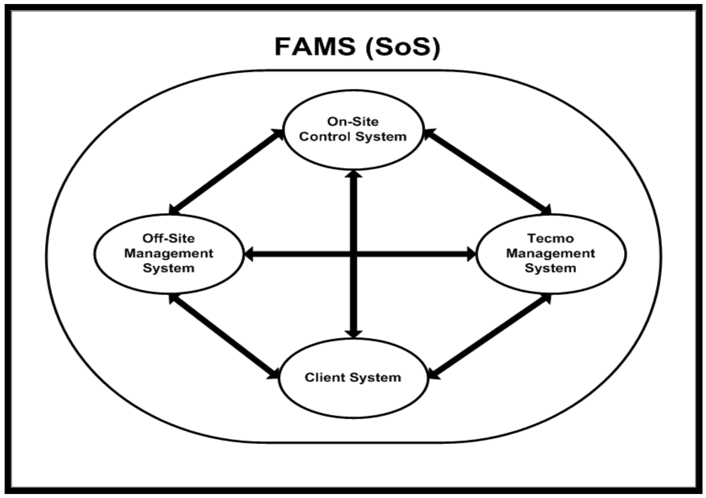

Figure 3: FMS System-of-Systems Overview (FMS Internal, 2010)

From figure 3, Annexure B and an interview held with Newcom's system engineer (Van Huyssteen, personal communication, Feb 2011); it was found that there is no dedicated maintenance management strategy developed for the Newcom FMS solution.

In order for the FMS system to continue to perform the functions it is intended to perform at the specified performance level (Moubray, 1997:7), the proposed maintenance system element required can visually be displayed as follows:

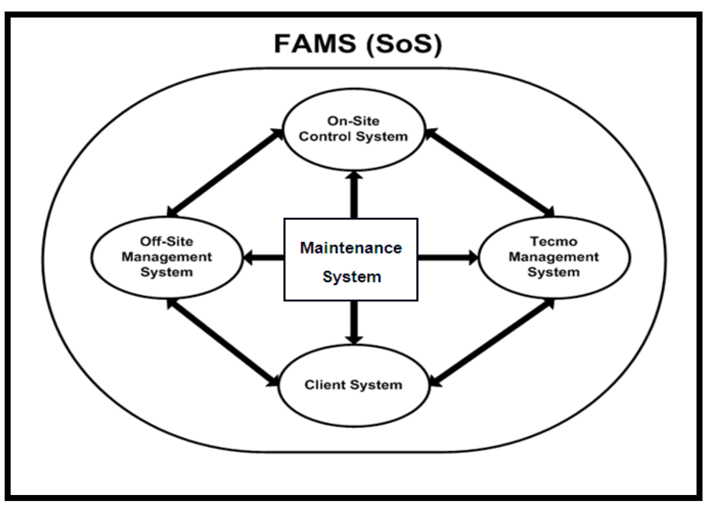

Figure 4: FMS System-of-Systems w/ Maintenance System Integration

The information identified in figure 3 and 4 translates into the following being necessary for the optimal performance of the FMS system:

- Integrated maintenance strategy which considers the needs of all the aspects of the entire FMS system;
- Maintenance strategy which takes into account the sensitivity of the current economic environment by being cost effective and sustainable; and
- A strategy which makes provision for continuous growth to allow for continuous improvement of the strategy and the FMS system.

1.3 Problem Statement

The primary business model of the Newcom FMS solution to clients is based on a rental acquisition model (Van Huyssteen, personal communication, Feb 2011). This rental model states that Newcom renders a service of total fluid management or wet stock management for a client at a fixed monthly fee (Van Huyssteen, personal communication, Feb). The result is that Newcom must provide and maintain all the FMS system equipment and services required by a client to effectively manage a client's fuel and lubricant resources at a fixed monthly income.

The current skill shortage in RSA (Solidarity Research Institute, 2008) equates to there being a scarcity of highly skilled technical personnel available at client organisations. The shortage in skilled staff increases the difficulty to optimise business processes due to the lack in knowledge and skills. The global economic crisis (SA Reserve Bank Annual Report 2008/2009) has also added pressure on organisations in South Africa to further improve process efficiency whilst achieving improvements cost effectively.

As the economic constraints are no different for Newcom, this difficult socio-economic situation further complicates the idea of developing and implementing a sustainable maintenance management methodology for a sophisticated multi-dimensional technological system managing crucial fuel and lubricant resources for client organisations.

The problem is therefore that if Newcom delivers the FMS solution on a rental basis to clients, the Newcom business model must be sustainable. One of the core factors which directly influence the sustainability of this model is an effective maintenance management strategy for the FMS solution on a rental model to a client. If the maintenance strategy fails to satisfy its maintenance goals, both the client and Newcom will be liable for financial losses.

A maintenance management strategy must be developed specifically for the FMS system when delivered to a client via a rental business model. The maintenance strategy needs to be researched for the specific environment and the operating context for the FMS system in that environment.

The findings resulting from this research must lead to the development of an effective maintenance strategy which needs to be implemented in a real world scenario by Newcom. The reliability and availability of such a FMS is a crucial element for the maintenance strategy as the availability of a client's systems is very important to ensure that a client remains profitable.

Typically the FMS solution must aim for a 0.90 system availability value (Van Huyssteen, personal communication, Feb 2011). The availability of the FMS will lead the cost effectiveness of the maintenance strategy. Unreliable system elements will equate to more time and material being spent on these system elements whilst not obtaining more money for the increased maintenance intensity. Reliability is therefore a critical part of the maintenance strategy.

1.4 Possible Results of Effective Research

Consider the rental business model for a FMS system delivered to a client. If an optimal maintenance strategy can be developed and successfully implemented; the client's system downtime can be minimised while controlling the financial risk to Newcom (Van Huyssteen, personal communication, Feb 2011).

Every time when Newcom allocates time and resources to unforeseen maintenance tasks, it increases the financial risk of a FMS system and reduces the sustainability. By improving on FMS system availability and reliability, the financial risk can be minimised by Newcom. Also, as most of the current FMS client's production is directly linked to the successful availability of fuels and lubricants, (Van Huyssteen, personal communication, Feb 2011) maximum system availability will ensure maximum production and in turn maximise client income (Longnecker et al, 2003:10).

Implementing a successful reliability focused maintenance strategy, and managing it properly, will not only potentially ensure stable operations for the client and Newcom, but it might also contribute to sustainable growth for all stakeholders involved by ensuring continued production of the client process by allowing fuels and lubricants to be readily available when required for production as well as ensuring the sustainability of the Newcom rental business model.

The primary function of the FMS system is to manage the wet stock or fluid resources of an organisation. Consider a client in the mining sector. Most mines are very dependent on the availability of diesel fuel for almost all production actions. Consider the following two scenarios which motivate proper maintenance on a fluid management system:

a) The FMS sub-system indicating the current stock level of fuel stocks in the main storage tanks do not function as specified. If at any point in time the diesel fuel is depleted due to a system error, production can, in worst case scenario, be halted entirely because of depleted stock.

b) If at any point in time in the production process there is an error with the dispensing system which dispenses diesel fuels in a controlled manner, vehicles and equipment which require fuels and lubricants to operate will be unable to deliver any further production until the fuel dispensing system faults are rectified.

These losses in production can equate to astronomical amounts of lost income due to poor maintenance management through operational assets not being maintained properly and not being available when required (Mateko, 2010:2).

These two scenarios are merely discussed to motivate the necessity for a proper fluid management system and the proper maintenance of such a system. The implications of the above scenarios can have a huge economic impact on all stakeholders including workers, families of workers, shareholders, local community dependent entities, etc.

The optimal management and maintenance of the FMS system is therefore critical as an optimal system will ensure a sustainable fluid management solution for all stakeholders.

1.5 Research Aims and Objectives

i. The main aim of the research is to:

- Develop a maintenance strategy for the FMS system which will ensure stable operations and a high level of client system availability, typically in the region of 90% and higher.
- Develop a reliable and effective maintenance solution which will add value for all stakeholders including Newcom, current clients and future clients. The value can be measured in terms of the availability of the FMS system, the overall expenditure on maintenance of Newcom and the resource usage.

ii. The specific objectives are therefore to:

- Develop a maintenance strategy for the Newcom Fluid Management System which must aim to achieve a 20% saving on total maintenance expenditure equal compared to the current maintenance expenditure resulting from the current maintenance strategy deployed by Newcom;
- Achieve a FMS system availability figure of 0.9 or managing the maintenance of the FMS system such that it is available for operations at least 90% of the time.
- Ensure that current and future maintenance resources of Newcom will be optimally used to allow Newcom to be as competitive as possible whilst still providing excellent products and services.

1.6 Research Methodology

The methodology to be followed for the research and the development of a maintenance management strategy for the FMS solution will be discussed below:

1. **Analysis of literature and information sources**

    - Conduct a literature study on the theory concerning maintenance management;
    - Conduct a literature study on Systems Engineering principles and the application of the principles of System-of-Systems on the FMS system in defining and understanding the dynamics of a typical FMS system and
    - Identify and research additional functions of a maintenance strategy such as human resources management, information management and continuous improvement.

2. **The Experimental tests and results**

    - A maintenance strategy will be developed for the FMS system;
    - The new maintenance strategy will be implemented at a current group of Newcom clients located in a geographical location;
    - The new strategy results will be compared against the current Newcom strategy results. This will be done by considering two geographical test groups of clients. One group will be maintained using the newly developed experimental maintenance strategy and the other group will be maintained using the current Newcom corrective strategy. Refer to Annexure C for a functional description of the current Newcom maintenance strategy;
    - The system availability (0.00 – 1.00), operational expenditure (in ZAR), resource usage and client/Newcom satisfaction of both strategies will be measured, compared, analysed and recommendations will be made.

3. **Results Analysis and Trade Off Analysis**

    An analysis will be completed on the two data sets including a trade-off analysis. The trade-off analysis will include the following:

- Economic Impact:

  Capture and Measure the operational expenditure of the two different maintenance strategies for the test period.

- Human resources:

  Measure the impact on Newcom's available human resources to successfully manage the two maintenance strategies.

- Technical Complexity:

  Measure the technical complexity of implementing and managing the two management strategies. This can be done by obtaining feedback from Newcom personnel involved with the maintenance and considering the client system availability.

- Environmental Impact:

  Determine what the impact on the environment might be from a failing client process due to the FMS system. Establish how the maintenance strategy will satisfy those needs.

- Sustainability:

  Considering the growth of an expected x% of Newcom as a company and as a result more clients will potentially be added to the company, determine if the newly developed maintenance strategy can still satisfy the needs of a growing maintenance management need.

All of the above parameters will contribute to the success of a maintenance strategy for Newcom. These parameters will be evenly weighted, summarised and a total success value will be coupled to each maintenance strategy employed during the test period.

4. Conclusion

- Based on the results of the analysis a conclusion will be drawn up for the two maintenance strategies employed for the test period.

- Recommendations will be provided specifying the proposed way forward based on the findings of the research
- The possible areas where further research might be required will also be highlighted.

1.7 Newcom Fluid Management feedback

A report will be compiled from the research findings. The report will be presented to Newcom during a board meeting and the possible implications of the research will be discussed with all relevant role players. The findings can be used to determine the path forward for both Newcom and the FMS system.

1.8 Conclusion

Chapter 1 investigated the current Newcom FMS maintenance requirements of Newcom based on a South African context. The investigation led to the identification of a primary research need which was discussed to be the development of a maintenance strategy for Newcom to satisfy the criteria.

Chapter 2 will proceed to investigate and review literature on the subject of maintenance management. The information yielded from chapter 2 will be used to develop a maintenance strategy for Newcom for the Newcom FMS system which can satisfy the identified criteria.

2 LITERATURE REVIEW

2.1 Introduction

In this modern era which engineers and companies find themselves in, maintenance and maintenance management are very complex sciences which need to be properly understood & implemented within an organisation in order for the maintenance function to add value to the organisation (Wireman, 2004:55)

In this chapter maintenance and maintenance management will be researched to facilitate the development of a maintenance management strategy specifically for the Newcom FMS solution. Upon concluding the chapter, the knowledge will be available to develop a feasible maintenance strategy for Newcom.

2.2 Maintenance Improvement Motivation

According to Wireman (2004:55) the maintenance function within an organisation should have the goal of a positive contribution positively to the financial bottom line of the organisation. Maintenance therefore can then be regarded as a valuable source of potential indirect income for an organisation.

The Newcom FMS business model allows for much room for improvement (Van Huyssteen, personal communication, Feb 2011). According to Mr. HD van Huyssteen one of the potential improvement areas identified is the maintenance function for the FMS system which is currently a major contributor to overall expenses. As suggested by Wireman (2004:55) the maintenance function can have a significant impact on the profitability of the organisation and it is critical to develop and implement an optimal maintenance strategy.

Another important aspect is discussed by INCOSE (2000:21) and states that, “The visible costs of any purchase represent only a small portion of the total cost of ownership”. INCOSE argues that over the life span of a system, the costs associated with operating and maintaining a system can be exponentially more than the initial procurement costs.

Developing and implementing an optimal maintenance management strategy can therefore not only assist with equipment reliability and availability, but the optimal maintenance strategy will also contribute positively to the financial bottom line of Newcom.

2.3 The maintenance function: An overview

Mowbray (1997:7) defines maintenance as "ensuring that physical assets continue to do what their users want them to do". The statement made is extremely complex taken into account the complexity of assets which need to be maintained (Wireman, 2004:1). Newcom has realised that these complex assets which Newcom use to render a fluid management service to clients are in need of a proper maintenance strategy to ensure that assets "continue to do what their users want them to do".

Wireman (2004:1) explains that the discipline of maintenance management has undergone major changes over the recent decades. Wireman goes on to explain that the traditional maintenance management models have also changed – more so than many other management disciplines. The same author attributes the phenomenon to the technological advances in the world which resulted in a huge increase in the number and variety of physical assets such as plant, equipment and buildings.

The rapid evolution, discussed by Wireman, needs to be taken into account when developing the maintenance strategy for Newcom as the industry will continuously evolve and Newcom will require a strategy to stay current and optimal.

2.3.1 Maintenance outcomes & objectives

The goal of any company is to become more profitable (Wireman, 2004:32) and this is also confirmed by Newcom (Van Huyssteen, personal communication, Feb 2011). According to Wireman (2004:32), the maintenance management function of a company can assist in achieving this goal mainly in two ways: decreasing operating costs or increasing production capacity.

Examining the economic environment in South Africa, Mateko (2010:1) states that “a good maintenance strategy, properly formulated and executed, can be a source of competitive advantage”. As discussed in section 2.2, maintenance must be a positive contributor to an organisation’s bottom line. For the FMS system in this case, the need exist for the maintenance function to allow Newcom to become more profitable in operating and maintaining the FMS system.

The role the maintenance strategy plays in contributing to the above mentioned needs is to insure that a company’s assets meet and continue to meet their design functions (Wireman, 2004:38). The effective outcome from this statement is that the maintenance management function for the Newcom FMS system must be able to ensure that the current income generating FMS systems must continuously meet their design functions to continuously generate income.

When considering the theory: there are several goals when doing maintenance in an organisation. The following points are identified as typical goals and objectives for maintenance management (Wireman, 2004:55):

- Maximise production at the lowest cost with the highest quality and optimum safety standards;
- Identify and implement cost reductions;
- Provide accurate equipment maintenance records;
- Collect the necessary maintenance cost information;
- Optimise maintenance resources;
- Optimise capital equipment life;
- Minimise energy usage; and
- Minimise inventory on hand.

Newcom is a unique organisation and at present have identified first phase goals for their maintenance strategy (Van Huyssteen, personal communication, Feb 2011). From information obtained in section 1.3 and the theoretical knowledge obtained in the previous paragraphs, the following objectives have been identified for the FMS maintenance system (Van Huyssteen, personal communication, Feb 2011):

- The maintenance strategy must identify and implement cost reductions;
- The strategy must compile and provide accurate equipment maintenance records; and
- The strategy must optimise current maintenance resources.

The research conducted for developing the required maintenance strategy will have to comply with the goals of satisfying the above mentioned points. These points are important to realise a successful maintenance strategy for Newcom (Van Huyssteen, personal communication, Feb 2011).

2.3.2 Goal number 1: Identify and implement cost reductions

An important statement by Wireman (2004: 31) is that maintenance should be used as a total calculation and not for a per-production unit calculation. In the case of the FMS system, the maintenance costs must be considered on all of the operational integrated systems and not on a per stand-alone system basis. If the total cost for all the operational system elements can be reduced, then a cost reduction would have been identified, thereby satisfying criteria number 1.

Maintenance can reduce the overall system operational cost in several ways. These reductions can include (i) to lengthen production run times and increase capacity, and (ii) enable adjustments to tools, training, procedures, etc. (Wireman, 2004:56). Before implementing any changes, however, studies might need to be conducted to demonstrate the before- and after result of each change. The quantifying of such results achieved from implementing a reduction mechanism builds management support for maintenance activities (Wireman, 2004:56). It will therefore be important in the FMS framework to demonstrate the potential quantifiable results of a newly developed maintenance strategy before implementing it.

2.3.3 Goal number 2: Compile and provide accurate equipment maintenance records

Wireman (2004:57) explains that having accurate maintenance records on equipment can enable an organisation to track the equipment. If equipment can accurately be tracked, equipment can be managed and maintained before a severe failure can occur. Accurate record keeping is critical and part of the success of a maintenance strategy (Wireman, 2004:57). Accurate records on operational systems and system elements will allow Newcom to consider ineffective components with a higher failure rate and drive down potential unnecessary expenditure (Van Huyssteen, personal communication, Feb 2011).

2.3.4 Goal number 3: Optimise resources

In the business context of Newcom and the FMS system, resources are already scarce and they need to be managed properly (Van Huyssteen, personal communication, Feb 2011). Optimising resource usage will not only lead to indirect company income (Wireman, 2004:55), but it will also assist Newcom to be more competitive in the market place by providing a sustainable solution. Optimised resource usage can also enable Newcom to put in place a solid growth plan with an accurate account of required resources (Van Huyssteen, personal communication, Feb 2011).

From figure 3, the Newcom FMS system consists of the following sub-systems:

- On-Site Control System or Depot Management System (DPM);
- Central Data Management System (DMS);
- Newcom System; and
- Client System (Client Organisation).

The sub-systems in turn each consist of the following system elements (Wichers, 2009):

i. Plant and equipment;

ii. Documentation and data;

iii. Personnel and training;

iv. Software; and

v. Logistics and support services.

These elements of the various sub-systems can be viewed as the system resources. The maintenance sub-system must therefore have the goal to optimise any one or more of these different resources which can lead to an overall optimisation of FMS system resources.

2.4 Maintenance strategies

2.4.1 Different maintenance strategies

Ewulum (2007: 11) defines a maintenance strategy as a "long-term plan, covering all aspects of maintenance management which sets the direction for maintenance management, and contains firm action plans for achieving a desired future state for the maintenance function".

The figure on the next page provides a classification of important maintenance strategies (IEEE/PES, 2001:639).

As can be seen from the figure, different maintenance needs of organisations give birth to different maintenance philosophies or strategies. Wireman (2004:60) explains that companies should base their decision for the type of maintenance strategy on the "amount of service required from the equipment, along with its resultant costs".

An investigation will be done into the different maintenance strategies available for Newcom. The desired strategy will be measured against the criteria of section 2.3.1 which encompasses the strategy selection criteria as mentioned by Wireman (2004:60). From this investigation a potential maintenance strategy will be identified for the needs of Newcom and studied in more detail.

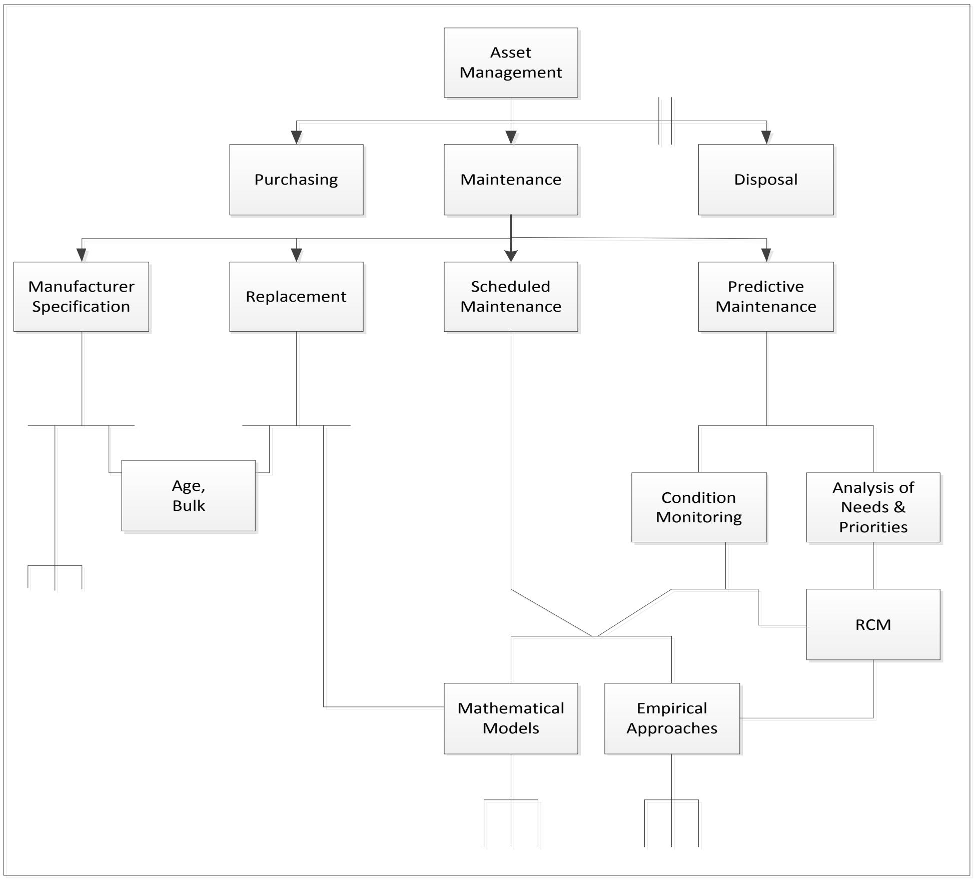

Figure 5: Overview of maintenance strategies (IEEE/PES, 2001:639)

2.4.2 Maintenance strategy investigation

Maintenance strategies identified for further analysis are (Wireman, 2004:61 & IEEE/PES, 2001:639):

i. Replacement or reactive maintenance;

ii. Scheduled or preventative maintenance;

iii. Predictive Maintenance

iv. Condition monitoring maintenance;

v. Reliability centered maintenance;

vi. Mathematical and empirical model maintenance; and

vii. Total productive maintenance.

According to Wireman (2004:55) there are several other maintenance strategies available Wireman (2004:1) also states that more strategies are being developed annually because of continuous asset changes and asset improvements, but these strategies will not be investigated due to the above mentioned strategies being the most common strategies found in the industry (Wireman, 2004:61 & IEEE/PES, 2001:639). Future strategy improvements can investigate other maintenance strategies.

The above mentioned strategies will be investigated in more detail and one of these strategies will be selected to consider in more detail based on the criteria as set out in section 2.3.1.

i. <u>Reactive Maintenance:</u>

Reactive maintenance (also called corrective maintenance) is performed for items that are selected to run to failure or those that fail in an unplanned or unscheduled manner. Assets are maintained or repaired when they fail and no additional preventative task or resources are spent. This is also referred to as a “Run to Failure” approach (DoD, 2008:2-1).

Reactive maintenance has the result of unplanned downtime, damaged machinery, and overtime expenditure which have always equated to relatively high costs for the implementation of reactive maintenance (Odeyinde, 2008:17).

Reactive or corrective maintenance may be considered when the following criteria apply to assets (CHOA, 2012:2):

- Assets that are not maintainable;
- Assets that are disposable and cheaper to replace than to fix;
- Small assets without significant financial value;
- Assets whose downtime is non-critical;
- Assets that are not subject to wear and tear;
- Assets that are unlikely to fail during their life cycle; and

- Assets that are prone to technological obsolescence.

ii. Preventative Maintenance

Preventive or scheduled maintenance can be based on calendar time, equipment operating time or a cycle (such as number of starts, air vehicle landings, and rounds fired or miles driven). Preventive maintenance may be either scheduled or unscheduled; that is, it is initiated based on predetermined intervals or, alternatively, triggered after detection of a condition that may lead to failure or degradation of functionality of the weapon, equipment, or component. (DoD, 2008:2-2).

A preventative maintenance approach is most appropriate when assets meet one or more of the following criteria (CHOA, 2012:3):

- Assets that are subject to predictable wear-out and consumable replacement;
- Assets whose failure patterns are known and can be modeled;
- Assets that are highly regulated for health and safety; and
- Assets that can be effectively captured under a service contract.

iii. Predictive maintenance:

Predictive maintenance refers to maintenance based on the actual condition of a component. Maintenance is not performed according to fixed preventive schedules but rather when a certain change in characteristics is noted (NACE International, 2012).

Predictive maintenance consists of performing maintenance activities on assets before a failure can occur. This strategy then obviously also has to encompass the prediction of possible equipment failures based on actual equipment status (Referenceforbusiness.com, 2012).

For the strategy to be able to perform predictions, the following data on variables that can be used to indicate an impending failure must be collected: vibration, temperature, sound, color, running hours, etc. This data is then analysed to approximate when a failure will occur and maintenance is then scheduled to take place prior to this time (Referenceforbusiness.com, 2012).

The predictive maintenance approach lends itself well to some electrical and mechanical systems and assets with the following attributes (CHOA, 2012):

- Assets with random failure patterns;
- Assets that are not subject to straight-line wear;
- Assets that will significantly impact the business' operations if there is any downtime; and
- Assets with measurable performance thresholds.

iv. Condition Based Maintenance:

Condition Based Maintenance (CBM) is the application and integration of appropriate processes, technologies, and knowledge-based capabilities to improve the reliability and maintenance effectiveness of systems and components (DoD, 2008:1-1).

At its core, CBM is maintenance performed based on evidence of need provided by enabling processes and technologies. CBM uses a systems engineering approach to collect data, enable analysis, and support the decision-making processes for system acquisition, sustainment, and operations (DoD, 2008:1-1).

"The goal of CBM is to perform maintenance only when there is evidence of need." (DoD, 2008:1-3.)

From the DoD (2008:1-4), it was learnt that condition monitoring maintenance can include, but is not limited, to the following examples of maintenance activities:

- Hardware—system health monitoring and management using embedded sensors and integrated data busses
- Software—decision support and analysis capabilities both on and off equipment; appropriate use of diagnostics and prognostics; automated maintenance information generation and retrieval.

v. Reliability centered maintenance:

Moubray (1997:7) defines the RCM process as a "process used to determine what must be done to ensure that any physical asset continues to do what its user wants it to do in its present operating context".

RCM is a predictive maintenance methodology that is also used to improve asset performance as well as the reliability of the end product. The success of RCM leads to an increased understanding of cost effectiveness and risk levels (Hogan, et al, 2011:2).

Reliability centered maintenance (RCM) involves the establishment or improvement of a maintenance program in the most cost-effective and technically feasible manner. RCM represents a shift away from time-based maintenance tasks and emphasises the functional importance of system components and their failure/maintenance history (NACE International, 2012).

According to the SAE JA1011 (SAE, 2002) & Moubray (1997:7), a reliability centered maintenance process or framework answers the following seven questions about a process/system:

a. What are the functions and the associated performance standards of the asset in its present operating context?

b. In what way does it fail to fulfill its operating context?

c. What causes each functional failure?

d. What happens when each failure occurs?

e. In what way does each failure matter?

f. What can be done to predict or prevent each failure?

g. What should be done if a suitable proactive task cannot be found?

Reliability Centered Maintenance (RCM) is defined as a more advanced maintenance philosophy. It involves structuring a maintenance program based upon the understanding of equipment needs and priorities, as well as available financial and personnel resources, to plan activities such that equipment maintenance is prioritised while operations are optimised. (AberdeenGroup, 2006)

Reliability Centered Maintenance integrates Preventive Maintenance (PM), Predictive Testing and Inspection (PT&I), Repair (reactive maintenance), and Proactive Maintenance to increase the probability that a machine or component will function in the required manner over its design life-cycle with a minimum amount of maintenance and downtime. These principal maintenance strategies, rather than being applied independently, are optimally integrated to take advantage of their respective strengths, and maximise facility and equipment reliability while minimising life-cycle costs (NASA, 2000:1-1).

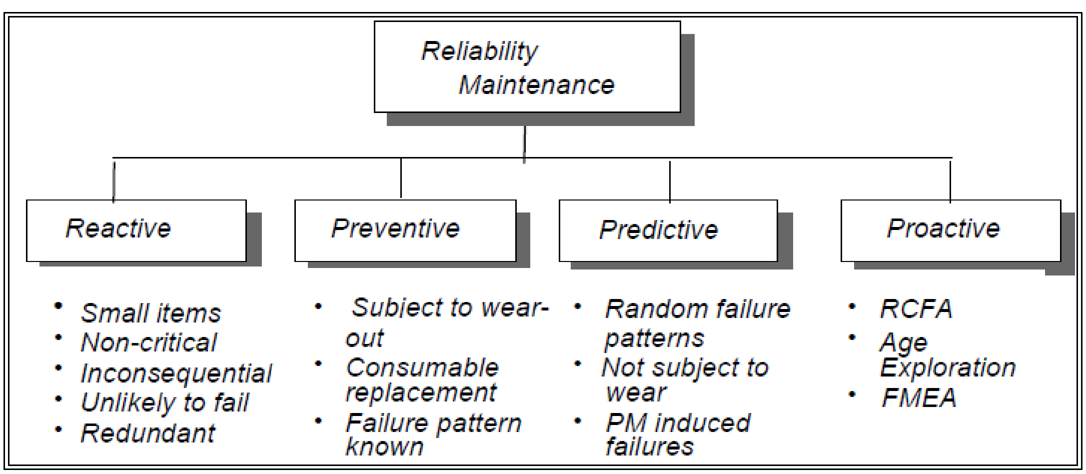

Figure 6: Components of RCM (NASA, 2000:1-1)

vi. Mathematical and empirical model maintenance

Mathematical and empirical maintenance strategies are combinations of preventative and predictive maintenance strategies. Maintenance and empirical strategies aim to optimise and improve preventative and predictive strategies deployed by organisations (IEEE/PES, 2001:639).

Within the predictive strategy – the mathematical and empirical strategies also incorporates condition based functions to continuously measure current statuses of assets (IEEE/PES, 2001:639).

Mathematical based maintenance strategies seek to optimise maintenance schedules by measuring parameters and calculating optimal maintenance tasks and task intervals (Lorden and Remer, 1979:139). To make numerical predictions of maintenance tasks and activities and therefore carry out strategy optimisations, mathematical models are needed which can represent the effects of maintenance on reliability (IEEE/PES, 2001:641).

Lorden and Remer (1979: 147) argue that although powerful, mathematical maintenance models are not always straightforward computations. There are multiple variables influencing maintenance on assets which are not always taken into account. It would not be difficult to modify the mathematical models to incorporate the additional parameters, but these variables must be identified and quantified (Lorden and Remer, 1979:139).

vii. Total productive maintenance (TPM)

TPM involves the cooperation of the entire organisation from top management to the staff on the production floor in an effort to reduce costs and improve workplace efficiency throughout the organisation (Hogan, et al., 2011:2).

TPM is a maintenance and business approach that tries to eliminate failures as a way of improving the performance of maintenance activities within the main stream of production. TPM aims to increase the availability of the existing equipment and assets (Onyenanu, 2003:29).

TPM is preventive maintenance plus continuing efforts to adapt, modify, and refine equipment to increase flexibility, reduce material handling, and promote continuous flows (www.referenceforbusiness.com, 2012).

TPM can also be described as operator-oriented maintenance with the involvement of all qualified employees in all maintenance activities. TPM has been described as preventive maintenance with these three factors added (www.referenceforbusiness.com, 2012):

- Involve equipment and machine in first level maintenance tasks such as encouraging the operators to keep machines clean and well lubricated;
- Encouraging operators to report any fault or imminent failure to the maintenance department; and
- Establishing a maintenance education and training program.

Some of the main features and advantages of total productive maintenance are (IEEE/PES, 2001:639):

- The maximization of equipment effectiveness through the elimination of all machine losses;
- Creating a sense of ownership in the operators of the system; and
- The promotion of continuous improvement through small-group activities involving all departments of the enterprise.

2.4.3 **Maintenance strategy evaluation**

After considering the maintenance strategies in the previous section, a single strategy must be selected to be investigated in more detail. As discussed in section 2.3.1, the maintenance strategy must be able to satisfy three goals:

- The maintenance strategy must identify and implement cost reductions;
- The strategy must compile and provide accurate equipment maintenance records; and
- The strategy must optimise current maintenance resources.

The different maintenance strategies, which were discussed in the previous section, will briefly be considered against the above mentioned criteria to allow for the identification of a viable strategy for Newcom based on their requirements.

Table 2: Maintenance Strategy Evaluation

Description	Cost Reductions	Records	Resource Optimisation
Reactive	Lowest initial cost (DoD, 2008:2-1). Much more expensive in long run due to unexpected and unplanned failures (Odeyinde, 2008:17).	Poor maintenance record keeping practices (DoD, 2008:2-1). Record can be established over time.	Initially very light on resources – need no additional resources (DoD, 2008:2-1). As business and process grow, become more resource intensive due to random nature of failures and incidents (Odeyinde, 2008:17).
Preventative	High initial cost due to gathering of data, analysis on assets and creation of schedules (DoD, 2008:2-2). Can provide cost reduction over period of time through the effective planning and scheduling of maintenance activities (DoD, 2008:2-2).	Excellent records by completing asset register and getting equipment specific information to create preventative schedules (CHOA, 2012:2).	Can optimise resources much better than reactive approach through effective planning and scheduling and usage of maintenance and company resources (CHOA, 2012:2), (DoD, 2008:2-2).

	Might incur waste due to fixed repair/replace/ service cycles of assets if assets do not require the maintenance or if an asset fails before a planned interval (DoD, 2008:2-2).		
Predictive	High initial cost due to gathering of data, analysis on assets and creation of schedules (Referenceforbusiness.com, 2012). Can provide cost reductions over time through effective planning and scheduling of maintenance tasks. (NACE International, 2012). Might incur waste due to faulty repair/replace/ service prediction cycle of assets due to unforeseen changes such as in environment (NACE International, 2012).	Excellent records by completing asset register and getting equipment specific information to create predictive schedules (CHOA, 2012:3).	Can optimise resources much better than Reactive approach through effective planning and scheduling and usage of maintenance and company resources (NACE International, 2012).

CBM	High initial costs due to condition monitoring equipment (DoD, 2008:1-1). Additional costs on maintenance of condition monitoring equipment. (DoD, 2008:1-1). Lower maintenance cost on assets due to the elimination of wasteful maintenance activities (DoD, 2008:1-3).	Good record keeping facilities (DoD, 2008:1-1). New record must be opened for additional condition monitoring equipment (DoD, 2008:1-1).	Requires a lot of upfront resources in the form of condition monitoring equipment (DoD, 2008:1-1). Fewer maintenance resources required over time due to the exact monitoring and early identification of fault conditions (DoD, 2008:1-3). In the event of unplanned faults, additional resources will be needed (DoD, 2008:1-3).
RCM	High initial costs due to implementation requirements of RCM strategy (Moubray, 1997:20). Much lower long term cost due to optimised combined preventative, predictive and reactive approaches (NASA, 2000:1-1).	Excellent record keeping functions (SAE, 2002). Identify all assets through FMECA process (SAE, 2002). Can be updated by periodically revising FMECA process (SAE,	Require a lot of initial temporary resources for implementation (Moubray, 1997:20). Lower resources required over time due to optimised planning and scheduling as well as due to optimised combined preventative, predictive and reactive approaches

	Redesign option for assets which might increase costs of maintenance significantly (SAE, 2002).	2002).	(NASA, 2000:1-1).
Math & Empirical	High initial cost due to complex implementation process (Lorden and Remer, 1979:139). Optimised asset maintenance schedules and tasks can lead to lower overall maintenance costs (IEEE/PES, 2001:641).	Excellent record keeping functions (IEEE/PES, 2001:639). Continuously updates and improves records on assets (IEEE/PES, 2001:639).	Require a lot of initial temporary resources for implementation (Lorden and Remer, 1979:139). Lower resources required over time due to optimised planning and scheduling through effective data analysis and predictions (IEEE/PES, 2001:641).
TPM	Very high initial costs due to the organisational roll out and retraining of staff on all levels of organisation (Onyenanu, 2003:29). Optimised production & maintenance can provide more revenue to justify costs (IEEE/PES, 2001:639).	Good record keeping functions due to operators looking after assets (IEEE/PES, 2001:639). Might have problems with centralized data capturing (www.referenceforbusiness.com, 2012).	Require a lot of initial temporary resources for implementation (Onyenanu, 2003:29). Require continuous additional resources in the form of training and maintenance equipment for operators (Onyenanu, 2003:29).

	Very rarely succeeds (www.maintenanceworld.com, 2012).		When implemented successfully, TPM will not only optimise maintenance but also production (IEEE/PES, 2001:639).

2.4.4 Maintenance strategy selection

The results from the research done in section 2.4.2 and 2.4.3 were discussed with Newcom (Van Huyssteen, personal communication, Oct 2011). The following conclusions were drawn:

i. Reactive maintenance:

   The maintenance strategy can easily be adopted and deployed by Newcom. However, the lack of proper record keeping and high cost estimates of continuous system breakdowns did not make this option viable.

ii. Preventative maintenance:

   The strategy provides for excellent record keeping facilities. The strategy is also cost effective to implement. However, to spend maintenance resources continuously over time on maintenance actions when they might not be necessary was not acceptable for Newcom (Van Huyssteen, personal communication, April 2012). This will lead to an increase in resource usage and expenditure. This made preventative maintenance not viable.

iii. Predictive maintenance:

   The strategy has high implementation costs and a high level of complexity to implement. Another problem was the continuous upkeep of the prediction models as the expertise is currently not present in Newcom. The increases in resources and costs made pure predictive maintenance not viable.

iv. Condition based maintenance:

   The strategy provided Newcom with an extremely attractive solution which will allow Newcom to measure system statuses and only perform maintenance when it is needed. This ability can allow Newcom to save considerable on maintenance expenses and resources.

However, the additional costs and complexity for the condition monitoring equipment and the maintenance thereof made the strategy not viable as it will increase overall system costs and resources usage.

v. RCM:

The strategy will have a high cost to implement. The cost will subside when the initial RCM process is completed. The combination of reactive, preventative and predictive maintenance provides Newcom with the strengths of the individual strategies.

The strategy also allows for excellent record keeping and optimal usage of resources due to an optimised schedule and maintenance tasks.

The strategy satisfies the three criteria as set out in section 2.3.1 – 2.3.4.

vi. Mathematical based maintenance:

The strategy will be very complex and expensive to implement. The strategy will also require additional resources over time to maintain and improve.

The strategy might provide Newcom with a possible strategy for the future, but the additional resources and costs required to implement and run the strategy was not desirable.

vii. TPM:

The additional benefits provided by the strategy such as improved production made the option attractive. TPM provides excellent record keeping facilities but might have trouble to centralise and synchronise maintenance data.

Due to the complex nature of TPM and the additional resources required to roll out the strategy within the organisation, it was decided that TPM is not the desired strategy.

The above research yielded that the RCM strategy possibly provided Newcom with the best opportunity to satisfy the three criteria as set out in section 2.3.2 – 2.3.4 for a maintenance strategy. There was also decided that condition monitoring aspects will be incorporated within the RCM strategy to further enhance the maintenance tasks and schedules.

The following section considers more in-depth research of the RCM strategy.

2.5 RCM Process Overview

When executing a RCM process to develop a maintenance strategy for a specific process, the seven basic questions as mentioned in section 2.4.2-(v) must be asked. However, the answers to these questions reveal much more detail about the system in question (Moubray, 1997:20). Therefore it is necessary to understand each question's outcome in order to answer it properly and thoroughly.

A. Functions and Performance Standards

- What are the functions and the associated performance standards of the asset in its present operating context?

<u>DESCRIBING FUNCTIONS OF ASSETS:</u>

According to Moubray a common error made by maintenance personnel is to take care of an asset or maintain the asset such that it is in a good condition. However, this is an error made by many people as the goal should be to preserve the asset so it can "continue to do whatever its user wants it to do" (1997:21). Question 1 in section 2.4.2-v is focused on establishing what the functions of an asset are as these functions differs from the inherent capabilities of the asset.

RCM puts an emphasis on what the asset's function is - this fact is the most important single feature of RCM (Moubray, 1997:21). From Moubray we see that a function statement of an asset can be defined as a "function statement should consist of a verb, an object and a desired standard of performance*"* (1997:22).

PERFORMANCE STANDARD OF ASSETS:

The performance standard or the minimum standard for operation of an asset must be specified clearly for each asset or in this case the sub-system element (Moubray, 1997:23). The asset to perform the function must be designed to achieve more than this minimum performance standard level (Moubray, 1997:23). Assets deteriorate over time and it is required to design an asset with an acceptable level of capability such that deterioration can affect that asset whilst it still achieves the desired level of performance. From Moubray, we see that performance of an asset can be defined in two ways:

- The asset's desired performance (Moubray, 1997:23) and
- The asset's built-in capacity (Moubray, 1997:23).

The following figures demonstrate an asset which is maintainable and an asset which is not maintainable (Moubray, 1997: 24). The figures explain graphically the above two ways with which to define the performance of an asset:

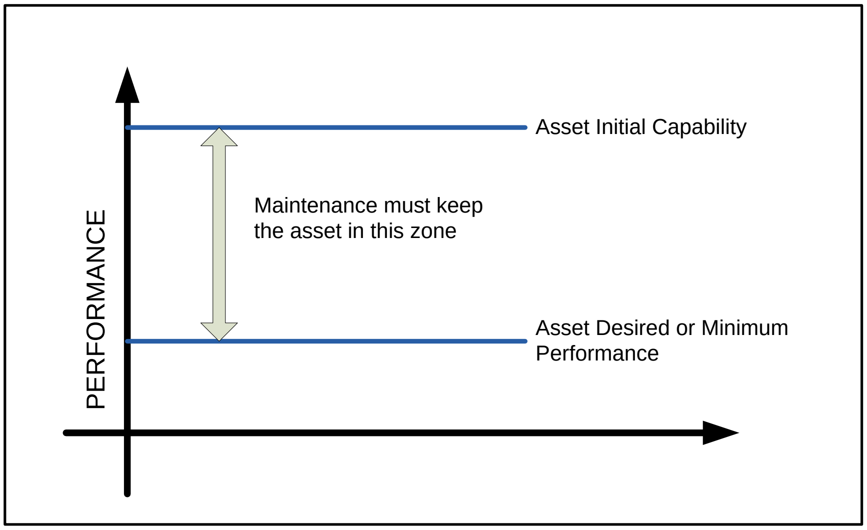

Figure 7: A Maintainable Asset (Moubray, 1997:24)

Figure 7 is an example of an asset or in this case a sub-system element which is maintainable. One can see that the initial capability of the asset is well above the minimum required performance level and the goal of maintenance is to keep the asset function above the minimum performance level.

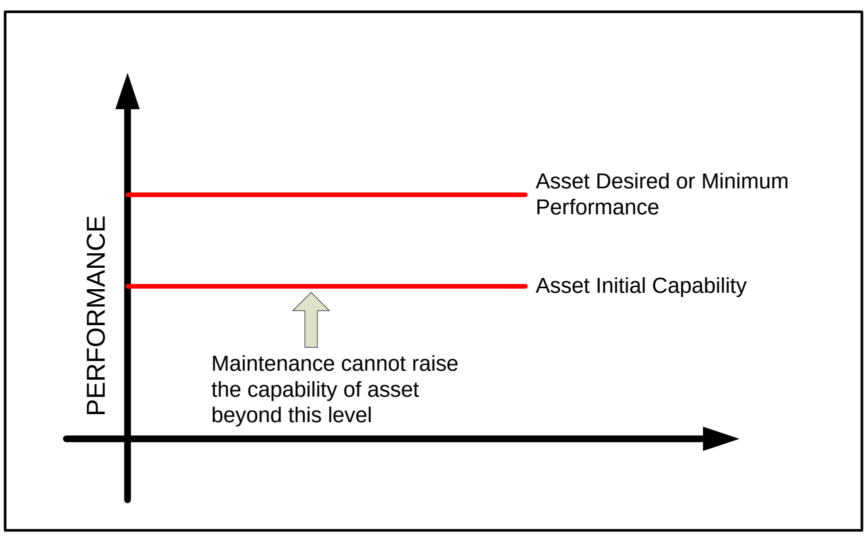

Figure 8: Non Maintainable Asset (Moubray, 1997:24)

Figure 8 displays an asset which cannot be maintained. This is due to the fact that the initial capability of the asset is less than the minimum performance level. Maintenance cannot raise the capability of the asset and thus this asset is not maintainable (Moubray, 1997:24).

Figure 7 and 8 allow for the following information to be derived:

- An asset can only be maintainable if its desired performance is less than its initial capability.

The performance standard of an asset can further be described in different aspects. In a single function statement several performance standards can be addressed (Moubray 1997: 25). The following performance standards are obtained (Moubray, 1997:25).

- Quantitative;
- Qualitative;
- Absolute;
- Variable; and
- Upper and Lower Limits.

OPERATIONAL CONTEXT OF AN ASSET:

The context in which an asset operates must be understood clearly before a function statement can be compiled. This is due to the fact that the operational context or operational parameters will influence the primary and secondary performance standards directly. The operational context will also influence the nature of the failure modes (Moubray 1997:28).

Factors which influence the maintenance strategy in the operational context are the following according to Moubray (1997:29-33):

- Type of Process i.e. Flow or Batch process;
- Asset Redundancy;

- Quality Standards required or enforced;
- Environmental Standards;
- Safety Hazards;
- Shift Arrangements;
- Work-in-Process materials;
- Repair time of an asset;
- Spares available;
- Market demands on products produced; and
- Raw materials supply.

The above discussion describes what is required for the proper understanding and documenting of the operational context of a system as this directly and indirectly influences the maintenance strategy.

DIFFERENT TYPES OF FUNCTIONS:

From Moubray (1997: 35-36) one finds that there are different types of functions an asset can perform. These functions are divided into two main categories (1997: 35-36):

- Primary Functions and
- Secondary Functions.

As the name implies, primary functions are the reason why the asset exist i.e. primary function of a crusher is to crush raw materials. Great care should be taken to define them as precisely as possible (Moubray, 1997:36).

Important features of primary functions are the following:

i. Multiple independent primary functions

This is considered when an asset has more than one primary function which it must perform. In this case the asset will have more than one function statement (Moubray, 1997:36); and

ii. Serial primary functions

This is considered when an asset has more than one primary function which it performs in series i.e. the one function is dependent on the previous function before it can be performed (Moubray, 1997:37).

Secondary functions are functions which an asset is expected to fulfilled, additional to the primary functions. From Moubray the secondary functions are divided into the following categories (1997:38):

i. Environmental integrity of an asset;
ii. Safety or structural integrity of an asset;
iii. Control, containment and comfort of an asset;
iv. Appearance of an asset;
v. Protection or protective devices of an asset;
vi. Economy and efficiency of an asset; and
vii. Superfluous functions of an asset.

B. Functional Failures

- In what way does it fail to fulfill its operating context?

A failure is defined as "the inability of any asset to do what its users intend it to do" (Moubray, 1997: 46).

Moubray explains that because assets have more than one function and each function may have more than one performance standard, it is not practical to view an asset as failed entirely while it just failed to perform a certain function at an acceptable level. For this reason RCM considers functional failures. Moubray goes on to define a functional failure as "the inability of an asset to fulfill a function to a standard of performance which is acceptable to the user" (Moubray, 1997:47).

According to Moubray there are different areas of functional failures. These can be categorised as follow:

i. Partial and Total Failure

   This failure condition exist when an asset suffers complete loss of function or when an asset still has the ability to function, but functions outside the acceptable performance standards. Because nearly all functional failures are caused by different failure modes of total failures (Moubray 1997:48), it is very important to capture and record all the functional failures associated with each function.

ii. Upper and Lower Limits

   According to Moubray, this functional failure occurs when an upper or a lower performance limit has been breached. It is important to distinguish between these two because the failure modes and the consequences are different for the upper and lower limit breach (Moubray 1997:48).

iii. Gauges and Indicators

   Moubray explains that it is also necessary to apply upper and lower limit specifications on devices such as gauges, protection devices and control systems. Depending on the failure modes and the failure consequences of these protection or indication assets, it may be necessary to list the functional failures as well (Moubray 1997:48).

iv. Operating Context

The failure of any asset is very dependent on the operational context of that asset. It is thus very important to clearly establish what a functional failure is (Moubray 1997:48).

In closing, Moubray warns that a great deal of frustration and confusion can be created when all the parties involved with an asset do not agree and together create a clear specification on what constitutes a failure. Examples of applicable parties or departments might be operations, maintenance and safety (Moubray 1997:49).

C. Failure Modes

- What causes each functional failure?

"A failure mode is any event which causes a functional failure." (Moubray, 1997: 53)

From previous sections it was learnt that for each function of an asset all functional failures must be listed. The failure mode is the cause of the failure and must be listed for each functional failure. The modes must at the very least include a verb and a noun, must be concise and explain the concept clearly (Moubray, 1997:56).

Moubray explains that maintenance should be managed at the level of each failure mode. Therefore it is very important to identify what the potential failure modes are or can be. From the successful identification it would be possible to develop a systematic maintenance strategy. It is also important to realise that not every failure mode is dealt with by scheduled maintenance, but training or redesign can also be employed (Moubray, 1997:56).

<u>CATEGORIES OF FAILURE MODES:</u>

Moubray argues that people often confuse maintenance dealings only with deterioration over a time of an asset. Moubray suggests that with the RCM approach maintenance actions must consider all the possible modes which can cause an asset to functionally fail (1997:58). These failures can include human errors and process changes. There are different categories for failure modes:

i. Failing Capability.

The category investigates an asset having an initial capability above the desired performance level and subsequently falls under the desired or required level of performance after being put into service. The causes are (Moubray, 1997:58):

- Deterioration;
- Lubrication failures;
- Dirt;
- Disassembly; and
- Capability reducing human errors.

ii. Increase in desired Performance.

This category of failure mode occurs when the asset is able to achieve the desired level of performance when put into production. But then the desired level of performances increase until the asset becomes incapable of delivering the desired level of performance. The above situation causes an asset to fail in one of two ways (Moubray, 1997:61):

- Desired level of performance rises until the asset is unable to deliver it; or
- Increase in stress causes the deterioration to accelerate so that the asset becomes unreliable.

iii. Initial Capability.

The category comprises of an asset's initial capability not being able to achieve the desired level of performance. This seldom affects an entire asset, but rather it can affect one or two functions of the asset (Moubray, 1997:64). These affected functions often create weak links in the production chain.

D. Failure Effects

- What happens when each failure occurs?

"A failure effect describes what happens when a failure mode occurs." (Moubray, 1997:73)

The following questions should be asked when considering a failure effect (Moubray, 1997:73):

- What evidence (if any) exists that the failure occurred?
- In what way (if any) does it pose a threat to safety or the environment?
- In what way (if any) does it affect production or operation?
- What physical damage (if any) is caused by the failure?
- What must be done to repair the failure?

For the failure effect statement to be described comprehensively, it should list the answers to the above questions. It is important to remember that this process aims to determine if proactive maintenance tasks are required for the system. For this reason, the effect must be described as if no maintenance has been done (Moubray, 1997:74).

SOURCES OF INFORMATION:

Moubray explains that one must always remember the need to be proactive when constructing a FMEA; therefore focus must be placed on what could happen. Sources of these types of information on an asset can be found in (Moubray, 1997:78):

- Manufacturer/Vendor of equipment;
- Generic lists of failure modes;
- Other users of the same equipment;
- Technical history records; and
- People who maintain and operate the asset or equipment.

LEVEL OF ANALYSIS ON FMEA WORKSHEET:

The level at which a FMEA analysis is done can influence the process. When an analysis is conducted on the complex asset or the system without considering detail assessment of system elements, potential problems can be (Moubray, 1997:81):

- Too difficult to define the performance standard;
- Too difficult to analyse the failure consequence;
- Too difficult to decide which components belong to which system; and
- Control and protective loops become too difficult to deal with.

Equally, when analysing a system in too great detail, the following can occur (Moubray, 1997:84):

- Too many failure modes can result in it being very easy to miss critical failure modes.

The best strategy to employ is to consider the intermediate level of the system or product when breaking it into smaller pieces (Moubray, 1997:81). It is also possible to consider different levels for different sub-systems in the FMEA process.

METHODOLOGY OF RECORDING FAILURE MODES AND EFFECTS PROPERLY:

When the appropriate level of analysis has been selected, and the sub-assembly still delivers too many failure modes, Moubray provides guidelines which can be used to determine the exact method to follow (1997: 86):

- Option 1: One can list the reasonably likely failure modes of the sub assembly individually as part of the main analysis;
- Option 2: A single failure mode can be listed of the sub assembly. Open up a new worksheet and list the specific information for that sub assembly separately;
- Option 3: List the failure of the sub assembly as a single failure mode;
- Option 4: Use a combination of options 1 & 3; and

- Services: The failure of services is treated as a single failure.

The resultant work arising from capturing the information from section 2.5, sub-sections A, B, C and D is the RCM Information Worksheet. The following table displays this worksheet:

Table 3: RCM Information Worksheet (Moubray, 1997:89)

System	System No	Facilitator	Date	Sheet No
Sub-System	Sub System No	Auditor	Date	of
Function	**Functional Failure**	**Failure Mode**	**Failure Effect**	

E. Failure Consequences

- In what way does each failure matter?

Failure consequences describe how and how much a possible functional failure of an asset can effect an organisation. Thus the nature and the severity of these failure effects must be described (Moubray, 1997:91).

"A proactive task is worth doing if it reduces the consequences of the failure mode to such an extent that justifies the direct and indirect costs of doing that task." (Moubray, 1997:91)

The RCM process provides a strategic framework with which to manage severe failures proactively. This framework includes the following (Moubray, 1997: 127):

- Provides a classification of failures based on the failure consequences. The framework identifies and separates evident and hidden failures. Finally the evident failures are ranked according to the failure consequence;
- The framework provides the user with a solid basis of deciding whether a proactive task is worth doing; and
- Assists the user with a suggested action to perform if a proactive task cannot be found.

The decision framework obtained from Moubray (1997:127) is as follow:

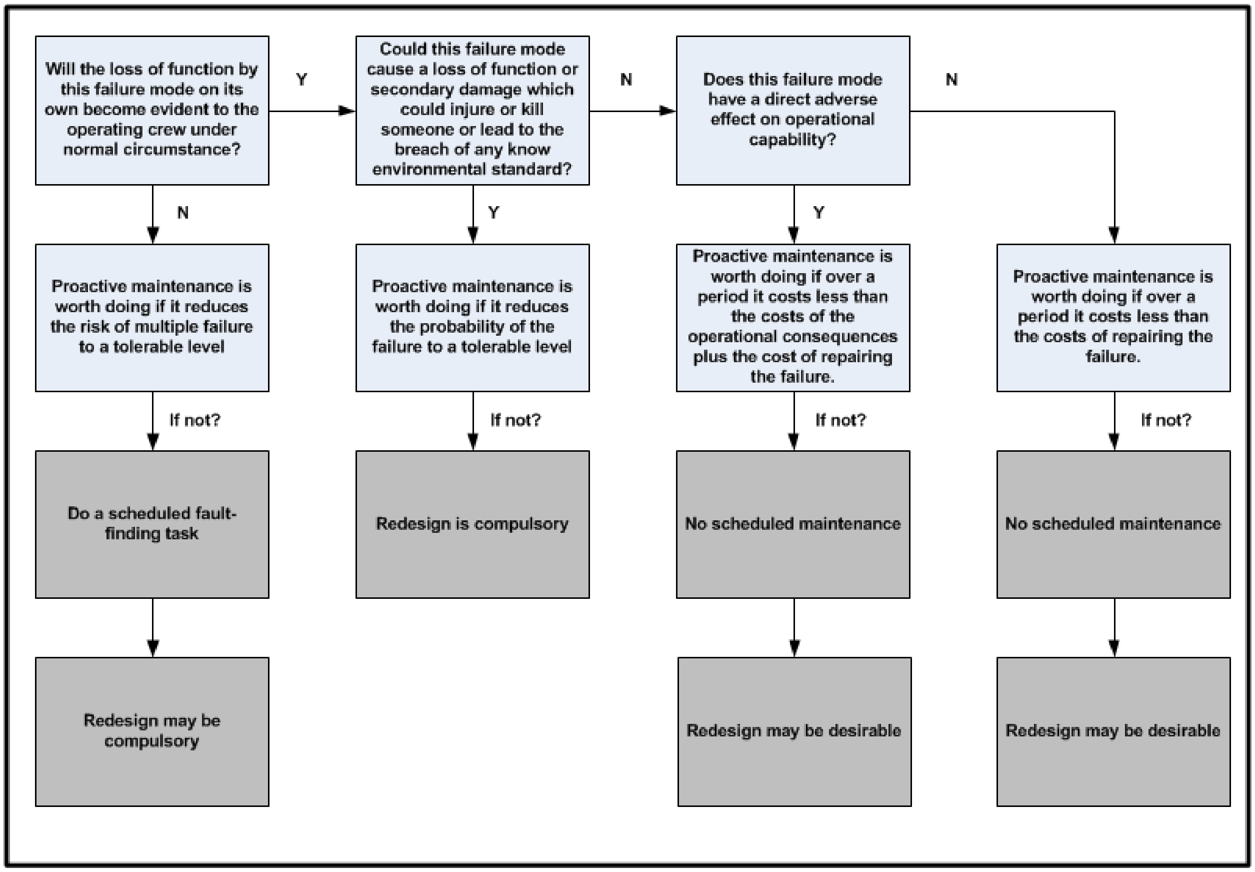

Figure 9: Evaluation of failure consequence (Moubray, 1997:127)

F. Proactive Tasks

- What can be done to predict or prevent each failure?

A proactive task is a task which is performed before a failure occurs in order to prevent the asset from going into a failed state (Moubray, 1997:129). Before a proactive task can be considered, the specific proactive task must be technically feasible. A proactive task is said to be technically feasible if it is physically possible for this task to "reduce, or enable action to be taken to reduce the consequence of the associated failure mode to an extent which that it might be acceptable to the owner or user of the asset" (Moubray, 1997:129).

Moubray suggests that there are two factors which dominate the selection of a proactive task from a technical view (Moubray, 1997:130). These factors are:

- Deterioration over time of the asset subjected to performing a function; and
- What happens once a functional failure has occurred?

AGE RELATED FAILURES:

Assets which are subjected to age related failures due to their operational context can have two strategies employed to enable a proactive task for the asset before it suffers a functional failure. These strategies consider the average life on an asset and implement either a Scheduled Restoration or Scheduled Discard task before the end of the asset's useful life (Moubray, 1997:132). Figure 10 displays the useful life vs. average life curve of a typical asset and displays when the probability of a functional failure increases.

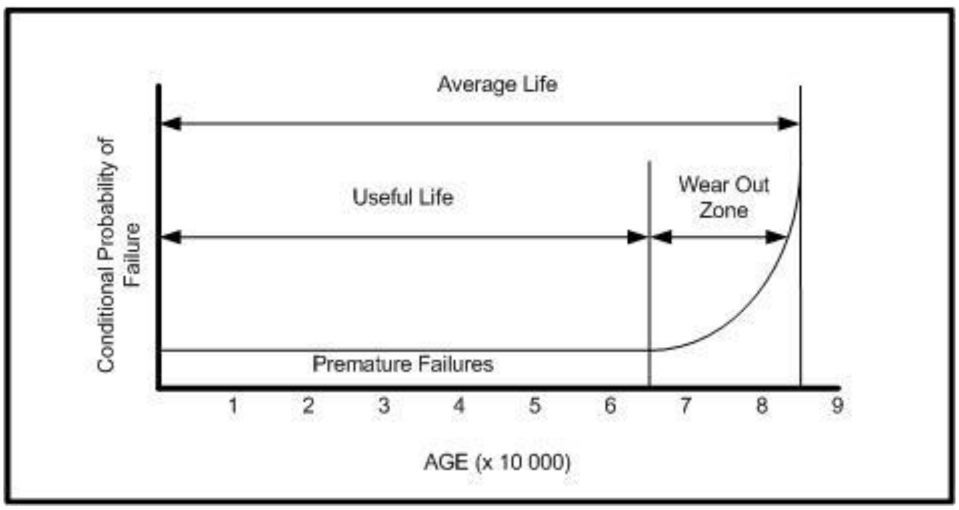

Figure 10: Useful Life vs. Average Life Curve

Scheduled Restoration can be defined as: "Restoring the initial capability of the item or component at or before a specified age limit, regardless of the apparent condition at the time" (Moubray, 1997:134).

Scheduled Discard can be defined as: "Discarding an item or component at or before a specified age limit, regardless of the apparent condition at the time" (Moubray, 1997:135).

The useful life of an asset can generally be classified as either a Safe-Life Limit or an Economic Life Limit. Moubray describes the two different life limits as follow:

- Safe life limit applies to failure which have a safety or environmental consequence; and
- Economic life limits applies to failures which have an economic consequence and no safety consequences.

A scheduled restoration task is technically feasible when (Moubray, 1997:138):

- An age is reached at which the item will show a rapid increase in the conditional probability of functional failure and the failure is identifiable;
- Most of such items in similar operational contexts survive to that age (note - all of the items should reach the age if the item has a safety or environmental impact); and
- The restoration restores the item to its original resistance-to-failure level.

A scheduled discard task is technically feasible when (Moubray, 1997:138):

- An age is reached at which the item will show a rapid increase in the conditional probability of functional failure and the failure is identifiable; and
- Most of such items in similar operational contexts survive to that age (note - all of the items should reach the age if the item has a safety or environmental impact).

Moubray concludes by explaining that even if a scheduled restoration or a scheduled discard task is technically feasible, it might not be worth doing i.e. it might not be cost effective. When faced with the selection of the implementation of either a scheduled restoration or scheduled discard task, careful consideration must be taken on the impact the tasks will have as oppose to the consequences of a failure. This is however true only if there are no safety or environmental consequences (Moubray, 1997:139).

NON AGE RELATED FAILURES:

Moubray discusses that in modern maintenance management very few failures actually conform to their age related failure patterns (Moubray, 1997:140). The following reasons are attributed to this fact:

- Variable stress affected on an asset – probability of consistent stress over a life time of an asset is very low; and
- The more complex an items is, the higher the probability for a functional failure.

The above points demonstrate that not all failures are due to normal conditions and very few sub systems or system elements conform to a standard curve. The result is that considerable care must also be taken to identify proactive tasks for irregular situations (Moubray, 1997:140).

PREDICTIVE TASKS

- What can be done to predict or prevent each failure?

Moubray states that most failures give some sort of warning before the failure occurs or if the failure is in the process of occurring. If this evidence of a failure can be found, the failure can be prevented (Moubray, 1997:144).

Figure 11 provides the P-F curve associated with a failure occurring. It explains when a failure starts to occur, when the failure can be detected (P) and the point, if not corrected, the element fails (F).

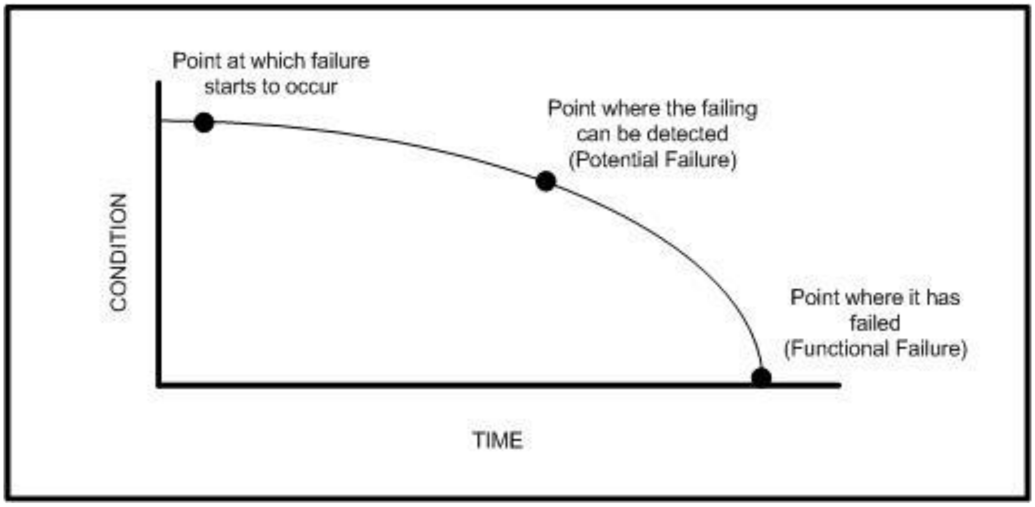

Figure 11: P-F Curve (Moubray, 1997: 144)

On-condition tasks can be described using figure 11: "On-condition tasks entail checking for potential failures, so that action can be taken to prevent the functional failure or to avoid the consequences of the functional failure" (Moubray, 1997: 145).

ON-CONDITION TECHNIQUES:

Moubray provides four mayor categories of on -condition techniques (Moubray, 1997:150):

i. Condition Monitoring

   Equipment is used to monitor the condition of other equipment;

ii. Product Quality Variation

   Often a defect in a produced product is directly related to a failure mode in the producing machine itself;

iii. Primary Effects Monitoring

   Primary variable or effects of a process can be monitored by either a human or a control system. Any variations from the desired performance level will indicate a potential failure; and

iv. The Human Senses

The human senses can be applied for inspection techniques at scheduled times.

It is important to be aware of the advantages and disadvantages of all the above inspection techniques. Furthermore it is also important to always consider the specific operating context before selecting the appropriate technique.

LINEAR AND NON-LINEAR PF CURVES:

Moubray suggests when a PF curve of an asset is considered for on-condition monitoring, special attention should be paid the curve shape i.e. is the curve linear or non-linear. This will influence the strategy employed to maintain the asset effectively.

ON-CONDITION JUSTIFICATION:

On-condition tasks are worth doing if they satisfy the following criteria (Moubray, 1997:166):

- The failure is hidden;
- The failure has safety or environmental consequences; and
- If the failure does not involve safety or the environment, then the task must be cost effective.

G. Default Action: Failure Finding Tasks

- What should be done if a suitable proactive task cannot be found?

The answer to the above question can be found in figure 9. The default actions for the specific instances are highlighted in the grey area of the figure. The default actions will now be discussed in more detail.

FAILURE FINDING:

Moubray (1997:173) describes failure finding tasks as tasks that entail checking a hidden function at regular intervals to find out if it has failed. Failure finding tasks only apply to hidden functions and hidden failures only affect protective devices (Moubray, 1997:172).

Failure finding tasks has several key issues which are worth mentioning when wanting to implement such tasks (Moubray, 1997:173):

- The entire protective system must be checked especially in the case of complex systems such as electrical circuits;
- The protective devices should be checked with no disturbance if possible;
- It must be physically possible to check the function of the protective device;
- It must be possible to conduct the failure finding task without increasing the risk for multiple failures; and
- The frequency of the failure finding tasks must be practical.

FAILURE FINDING INTERVAL:

From previous sections, it can be demonstrated that preventative and predictive maintenance task intervals are guided by the PF interval of an item. Moubray (1997:175) suggests that with failure finding tasks both availability and reliability must be used to deduce the failure finding interval of an asset or item.

It can be seen from Moubray (1997:180) that there exists various means by which to calculate and/or determine the failure finding interval. These techniques depend on the operating context and other variables of a system or item. Care should be taken to determine the correct failure finding interval. Some of the techniques which can be used are:

- Formulas using MTBF of protected function, protection device, etc.;
- Voting systems; and
- Deriving cost effective intervals for systems where multiple failures do not affect safety

or the environment.

In conclusion on fault finding task, these tasks must also be technically feasible. A fault finding task is technically feasible if (Moubray, 1997:185):

- It is possible to do the task;
- The task does not increase the risk of a multiple failures; and
- It is practical to do the task at the required interval.

Fault finding is a default action and must only be pursued if there is no feasible preventative or predictive task which can be done. If failure finding is not feasible, then a redesign will be compulsory if there are any safety- or environmental consequences. If not, then it can be possible to schedule a no-action task if the economic consequences are tolerable (Moubray, 1997:186).

DEFAULT ACTION: REDESIGN AND NO-SCHEDULED MAINTENANCE:

The failure finding task is a task which can be scheduled if no feasible preventative or proactive maintenance task can be found. Similarly there are other default actions which can be taken (Moubray, 1997:187). These actions consist of:

- No Scheduled Maintenance; and
- Redesign.

NO SCHEDULED MAINTENANCE:

From Moubray, it is shown that no scheduled maintenance is only valid for the following situations (1997:187):

- A suitable scheduled task cannot be found for a hidden function and the associated multiple failure does not have any safety or environmental consequences; and
- A cost-effective preventative task cannot be found for failures which have operational and non-operational failures.

REDESIGN:

Redesign of an item or asset can include any change to a specification of an item or any once-off change which can affect the operations of the process. Redesign can also consider a change in the training (Moubray, 1997: 188).

Redesign can be employed when the following scenarios have arisen (Moubray, 1997: 188):

- When a failure could have safety or environmental consequences and no preventative task or tasks can be found to reduce the risk of failure to a tolerable level; and
- If a technically feasible preventative task cannot be found for an operational or non-operational failure, the immediate default decision is to do no scheduled maintenance. Redesign may be desirable.

WALK-AROUND CHECKS:

Walk around checks are tasks scheduled to physically walk around the process and observe the normal operations. Walk around checks serve two purposes in a process (Moubray, 1997:197):

- Spot accidental damage; and
- Spot problems due to negligence or ignorance.

2.5.1 RCM Decision Worksheet

In section 2.5, sub-sections E, F and G essentially asked questions and the answers will populate the RCM decision worksheet. The decision worksheet is concerned with providing the following information to the RCM development process (Moubray, 1997:198):

- What routine maintenance is to be done and how often it is to be done;
- Which failures are serious enough to warrant redesign; and
- Cases where a deliberate decision has been made to let the failure happen.

Table 4 on the following page provides an overview of the RCM decision worksheet. The RCM decision diagram process as discussed by Moubray is depicted in Figure 12. The diagram shows the process followed to complete the RCM decision worksheet as displayed in Table 4.

Table 4: The RCM Decision Worksheet

System		**System No**			**Facilitator**		**Date**		**Sheet No**	
Sub-System		**Sub System No**			**Auditor**		**Date**		**of**	

Information Reference			**Consequence Evaluation**				**H1**	**H2**	**H3**	**PROPOSED TASK**	**INITIAL INTERVAL**	**CAN BE DONE BY**
F	**FF**	**FM**	**H**	**S**	**E**	**O**	**S1**	**S2**	**S3**			
							O1	**O2**	**O3**			
							N1	**N2**	**N3**			

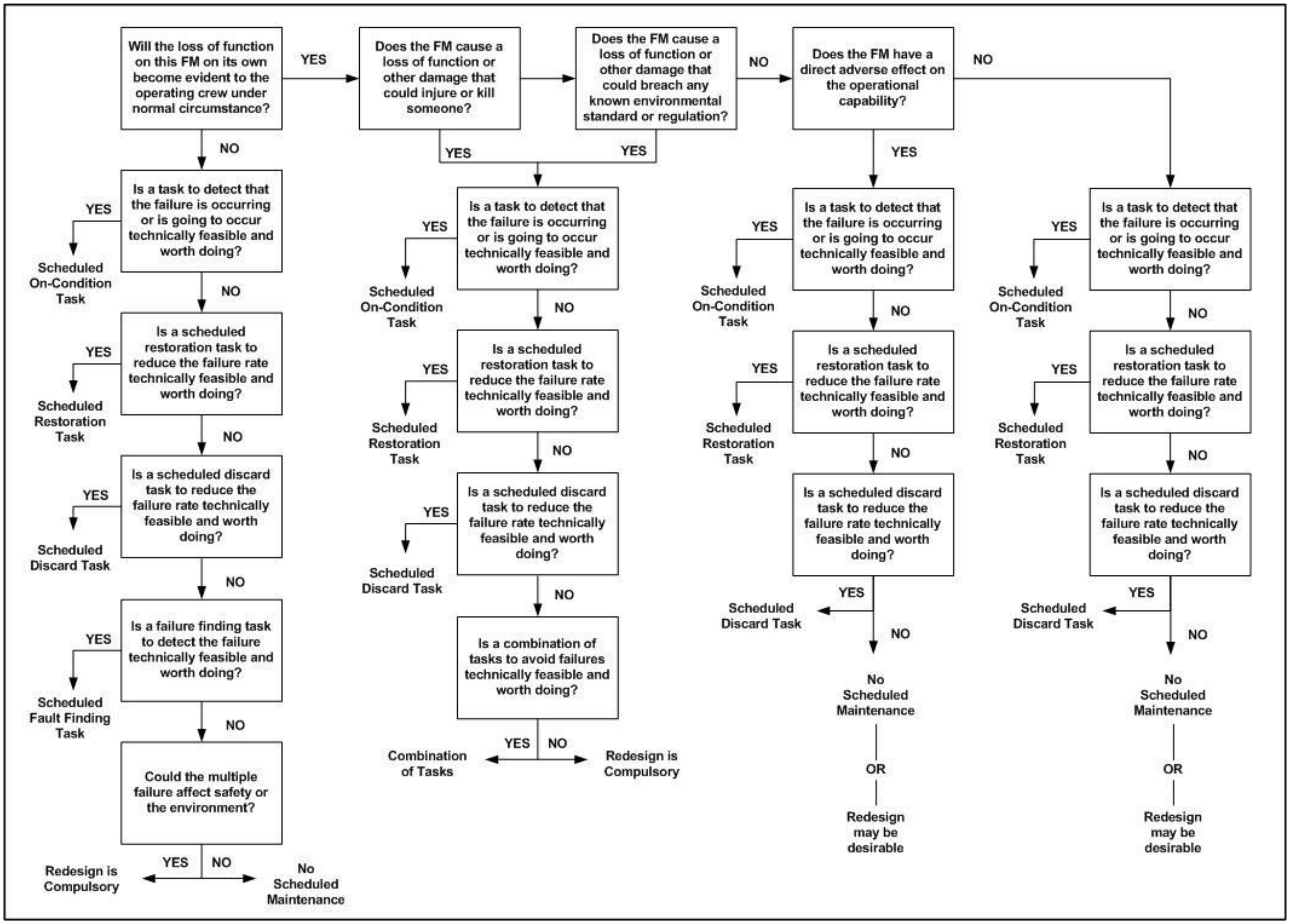

Figure 12: The RCM II Decision Diagram (Moubray, 1997:200)

2.6 Maintenance structure in an organisation

2.6.1 Maintenance Organisation Structure

The maintenance function can be organised into various configurations within an organisation. It is important to consider the dynamics of a specific organisation before the maintenance organisation can be developed. This maintenance organisation can be created based on 2 primary criteria: geographical location (Wireman, 2004:64) and reporting structure (Wireman, 2004:66).

GEOGRAPHICAL LOCATION:

There are three different geographical configurations in which a maintenance organisation structure can be found (Wireman 2004:64). These are:

- Centralised Organisation:

  In such a structure all maintenance personnel report to a central location from which they are directed to work in certain locations (Wireman, 2004:64);

- Organisation by Areas:

  In this configuration maintenance personnel are assigned to geographical areas within a plant or organisation (Wireman, 2004:65); and

- Hybrid Organisation

  A hybrid organisation structure is a combination between a centralised and area-based organisational structure (Wireman, 2004:65).

REPORTING STRUCTURE:

Another important aspect in the maintenance organisation is the reporting structure (Wireman, 2004:66). The following three models are considered:

- Maintenance Centric Structure

  In this model the maintenance manager reports directly to the plant manager (Wireman, 2004:66). No other section can directly deploy maintenance personnel.

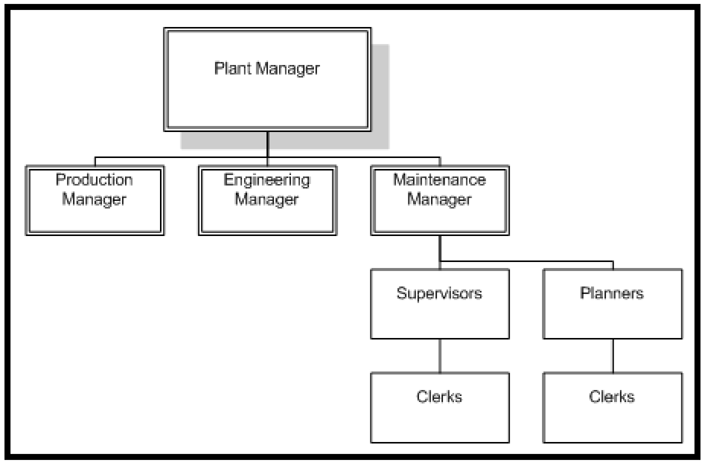

Figure 13: Maintenance Centric Structure (Wireman, 2004:66)

- Production Centric Structure

  In this model the maintenance resources are managed and deployed by the production manager. According to Wireman (2004:67) this model rarely works due to the technical shortcomings of production managers in the field of maintenance management .See figure 14 on the next page.

- Engineering Centric Structure

  In this model the maintenance resources are managed and deployed by the plant engineer. Wireman suggests that this model can result in problems due to the priorities of the plant engineer's attention being diverted to more important project matters (2004:68). See figure 15 on the next page.

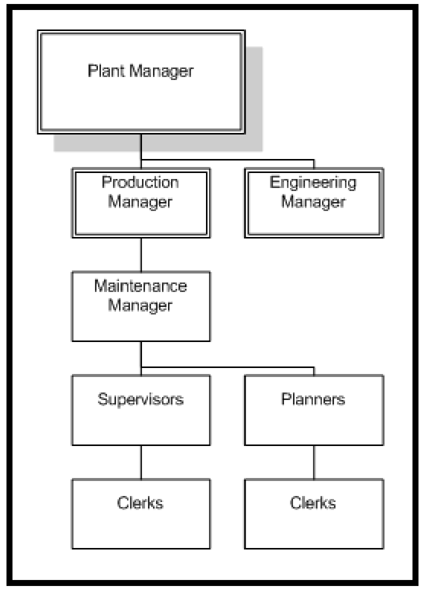

Figure 14: Production Centric Structure (Wireman, 2004:67)

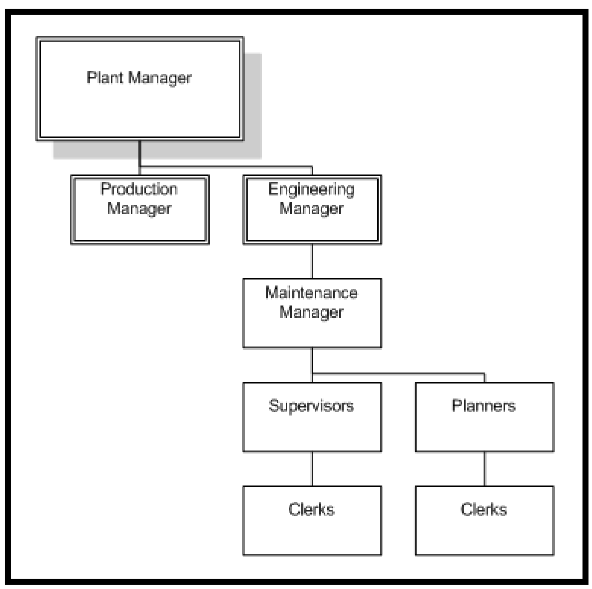

Figure 15: Maintenance Centric Structure (Wireman, 2004:69)

2.6.2 Maintenance Staffing

Maintenance requires staff to perform the physical maintenance actions (Wireman, 2004:62). The staff can be organised in different methods. The following are examples of typical staffing methods for a maintenance function (Wireman, 2004:62):

- Complete in-house staff – all staff are located within the specific organisation;
- In-house and contract staff – combination of in-house and outside contracted staff;
- Contract maintained staff – contract staff combine with supervisors to perform all maintenance work; and
- Complete contract maintenance – all maintenance work is performed by outside the organisation contracted staff. The contract staff will reports are given to the plant engineer on all work.

2.7 Maintenance as a system

2.7.1 Systems and Systems Engineering

In section 1.2 it was mentioned that the Newcom FMS system can be portrayed as a system of systems (SoS). First, consider the definition of a system obtained from Blanchard and Fabrycky (2006:3):

"A system is an assemblage or combination of elements or parts forming a complex or unitary whole."

Blanchard and Fabrycky explain that a system consists of the following (2006:3):

- Components – the components are considered the operating parts of a system;
- Attributes – the attributes showcase the properties of the components and characterise the system; and
- Relationship – relationships provide the link between the components and attributes.

As displayed in section 1.2, the different components of the Newcom FMS system can be seen in figure 4. However, each system component is very complex and can also be classified as a system. When encountered with a complex scenario as mentioned above, INCOSE defines a System-of-Systems as an interoperating collection of component systems that produce results unachievable by the individual systems alone (3, 2006:2.2).

The Newcom FMS can therefore be considered as a SoS and the maintenance system within this SoS must be considered and developed accordingly.

INCOSE proceeds to give typical challenges which face the realisation of SoS (3, 2006:2.3):

i. System elements operate independently;
ii. System elements have different life cycles;
iii. The initial requirements are likely to be ambiguous;
iv. Complexity is a major issue;
v. Management can overshadow engineering. Since each system element has its own product/project office, the coordination of requirements, budget constraints, schedules, interfaces, and technology upgrades further complicate the development of SoS;
vi. Fuzzy boundaries cause confusion; and
vii. SoS engineering is never finished.

If the maintenance system within the Newcom SoS is better understood, then the next step would be to realise this system. From Ramo (as quoted by INCOSE, 3, 2006:2.1), the following definition is provided for systems engineering: "Systems engineering is a discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspect."

Systems engineering can also be defined as: "An interdisciplinary approach that encompasses the entire technical effort, and evolves into and verifies an integrated and life cycle balanced set of system people, products, and process solutions that satisfy customer needs" (EIA Standard, 1994).

In summary, Systems Engineering is an “interdisciplinary engineering management process that evolves and verifies an integrated, life-cycle balanced set of system solutions that satisfy customer’s need” (DoD, 2001:3).

The purpose of SE can be described as: “…to provide a structured but flexible process that transforms requirements into specifications, architectures, and configuration baselines…” (DoD, 2001:4).

The objective of SE then can be considered as: “…to see to it that the system is designed, built, and operated so that it accomplishes its purpose in the most cost-effective way possible, considering performance, cost, schedule, and risk” (NASA, 1995:3).

In other words, systems engineering (SE) must see to it that a system (product) is delivered to a client successfully.

2.7.2 SE Process

INCOSE (2a, 2004:16) defines the SE process as an “iterative process of technical management, acquisition and supply, system design, product realization, and technical evaluation at each level of the system, beginning at the top (the system level) and propagating those processes through a series of steps which eventually lead to a preferred system solution. At each successive level there are supporting, lower-level design iterations which are necessary to gain confidence for the decisions taken.”

There are several SE process models which can be deployed by an organisation (Blanchard and Fabrycky, 2006:32). Some of the models are displayed in figures 16, 17 and 18.

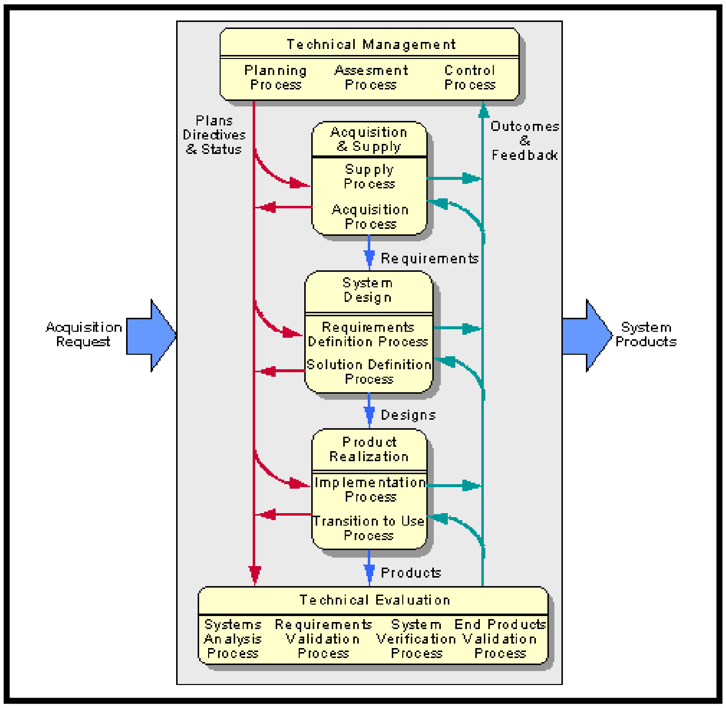

Figure 16: INCOSE SE Process (INCOSE, 2004:17)

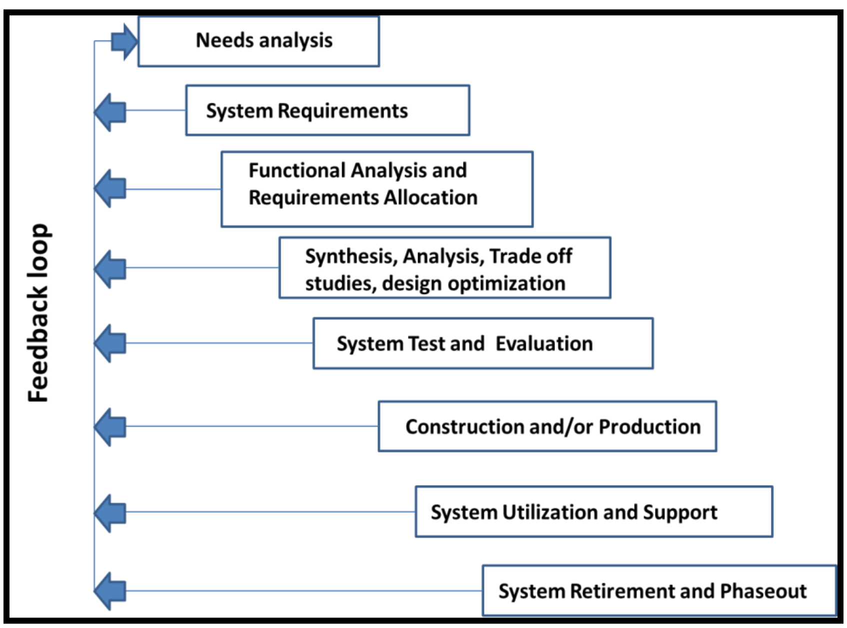

Figure 17: SE Process (Blanchard and Fabrycky, 2006:31)

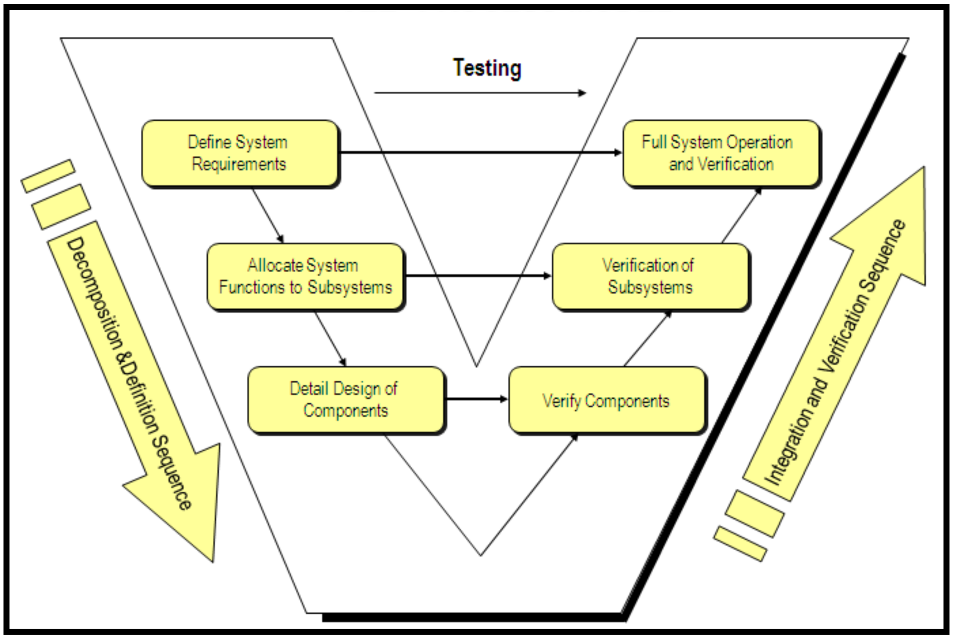

Figure 18: VEE SE Process (Blanchard and Fabracky, 2006:34)

It is recommended that an organisation use a SE process only as a backbone for the development of the organisations' own process. The specifically developed process of an organisation must take into account the organisations' own terminology, development and support approaches (Blanchard and Fabrycky, 2006:32).

2.8 The advantage of statistics in maintenance

2.8.1 Introduction

The FMS system will continuously be operated and maintained by Newcom (Van Huyssteen, personal communication, Feb 2011). When actively maintaining the FMS solution, the system availability and functional failures must be continuously captured and recorded.

The operational and failure data can be used to identify behavior information from an individual remote system (Devore and Farnum, 2005:1). This behavior information can lead to the identification of inhibitors and the improvement of future maintenance on a per field system basis as each system will operate in a unique environment.

Devore and Farnum states that statistics can enable an individual or an organisation to make "intelligent judgments and informed decisions in the presence of uncertainty and variation" (2005:1). Consider the proposed Newcom FMS solution - the different elements and sub-systems which make up the Newcom FMS SoS (NFM FMS, 2011:4) allows for uncertainty to be present in the operational behavior of the Newcom FMS system.

2.8.2 Failure frequency and relative frequency

In the newly developed Newcom FMS maintenance strategy, the frequency and relative frequency of functional failures must be investigated. The frequency can be determined by the amount of functional failures of a system element within a predefined time period (Devore and Farnum, 2005:12).

The relative frequency can be defined as the proportion of time the functional failure occurs (Devore and Farnum, 2004: 12) and can be expressed mathematically as:

$$\mathbf{Rf = (X) / (Y)}$$

where

Rf: Relative frequency of a functional failure

X: Number of time failure occurs

Y: Number of observations in data set or time period of data set

Histograms can be used to graphically interpret the frequency and relative frequency of functional failures (Devore and Farnum, 2005:12). A set of functional failures can be identified for the Newcom FMS and can be monitored. This will allows Newcom to identify, over a period of time, the sub-systems which might be in need of improvement – be it redesign of the system element or the reassessment of maintenance actions.

2.8.3 **Results from data**

Newcom stated that if a practical method can be developed to identify and quantify functional failures, the method can greatly assist in creating a sustainable and continuous improving maintenance strategy (Van Huyssteen, personal communication, Feb 2011).

By obtaining the relative frequency information of the functional failures and giving them a weight which is coupled to the direct financial value of correcting that functional failure, a simple yet powerful mechanism can be provided for Newcom to continuously capture and measure the impact of functional failures in the Newcom FMS system and sub systems. These parameters can also be used to measure the effectiveness of the implemented maintenance strategy.

2.8.4 **Maintenance Predictions**

Devore and Farnum (2005:99) suggests that if a relationship between variables can be determined and represented on a graph, it would be possible to use this graph and data to perform predictions on the possible next functional failure. A correlation coefficient is a "quantitative assessment of the strength" of a relationship between tow variables, x and y (Devore and Farnum, 2005:105).

If a correlation can be found between functional failures and a certain operational parameter which will enable Newcom to possibly predict a functional failure, the maintenance strategy can be adapted to manage such incidents.

Devore and Farnum (2005:137) explain that predictions can be done in the following manner:

- Data can be obtained from the Newcom FMS system as well as of the functional failures;
- The data can be plotted on a graph;
- If possible a straight line can be fit to the data or otherwise a curve can be fit to the data; and
- This curve or line equation can then be utilized to predict the failures (denoted by Y) in the events of a certain operational variable (denoted by X).

The following graph in figure 19 uses fictional data to demonstrate the potential relationship of the failure of a system element of the Newcom FMS system versus the amount of workload of the system depicted by the amount of liters fuel dispensed.

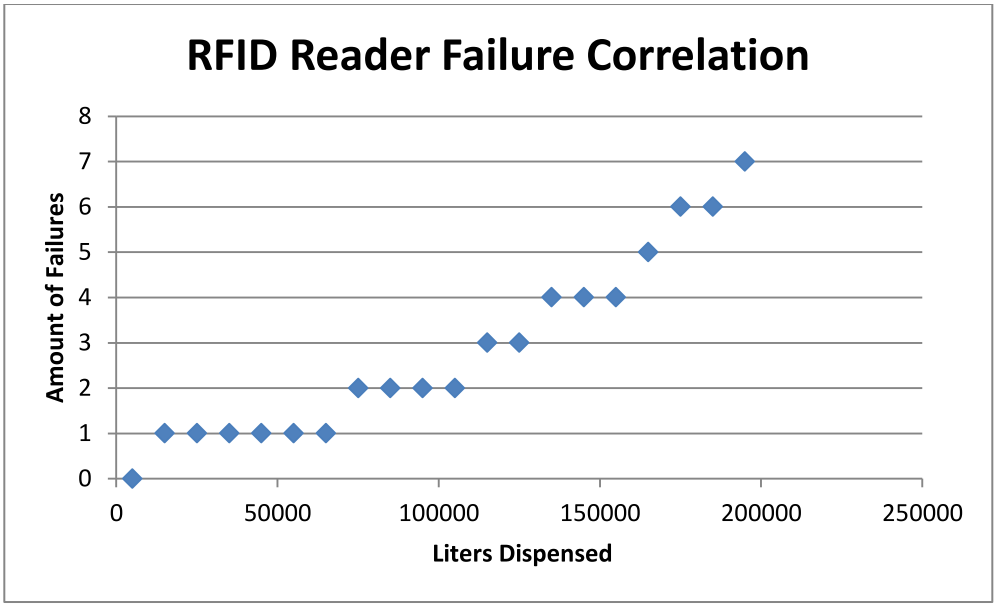

Figure 19: Demonstration of a Correlation Graph for the Newcom FMS

The graph demonstrates the correlation between the amount of fuel dispensed and the amount of failures on the RFID Reader Failure of the Newcom FMS (NFM FMS, 2011:4). A potential failure probability can be determined by investigating the strength of the relationship between X (Amount of Failures) and Y (Liters Dispensed) and can be denoted as a correlation coefficient (Devore and Farnum, 2005:105).

When considering the graph in figure 19, the following Pearson sample correlation (r) formula can be used to determine the correlation between x and y (Devore and Farnum, 2005:105):

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

As stated earlier, this correlation coefficient (r) is an indicator of the strength of the relationship of x and y. In the above graph it can be interpreted as: The more liters of fuel dispensed (x) the higher the probability of a functional failure on the RF Reader (y).

The above correlation coefficient methodology must be implemented with the new maintenance strategy to be developed for Newcom for the Newcom FMS SoS.

2.9 Literature Review Conclusion

Chapter 2 has provided information on the theory of maintenance management. The goal of chapter 2 was to identify and research possible information to develop a viable maintenance strategy which can be implemented for the Newcom FMS system.

The concept of systems and system engineering was investigated to enable the Newcom FMS maintenance system to be seen and managed in the correct context with all the effects taken into account. The researched system and systems engineering information can allow for the analysis of the Newcom FMS SoS and the realisation of the maintenance system.

The next chapter will focus on implementing the knowledge obtained in section 2 to facilitate the development of a RCM based maintenance strategy for Newcom for the Newcom FMS system.

3 EXPERIMENTAL MAINTENANCE STRATEGY

3.1 Methodology

With the theory researched in chapter 2, chapter 3 will consider the development and implementation of the experimental strategy by utilising the newly found knowledge. This methodology will consist of the following:

- SE process description – outline the process to follow for the realisation of a RCM based maintenance strategy for the Newcom FMS;
- System analysis of the FMS maintenance system – perform a functional analysis on the Newcom FMS to identify the functions for the RCM process;
- RCM process development for the FMS system – execute the RCM process on the Newcom FMS system and eventually identify the maintenance tasks and the required personnel;
- Development of maintenance organisation which will be able to successfully execute the maintenance tasks and activities;
- Maintenance reporting structures – develop a mechanism to capture, investigate and implement changes based on information gathered from maintenance tasks, field observations and operational data analysis;
- Statistical failure data and predictions – identify a methodology to allow for the capture of parameters which can provide Newcom with information on failure instances and failure predictions; and
- Summary of the maintenance system.

The goal of this chapter is realise a realistic maintenance strategy which can be implemented and used by Newcom to improve the maintenance management of the current Newcom FMS system.

3.2 Newcom FMS maintenance SE process

The SE process to be followed is modeled on the process obtained in figure 17 in section 2.7.2. The generic process in figure 17 was adapted to suit the needs of this specific system realisation for the Newcom FMS and can be shown as:

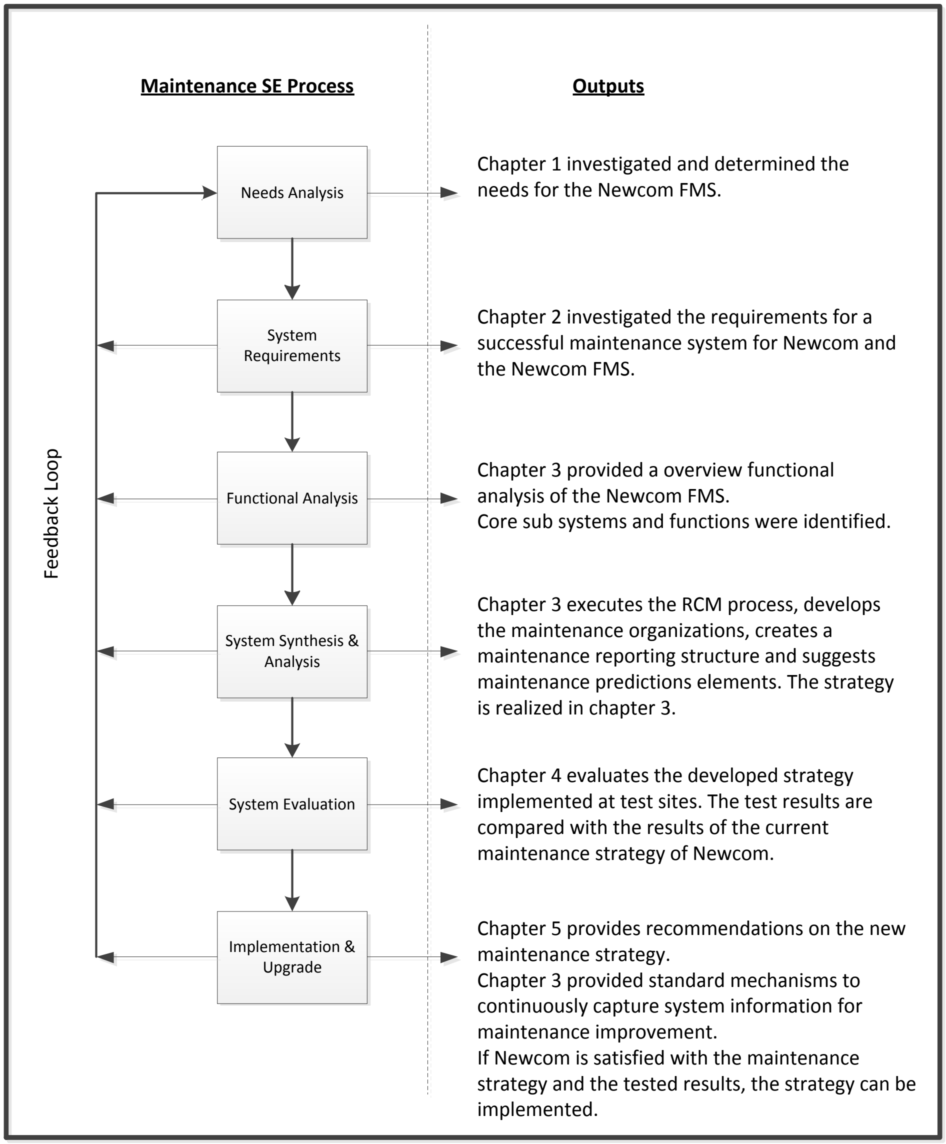

Figure 20: Newcom Maintenance System SE Process

The above process provides a framework to realise the maintenance strategy for the Newcom FMS.

The above process also provides a mechanism on how to iterate and improve the maintenance system in the future. The improvement mechanism is visually displayed as the feedback loops from each phase of the realisation.

An example of a possible system improvement is, if the results obtained during the system evaluation phase are not satisfactory, the data obtained from the system evaluation can be used as a process input into previous phases to iterate those previous phases to improve the system and allow for the provision of improved results in evaluation phase.

The first two phases in figure 17 have already been completed in chapter 1 and 2. The next two steps of the process will be completed in this chapter. The process phases are:

- Functional Analysis; and
- System Synthesis and Analysis.

3.3 Functional Analysis of the FMS System

This phase involves identifying the primary functions of the Newcom FMS. The functions will be used in the RCM process as part of the synthesis of the maintenance system.

The Newcom Fluid or Fuel Management Solution is a complex, multi discipline system involving several system elements or sub-systems. The elements must work in harmony to achieve the intended goal of the FMS. As displayed in figure 4, the FMS SoS consists of:

- On-Site Control System;
- Off-Site Management System;
- Newcom Management System;
- Client System; and
- Maintenance System.

In the following two figures a functional flow block diagram (FFBD) of the Newcom FMS is displayed. This FFBD demonstrates how the Newcom FMS sub-systems with their functions work in unison to achieve the system goal of the Newcom FMS. The FFBD's are provided in a basic representation and a more detailed representation respectively:

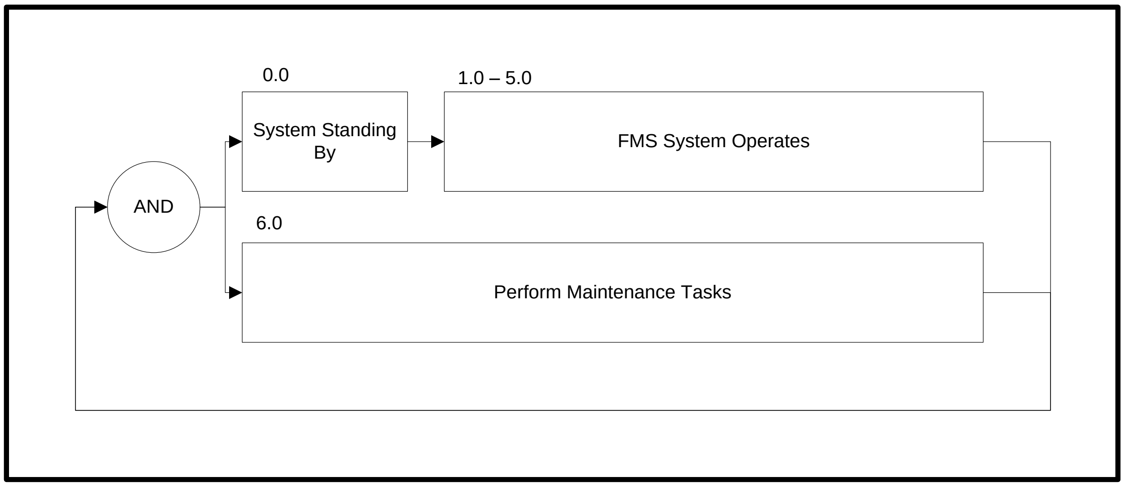

Figure 21: Basic FFBD of FMS

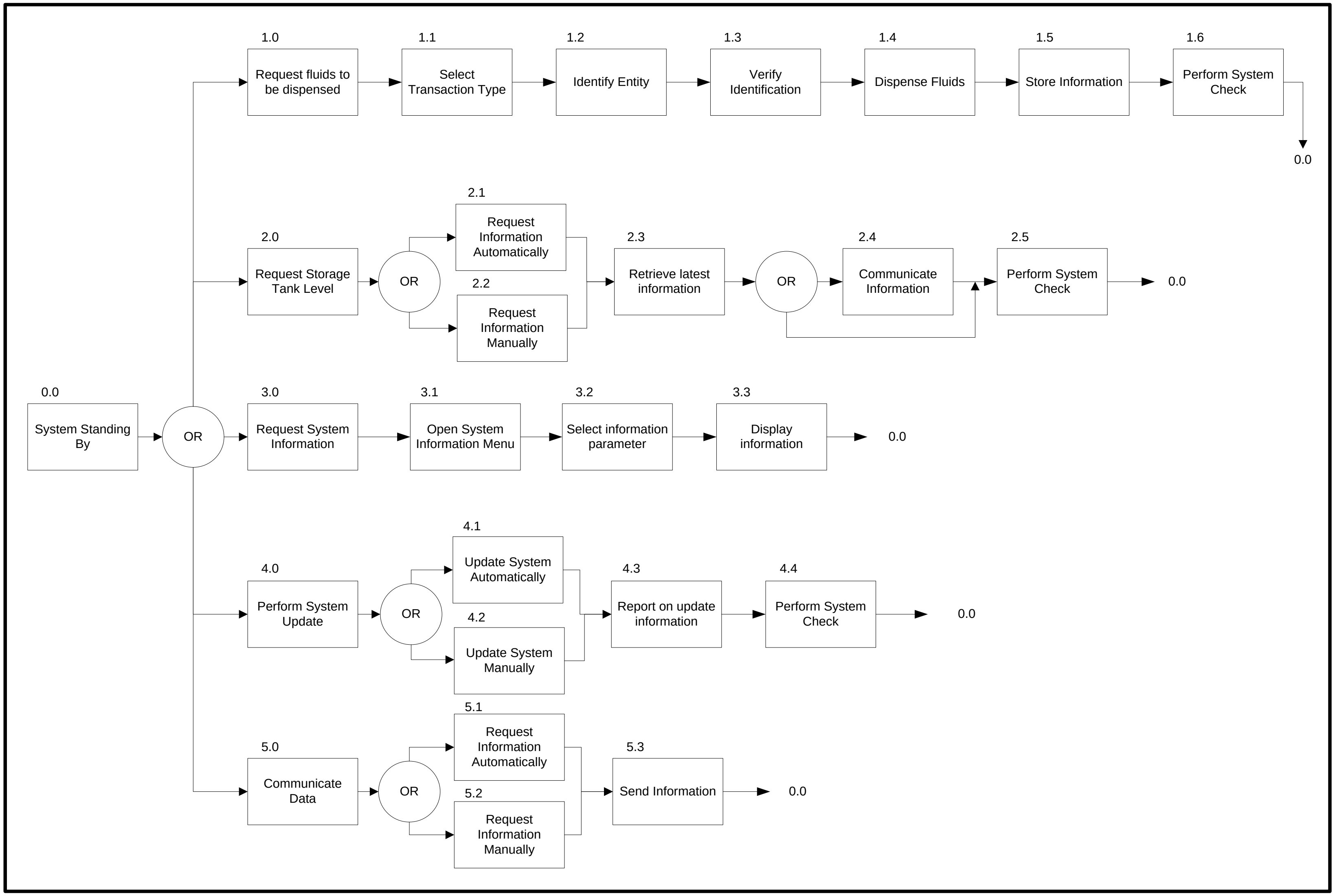

Figure 22: Detail FFBD of FMS - without Maintenance Function

Each of the functions (1.1 – 5.3) in figure 22 can be considered in more detail, but for the purposes of the first iteration of the maintenance strategy, (1.1 – 5.3) will only be considered in the detail as provided in the above figures.

All of the sub-systems of the Newcom FMS work together to execute the functions as identified in the above FFB diagrams. The functions will be considered in the next phase in the synthesis of the maintenance strategy.

3.4 RCM Process Development

The RCM development process is discussed in section 2.5. There are several steps in the process to be followed to create a RCM strategy in terms of the seven questions which need to be answered and the mechanism with which to capture the information.

The maintenance strategy information will be captured using the RCM information worksheet and the RCM decision worksheet. As discussed in section 3.3, the RCM process will be an iterative process which entails continuous improvement to obtain the desired results. This document will only consider the first iteration of the RCM process, but the SE process discussed in section 3.2 can allow Newcom to iterate the RCM process using the developed SE process.

Once the initial RCM worksheets have been completed, the next steps can be taken to - together with Newcom - capture and populate the information into a schedule with the responsibilities allocated to personnel.

3.4.1 **Operating Context**

At this point it is important to discuss the operating context of the operational fuel management system as this will have an impact on the system functions. The operational context for the Newcom FMS will be discussed at the hand of the parameters identified in section 2.5. A.

i. Type of Process:

The entire process is a simple linear flow process. The Newcom FMS is not a batch process.

ii. Asset Redundancy

The field systems are not configured in redundant states

The Off-Site Management and Newcom Management Systems are redundant.

iii. Environmental Standards

The system does not directly impact the environment except when disposal of the equipment is required at the end of the equipment life-cycle.

iv. Safety Hazards

The on-site control system and off-site management system have electrical shock risks.

3.4.2 The RCM Process Team

The RCM development process requires a team to answer the RCM questions. The development team consisted of the following personnel:

- 1 x System Engineer;
- 1 x Technical Product Engineer;
- 1 x Maintenance Manager;
- 1 x Financial Manager; and
- 1 Hour sessions at a time with 15 x minute breaks between sessions.

The above process was repeated until the first versions of the RCM Information and Decision worksheets were compiled. Using the data captured in the RCM worksheets, a schedule could be established, the required personnel could be estimated and responsibilities allocated.

3.4.3 RCM Information Worksheet

The answers on the first three questions of the RCM process were captured using the information worksheet of the RCM process. The RCM team had enough system knowledge to answer all the questions regarding the functions of the specific assets, the performance standards and the operating context.

Where there was no clear information on a variable, the development team provided requirements obtained from their clients who were used as a baseline (Van Huyssteen, personal communication, Oct 2011).

The detailed RCM Information Sheet can be seen in Appendix A.

3.4.4 RCM Decision Worksheet

The answers on the last four questions of the RCM process were captured using the decision worksheet of the RCM process. The RCM team had enough system knowledge to answer all the questions regarding the impact or severity of failures and the possible consequences. The teams could also discuss maintenance actions and assign responsibilities.

Where there was no clear information on a specific variable, the development team considered industry standards to use as a baseline (Van Huyssteen, personal communication, Oct 2011).

The detailed RCM Decision Sheet can be seen in Appendix A.

3.4.5 RCM Process Results and Schedule

The RCM process yielded the following results:

i. Maintenance tasks to be done;

ii. Maintenance task frequencies; and

iii. Responsible people to perform maintenance tasks.

The information can be used to compile a schedule for maintenance work. This schedule can be used and changed by Newcom to fit their process. The initial proposed schedule can be discussed as:

a) Physical maintenance tasks and actions identified in the RCM process and specified in Appendix A;

b) The suggested time interval associated with each maintenance tasks to be completed;

c) Human resources required to perform the tasks which will consist of Newcom personnel, external contractors and the staff of the clients;

d) Training required for the specific personnel to perform their respective maintenance tasks. A periodic retraining program can also be established in the future; and

e) Resources required to successfully complete the maintenance tasks in the scheduled intervals.

The above points will form the backbone for the first iteration of the maintenance strategy. The next step is to develop the maintenance organisation.

3.5 Maintenance organisation

The maintenance tasks, the required personnel for those tasks and the maintenance task frequencies have been identified in the previous section. An organisation must now be developed which can successfully execute the identified maintenance tasks.

The maintenance organisation will consist of the:

- Geographical maintenance organisation structure (section 2.6.1);
- Maintenance staffing (section 2.6.2); and
- Maintenance reporting structure (section 2.6.1).

The research conducted in the document will not consider the details of the human resources planning, but rather this research document will provide a maintenance strategy with a proposed human resource platform who can execute the maintenance tasks. Depending on the results that the strategy delivers and the ever changing market conditions, the human resource platform can continuously be updated and improved as with the entire maintenance strategy.

3.5.1 Organisational structure

A hybrid organisation was selected as the desired organisational structure. This structure is a combination between a centralised and area-based organisational structure. The reasons why this structure was selected are:

- Maintenance tasks must be conducted at remote sites located in different geographical locations; and
- Maintenance tasks must be conducted at Newcom head offices.

The hybrid maintenance organisation translates into:

- Maintenance task teams will be based at Newcom head offices which will conduct the maintenance tasks as identified in the RCM process;
- Maintenance field teams will be located in strategic areas where strategic business areas will be identified. From these strategic areas maintenance teams can perform the maintenance tasks as identified in the RCM process; and
- The maintenance strategy and the effectiveness thereof will be monitored and managed from the Newcom head offices.

3.5.2 Maintenance staff parameters

The first iteration strategy will consider maintenance staffing based on the inputs from the following sources:

- RCM process results;
- Newcom previous experience, and
- Estimations on required personnel.

Based on the research conducted in section 2.6.2, a combination between the in-house staff and contract staff maintenance staffing model has been selected. The selection was based on the following:

- Maintenance tasks to be done on-site by contract staff and Newcom staff; and
- Maintenance tasks to be done at Newcom headquarters by in-house staff.

3.5.3 Reporting structure

With the information obtained in section 2.6.1, it was decided to select a Maintenance Centric reporting structure. The model dictates that:

- The maintenance manager reports directly to the plant manager (Wireman, 2004:66). No other section can directly deploy maintenance personnel.

In the case of the specific maintenance strategy for Newcom, the following reporting structure was constructed:

- In-house and contract field technicians report directly to the Newcom FMS manager;
- The data clerks report directly to the Newcom FMS manager;
- The systems engineer report directly to the Newcom FMS manager; and
- The hardware and software engineers report to the system engineer.

3.5.4 Maintenance organisation summary

Based on the findings in sections 3.5.1, 3.5.2 and 3.5.3, the following maintenance organisational chart can be constructed for the Newcom FMS system:

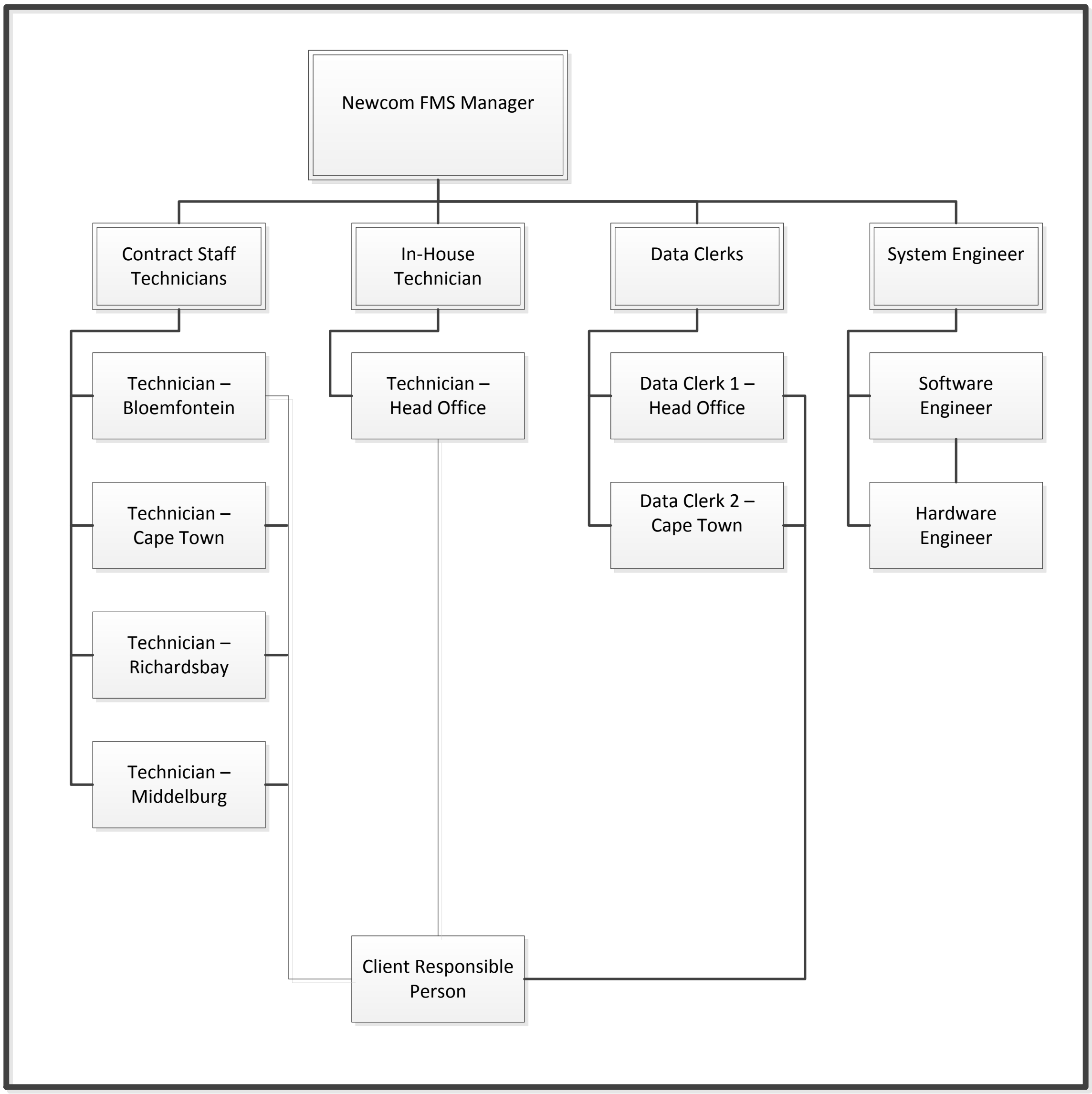

Figure 23: Newcom FMS Organisational Chart

Figure 23 above displays the first iteration of the following:

- Personnel in the Newcom FMS system;
- Reporting structure; and
- Staffing model.

The maintenance organisation in figure 23 will be implemented with the finding of the RCM process for a first iteration maintenance strategy.

For continuous improvement and maintenance optimisation, section 2.8 discussed how capturing data on the operational systems as well as the failures can improve the maintenance function. The following section will consider this aspect.

3.6 Maintenance data capture and maintenance improvements

In the first iteration of the maintenance strategy, the following will be considered as part of the continuous maintenance improvement process:

i. Job cards for maintenance tasks and a database for work completed;
ii. Database of functional failures, failure modes and consequences;
iii. The monitoring of the relative frequency of functional failures; and
iv. Failure prediction based on the measurement of key operational parameters.

The above data sets to be monitored will provide Newcom with continuous feedback on work completed, ineffective maintenance tasks and faulty system elements. This will provide key inputs into future system design and system maintenance processes.

3.6.1 **Job Card and Tracking Database**

The job card will allow the tracking of the tasks as specified in the schedule which was developed in section 3.4.5. The job card data can be populated into a database of all maintenance work done. This in turn can serve as information to be investigated when the maintenance function is reviewed.

By identifying ineffective maintenance tasks or by optimising or adding additional maintenance tasks, the maintenance function can continuously be optimised which in turn can optimise the entire system. An initial example of the job card and work completed database can be provided as:

Table 5: Job Card Example & Work Completed Database

	Database:	Maintenance Job-Card						
	Date	Person	Sub-System	Maintenance Interval	Task Scheduled	Completed	Additional Actions	Client Sign-Off
1	2012/03/10	F.O.	On-Site C.S.	Quarterly	Perform task X, Y and Z	Yes	Had to replace part YYY	xxx
2								
3								
4								
5								
6								

3.6.2 Failure Database

The failure database will be populated with any and all failure information. This failure information will be used to monitor the efficiency of not only the maintenance strategy, but also the maintenance personnel.

The maintenance schedule and/or task can be optimised if it is learnt that the proposed maintenance tasks are not sufficient in preventing a failure.

An example of this database:

Table 6: Failure Database (FDat)

	Sub System:	On-Site Control System				
	Failure	Failure Mode	Failure Effect	Consequence	Restoration Task	Performed By
1						
2						
3						
4						
5						

3.6.3 Relative Frequency Indicators

The functions which were considered in the RCM process will be monitored for failures. This process of determining the relative frequency of failures can be described as:

- A database will be created to identify and measure the relative frequencies of functional failures for the sub-systems of the Newcom FMS System;
- The functions will be listed in a spreadsheet;
- The functional failures and observations will be captured for each function;
- The relative frequency of each functional failure for each function will be displayed in histogram format;
- The maintenance management team of Newcom must periodically review this information and improve the maintenance function accordingly; and
- An initial proposal is to review the information on a quarterly basis.

An example of this database can be displayed as:

Table 7: Relative Frequency Database Example

No.	Function	Functional Failure	Failure Quantity	Time in Days	Relative Frequency
1	On-Site Control System	Obtain no signal information from flow meter	3	365	121.6666667
2	On-Site Control System	Obtain no level sensor signal information	1	365	365
3	On-Site Control System	Pump does not switch on	4	365	91.25
4	On-Site Control System	Control Unit's does not display any information but the control unit is in an on-state	2	365	182.5
5	On-Site Control System	No data is communicated	5	365	73
6	On-Site Control System	Control unit is not active	7	365	52.14285714
7	On-Site Control System	No power or information is sent via cables	1	365	365

The above relative frequency data can be displayed as follow:

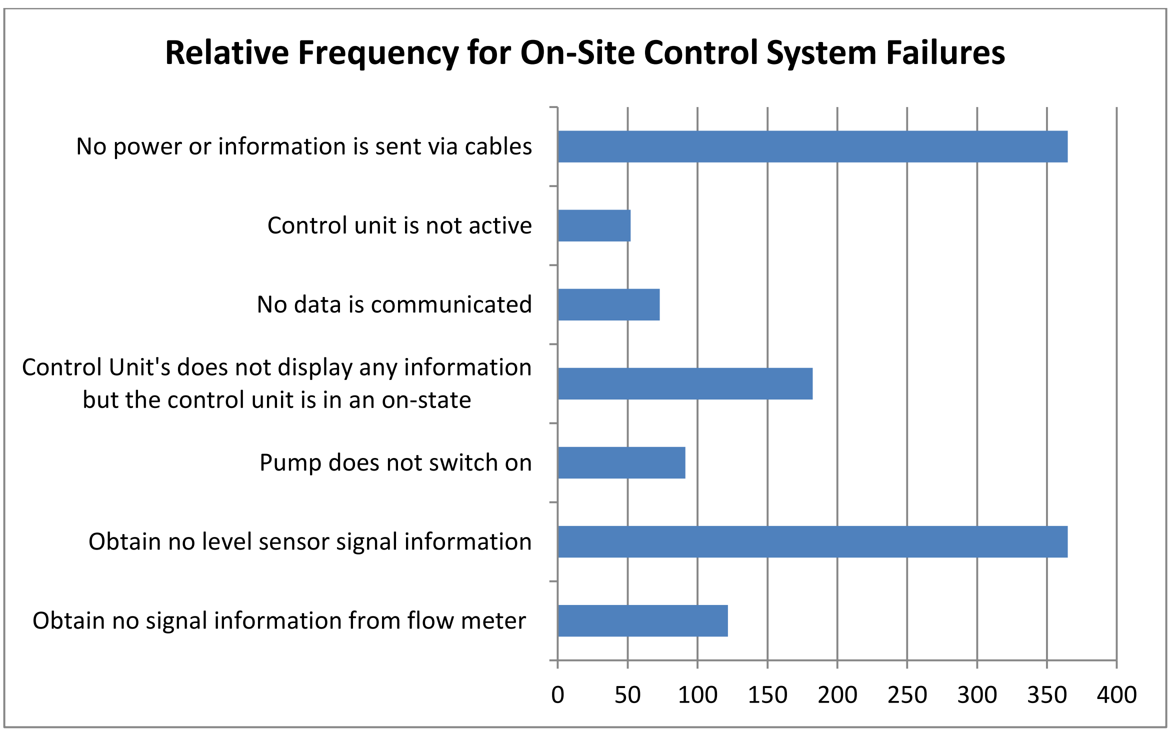

Figure 24: Relative Frequency Comparison Chart

When considering the above chart, the shorter frequency intervals depicted by the short histograms translate into functional failures with high frequencies. This information will allow Newcom to consider the specific function and the surrounding maintenance tasks and improve where necessary.

3.6.4 Pro-Active System Failure Indicators

This aspect, as discussed in section 2.8.4, will enable Newcom to estimate a probability of a functional failure by monitoring an operational parameter and determining the correlation with a functional failure.

With the creation of the first iteration of the maintenance strategy, there was no data available to create a dependable correlation between operational parameters and functional failures. This section will therefore provide a process for Newcom to create a quantitative correlation between two parameters as more data is captured on operational parameters and functional failures.

Firstly, the operational parameters to be monitored must be identified. After considering the Newcom FMS system, the following parameters were identified as the first iteration operational parameters:

- Amount of transactions at a field system – indicator of the amount of time the system is used;
- Amount of liters of fluids dispensed – indicator of how intensive the system is used; and
- Time period – indicator on how long the current system is in operation.

A database must be constructed to capture the above mentioned information together with the functional failure database (FDat) found in section 3.6.2. The additional operational parameters will be captured in an operational parameter database:

Table 8: Operational Parameters Database

Functional Failure	Transaction Amount	Litres Dispensed (L)	Time Active (hr.)

The functional failure will correspond to the index or primary key of the functional failure database (FDat).

The process to obtain a correlation between failures and operational parameters will be executed as follow:

- Capture and complete the functional failure and operational parameter information;
- Perform the Pearson Sample Correlation on the following sets of parameters:
    - Failure (y) & Transaction Amount (x);
    - Failure (y) & Liters Dispensed (x); and
    - Failure (y) & Time Active (x).
- The above correlation formula will yield a value (r) for each set of parameters. This r value will provide Newcom with an indication of the strength of the relationship of the failure and the operational parameter;
- Additional maintenance decisions can be made based on the value of r yielded by this process; and
- The maintenance schedule can be reassessed every six months with the additional correlation data to improve the overall maintenance system where necessary or to implement automated checks for probable failures.

3.7 Maintenance Strategy Summary

This section will summarise the steps taken to develop the strategy.

3.7.1 **Maintenance system elements**

The maintenance strategy was defined as a system. According to Wichers (2009), a system comprises of the following:

- Plant and Equipment;
- Documents and Data;
- Logistics and Support;
- People and Training; and
- Program and Software.

Considering the maintenance system, it will comprise of the following:

i. Maintenance Tasks

For the different system elements, the physical maintenance activities, frequencies and responsible personnel will be identified with the RCM process found in Appendix A.

ii. Maintenance procedures and documentation

Procedures must be created for maintenance tasks to standardise activities and also to motivate personnel to complete the required documentation to capture all the information required for future improvements.

iii. Schedule and Reassessment Cycles

The schedule governs all maintenance activities and was created through the RCM process found in Appendix A. The schedule will be reassessed periodically based on the continuous input of information from maintenance operations.

iv. Maintenance personnel and continuous training

Personnel and training programs to successfully execute maintenance activities.

v. Information capturing and monitoring systems

This element includes the process where all maintenance and operational system information is captured and analysed to improve the Newcom FMS system and the maintenance system.

3.7.2 Relationships of maintenance elements

The relationships between the maintenance system elements are explained in the following matrix:

Table 9: Maintenance system relationships

	Maintenance Tasks	Maintenance procedures & documentation	Schedule & Reassessment Cycles	Maintenance personnel & continuous training	Information capturing and monitoring systems
Maintenance Tasks	N/A	Use procedures for maintenance tasks & document all findings	Perform tasks according to schedule. Assess effectiveness	People perform tasks & need to be trained for work	Process & tools to capture and track maintenance status and failure information
Maintenance procedures & documentation	Already discussed	N/A	Documented schedule and information for reassessments	Personnel follow procedures and complete documents	Procedures to capture and process information. Provide reports to management
Schedule & Reassessment Cycles	Already discussed	Already discussed	N/A	Personnel follow schedule and perform reassessments	Schedule information and results are input to improve schedule and tasks
Maintenance personnel & continuous training	Already discussed	Already discussed	Already discussed	N/A	Provide information on tasks completed by whom to monitor personnel competence
Information capturing and monitoring systems	Already discussed	Already discussed	Already discussed	Already discussed	N/A

3.7.3 Strategy Flow-Diagram

The maintenance strategy can be displayed with the following flow diagram:

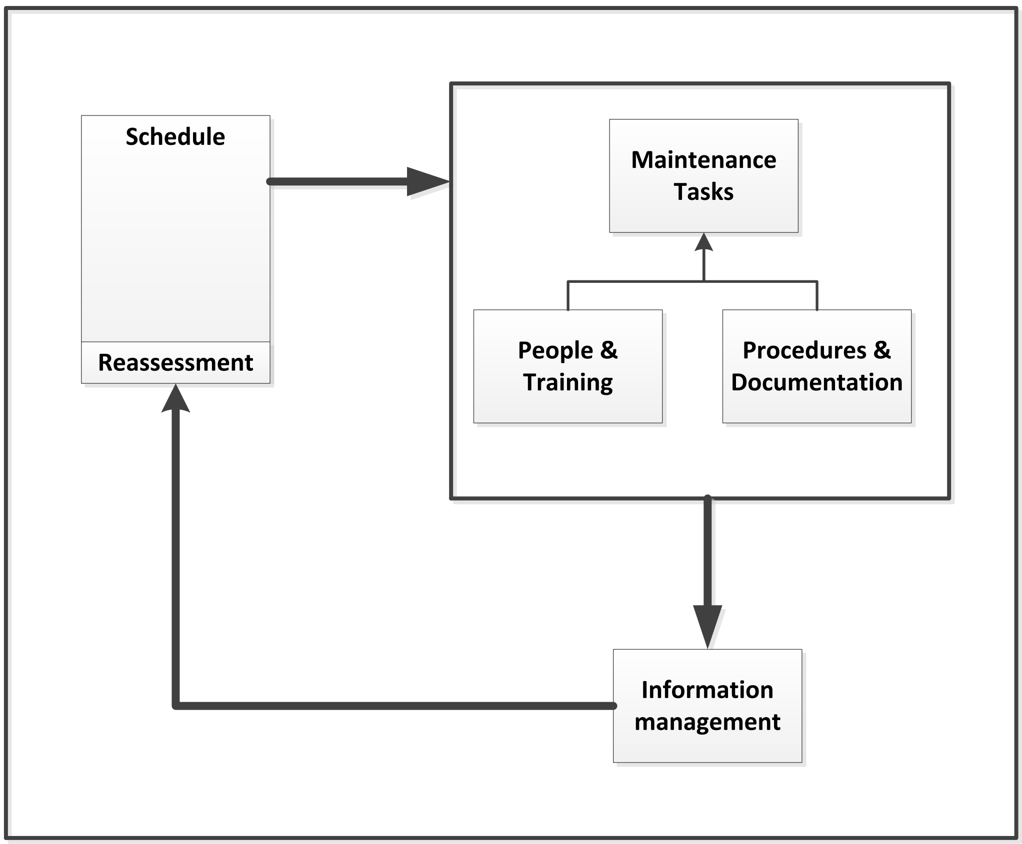

Figure 25: Maintenance strategy flow diagram

The schedule will provide inputs for the maintenance tasks to be done, the required human and additional resources and the procedures on how to complete the work.

The tasks, personnel to execute the activities and the documents to control and manage the activities all provide inputs for the information systems to process the maintenance and system data in order to identify and implement improvements in the maintenance management.

Feedback is given and the schedule is updated accordingly.

3.8 Maintenance Strategy "Product"

The above process can be packaged into a strategy methodology product which similar system or companies can deploy in the future:

i. System Engineer of the Maintenance System – Consider the maintenance function within an organisation as an inter-related system and realise the system using SE principles;

ii. Identify main system elements from the SE process and execute a RCM process on these elements;

iii. Obtain tasks, schedules and responsible personnel from the RCM process;

iv. Identify specific needs of each field system and create a personalised schedule for each field system;

v. Monitor work-flows and capture data regarding the maintenance process and the resulting impact. Data can include work done, functional failure and operational parameters;

vi. Continuously analyse data to determine RF of failures and predictions on potential failures;

vii. Routinely assess the captured and processed maintenance data to determine if the system and/or the maintenance strategy are still effective; and

viii. Update or change either the system design or the strategy design if required.

The previous section (3.7) provides examples of each one of these steps as well as a recommendation on the data to be captured and the data capturing process.

The goal of this strategy is to continually grow with the companies' and clients' need as technology and productivity changes during the process. When the strategy is tested in the field, inevitably shortfalls will be identified and the strategy can be improved.

3.9 Conclusion

In closing, the information obtained in section 2.7 suggested that the maintenance strategy development process is not a single step exercise, but rather a process which will need to be iterated to obtain the best possible result for Newcom. Possible future inputs for strategy iteration and improvement will consist of:

- Measured uptime of client FMS System – initial baseline vs. new strategy values;
- Total expenditure of maintenance system of Newcom – initial baseline vs. new strategy values;
- Other identifiable improvements – initial baseline vs. new strategy values;
- Newcom FMS Clients and Newcom staff feedback ; and
- Technology improvements.

The maintenance system has been defined in terms of the different elements which all affect the maintenance system and the larger Newcom FMS SoS.

This maintenance system needs to be implemented and the results of the new strategy will need to be tested to determine if the original research goals have been met.

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4 EXPERIMENTAL STRATEGY RESULTS

4.1 Introduction

This chapter discusses the implementation of the experimental strategy developed in section 3. The chapter will investigate the experiment as well as provide the results obtained from the experiment.

The analysis of the experiment results will entail that a qualitative and quantitative analysis be done on the data yielded by both the experimental maintenance strategy and the corrective or reactive strategy. The results from the analysis can be used in the next chapters to make a conclusion and recommendations on the experimental strategy going forward.

Note: The data used for the analysis could not in all instances be captured 100% correctly due to operational and communication issues between the research party and Newcom. Some data was estimated and closest assumptions were used where required. Newcom agreed that where the data was estimated, the data should be sufficiently accurate to provide proper results (Van Huyssteen, personal communication, April 2012).

4.2 Data analysis Results

The goals of the experimental maintenance strategy were identified in section 2.3.1. These goals were to:

- Identify and implement cost reductions to Newcom and the client;
- Compile and provide accurate equipment maintenance records for Newcom and the client; and
- Optimise Newcom's resources.

The qualitative and quantitative analysis mentioned in section 4.1 will be aimed at delivering effective feedback on the above mentioned points.

4.3 Experiment Overview

Table 10: Experiment construction

Description	Geographical-Area 1	Geographical-Area 2
Maintenance Strategy	Experimental	Corrective
Time period	Sept 2012 – Aug 2013	Sept 2012 – Aug 2013
Area description	Douglas, NC	Koppies, FS & Johannesburg, GP
Workload	12 x Systems	12 x Systems
Technician availability	250km from area	120km from area
Structure	On-site client representative Remote Technician & Central Data clerk Maintenance personnel report to maintenance manager (MM) MM report directly to owner	Remote Technician Central Data clerk Personnel report to maintenance manager (mm) MM report directly to owner
Environment	Agriculture, Mining & Transport	Agriculture, Transport, Mining & Construction
Schedule	Create/Update equipment database Obtain exact tasks from RCM process for client systems	Wait for system failure Activate restore action after a failure is encountered
Data Capture	Tasks done via procedures Job Cards for all work Failure reports for failures All operational expense captured	Job cards for all work Tasks done via procedures All operational expense captured
Sustainability	Relative frequency of failures Failure correlation analysis Feedback to original schedule Periodic assessments	Yearly assessments

4.4 Experimental Process

The experiment was conducted according to the specifications in section 4.3.

<u>SPECIAL NOTE:</u>

The experiment will be conducted for the period as indicated in table 10. Therefore the data from the experiment could not entirely be collected for analysis by the time that this document was compiled. The data which have been captured thus far in the experiment will however be investigated to consider the impact the experiment thus far had.

The data to be yielded from the experiment will be captured by Newcom and, if so desired, another research party. The future collected data can be used to assess the maintenance strategy and provide inputs to further strategy improvement processes.

4.4.1 Experimental Maintenance Strategy Data

i. Create/Update equipment database

Table 11: Equipment Database

Site Name	Equipment	Quantity	Information
Delpa Boerdery	Sites	1	
	Fixed Control Stations	2	
	Mobile Control Stations	1	
	Tank Level System	1	
	Tank-to-Nozzle Systems	3	One per Station
	Data Management System	1	Located at Data Centre
Human's	Sites	2	

	Fixed Control Stations	2	
	Mobile Control Stations	2	
	Tank Level System	2	One per Tank
	Tank-to-Nozzle Systems	2	One per Station
	Data Management System	1	Located at Data Centre
Van Bergen's	Sites	3	
	Fixed Control Stations	4	One/Two per Site
	Tank Level System	4	One/Two per Site
	Tank-to-Nozzle Systems	2	1/station on 2 x sites
	Data Management System	1	Located at Data Centre
De Hoek Sand	Sites	1	
	Fixed Control Stations	1	
	Tank Level System	1	
	Data Management System	1	Located at Data Centre

ii. Obtain schedule tasks from RCM process for equipment

A schedule matrix have been developed and supplied to all maintenance role players. These schedules provide the following:

- Maintenance member description;
- Task interval; and
- Task description.

The role players identified for maintenance tasks were:

- On-site operators or responsible person;
- Newcom system technician;
- Newcom data clerks;
- Software engineer; and
- System Engineer.

The matrixes were created from the data yielded by the RCM process. The RCM process results can be obtained in Appendix A.

These task matrixes were used to complete the maintenance work during the trial phase. The different matrixes can be seen on the following pages:

Table 12: Operator Maintenance Matrix

	Daily		Monthly	Quarterly	Six Months	Occurrence
Client On-Site Responsible Person	When dispensing fluid, always inspect flow meter visually for correct readings and overall condition. Feedback to supervisor on any incidents.	Inspect tank level data to determine sensor integrity. Visually inspect sensor cabling.	Inspect stock levels & take manual hand readings to verify electronic signal is correct	Inspect communication & power cables when visiting a site	Training user of system to be competent and provide standard set of operational procedures.	Power must be restored to the control unit in order for the system to operate successfully.
	Inspect flow meter reading on control station to verify signal integrity. Feedback to supervisor on any incidents.	Inspect stock levels on the software system	Inspect pump operation when active & inspect cabling between pump on/off switch & control unit	Create, implement & improve maintenance work schedule. Include all relevant stakeholders		
	Visually inspect the unit and verify all actions are being performed without intermittent faults	Inspect pump operation when active. Service the pump & motor at the specified service intervals				
	Inspect the volume of fluid dispensed every time fuel is dispensed to ensure to a degree that the fluids seem normal. Calibrate pumps	Inspect pump operation when active & inspect cabling between pump on/off switch & control unit				
	Inspect & verify correct installation. Inspect pipe work on every transaction. Newcom can perform a system inspection.	Inspect & reboot the GPRS gateway if required to establish a new GPRS connection.				
	Inspect tank level reading to determine sensor integrity	Inspect & reboot the field control station if required to establish a new connection to the server. If it does not work, proceed to change control station.				

Table 13: Newcom Technician Maintenance Matrix

	Weekly	Monthly	Bi-Monthly	Quarterly	Six Months	Yearly	Occurrence
Newcom Technician	Inspect stock levels on the software system	Ensure all clerks, technician and engineers have recent training and are competent with system. Software Engineer can have random work assessments of clerk & technicians work.	When dispensing fluid, always inspect flow meter visually for correct readings and overall condition. Feedback to supervisor on any incidents. Periodic Inspection by Newcom personnel & system re-calibrate	Verify correct setup with installation. Verify correct setup periodically by inspecting internal setup file of control unit	Inspect & verify correct installation. Inspect pipe work on every transaction. Newcom can perform a system inspection.	User must ensure the correct steps are followed for updating as well as that the user has received the necessary training	Power must be restored to the control unit in order for the system to operate successfully.
	Inspect & reboot the field control station if required to establish a new connection to the server. If it does not work, proceed to schedule change of control station.	Create data capture system (forms, questionnaires, etc.) to allow data to be effectively captured in order to improve maintenance	Inspect flow meter reading on control station to verify signal integrity. Feedback to supervisor on any incidents. Periodic Inspection by Newcom personnel & system re-calibrate	Inspection & maintain refuelling infrastructure according to the desired manufacturer specification	Inspection on communication server and routine server maintenance as required to ensure server is stable and up to date	Develop of proper maintenance strategy and allocate resources. Monitor operations and improve on short comings.	Verify all installation & connections have been done properly upon installation
			Visually inspect the unit and verify all actions are being performed without intermittent faults	Inspect & verify correct installation. Inspect pipe work on every transaction. Newcom can perform a system inspection.	Training user of system to be competent and provide standard set of operational procedures.		If data can be captured in the following download cycle, which is acceptable. If this happens constantly - redesign of the collection mechanism is necessary
			Inspect tank level data to determine sensor integrity	Verify correct setup with installation. Verify correct setup periodically by inspecting internal setup file of control unit	Train operators & users of system in regular intervals. Provide training documentation which must include operational procedures		Upon installation verify signal strength. Verify the consistency of collected data quality and frequency. If signal quality is in general poor, then redesign antenna of field control station.

			Inspect tank level data to determine sensor integrity. Visually inspect sensor cabling.	Newcom must provide training & retraining on the system for any and all operators as well as provide training documentation	Train other staff as clerks & technicians to serve as backup when primary clerks & technicians are unavailable		Wait for next download cycle. If unit responds, the all is o.k. If unit does not respond, proceed to reboot field unit. If unit responds, all is o.k. If unit does not respond, proceed to change field control station.
			Inspect stock levels & take manual hand readings to verify electronic signal is correct	Routine clean-up of control unit & fastening of sealed parts. Visual inspection and change of equipment in event of excessive dirt or moisture.			
			Inspect stock levels on the system	Verify GPRS status on field station. Reboot station if no GPRS connection is present			
				Create, implement & improve maintenance work schedule. Include all relevant stakeholders			

Table 14: Data Clerk Maintenance Matrix

	Daily	Weekly	Monthly	Quarterly	Six Months	Yearly	Occurrence
Data Clerk	Inspect stock levels on the software system	Newcom must inspect the data received as well as the data communication status to verify the health status of equipment	Ensure all clerks, technician and engineers have recent training and are competent with system. Software Engineer can have random work assessments of clerk & technicians work.	Create, implement & improve maintenance work schedule. Include all relevant stakeholders	Training user of system to be competent and provide standard set of operational procedures.	Develop of proper maintenance strategy and allocate resources. Monitor operations and improve on short comings.	In event of system changes, Inform personnel with necessary rights to perform changes
	Verify GPRS status on field station. Reboot station if no GPRS connection is present	Continuously support the client and enquire if the operator understands the system. If not, operator must receive training & instruction pamphlets can be mounted at operating points.	Create data capture system (forms, questionnaires, etc.) to allow data to be effectively captured in order to improve maintenance		Train operators & users of system in regular intervals. Provide training documentation which must include operational procedures		Obtain contact details from client if none exist
	Inspect & reboot the GPRS gateway if required to establish a new GPRS connection.	Newcom must inspect the quality and integrity of the data received to verify the health status operations			Train other staff as clerks & technicians to serve as backup when primary clerks & technicians are unavailable		If none exist, create standard operating procedure and implement.
	Inspect & reboot the field control station if required to establish a new connection to the server. If it does not work, proceed to change control station.	Get routine updates from GSM service provider to enquire about possible problems with GSM network. In such an event, switch over to email alarms or alternative mechanisms incl. informing the client about situation					

	Contact on-site responsible personnel to switch on the system. Verify all is working fine by forcing a data download cycle.						
	Visual inspection to verify all servers are up and running						

Table 15: Software Engineer Maintenance Matrix

	Daily	Weekly	Monthly		Quarterly	Six Months	Yearly
Software Engineer	Inspect data collector data capture interface to verify data which was not captured. Rectify by inspecting data availability & signal quality.	Execute programs verifying quality of communications between servers	Perform routine inspections & reboot actions on the data collector server & keep up to date all required software on the computer incl. AV, system updates, etc.	Review alarm database to estimate saturation point.	Create, implement & improve maintenance work schedule. Include all relevant stakeholders	Training user of system to be competent and provide standard set of operational procedures.	Develop of proper maintenance strategy and allocate resources. Monitor operations and improve on short comings.
	Inspect data collector data capture interface to verify data which was not captured. Rectify by allowing another capture cycle. If same problems exist, reboot data collector computer. Of same problem exists, switch to backup computer.		Inspect the data collector computer & perform hardware check incl. physical clean up, hardware scans and other action which is required to maintain the computer	Run diagnostic program or procedure to verify the amount of data captured to be processed and published can be done in the allocated time.			
	Execute programs verifying quality of communications of server publishing data on internet		Execute programs verifying quality of communications between servers	Create data capture system (forms, questionnaires, etc.) to allow data to be effectively captured in order to improve maintenance			
			Review database size and project time to saturation				
			Ensure all clerks, technician and engineers have recent training and are competent with system. Software Engineer can have random work assessments of clerk & technicians work.				

Table 16: System Engineer Maintenance Matrix

	Daily	Monthly	Quarterly	Yearly	Occurrence
System Engineer		Create data capture system (forms, questionnaires, etc.) to allow data to be effectively captured in order to improve maintenance	Review maintenance operations to determine improvements & train staff on improvements	Develop/Re-evaluate/Improve maintenance strategy and allocate resources. Monitor operations and improve on short comings.	Investigate resource shortage and resolve problem with appropriate action.
			Review resource usage of maintenance operations as well as expenditure versus income. Plan with & train staff with improvements		
			Regular training and feedback of personnel if is done training effectively.		

iii. Job Cards for all work done

- The maintenance strategy dictated that a job card document be completed for all work done by Newcom staff on the entire Newcom FMS system;
- No effective strategy could yet be developed to allow the client system operators to complete job cards for their relevant maintenance actions;
- Only the Newcom staff including the technician, data clerk, software engineer and system engineer could effectively compile job cards; and
- Newcom technicians and data clerks had discussions and interviews with the client system operators and supervisors to determine the continuous maintenance status of the on-site sub-systems as no job cards could be obtained.

The job cards were not captured in this research document as the specific work to be done was stipulated in the individual schedules. The completed job cards are however available from Newcom or the researcher upon request.

iv. Tasks done via standard operating procedures

- The maintenance strategy dictates that all actions of the Newcom FMS must be governed by standard operating procedures;
- Such procedures did not yet exist at the time of compilation of this research document, but Newcom was in the process of creating such procedures whilst completing the experiment as discussed in table 10;
- The Newcom staff relied on their training, knowledge and experience of the Newcom FMS system to perform all the maintenance actions and to create these maintenance operating procedures;
- System operational procedures were also created during this research study for clients to enable client personnel to operate the Newcom FMS successfully; and
- These system operational procedures were also not captured in this research document due to the fact that these procedures were still being compiled during the completion of this study.

v. Failure reports for failures

- The strategy made provision for all functional failures to be captured. These failures can be analysed further for future input into improvement processes.
- The failure reports captured in this study until time of compilation are:

Table 17: Failure Report Table

	Failure	Failure Mode	Failure Effect	Consequence	Restoration Task	Performed By
	Delpa Boerdery – 2012/09					
6	Not reading tags	Tag Reader broken wire	Manual System entries	Slowdown in production	Replace broken wire	Technician
16	No comms to DMS	GPRS connection is down	No new data available for clients	Client processes are unable to be updated and poor service is rendered to client	Hard power down of station power supply	Client operator
	Human Boerdery 2012/09					
6	Station down	Unknown	System override	Halted & poor production	Replace control station	Technician
17	No comms to DMS	GPRS connection is down	No new data available for clients	Client processes are unable to be updated and poor service is rendered to client	Hard power down of station power supply	Client operator
	Van Bergen and De Hoek Sand					
17	No comms to DMS	GPRS connection is down	No new data available for clients	Client processes are unable to be updated and poor service is rendered to client	Hard power down of station power supply	Client operator

vi. Operational expenses

- A breakdown of the operational expenses for the sustaining of the experimental maintenance strategy were:

Table 18: Experimental Strategy Sept 2012 Expenses

Description	Value
Fuel & Travel Expenses	R 1 100.00
Vehicle Expenses	R 1 000.00
Spares Expenses	R1 000.00
Communication Costs	R 300.00
Total	R 3 400.00

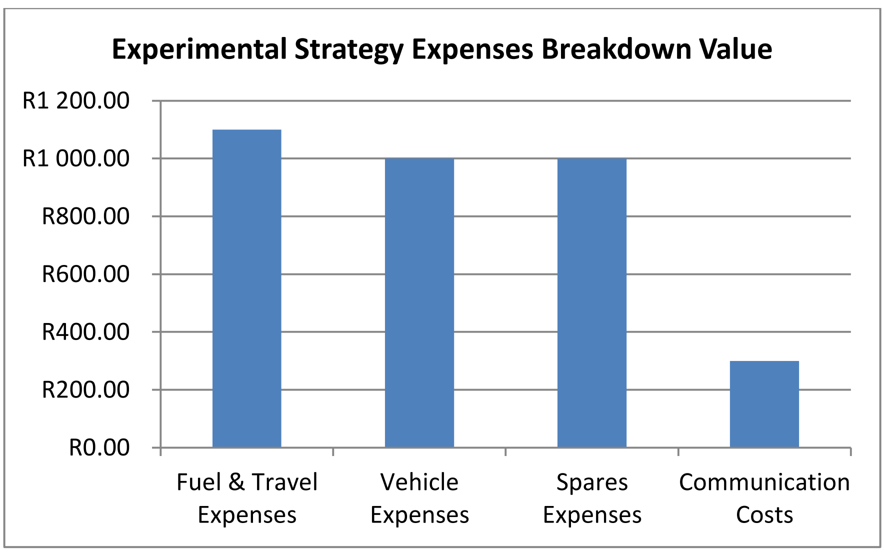


Figure 26: Experimental Strategy Expenses - Graph Format

vii. Relative frequency of failures

Table 19: RF Experimental Information

No.	Function	Functional Failure	Failure Quantity	Time in Days	Relative Frequency
1	On-Site Control System	Unable to identify a user	1	30	30
2	On-Site Control System	Control Station is not active	1	30	30
3	On-Site Control System and Data Management System	Servers are unable to communicate with field station	4	30	7.5

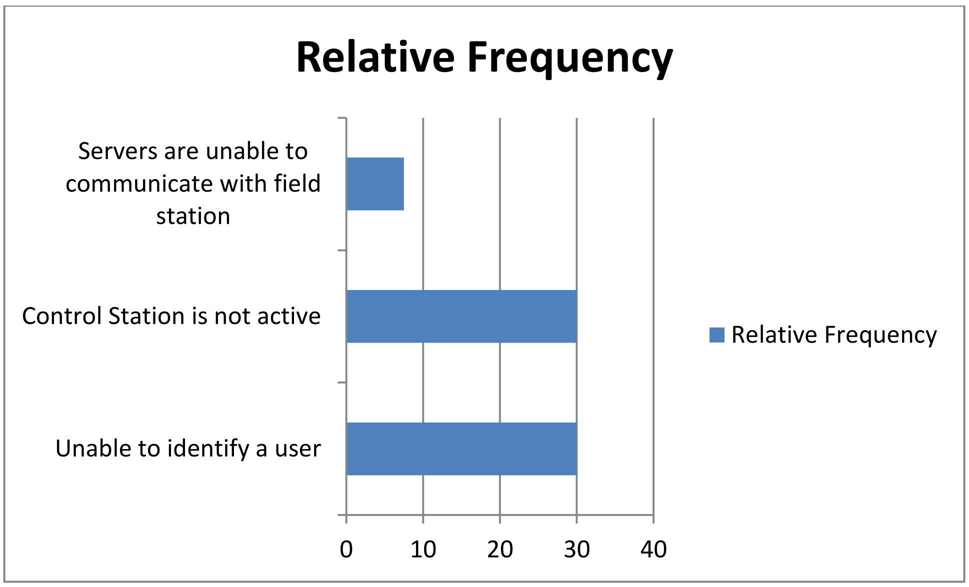


Figure 27: RF Experimental Graph

viii. Failure correlation analysis

The parameters to be captured from section 3.6.4 are:

- Functional failure;
- Amount of transactions at a field system – indicator of the amount of time the system used;

- Amount of liters of fluids dispensed – indicator of how intensive the system is used; and
- Time period – indicator on how long the current system is in operation.

Table 20: Experimental Parameters Database

Date & Client	Functional Failure	Transaction Amount	Litres Dispensed (L)	Time Active (hr.)
2012/09/06_DB	Not ID Equipment	3 600	480 000	21600
2012/09/06_HB	Field Station inactive	3000	250 000	17280
2012/09/16_DB	No comms via GPRS	3 800	427 000	21600
2012/09/17_HB	No comms via GPRS	3000	200 000	17280
2012/09/17_VB	No comms via GPRS	3600	1 396 800	17280
2012/09/17_DS	No comms via GPRS	800	100 000	2880

The process to obtain a correlation between failures and operational parameters will be executed as follow:

- Capture and complete the functional failure and operational parameter information;
- Perform the Pearson Sample Correlation on the following sets of parameters:
    - Failure (y) & Transaction Amount (x);
    - Failure (y) & Liters Dispensed (x); and
    - Failure (y) & Time Active (x).

Unfortunately at the time of compilation of this study, only limited data existed on both the functional failures as well as the operational parameters to effectively perform the Pearson correlation analysis. The following steps must be completed during the experiment period:

- Capture the functional failures;
- Capture the specific parameters as discussed;
- When sufficient data is available, perform Pearson calculation. The r-value can provide important failure probability information to improve overall maintenance tasks;
- Continuously perform Pearson calculation with reception of new data on all parameters;

and

- A graph can also be compiled to study the behavior of a functional failure vs. the operational parameters.

The analysis was done on the following functional failure to demonstrate the process:

Table 21: Function Failure & Prediction Data

Date	Functional Failure	Number	Transaction Amount	Litres Dispensed (x 1000 L)	Time Active (x 10 hr.)
2012/09/16_DB	No comms via GPRS	1	800	100	288
2012/09/17_HB	No comms via GPRS	2	3000	200	1728
2012/09/17_VB	No comms via GPRS	3	3600	427	1728
2012/09/17_DS	No comms via GPRS	4	3 800	1396.8	2160

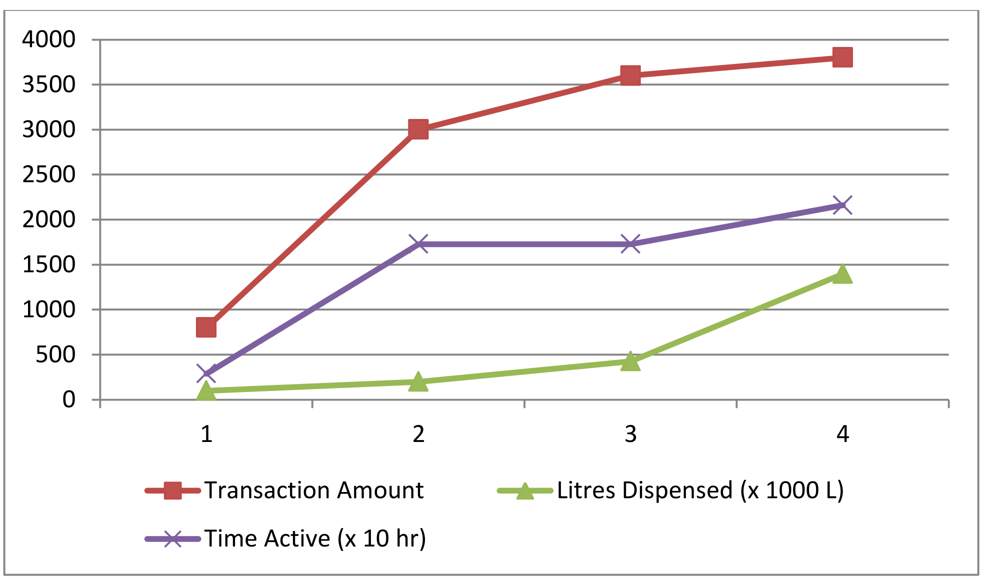


Figure 28: Graph indicating amount of failures vs. operational parameters

Table 22: Table with Pearson Values

Correlation for FF to:	Indication	Value
Transaction Amount	r(TA)	0.90070395
Litres Dispensed	r(LD)	0.896041253
Time Active	r(TI)	0.886592641

ix. Feedback to Newcom and periodic maintenance strategy assessments and improvements

- The data captured in sections i – viii can be used in reassessments of the maintenance strategy and for improvements;
- Initial review schedules will be conducted every four to six months. The maintenance strategy will be adapted to improve on areas where Newcom identifies shortfalls;
- Areas for improvement can include:
  - Maintenance tasks, frequency and schedule;
  - System element redesign;
  - Maintenance expenses reducing processes; and
  - Additional pro-active preventative maintenance approaches on system elements which demonstrate higher failure probabilities.

CORRECTIVE MAINTENANCE STRATEGY PROCESS:

i. Operational sites monitored:

Table 23: Equipment Database

Cairo Group
JP v Biljon Trust
Trent Trucking
Ash Plant Hire
ALS Lyttleton
Esorfranki BG3
Sizwe IT

i. Wait for system failure

System functional failures were identified in the following manner:

- System failure identification via routine data inspection;
- System failure identification by contacting responsible client personnel; and
- Client contact Newcom with information on a possible functional failure.

ii. Job card for all work

The maintenance strategy dictated that a job card be completed for all work done by Newcom staff on the entire Newcom FMS system. As with the experimental maintenance strategy, the following data was captured regarding the job card system:

- No effective strategy could yet be developed to allow the client system operators to complete job cards for their relevant maintenance actions;
- Only the Newcom staff including the technician, data clerk, software engineer and system engineer could effectively compile job cards; and
- Newcom technicians and data clerks had discussions and interviews with the client system operators and supervisors to determine if a failure had occurred as no job cards could be obtained.

The job cards were not captured in this research. The completed job cards are however available from Newcom or the researcher upon request.

iii. Tasks done via procedures

- All work done in repairing the Newcom FMS system was done by Newcom personnel who had received the necessary training on the system.
- No operational procedures were created or followed during this maintenance process.

iv. All operational expenses must be captured

Table 24: Reactive Maintenance Strategy expenses for Sept 2012

Description	Value
Fuel & Travel Expenses	R 1 500.00
Vehicle Expenses	R 1 200.00
Spares Expenses	R 700.00
Communication Costs	R 1 000.00
Total	R 4 400.00

A graph visually indicating the information contained in the above table is presented on the next page. Such a graph can be used to determine the biggest expense factor of the maintenance strategy.

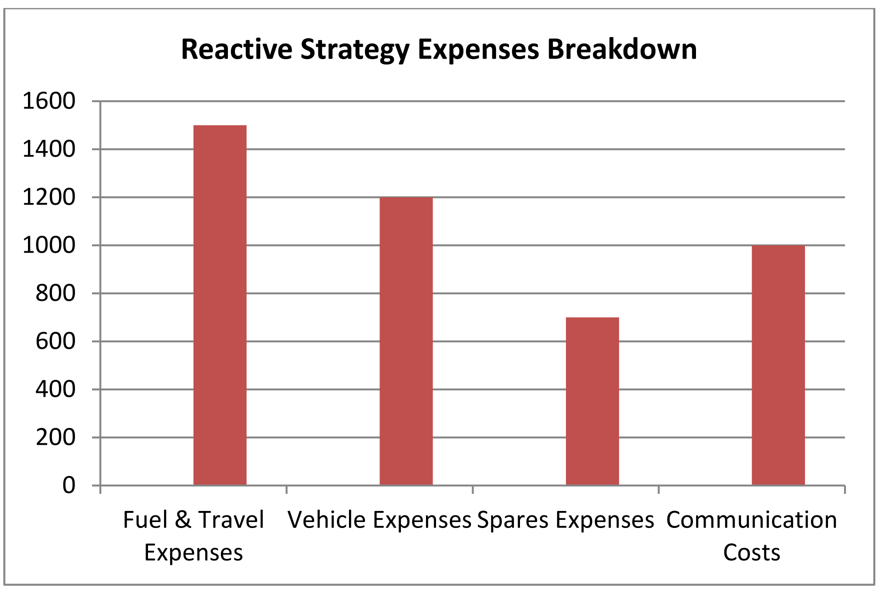


Figure 29: Graph of Reactive Strategy expenses for Sept 2012

v. Yearly assessments

- Complete a yearly assessment on maintenance action and determine system components to be improved.

4.5 Qualitative Analysis

As discussed in section 1.6 - bullet 3, the following qualitative assessments were required on the maintenance strategy:

- Impact on human resources;
- Technical complexity of the strategy;
- Environmental impact of Newcom FMS by following the strategy; and
- Sustainability of incorporating the strategy in a real work environment.

Newcom proceeded to conduct the experiment as discussed in section 4.3. The experiment also included a qualitative analysis to be completed primarily in the form of questionnaires. The results from the questionnaires provided feedback on the two different maintenance strategies employed i.e. experimental strategy in an operational area versus the corrective/reactive strategy.

A questionnaire was created for completion by the client as well as by Newcom staff. The questionnaire process was as follow:

- Undertaken by the technicians, data clerks, maintenance manager, software engineer, Newcom director and the client responsible person;
- Each answer for a question for a specific strategy will carry a weight of 1 point;
- A "DON'T KNOW" answer will have a 0 weight;
- Marks will be summated after each questionnaire. The strategy with the highest mark will be deemed the most effective and favorable; and
- Two different questionnaires were provided to obtain the results from the different system stakeholders:
  - Newcom internal systems questionnaire – Newcom and Newcom Staff
  - Client questionnaire – Client.

The questionnaires and the overall results were as follow:

Table 25: Newcom Internal Questionnaire

Question:	Experimental	Corrective	Don't Know
Human Resources			
Which strategy was better overall in your opinion?			
Which strategy provided a safer work environment?			
Which strategy was more effective for you?			
Which strategy provided greater client satisfaction?			
Environment			
Which strategy had a greater positive effect on the environment?			
Which strategy could manage potential environmental impact better?			
Which strategy makes provision for future inputs in changes in environmental regulations?			
Complexity			
Which strategy was less complex to implement?			
Which strategy was less complex to manage?			
Which strategy was more flexible to update and/or change?			
Which strategy yielded less complex work?			
Sustainability			
Which strategy do you think is more sustainable?			
Which strategy do you think will require fewer resources in the future?			
Which strategy do you think will be more successful in the future?			
TOTAL			

The following questionnaire was completed by the clients.

Table 26: Client Questionnaire

Question:	Yes	No	Don't Know
Is the Newcom FMS maintained effective?			
Is the system availability acceptable?			
Is Newcom informing you sufficiently on maintenance?			
Are you an active part of the maintenance?			
Is there means to provide input for maintenance improvement?			

The following entities were asked to complete the respective questionnaires:

- 2 x Newcom technicians;
- 1 x Data clerks;
- 1 x Software Engineer;
- 1 x Maintenance Manager;
- 1 x Newcom Director; and
- 4 x Clients – 2 x Experimental & 2 x Old Corrective.

The experiment has not yet been concluded and the questionnaires should only be completed at the end of the experimental period. However, the questionnaires were completed at the end of September 2012 to obtain an initial feedback poll on the strategies thus far. The same analysis will be done when the final questionnaires are captured at the end of the experiment.

The detailed completed questionnaires are available from the researcher if desired but are not included in this document.

The results for the analysis are found in the following table.

Table 27: Questionnaire Results Summary

Human Resources	**Experimental**	**Corrective**
Technician 1	4	0
Technician 2	2	0
Data Clerk	3	0
Maintenance Manager	4	0
Software engineer	3	0
Newcom Director	4	0
Human Resources Total	**20**	**0**

Environment	**Experimental**	**Corrective**
Technician 1	3	0
Technician 2	3	0
Data Clerk	2	0
Maintenance Manager	3	0
Software engineer	3	0
Newcom Director	3	0
Human Resources Total	**17**	**0**

Complexity	**Experimental**	**Corrective**
Technician 1	2	2
Technician 2	1	2
Data Clerk	4	0
Maintenance Manager	2	2
Software engineer	1	3
Newcom Director	1	3
Human Resources Total	**11**	**12**

Sustainability	**Experimental**	**Corrective**
Technician 1	2	1
Technician 2	1	1
Data Clerk	2	1
Maintenance Manager	2	1
Software engineer	2	1
Newcom Director	1	2
Human Resources Total	**10**	**7**

Totals	**Experimental**	**Corrective**
Technician 1	11	3
Technician 2	7	3
Data Clerk	11	1
Maintenance Manager	11	3
Software engineer	9	4
Newcom Director	9	5
Total	**58**	**19**

Graphically the results can be shown as:

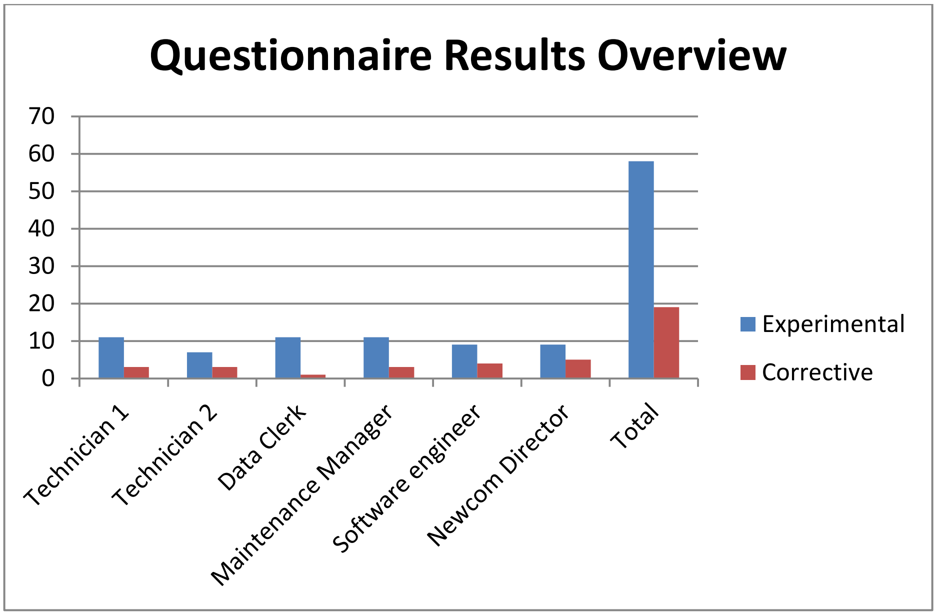


Figure 30: Overall Strategy Comparison

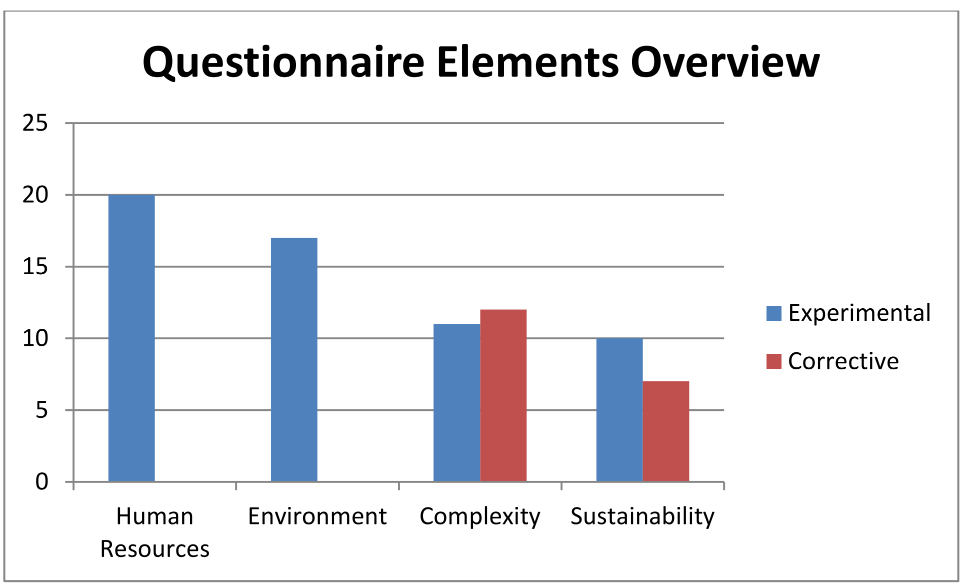


Figure 31: Questionnaire elements comparisons

The client questionnaire data was as follow:

Table 28: Experimental strategy client questionnaire

	Client 1 - Experimental Strategy			Client 2 - Experimental Strategy		
Question:	**Yes**	**No**	**Don't Know**	**Yes**	**No**	**Don't Know**
Is the Newcom FMS maintained effective?	1			1		
Is the system availability acceptable?	1			1		
Is Newcom informing you sufficiently on maintenance?	1			1		
Are you an active part of the maintenance?	1			1		
Is there means to provide input for maintenance improvement?	1			1		
Totals	5	0	0	5	0	0

Table 29: Corrective strategy client questionnaire

	Client 3 - Corrective Strategy			Client 4 - Corrective Strategy		
Question:	**Yes**	**No**	**Don't Know**	**Yes**	**No**	**Don't Know**
Is the Newcom FMS maintained effective?			1	1		
Is the system availability acceptable?	1			1		
Is Newcom informing you sufficiently on maintenance?			1		1	
Are you an active part of the maintenance?		1				1
Is there means to provide input for maintenance improvement?			1	1		
Totals	1	1	3	3	1	1

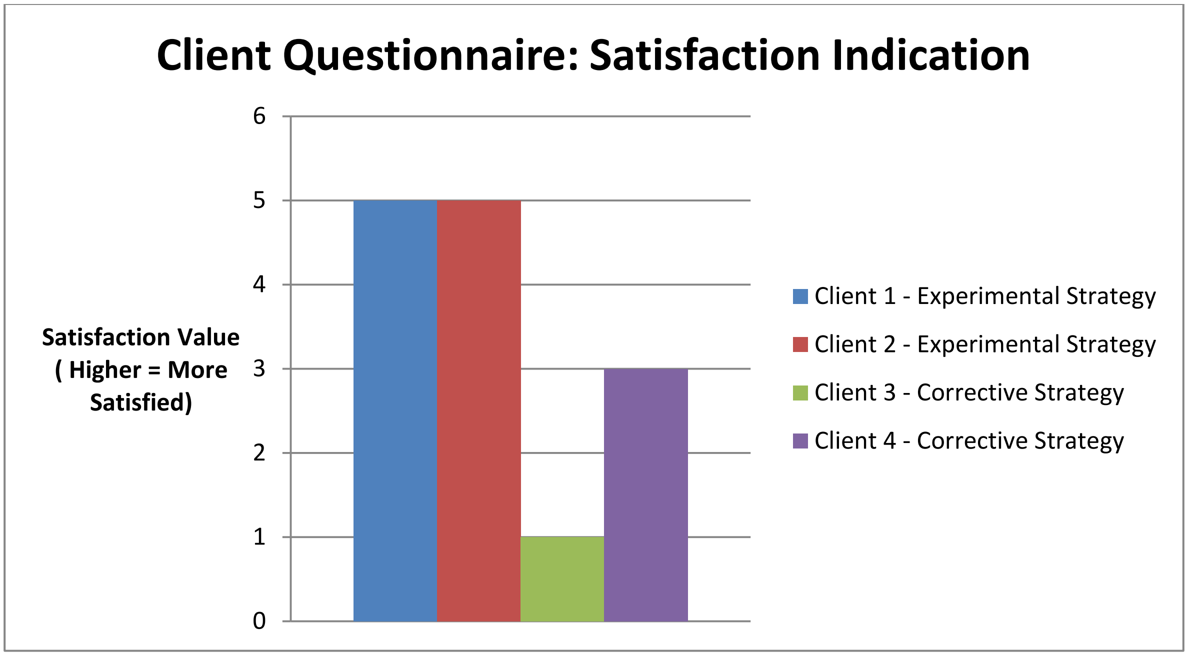


Figure 32: Results from Customer Questionnaire

4.6 Quantitative Analysis

The quantitative analysis will consider the following parameters:

- Total maintenance expenditure for a period;
- Resource usage; and
- Client system availability.

The above parameters were considered for both the experimental strategy as well as the corrective strategy. The data for each strategy was compared to each other.

NOTE: The experiment's end date has not yet been reached and the data obtained was incomplete at the time of compiling this report. The data which was already gathered for the period thus far was used in the following analysis.

4.6.1 Total maintenance expenditure for a period

The recorded expenditure can be considered as:

Table 30: Summary of strategies costs

Description	**Experimental**	**Corrective**
Fuel & Travel Expenses	R 1 100.00	R 1 500.00
Vehicle Expenses	R 1 000.00	R 1 200.00
Spares Expenses	R 1 000.00	R 700.00
Communication Costs	R 300.00	R 1 000.00
Total	**R 3 400.00**	**R 4 400.00**

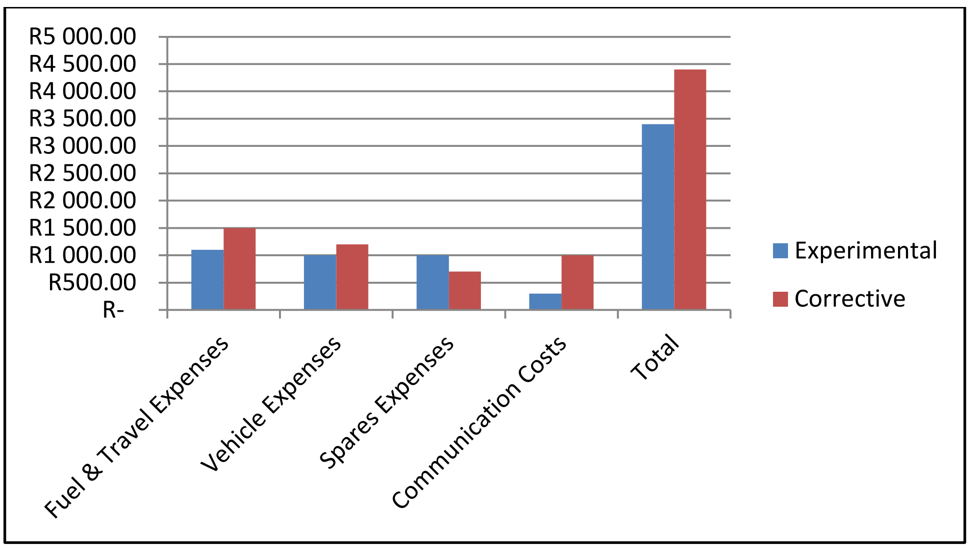


Figure 33: Summary of strategy costs - chart format

4.6.2 Resource usage

The resources used to execute the different maintenance strategies could not accurately be captured in the time from the start of the experiment until the compilation of this report.

The data on the resources used will continue to be captured for an analysis at the end of the experiment.

4.6.3 Client system availability

The client system availability was one of the most important factors to be evaluated to assess to effectiveness of the experimental maintenance strategy versus the corrective strategy. Although the importance of availability varies from client to client due to the different operation dynamics (Van Huyssteen, personal communication, Feb 2011), it is still one of the most important factors to be considered.

As with 4.6.1 and 4.6.2, insufficient data was available at the time of compiling this report. The data will continue to be captured for proper analysis after the experimental period. The data available for analysis thus far was incorporated in the initial analysis and the results were:

Table 31: Corrective & Experimental Strategy Availability Data

	Corrective Strategy - Availability Figures	Number of Units	Daily Operational Hr.	Total Hr. for Sept 2012	Down Time	Sep-12
1	Cairo Group	4	12	1440	84	0.9417
2	JP v Biljon Trust	1	12	360	2	0.9944
3	Trent Trucking	1	12	360	0	1
4	Ash Plant Hire	1	12	360	6	0.9833
5	ALS Lyttleton	2	18	1080	12	0.9889
6	Esorfranki BG3	2	12	720	8	0.9889
7	Sizwe IT	1	12	360	0	1
	Average Availability					**0.9853**
	Experimental Strategy - Availability Figures	**Number of Units**	**Daily Operational Hr.**	**Total Hr. for Sept 2012**	**Down Time**	**Sep-12**
1	Delpa Boerdery	3	16	1440	6	0.9958
2	Human's	4	16	1920	36	0.9813
3	Van Bergen's	4	12	1440	24	0.9833
4	De Hoek Sand	1	12	360	4	0.9889
	Average Availability					**0.9873**

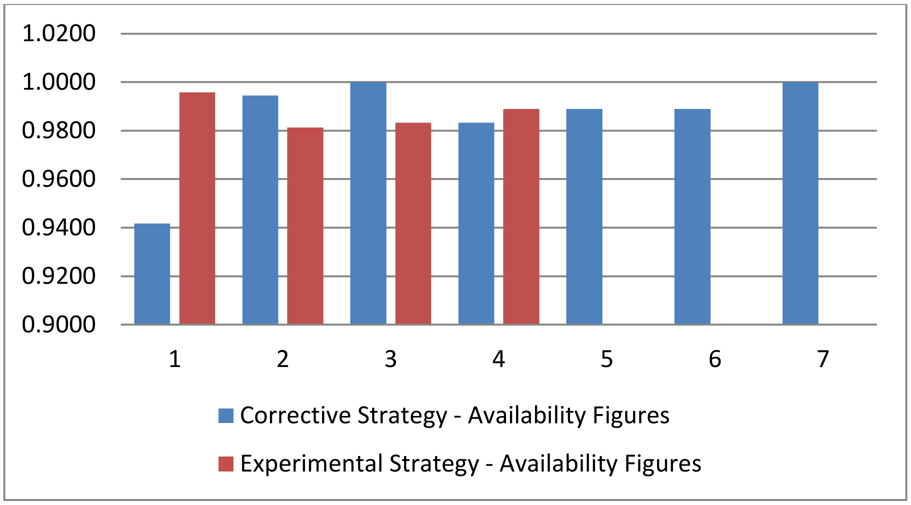


Figure 34: Availability Data for Sept 2012

4.7 Conclusion

The experiment was discussed and executed as described in this section.

The data was limited and only allowed partial analysis to be completed. As the experiment continues to be executed and new data is continuously captured, the analysis can be iterated to obtain more accurate results.

The results from the analysis can now be used to make conclusions and recommendations. This will be done in the following chapter.

5 RESULTS DISCUSSION

5.1 Introduction

This section will proceed to discuss the data obtained with the experimental analysis. From the results obtained and discussed, recommendations can be made.

5.2 Results Discussion

The information obtained from chapter 4 on the experiment will be considered and the results discussed under the following headings:

i. Expenditure and Value Adding

- It was observed that the expenditure was overall HIGHER for the period September2012 for the corrective strategy compared to the experimental strategy;
- The experimental strategy yielded a R 1000.00 less expenditure or a 22.72% saving on overall expenses for the period in question;
- This satisfied the initial target of achieving at least a 20% saving on maintenance expenditure; and
- However, the experiment must still be completed to have accurate results of the expenditure over a longer period of time.

ii. Availability

- From the data obtained in the initial experimental period, the experimental strategy delivered an overall availability of the Newcom FMS system of 0.9873 and the corrective strategy delivered a value of 0.9853;
- Both values met the desired research objective of achieving a system availability figure of 0.9 and higher; and
- The figure, however, needs to be calculated over a longer period of time to achieve more

accurate feedback.

iii. Resources Usage

- Both maintenance strategies used the same amount of resources in the initial experiment period when executing the maintenance strategies;
- From the questionnaires the Newcom staff all indicated that the experimental strategy was more complex to implement and operate which would suggest that the experimental strategy might be more resource intensive in the future; and
- The experiment must be completed to obtain more accurate data over a longer period of time.

iv. Human Resources

- From the data obtained in the questionnaires, it was evident that the experimental strategy was preferred over the corrective strategy by the Newcom personnel;
- According to the questionnaires completed by the Newcom personnel the experimental strategy provided an overall lower risk to the personnel.
- The Newcom personnel selected the experimental strategy to be more effective in conducting on-going maintenance on the Newcom FMS; and
- According to the Newcom personnel, the experimental strategy provided greater client satisfaction.

v. Environment

- The experimental strategy provided for overall lower risk to the environment; and
- The experimental strategy also made provision for continued improvements if any changes in environmental legislation should occur.

vi. Complexity

- According to the Newcom staff the experimental strategy proved to be much more complex to implement and to manage compared to the corrective strategy;
- According to the questionnaires the experimental strategy did, however, provide more flexibility to update and/or change processes and/or tasks within the strategy; and
- According to the Newcom staff the experimental strategy and corrective strategy delivered the same level of complexity of general work packages.

vii. Sustainability

- The corrective strategy was selected as the strategy which will require fewer resources in the future to employ; and
- The experimental strategy was selected as being more sustainable and successful in the future.

viii. Client Feedback

- The clients were more satisfied with the overall system maintenance where the experimental strategy was employed;
- The experimental strategy incorporated the clients more with maintenance tasks which led to the clients being more aware of the maintenance status;
- Clients who tested the experimental strategy were also more aware of providing feedback to possibly improve maintenance actions on the Newcom FMS solution; and
- Overall the clients where the experimental strategy was employed appeared to be more satisfied with the system maintenance.

ix. System Equipment Database

- The experimental strategy made provision to capture all system equipment located at the clients' sites;

- The equipment database allowed the experimental strategy to tailor a maintenance schedule for each client by allowing the corresponding maintenance personnel to perform only the tasks on the assets located at the specific client;
- The corrective strategy did not make provision for capturing the most recent status of a client system configuration; and
- The experimental strategy led to less spare parts being used as more thorough planning could be done.

5.3 Conclusion

The results were obtained and discussed. The next chapter will consider the results and provide recommendations on the research.

6 RECOMMENDATIONS

The recommendations will be made based on the experimental data and the above results. The recommendations will be focussed on the research goals identified section 1.5.

6.1 Overall Recommendation

The experimental strategy was based on a RCM strategy. This RCM based strategy proved to be very effective according to the expenditure, resources usage and availability. No exact recommendation can be made due to the incomplete experiment, but the initial indication does suggest that the experimental strategy might be viable for the future.

The only area for initial concern is that the RCM based strategy proved immensely complex to implement. It might prove to be too resource intensive and expensive for a small organisation to implement such a comprehensive maintenance system. Ultimately, the recommendation is that smaller organisations will be unable to implement such a RCM strategy and reap the benefits thereof.

One solution for this problem of complexity is the identification of Maintenance Significant Items (MSI). These MSI's represent the most important or critical assets or sub-systems to be incorporated in a RCM maintenance strategy. These MSI assets can represent critical operational assets, human safety assets, hazardous environmental assets and other user definable criteria.

The experimental strategy also proved more complex to manage and operate. The possibility exists that as the personnel become more comfortable with the strategy and they become more competent in executing the strategy, the overall complexity level will be reduced.

6.2 Maintenance Significant Items (MSI)

As stated above, a MSI represents the most important or critical assets in a process. To properly identify the MSI assets or sub-systems, a MSI filter must be developed which will clearly specify the criteria a MSI must adhere to. All assets meeting the MSI criteria are classified as MSI’s and only these assets or systems are considered in the maintenance strategy. This can significantly reduce the complexity of implementing a RCM strategy and make it more viable for smaller organisations to implement and manage such a RCM maintenance strategy.

It is recommended that Newcom consider implementing a MSI filter on the next iteration of the RCM process. In this process, Newcom can specify the MSI criteria and proceed to identify the most significant items in the Newcom FMS solution. This will allow Newcom to focus on the important maintenance aspects in more detail while reducing the overall maintenance strategy complexity.

6.3 Expense Management

The initial data indicated that the experimental strategy can save on overall maintenance costs. This statement however must be tested by completing the initial experiment over the specified period.

The initial costs of the experimental strategy can be very high for a small organisation due to the comprehensive nature of implementing a RCM strategy in an organisation. However, in this experiment the researcher performed most of the initial RCM processes which reduced the overall costs to Newcom and allowed Newcom to deploy the strategy without the initial costs and resource burden.

It is also plausible to assume that over time the experimental strategy might even have lowered overall costs. Factors which could influence this outcome could be:

- Increased standardisation of operational tasks as personnel become more comfortable with the strategy and execution thereof;
- Synergistic usage of resources including personnel and client personnel;
- More reliable systems and system elements due to continuous feedback from the maintenance strategy;

- Less stock to be carried and managed due to continuous updated client databases. An up to date client equipment database can lead to the elimination of unnecessary spares being kept in stock; and
- Staff can be personally involved with all work by introducing a performance bonus if a maintenance budget is under used. The argument can be made that staff will look better after their assets as it will increase their potential income.

The experimental strategy is recommended as the desired strategy for future maintenance operations. The introduction of MSI can also potentially assist in driving down costs by focusing on important assets.

6.4 System Availability

For the initial period that the data was captured, both the experimental maintenance strategy (ES) and corrective maintenance strategy (CS) delivered the desired availability level of 0.9 or higher. The availability figures were 0.9873 for the ES and 0.9853 for the CS. The experiment must however be completed to provide a more detailed view of the availability of the different strategies.

After the investigation of the ES availability data, certain aspects were identified to be improved on in the future. These aspects were:

- System design flaws – sub-systems or elements which possibly require a redesign process to improve the inherent reliability;
- New strategy implementation – more training required for maintenance staff; and
- Improved inspection of client data – automatic algorithms required versus human eye.

The ES availability figure can be attributed to the following factors:

- Captured data on the functional failure and the statistics on the relative frequencies of failures can provide valuable inputs into the redesign process;
- The increase in frequency of maintenance visits and the improved focus of maintenance

visits;

- Improved structure in maintenance tasks and the cohesion in the maintenance team;
- Standardisation of work using work procedures;
- Incorporation of the client's resources to assist in executing maintenance tasks;
- Continuous review process to continuously obtain data to enhance the maintenance process; and
- Error data which will be captured can provide feedback on the increase of probability of possible functional failures.

Based on the obtained results, and the above points, it was determined that the ES is the more favourable strategy for Newcom in terms of system availability for the future.

6.5 Resource Management

From the research data, it was determined that the experimental strategy will be more resources intensive initially. The additional resources were identified in section 4.5. However, the complexity of the ES can significantly be reduced by implementing a MSI filter as discussed earlier.

The initial experiment data also suggested when considering the sustainability of the experimental strategy (ES) versus the corrective strategy (CS), that although the ES consumed more resources, it will be much more sustainable in the medium to long term. This can potentially be attributed to:

- Introduction of standardised work procedures and processes;
- Enhanced training program of staff;
- Improved scheduling of maintenance tasks;
- Improved record keeping of client system equipment and the management thereof reducing waste in keeping spares for a client;
- The continuous feedback of data from the ES will provide information to identify where resources can be optimised. These resources can include human resources, equipment and

tools, vehicles, tasks and procedures, etc.; and

- The ES provides Newcom with a continuous iteration process. This can allow Newcom to adapt and change the ES in the future if new technology or market conditions necessitate a change in maintenance.

Due to the sustainable nature if the ES, it was decided that the ES was the more favorable strategy in terms of resources usage.

6.6 ES - Possible Faults and Shortfalls

The experimental maintenance strategy does provide several advantages which can contribute significantly to Newcom's overall bottom line in the future. However, the ES also provide several shortfalls. These shortfalls and problems must be identified and improved on in the future iterations of the experimental strategy.

Shortfalls identified with possible rectification options are:

- Complex and therefore expensive implementation process – reduce complexity by implementing MSI filters;
- The ES might require staff to do more work and therefore consume more resources – the maintenance strategy must continuously be monitored and regularly updated to allow staff to be optimally used; and
- Lack of experimental data – the experimental process must be completed and the analysis must be done thoroughly. Accurate experimental results must be obtained of the ES versus the CS.

6.7 Future Considerations

The future of the maintenance management strategy for Newcom and the Newcom FMS system will need continuous reassessment and adjustment. Due to the constant change in the market place and the need to continuously manage systems with reduced budgets, the experimental strategy will need constant evolution if it is to stay effective.

The follow up research of this research process will include the following:

- The completion of the experiment and capturing of all data;
- The conclusion of the analysis of the experiment;
- The investigation of the completed experimental data; and
- The captured experimental data can also be used for a second iteration of the maintenance strategy and again tested to verify the effect.

6.8 Additional Recommendations

Additional to the above recommendations, the following aspects were also identified as possible sources for improvement:

- Improved documentation and a change control system are required to manage all new and changed documentation;
- An audit and update on all system documentation and design documentation on a per client basis is required. This is attributed to the fact that client systems differ and each system needs to be documented in full; and
- Improve awareness of field technicians on client infrastructure and operations – Newcom technicians and data clerks must establish a good operational relationship with the client responsible person. Newcom must also study and understand the client organisation's fuel/lube usage dynamics in order to identify errors before an incident occurs. This knowledge of a client system can also enhance the service rendered to the client from Newcom.

6.9 Recommendation Conclusion

The research information available provided for excellent analysis on initial results of the ES versus the CS.

The initial results were studied and recommendations were made based on the results.

Recommendations were also made on potential shortfall areas and future considerations. This information can be used to improve the experimental strategy.

The next chapter will conclude this research document.

7 RESEARCH CONCLUSION

7.1 Background

The research has indicated the need to optimise resources of a company in current economic times (RSA Reserve Bank, 2008/2009). Organisations need to be inovative and consider new solutions within the environments they operate.

Organisations utilising hydrocarbon products are no different with oil resources becoming more and more scarce due to an increase in demand by the world population (OPEC Report, 2011:26). The need to properly manage these hydrocarbon resources gave birth to the Newcom Fluid Management solution (Van Huyssteen, personal communication, Feb 2011). The current market conditions provide an ideal field of opportunities for Newcom to market and deliver the Newcom FMS.

However, as stated earlier, Newcom must also optimise resources. One such optimisation strategy identified was the development of a maintenance strategy for the Newcom FMS. Such a maintenance strategy had to optimise the resources available to Newcom which in turn could lead to a greater net profit.

7.2 Newcom FMS Maintenance Strategy

To better understand the Newcom FMS and to insert an additional system element into the current Newcom FMS system, the Newcom FMS was considered as a system of systems (INCOSE 3, 2006:2.2).

The maintenance strategy or maintenance system was visually explained as inserting into the SoS in the following manner:

Before:

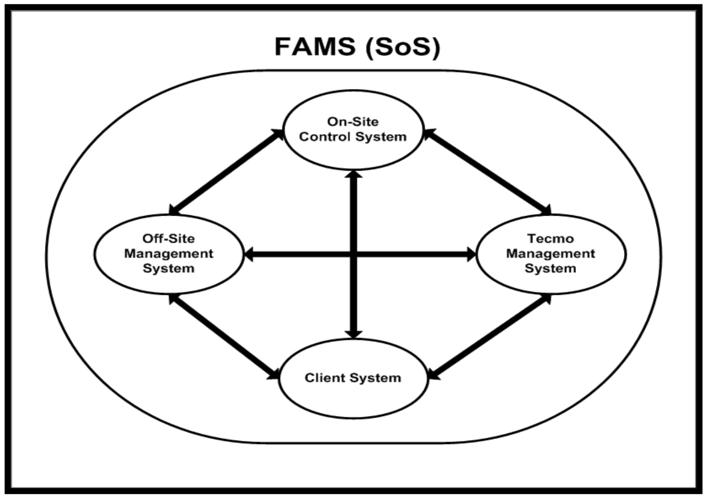


Figure 35: FMS System-of-Systems Overview (FMS Internal, 2010)

After:

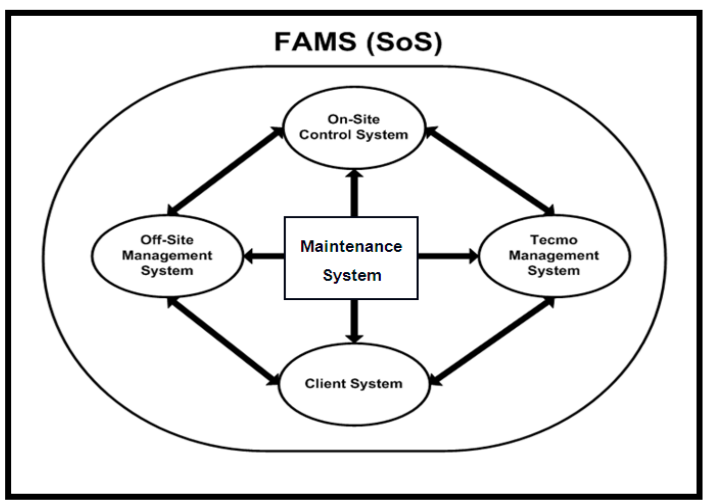


Figure 36: FMS System-of-Systems w/ Maintenance System Integration

In order for a maintenance strategy to be of benefit to Newcom, the strategy had to interface with all other system elements as depicted in figure 36.

7.3 Problem Statement

The problem was identified as the following: If Newcom delivers the FMS solution on a rental-basis to clients, the Newcom business model must be sustainable. One of the core factors which directly influence the sustainability of this model is an effective maintenance management strategy for the FMS solution on a rental model to a client. If the maintenance strategy fails to satisfy its maintenance goals, both the client and Newcom will be liable for large financial losses.

A maintenance management strategy must be developed specifically for the FMS system when delivered to a client via a rental business model. The maintenance strategy needs to be researched for the specific environment and operating context for the FMS system.

7.4 Possible Results of Effective Research

It was envisioned that plausible effects of an effective maintenance management strategy could be:

- Greater availability of client processes – improved client turnover;
- Improved awareness of system operations for Newcom and client – improve reliability safety and environmental impact; and
- Satisfied clients can lead to greater income generation opportunities for Newcom.

In the initial experimental maintenance test group, clients and Newcom staff overall responded positively towards the strategy and the results thereof. With completion of the experiment, proper statements could be made on the possible effect of an optimised maintenance management strategy.

7.5 Research Aims and Objectives

The main aim with the research was to:

- Develop a maintenance strategy for the FMS system which will ensure stable operations and a high level of client system availability, typically in the region of 90% and higher; and

- Develop a reliable and effective maintenance solution which will add value for all stakeholders including Newcom, current clients and future clients. The value can be measured in terms of the availability of the FMS system, the overall expenditure on maintenance of Newcom and the resource usage.

Initial data obtained from the experiment suggested that the above goals were reachable. It was however stated that the experiment must be concluded in full to demonstrate the results accurately.

It was noted that the implementation process of the strategy proved to be too complex and as a result, too expensive for a small organisation. The recommendation made was to implement a MSI-Filter to identify and manage critical elements within the system. This can result in reduced complexity and costs of strategy implementation.

7.6 Research Methodology

The research methodology followed was:

1. **Analysis of literature and sources of information;**
2. **The Experimental tests and results;**
3. **Results Analysis and Trade Off Analysis;**
4. **Results Discussion;**
5. **Recommendation; and**
6. **Experiment Conclusion.**

7.7 Newcom Fluid Management feedback

A report on the initial experimental findings was presented to Newcom for initial feedback.

Newcom's director of operations provided a report to suggest that the initial work "showed a lot of promise” and that Newcom would “definitely consider implementing that strategy” based on the initial results. (Newcom Feedback Report, 2012).

Newcom explained that although the strategy might be somewhat resource intensive and complex to execute, it can provide them and investors with a stable platform in the future on which to conduct operations.

7.8 Conclusion

Although the experimental process was not fully completed, the initial results showed a lot of promise in terms of optimising resources and meeting the desired goals of Newcom for a maintenance strategy.

The recommended work to complete for the future was stipulated and examples were provided on the analysis of the future data.

It is the conclusion of the researcher that the strategy can prove to be invaluable to Newcom if it is implemented and managed properly. With constant improvement of not only the strategy, but the entire Newcom FMS, Newcom can continue to grow in business and stay competitive in the market place.

8 REFERENCES

[1] Blanchard, B.S., and Fabrycky, W.J. 1998. *Systems engineering and analysis*. 3rd ed. Upper Saddle River, NJ: Pearson Prentice Hall. 804 p. ISBN 0-13-135047-1

[2] Blank, L., and Tarquin, A. 2005. *Engineering Economy*. Sixth Edition. New York: McGraw Hill. 770 p. ISBN-13 978-0-07-111558-2

[3] Condonium of Home Owners Association (CHOA). http://www.choa.bc.ca/_resources/Bulletin05_What_is_maintenance.pdf. 5th August 2012.

[4] Devore, J., and Farnum, N. 2005. *Applied statistics for scientists and engineers*. 2nd ed. Belmont, CA: Thomson Brooks/Cole. 606 p. ISBN 0-534-46719-9

[5] EIA Standard IS-632. Systems Engineering. December 1994

[6] Ewulum, O.K. 2008. *A new maintenance strategy for power holding company Nigeria to contest the current power demand problem.* Potchefstroom: NWU. (Dissertation – M. Eng.) 100 p.

[7] Gonzalez, M. (2008). Integrating asset management and maintenance. P.A.C.E. Journal, 22, 1-6.

[8] Hogan, F. Hardiman and M. Da. Naughton. Asset Management: A Review of Contemporary & Individualised Strategies. Proceedings of the World Congress on Engineering 2011 Vol I WCE 2011, July 6 - 8, 2011, London, U.K.

[9] http://en.wikipedia.org/wiki/Petroleum. 21 September 2012.

[10] http://www.maintenanceworld.com/Articles/reliabilityplant/TPM-Tecate-new-translation.html. 6th August 2012.

[11] http://www.referenceforbusiness.com/management/Log-Mar/Maintenance.html. 4th August 2012

[12] IEEE/PES Task Force on Impact of Maintenance Strategy on Reliability. The present status of maintenance strategies and the impact of maintenance on reliability. 2001. 4th Edition. IEEE Trans. Power Systems, vol. 16, issue 4, pp. 638- 646.

[13] INCOSE (International Council on Systems Engineering). 2004. *Systems engineering handbook: A "what to" guide for system engineering practitioners. 2a* ed. 308 p.

[14] INCOSE (International Council on Systems Engineering). 2006. *INCOSE systems engineering handbook: A guide for system life cycle processes and activities.* 3rd ed. 185 p.

[15] Kreitner, R. and Kinicki, A. 2004. *Organisational Behaviour.* 6th ed. New York: McGraw-Hill/Irwin. 709 p. ISBN0-07-253525-3.

[16] Longnecker, J.H., Carlos, W.M. and William Petty, J. 2003. Small business management: An entrepreneurial emphasis. 12th ed. Mason: Thomson South-Western. 786 p. ISBN 0-324-06554-X

[17] Lorden, G. and D.S. Remer. Mathematical Model for Preventive Maintenance Scheduling. 1979.

[18] Mateko, N.S. 2010. *The nature of alignment/fit between business strategy and maintenance strategy in industries in South Africa*. Pretoria: UP. (Dissertation – MBA) 96 p.

[19] Mechefske, C.K. 2005. *Machine Condition Monitoring and Fault Diagnostics*, *Vibration and Shock Handbook*. Edition. Florida, USA: CRC Press, Taylor and Francis Group. Chapter 25, p25-1 to 25-35.

[20] Moubray, J. 1997. *Reliability Centered Maintenance.* 2nd ed. New York: Industrial Press Incorporated. 426. ISBN 0-8311-3078-4

[21] Muchinsky, P., Kriek, H.J., and Schreauder, D. 2002. *Personnel Psychology.* Second Edition. Cape Town, RSA: Oxford University Press Southern Africa. 391 p. ISBN 0 19 578056 6

[22] Mutloane, O.E. 2009. *Maintenance management for effective operations management at Matimba Power Station*. Potchefstroom: NWU. (Dissertation – M. Eng.) 80 p.

[23] NACE International. http://events.nace.org/library/corrosion/Inspection/Strategies.asp. 4th August 2012.

[24] NASA. 2008. Reliability Centered Maintenance Guide for Facilities and Collateral Equipment. National Aeronautics and Space Administration, Washington, D.C

[25] National Aeronautics and Space Administration. *NASA Systems Engineering Handbook*. 1995. 149 p. SP-610S

[26] Newcom Fluid Management (Pty) Ltd. 2011. *Fluid Management Solutions*. 3rd ed. Vanderbijpark.

[27] Odeyinde, O. 2008. Optimizing rotating equipment maintenance management in Nigerian

refineries. Potchefstroom: NWU (Dissertation – M. Eng.). 92 p.

[28] Oilnergy. 2012. IPE Brent crude oil price. http://www.oilnergy.com/ 1obrent.htm#since88. Date of access: 6 September 2010.

[29] SAE. 2002. A Guide to the Reliability - Centered Maintenance Standard. 2002. SAE JA1012.

[30] SAPIA (South African Petroleum Industry Association). 2008. Q*uarterly Cumulative Fuel Sales By Market Category and Province*. 1.

[31] SARB (South African Reserve Bank). 2009. *South African Reserve Bank Annual Report* 2008/2009. 141 p.

[32] SRI (Solidarity Research Institute). 2008. *Skills Shortage in South Africa: Original Summary of facts per sector regarding this issue.* 7 p.

[33] Steyn, H., Basson, G., Carruthers, M., Du Plessis, Y., Kruger, D., Pienaar, J., Prozesky-Kuschke, S., and Visser, K. 2008. *Project management: A multidisciplinary approach*. 2nd revised ed. Pretoria, RSA: FPM Publishing. 445 p. ISBN 978-0-620-39357-7

[34] United Nations Department of Economic and Social Affairs' Population Division. 2004. World Population to 2300. New York: United Nations Economic and Social Affairs. 254.

[35] UNITED STATES OF AMERICA. Department of Defense. 2008. Condition Based Maintenance Plus DoD Guidebook. Washington: Deputy Undersecretary of defense for logistics and materiel readiness. 116 p.

[36] USA Department of Defense, *System Engineering Fundamentals*. Defense Acquisition University Press, Fort Belvoir, Virginia. January 2001. ISBN 22060-5565

[37] VAN HUYSSTEEN, H.D. April 2012. Verbal communications with Newcom Fluid Management owner and director of operations. Vanderbijlpark. (Notes attached in Appendix D)

[38] VAN HUYSSTEEN, H.D. February 2011. Verbal communications with Newcom Fluid Management owner and director of operations. Vanderbijlpark. (Notes attached in Appendix D)

[39] VAN HUYSSTEEN, H.D. October 2011. Verbal communications with Newcom Fluid Management owner and director of operations. Vanderbijlpark. (Notes attached in Appendix D)

[40] WICHERS, H. 2009. Presentation on systems engineering. (Presentation delivered as part of the lecture presented at the NWU CRCED Vaal April 2009). Vanderbijlaprk.

[41] Wikipedia. 2011. Brent Crude. http://en.wikipedia.org/wiki/Brent_Crude. Date of access: July 2011.

[42] Wireman, T. 2004. *Benchmarking best practices in maintenance management.* 1st ed. New York: Industrial Press Incorporated. 212 p. ISBN 0-8311-3168-3

APPENDIX A: RCM Information & Decision Worksheets

System: Newcom FMS		System No: NFM_FMS_SE_00		Facilitator: F. Oosthuizen		Date 2012/02/13 Sheet No 1
Sub-System: On-Site Control System		Sub System No: NFM_FMS_SE_01		Auditor: N. Oosthuizen		Date 2012/02/19 of
Function		**Functional Failure**		**Failure Mode**		**Failure Effect**
1	To capture all electronic volumetric flow signals up to 150Hz	A	Obtain no signal information from flow meter	1	Flow meter is damaged	The control system will not allow any fluids to be dispensed due to the lack of flow information. Downtime can be the time until a new part is installed and configured correctly.
				2	Flow meter information cable is damaged	The control system will not allow any fluids to be dispensed due to the lack of flow information. Downtime can be the time until the cable is fixed or replaced.
				3	Control unit has incorrect setup	The control system will not allow any fluids to be dispensed due to the lack of flow information. Downtime can be the time until the correct configuration is setup which is not longer than 1 day.
				4	There is no flow of fluids	The control system will not allow any fluids to be dispensed due to the lack of flow information. The pump may be faulty or in an off-state resulting in no fluids being pumped through the flow meter. Depending on the fault, the down time can either be very long or very short.
				5	Faulty flow meter connection	The control system will not allow any fluids to be dispensed due to the lack of flow information. The downtime is no longer than 1 day.
				6	Faulty flow meter installation	The control system will not allow any fluids to be dispensed due to the lack of flow information. Downtime can be up to 1 day - 1 week.
				7	The control unit is damaged	No action will take place or abnormal actions might take place if the control unit is damaged. Downtime can be 1 day - 2 weeks.
		B	Obtain poor signal from flow meter	1	Flow meter is damaged	The control system will allow fluids to be dispensed but the volume reading may be incorrect. Downtime can be the time until a new part is installed and configured correctly.
				2	Flow meter information cable is damaged	The control system will allow fluids to be dispensed but the volume reading may be incorrect. Downtime can be the time until the cable is fixed or repaired.
				3	Control unit has incorrect setup	The control system will allow fluids to be dispensed but the volume reading may be incorrect. Downtime can be the time until the correct configuration is setup which is not longer than 1 day.

				4	There is an abnormal flow of fluids	The control system will allow fluids to be dispensed but the volume reading may be abnormal. The pump may be faulty or in an off-state resulting in no fluids being pumped through the flow meter. There also might be some blockages in the pipe line. Depending on the fault, the down time can either be very long or very short.
				5	Faulty flow meter connection	The control system will allow fluids to be dispensed but the volume reading may be incorrect. The downtime is no longer than 1 day.
				6	Control unit has faulty input electronic signal detection circuit	The control system will allow fluids to be dispensed but the volume reading may be incorrect. Downtime can be 2 days - several weeks.
				7	The control unit is damaged	No fluid dispensing or any other action will take place or abnormal actions might take place if the control unit is damaged. The control unit must be replaced or repaired. Downtime can be 1 day - 2 weeks.
2	To capture all electronic level signals from the level sensor with an accuracy of better than 0.5%	A	Obtain no level sensor signal information	1	Level sensor is damaged	There exist the risk of feeding dangerous levels of electricity to the tank and no stock volume will also be shown on the control unit. Faulty or no tank level information can be displayed resulting in incorrect reports and alarms. Downtime can be the time until a new part is installed and configured correctly. 1 day - 3 weeks
				2	Level Sensor information cable is damaged	No tank level information or faulty tank level information can be displayed. Downtime 1 day - 2 weeks
				3	Control unit has incorrect setup	The control system will display incorrect or no tank level information resulting in incorrect reports and alarms. Downtime can be 1 day - 2 weeks
				4	There is no stock in the tank	The control unit will display 0 values for the tank.
				5	Faulty level sensor connection	The incorrect tank level reading will be shown on the system resulting in incorrect reports and alarms. Downtime can be 1 day - 2 weeks.
				6	Faulty level sensor installation	The incorrect tank level reading will be shown on the system resulting in incorrect reports and alarms. Downtime can be 1 day - 2 weeks.
				7	The control unit is damaged	No tank level information will be shown or abnormal tank level information will be shown resulting in incorrect or no reports & alarms. Downtime can be 1 day - 2 weeks.

		B	Obtain poor level sensor signal information	1	Level sensor is damaged	There exist the risk of feeding dangerous levels of electricity to the tank and no stock volume will also be shown on the control unit. Faulty or no tank level information can be displayed in incorrect reports and alarms. Downtime can be the time until a new part is installed and configured correctly. 1 day - 3 weeks
				2	Level Sensor information cable is damaged	Obtain faulty or no tank level information. Downtime 1 day - 2 weeks
				3	Control unit has incorrect setup	The control system will display incorrect or no tank level information resulting in incorrect reports and alarms. Downtime can be 1 day - 2 weeks
				4	There is no stock in the tank	The control unit will display 0 values for the tank.
				5	Faulty level sensor connection	The incorrect tank level reading will be shown on the system resulting in incorrect reports and alarms. Downtime can be 1 day - 2 weeks.
				6	Faulty level sensor installation	The incorrect tank level reading will be shown on the system resulting in incorrect reports and alarms. Downtime can be 1 day - 2 weeks.
				7	The control unit is damaged	No tank level information or abnormal tank level information will be shown resulting in incorrect or no reports & alarms. Downtime can be 1 day - 2 weeks.
3	To switch on and off the dispensing pump within 2 seconds of activation from the control unit	A	Pump does not switch on	1	Pump is faulty	No fluid products can be supplied with a faulty pump. Downtime is 1 week - 4 weeks
				2	Pump has no power supply	No fluids products can be supplied. Downtime 1 day - 1 week.
				3	Control unit has incorrect setup	Pump will not be switched on by control unit resulting in no fluids being available. Downtime 1-2 days
				4	Control unit is damaged	Pump will not be switched on by control unit resulting in no fluids being available. Downtime 2 day -2 weeks
				5	Faulty connection between control unit & pump switch	Pump will not be switched on properly by control unit resulting in very little or no fluids being available. Downtime 2 day - 1 weeks
				6	Damaged signal cable between pump & control unit	Pump will not be switched on properly by control unit resulting in very little or no fluids being available. Downtime 2 day - 1 weeks
		B	Pump does not switch off	1	Pump is faulty	Continuous fluid products and pressure will be supplied with the running pump. Downtime is 2 week - 4 weeks
				2	Pump has fault condition in the power supply	Continuous fluid products and pressure will be supplied with the running pump. Downtime is 1 day - 1 week
				3	Control unit has incorrect setup	Continuous fluid products and pressure will be supplied with the running pump. Downtime is 1 day

				4	Control unit is damaged	Continuous fluid products and pressure will be supplied with the running pump. Downtime is 2 days - 2 weeks
				5	Faulty connection between control unit & pump switch	Pump will not be switched off properly by control unit resulting in continuous fluids being pumped. Downtime 1 day - 1 weeks
				6	Damaged signal cable between pump & control unit	Pump will not be switched off properly by control unit resulting in continuous fluids being pumped. Downtime 1 day - 1 weeks
		C	Pump does not switch on/off in the designated time	1	Pump is faulty	Continuous fluid products and pressure will be supplied with the running pump. Downtime is 2 week - 4 weeks
				2	Pump has fault condition in the power supply	Continuous fluid products and pressure will be supplied with the running pump. Downtime is 1 day - 1 week
				3	Control unit has incorrect setup	Continuous fluid products and pressure will be supplied with the running pump. Downtime is 1 day
				4	Control unit is damaged	Continuous fluid products and pressure will be supplied with the running pump. Downtime is 2 days - 2 weeks
				5	Faulty connection between control unit & pump switch	Pump will not be switched off properly by control unit resulting in continuous fluids being pumped. Downtime 1 day - 1 weeks
				6	Damaged signal cable between pump & control unit	Pump will not be switched off properly by control unit resulting in continuous fluids being pumped. Downtime 1 day - 1 weeks
4	To display all information on the local display of the control unit to an operator successfully	A	Control Unit's does not display any information but the control unit is in an on-state	1	Control Unit is faulty	No actions can be performed by the control unit and no fluids can be dispensed. Downtime 1 day - 1 week
				2	Control Unit is not setup properly	Control unit will not function according to specification and fluids can be dispensed incorrectly. Downtime 1 day - 1 week
		B	Operator does not understand information	1	No on-site system pamphlets	Operator will not be able to operate the control system resulting in poor production because of poor fluids availability. Downtime 1 day
				2	Lack of training results in improper operation	Operator will not be able to operate the control system resulting in poor production because of poor fluids availability. Downtime 1 day
		C	Control Unit's display is not active	1	Control unit has no power supply	No fluids can be dispensed while the control system does not have a power supply. Downtime 1 day
				2	Control Unit is faulty	Very limited actions can be performed by the control unit and little to no fluids can be dispensed. Downtime 1 day - 1 week

5	To capture every key strokes input by an operator on the control unit where the input rate can be as high as 4Hz	A	The Keypad is not active	1	Control unit has no power supply	No fluids can be dispensed while the control system does not have a power supply. Downtime 1 day
				2	Control Unit is faulty	Very limited actions can be performed by the control unit and little to no fluids can be dispensed. Downtime 1 day - 1 week
		B	The Keypad does not respond at the specified rate	1	Control Unit is faulty	Very limited actions can be performed by the control unit and little to no fluids can be dispensed. Downtime 1 day - 1 week
				2	Improper use of control unit by operator	Wrong information will be captured resulting in wrong fluids being dispensed or no fluids being dispensed. Downtime 1day - 1week
		C	The keypad displays the wrong information	1	Control Unit is faulty	Very limited actions can be performed by the control unit and little to no fluids can be dispensed. Downtime 1 day - 1 week
				2	Improper use of control unit by operator	Wrong information will be captured resulting in wrong fluids being dispensed or no fluids being dispensed. Downtime 1day - 1week
6	To communicate all data from the control unit back to the Data Management Software every 30 minutes	A	No data is communicated	1	Control unit has no power supply	No fluids can be dispensed & no information can be communicated to the central data servers while the control system does not have a power supply. Downtime 1 day
				2	Control Unit is faulty	Very limited actions can be performed by the control unit including little to no communications capabilities. Also, little to no fluids can be dispensed. Downtime 1 day - 1 week
				3	GSM Network is problematic	Cannot communicate with control unit by servers as well as maintenance staff to retrieve site data or to implement changes or diagnostic actions. Downtime 1 day - 3 days
				4	Communication server is down	Cannot retrieve data from site and update information for client reports. Downtime 1 day
				5	There is no data	No data can be displayed on the reports. This might not be an error, might just be a quiet time at client site. Might be a fault in the control unit. Downtime none - 1 week
		B	Poor or Incorrect data quality is communicated	1	Control Unit is faulty	Very limited actions can be performed by the control unit including little to no communications capabilities. Also, little to no fluids can be dispensed. Downtime 1 day - 1 week

				2	GSM Network is problematic	Cannot successfully communicate with control unit by servers as well as by maintenance staff to retrieve site data or to implement changes or diagnostic actions. Downtime 1 day - 3 days
				3	Communication server is faulty	Cannot retrieve correct information from site and update information for client reports. Downtime 1 day
7	To stay free of moisture & dust in the inner electronics of the control unit	A	Control unit is not active	1	Short circuit in control unit due to on-site dust or moisture	No fluids can be dispensed & no information can be communicated to the central data servers while the control system does not have a power supply. Downtime 1 day - 3 days
		B	The control unit is not functioning properly	1	Hardware failure in control unit due to on-site dust or moisture	Little to no actions can be performed by the control unit. Downtime 1 day - 3 days
		C	There is an negative influence on the client site due to the control unit malfunction	1	Client site experiences a power outage due to a short-circuit of a circuit in the control unit fed from a client distribution panel.	No fluids can be dispensed & no information can be communicated to the central data servers while the control system does not have a power supply. The client site can also experience a power outage. Downtime 1 day
8	To ensure that all the wire & cables feeding information & power to the control unit do not get damaged	A	No power or information is sent via cables	1	Wire is damaged	The control unit will not receive any power supply or information signals resulting in no fluids being able to be dispensed. Downtime 1 day - 3 days
				2	Wire connection is faulty	The control unit will not receive any power supply or information signals resulting in no fluids being able to be dispensed. Downtime 1 day
				3	Wrong connection	The control unit will not receive any power supply or information signals resulting in no fluids being able to be dispensed. Downtime 1 day
		B	Poor power or signal quality is sent via cables	1	Wire is damaged	The control unit will receive poor power supply quality or information signals resulting in no or incorrect operations of the control unit. Downtime 1 day - 1 week
				2	Wire connection is faulty	The control unit will receive poor power supply quality or information signals resulting in no or incorrect operations of the control unit. Downtime 1 day - 1 week
9	To ensure that the control unit updates configuration settings every time it is requested to do so	A	No updates action can be done	1	Control unit is faulty	Very limited actions can be performed by the control unit and little to no fluids can be dispensed. Downtime 1 day - 1 week

				2	Control unit has no power supply	No operations can be performed by the control unit including no fluids can be dispensed & no information can be communicated to the central data servers while the control system does not have a power supply. Downtime 1 day
				3	GSM network is down	Cannot successfully communicate with control unit by servers as well as by maintenance staff to retrieve site data or to implement changes or diagnostic actions. Downtime 1 day - 3 days
				4	Faulty wire connection	The control unit will receive poor power supply quality or information signals resulting in no or incorrect operations of the control unit. Downtime 1 day - 1 week
				5	Improper operation by person	Operator will not be able to operate the control system resulting in poor production because of poor fluids information availability. Downtime 1 day
		B	Only partial information can be sent	1	Control unit is faulty	Very limited actions can be performed by the control unit and little to no fluids can be dispensed. Downtime 1 day - 1 week
				2	GSM network is unhealthy	Cannot successfully communicate with control unit by servers as well as by maintenance staff to retrieve site data or to implement changes or diagnostic actions. Downtime 1 day - 3 days
				3	Faulty wire connection	The control unit will receive poor power supply quality or information signals resulting in no or incorrect operations of the control unit. Downtime 1 day - 1 week
				4	Improper operation by person	Operator will not be able to operate the control system resulting in poor production because of poor fluids information availability. Downtime 1 day

System	Newcom FMS	System No	NFM_FMS_SE_00	Facilitator	F.O.	Date	2012/03/07	Sheet No	5
Sub-System	On-Site Control System	Sub System No	NFM_FMS_SE_01	Auditor	N.O.	Date	2012/03/08	of	

Information Reference			Consequence Evaluation				H1	H2	H3	PROPOSED TASK	INITIAL INTERVAL	CAN BE DONE BY
F	FF	FM	H	S	E	O	S1 / O1 / N1	S2 / O2 / N2	S3 / O3 / N3			
1	A	1	N	N	N	Y	Y			When dispensing fluid, always inspect flow meter visually for correct readings and overall condition. Feedback to supervisor on any incidents. Periodic Inspection by Newcom personnel & system re-calibrate	Every transaction & once every 8 weeks	Operator & Newcom technician
1	A	2	N	N	N	Y	Y			Inspect flow meter reading on control station to verify signal integrity. Feedback to supervisor on any incidents. Periodic Inspection by Newcom personnel & system re-calibrate	Every transaction & once every 8 weeks	Operator & Newcom technician
1	A	3	N	N	N	Y	Y			Verify correct setup with installation. Verify correct setup periodically by inspecting internal setup file of control unit	Installation & quarterly	Newcom technician
1	A	4	N	N	N	Y	Y			Inspection & maintain refuelling infrastructure according to the desired manufacturer specification	Quarterly	Client technician
1	A	5	N	N	Y		Y			Inspect & verify correct installation. Inspect pipe work on every transaction. Newcom can perform a system inspection.	Every transaction; once in 4 months	Client foreman & Newcom technician
1	A	6	N	N	N	N	Y			Installation technician must have necessary installation procedure and be competent to install flow meters	Upon installation	Installation technician
1	A	7	N	N	N	Y	Y			Visually inspect the unit and verify all actions are being performed without intermittent faults	Every transaction	Operator

1	B	1	N	N	N	Y	Y			When dispensing fluid, always inspect flow meter visually for correct readings and overall condition. Feedback to supervisor on any incidents. Periodic Inspection by Newcom personnel & system re-calibrate	Every transaction & once every 8 weeks	Operator & Newcom technician
1	B	2	N	N	N	Y	Y			Inspect flow meter reading on control station to verify signal integrity. Feedback to supervisor on any incidents. Periodic Inspection by Newcom personnel & system re-calibrate	Every transaction & once every 8 weeks	Operator & Newcom technician
1	B	3	N	N	N	Y	Y			Verify correct setup with installation. Verify correct setup periodically by inspecting internal setup file of control unit	Installation & quarterly	Newcom technician
1	B	4	N	N	N	Y	Y			Inspect the volume of fluid dispensed every time fuel is dispensed to ensure to a degree that the fluids seem normal. Calibrate pumps	Inspection at every transaction & calibration every year	Inspection by operator & Newcom. Calibration by SANAS technician
1	B	5	N	N	Y		Y			Inspect & verify correct installation. Inspect pipe work on every transaction. Newcom can perform a system inspection.	Every transaction & once in 4 months	Client foreman & Newcom technician
1	B	6	N	N	N	Y	Y			Installation technician must have necessary installation procedure and be competent to install flow meters	Upon installation	Installation technician
1	B	7	N	N	N	Y	Y			Visually inspect the unit and verify all actions are being performed without intermittent faults	Every transaction	Operator & Newcom technician
2	A	1	N	Y			Y			Inspect tank level data to determine sensor integrity	Daily	Operator & Newcom data clerk
2	A	2	N	N	N	Y	Y			Inspect tank level data to determine sensor integrity. Visually inspect sensor cabling.	Daily	Operator & Newcom data clerk
2	A	3	N	N	N	Y	N	N	N	Verify correct setup with installation. Verify correct setup periodically by inspecting internal setup file of control unit	Installation & quarterly	Newcom technician

2	A	4	N	N	N	Y	Y			Inspect stock levels & take manual hand readings to verify electronic signal is correct	Stock levels - daily. Dips - monthly	Operator or Newcom technician
2	A	5	N	N	N	Y	N	N	N	Inspect stock levels on the system	Daily	Operator or Newcom technician
2	A	6	N	N	N	Y	Y			Installation technician must have necessary installation procedure and be competent to install & set up a level sensor	Upon installation	Installation technician
2	A	7	N	N	N	Y	Y			Visually inspect the unit and verify all actions are being performed without intermittent faults	Every transaction	Operator & Newcom technician
2	B	1	N	N	N	Y	Y			Inspect tank level data to determine sensor integrity	Daily	Operator & Newcom data clerk
2	B	2	N	Y			Y			Inspect tank level data to determine sensor integrity. Visually inspect sensor cabling.	Daily	Operator & Newcom data clerk
2	B	3	N	N	N	Y	N	N	N	Verify correct setup with installation. Verify correct setup periodically by inspecting internal setup file of control unit	Installation & quarterly	Newcom technician
2	B	4	N	N	N	Y	Y			Inspect stock levels & take manual hand readings to verify electronic signal is correct	Stock levels - daily. Dips - monthly	Operator or Newcom technician
2	B	5	N	N	N	Y	N	N	N	Inspect stock levels on the system	Daily	Operator or Newcom technician
2	B	6	N	N	N	Y	Y			Installation technician must have necessary installation procedure and be competent to install & set up a level sensor	Upon installation	Installation technician

2	B	7	N	N	N	Y	Y			Visually inspect the unit and verify all actions are being performed without intermittent faults	Every transaction	Operator & Newcom technician
3	A	1	N	N	N	Y	N	N	N	Inspect pump operation when active. Service the pump & motor at the specified service intervals	Every transaction	Operator
3	A	2	N	N	N	Y	N	N	N	Inspect pump operation when active	Every transaction	Operator
3	A	3	N	N	N	Y	N	N	N	Verify correct setup with installation. Verify correct setup periodically by inspecting internal setup file of control unit	Installation & quarterly	Newcom technician
3	A	4	N	N	N	Y	Y			Visually inspect the unit and verify all actions are being performed without intermittent faults	Every transaction	Operator & Newcom technician
3	A	5	N	N	N	Y	N	N	N	Inspect pump operation when active & inspect cabling between pump on/off switch & control unit	Monthly	Operator
3	A	6	N	N	N	Y	Y			Inspect pump operation when active & inspect cabling between pump on/off switch & control unit	Monthly	Operator
3	B	1	N	N	Y		Y			Inspect pump operation when active. Service the pump & motor at the specified service intervals	Every transaction	Operator
3	B	2	N	N	N	Y	Y			Inspect pump operation when active	Every transaction	Operator
3	B	3	N	N	N	Y	N	N	N	Verify correct setup with installation. Verify correct setup periodically by inspecting internal setup file of control unit	Installation & quarterly	Newcom technician

3	B	4	N	N	N	Y	Y			Visually inspect the unit and verify all actions are being performed without intermittent faults	Every transaction	Operator & Newcom technician
3	B	5	N	N	N	Y	Y			Inspect pump operation when active & inspect cabling between pump on/off switch & control unit	Monthly	Operator
3	B	6	N	N	N	Y	N	N	N	Inspect pump operation when active & inspect cabling between pump on/off switch & control unit	Monthly	Operator
3	C	1	N	N	N	Y	Y			Inspect pump operation when active. Service the pump & motor at the specified service intervals	Every transaction	Operator
3	C	2	N	N	N	Y	N	N	N	Inspect pump operation when active	Every transaction	Operator
3	C	3	N	N	N	Y	N	N	N	Verify correct setup with installation. Verify correct setup periodically by inspecting internal setup file of control unit	Installation & quarterly	Newcom technician
3	C	4	N	N	N	Y	Y			Visually inspect the unit and verify all actions are being performed without intermittent faults	Every transaction	Operator & Newcom technician
3	C	5	N	N	N	Y	Y			Inspect pump operation when active & inspect cabling between pump on/off switch & control unit	Monthly	Operator
3	C	6	N	N	N	Y	Y			Inspect pump operation when active & inspect cabling between pump on/off switch & control unit	Monthly	Operator
4	A	1	N	N	N	Y	N	Y		Newcom must inspect the data received as well as the data communication status to verify the health status of equipment	Weekly	Newcom clerk
4	A	2	N	N	N	Y	N	N	N	Verify correct setup with installation. Verify correct setup periodically by inspecting internal setup file of control unit	Installation & quarterly	Newcom technician

4	B	1	N	N	N	Y	N	N	N	Newcom must continuously support the client and enquire if the operator understands the system. If not, operator must receive training & instruction pamphlets can be mounted at operating points.	Weekly	Newcom clerk & operator
4	B	2	N	N	N	Y	Y			Newcom must provide training & retraining on the system for any and all operators as well as provide training documentation	Quarterly	Newcom technician
4	C	1	N	N	N	Y	N	N	N	Power must be restored to the control unit in order for the system to operate successfully.	When incident occurs	Operator or Newcom technician
4	C	2	N	N	N	Y	N	Y		Newcom must inspect the data received as well as the data communication status to verify the health status of equipment	Weekly	Newcom clerk
5	A	1	N	N	N	Y	N	N	N	Power must be restored to the control unit in order for the system to operate successfully.	When incident occurs	Operator or Newcom technician
5	A	2	N	N	N	Y	N	Y		Newcom must inspect the data received as well as the data communication status to verify the health status of equipment	Weekly	Newcom clerk
5	B	1	N	N	N	Y	N	Y		Newcom must inspect the data received as well as the data communication status to verify the health status of equipment	Weekly	Newcom clerk
5	B	2	N	N	N	Y	N	Y		Newcom must inspect the quality and integrity of the data received to verify the health status operations	Weekly	Newcom clerk
5	C	1	N	N	N	Y	N	Y		Newcom must inspect the data received as well as the data communication status to verify the health status of equipment	Weekly	Newcom clerk

5	C	2	N	N	N	Y	N	Y		Newcom must inspect the quality and integrity of the data received to verify the health status operations	Weekly	Newcom clerk
6	A	1	N	N	N	Y	N	N	N	Redesign - Implement a system alarm to notify Newcom that a control unit has not been communicating. Notify client of event	On occurrence	Newcom & client
6	A	2	N	N	N	Y	N	Y		Newcom must inspect the data received as well as the data communication status to verify the health status of equipment	Weekly	Newcom clerk
6	A	3	N	N	N	Y	N	N	N	Redesign - Implement a system alarm to notify Newcom that a control unit has not been communicating. Notify client of event	On occurrence	Newcom & client
6	A	4	N	N	N	Y	Y			Inspection on communication server and routine server maintenance as required to ensure server is stable and up to date	Once in 6-Months	Newcom technician
6	A	5	N	N	N	Y	N	N	N	Wait for data to be created by user	Weekly	Newcom clerk
6	B	1	N	N	N	Y	N	Y		Newcom must inspect the data received as well as the data communication status to verify the health status of equipment	Weekly	Newcom clerk
6	B	2	N	N	N	Y	N	N	N	Redesign - Implement a system alarm to notify Newcom that a control unit has not been communicating. Notify client of event	On occurrence	Newcom & client
6	B	3	N	N	N	Y	Y			Inspection on communication server and routine server maintenance as required to ensure server is stable and up to date	Once in 6-Months	Newcom technician
7	A	1	N	Y			Y			Routine clean-up of control unit & fastening of sealed parts. Visual inspection and change of equipment in event of excessive dirt or moisture.	Quarterly	Newcom technician

7	B	1	N	N	N	Y	Y			Routine clean-up of control unit & fastening of sealed parts. Visual inspection and change of equipment in event of excessive dirt or moisture.	Quarterly	Newcom technician
7	C	1	N	N	N	N	N	N	N	Verify installation was done properly and test all control system elements interfacing with client site.	Installation & upon occurrence	Newcom technician
8	A	1	N	N	N	Y	N	N	N	Inspect communication & power cables when visiting a site	Quarterly	Newcom technician & operator
8	A	2	N	N	N	Y	N	N	Y	Verify all installation & connections have been done properly upon installation	Installation & Occurrence	Newcom technician
8	A	3	N	N	N	Y	N	N	Y	Verify all installation & connections have been done properly upon installation	Installation & Occurrence	Newcom technician
8	B	1	N	N	N	Y	N	N	N	Inspect communication & power cables when visiting a site	Quarterly	Newcom technician & operator
8	B	2	N	N	N	Y	N	N	Y	Verify all installation & connections have been done properly upon installation	Installation & Occurrence	Newcom technician
9	A	1	N	N	N	Y	N	Y		Newcom must inspect the data received as well as the data communication status to verify the health status of equipment	Weekly	Newcom clerk
9	A	2	N	N	N	Y	N	N	N	Redesign - Implement a system alarm to notify Newcom that a control unit has not been communicating. Notify client of event	On occurrence	Newcom & client
9	A	3	N	N	N	Y	N	N	N	Redesign - Implement a system alarm to notify Newcom that a control unit has not been communicating. Notify client of event	On occurrence	Newcom & client
9	A	4	N	N	N	Y	N	N	Y	Verify all installation & connections have been done properly upon installation	Installation & Occurrence	Newcom technician
9	A	5	Y				Y			User must ensure the correct steps are followed for updating as well as that the user has received the necessary training	Yearly	Newcom technician

9	B	1	N	N	N	Y	N	Y		Newcom must inspect the data received as well as the data communication status to verify the health status of equipment	Weekly	Newcom clerk
9	B	2	N	N	N	Y	N	N	N	Redesign - Implement a system alarm to notify Newcom that a control unit has not been communicating. Notify client of event	On occurrence	Newcom & client
9	B	3	N	N	N	Y	N	N	Y	Verify all installation & connections have been done properly upon installation	Installation & Occurrence	Newcom technician
9	B	4	Y				Y			User must ensure the correct steps are followed for updating as well as that the user has received the necessary training	Yearly	Newcom technician

System: Newcom FMS		System No: NFM_FMS_SE_00		Facilitator: F. Oosthuizen		Date 2012/02/20 Sheet No 2	
Sub-System: Off-Site Management System		Sub System No: NFM_FMS_SE_02		Auditor: N. Oosthuizen		Date 2012/02/21 of	
Function		**Functional Failure**		**Failure Mode**		**Failure Effect**	
1	To capture all data of all the field systems every 30 minutes via the GSM Network	A	Data cannot be captured	1	No or Poor GSM Signal of field system	No data can be sent from the field system to the database server. No new reports can be compiled and no alarms can be sent. Downtime 1 day - 1 week	
				2	No or Poor GSM Signal on central servers side	No data can be sent from the field system to the database server. No new reports can be compiled and no alarms can be sent. Downtime 1 day - 1 week	
				3	Field system is off or faulty	No data can be sent from the field system to the database server. No new reports can be compiled and no alarms can be sent. The client will also not be able to dispense fluids on site on the event of a field system failure. Downtime 1 day - 1 week	
				4	Data collector software failure	No data will be collected by the central server from any and all field systems. No new reports can be compiled and no alarms can be sent. Downtime 1 day - 2 day	
				5	Data collector hardware failure	No data will be collected by the central server from any and all field systems. No new reports can be compiled and no alarms can be sent. Downtime 1 day - 2 day	
		B	Data captured outside the 30 minute interval	1	Too much data to be captured in a single download cycle	Data might go missing because a new data capture cycle will have started whilst the previous one is still active. Client might receive data and alarms late or not at all. Downtime 1 week	
				2	No or Poor GSM Signal on field system for the data capture cycle	No data can be sent from the field system to the database server. No new reports can be compiled and no alarms can be sent. Downtime 1 day - 1 week	
				3	No or Poor GSM Signal on central servers side for the data capture cycle	No data can be sent from the field system to the database server. No new reports can be compiled and no alarms can be sent. Downtime 1 day - 1 week	
				4	Field system is off or faulty for the data capture cycle	No data can be sent from the field system to the database server. No new reports can be compiled and no alarms can be sent. The client will also not be able to dispense fluids on site on the event of a field system failure. Downtime 1 day - 1 week	

				5	Data collector software failure for the data capture cycle	No data will be collected by the central server from any and all field systems. No new reports can be compiled and no alarms can be sent. Downtime 1 day - 2 day
				6	Data collector hardware failure for the data capture cycle	No data will be collected by the central server from any and all field systems. No new reports can be compiled and no alarms can be sent. Downtime 1 day - 2 day
		C	Data is captured on time but the data is unhealthy	1	Field system is faulty	No data can be sent from the field system to the database server. No new reports can be compiled and no alarms can be sent. The client will also not be able to dispense fluids on site on the event of a field system failure. Downtime 1 day - 1 week
				2	Data collector is set up incorrectly	No data will be collected by the central server from any and all field systems. No new reports can be compiled and no alarms can be sent. Downtime 1 day - 2 day
2	To process data within 10 minutes when captured from the field	A	Data is not processed	1	Processing Server is down	Captured data cannot be processed and displayed or reported to clients in an understandable format. Downtime 1 day - 2 day
				2	Database Server is down	Captured data cannot be stored & client cannot analyse or compile reports due to the lack of storage of data. Downtime 1 day - 2 day
				3	No communications between Servers	New data cannot be sent from data collection server to database server and then processing server. Data cannot be made available to clients. Downtime 1 day
				4	Wrong processing setup of data	Raw data will be processed properly resulting in no or wrong reports for clients. Downtime 1 day - 1 week
		B	Data is processed outside the 10 minute window	1	Too much data to be processed for single server application	Data will be captured but not processed properly or not processed at all. Also, the processing server could potentially provide clients with incorrect data on client operations due to the bottleneck. Downtime 2 days
				2	Processing server is faulty	Captured & stored data cannot be processed and clients will not be able to receive alarms and production reports on operations. Downtime 1 day
				3	Data to be processed is not received on time by the processing server	Data which is not received cannot be processed and clients will not be able to receive alarms and production reports on operations. Downtime 1 day
		C	Processed data is unhealthy	1	Wrong data processing setup parameters	Data will be processed incorrectly resulting in wrong alarm reports and production reports. Downtime 1 day - 1 week

				2	Processing or Database servers are corrupted	Potentially no data to limited data will be available to clients. Downtime 1 day.
				3	Interference in data processing process	Data can be processed incorrectly or not at all resulting in wrong alarm reports and production reports. Downtime 1 day - 1 week
3	To store all data, processed & unprocessed, on 2 x locations	A	Data cannot be stored	1	Database server is faulty	Captured data cannot be stored on the central management system and clients will not be able to receive any new data, alarms and production reports on operations. Downtime 1 day
				2	Database server is off	Captured data cannot be stored on the central management system and clients will not be able to receive any new data, alarms and production reports on operations. Downtime 1 day
				3	Data collector engine is faulty or off	No data will be captured. Clients will not be able to receive any new data, alarms and production reports on operations. Downtime 1 day
				4	Database server capacity is full	No new data can be stored and/or processed resulting in clients not being able to receive any new data, alarms and production reports on operations. Downtime 1 day
		B	Data cannot be stored on 2 x locations	1	One or Both locations' servers are down or faulty	No new data can be stored and/or processed resulting in clients not being able to receive any new data, alarms and production reports on operations. Downtime 1 day
				2	Communication links are down between servers	Data cannot be backed up on the second servers system resulting in the probability of data loss in the event of the original system being down
				3	Both location's database server capacity is full	No new data can be stored and/or processed resulting in clients not being able to receive any new data, alarms and production reports on operations. Downtime 1 day
		C	Stored Data is unhealthy	1	Communication links have intermittent faults between servers	Client data might be incomplete or incorrect due to communication faults. Downtime 1 day - 1 week
				2	Database is corrupted	No data will be available to clients. Downtime 1 day
				3	Virus on database server	No data will be available to clients. Downtime 1 day
				4	Improper use by operator	Partial or incorrect data will be available to client. No downtime.
		D	Only partial data is stored	1	Communication links have intermittent faults between servers	Client data might be incomplete or incorrect due to communication faults. Downtime 1 day - 1 week
				2	Virus on database server	No data will be available to clients. Downtime 1 day
				3	Database is full	No data will be available to clients. Downtime 1 day

		E	Data cannot be processed	1	Communication link between database server & processing server is down or faulty	Client data might be incomplete or incorrect due to communication faults. Downtime 1 day - 1 week
				2	There is no data to be processed	No new data is available for server to process and display to client. No downtime
				3	Either one or both the processing servers and the database server is faulty or down	No new data can be stored and/or processed resulting in clients not being able to receive any new data, alarms and production reports on operations. Downtime 1 day
4	To send alarms & exception notifications within 5 minutes of data being processed	A	No alarms or exceptions are sent	1	Alarm servers are down or faulty	Alarms reports cannot be sent to clients on exception or abnormal operations found on-site. Downtime 1 day
				2	Communication link is down or faulty between the alarm server and the database server	Alarms reports cannot be sent to clients or alarm data might be faulty on the exception or abnormal reports for clients. Downtime 1 day - 5 days
				3	The GSM Network is down or faulty which prohibits SMS alarms & exception reports	No or partial alarm SMS reports can be sent to clients to report fault conditions on-site. Downtime 1 day - 1 week
				4	The main server's internet connection is down or faulty which prohibits email exception reports	No or partial email alarm reports can be sent to clients to report fault conditions on-site. Downtime 1 day - 1 week
				5	Incorrect alarm set up	No or partial alarm reports can be sent to clients to report fault conditions on-site. Downtime 1 day - 1 week
		B	Only partial alarms and exceptions are sent	1	Alarm servers are faulty	No or partial alarm reports can be sent to clients to report fault conditions on-site. Downtime 1 day - 1 week
				2	The GSM Network is faulty	No or partial alarm SMS reports can be sent to clients to report fault conditions on-site. Downtime 1 day - 1 week
				3	The Internet connection is faulty	No or partial email alarm reports can be sent to clients to report fault conditions on-site. Downtime 1 day - 1 week
				4	Incorrect alarm set up	No or partial alarm reports can be sent to clients to report fault conditions on-site. Downtime 1 day - 1 week
		C	Alarms & exceptions are not sent within the 5 minutes period	1	Alarm servers are faulty	No or partial alarm reports can be sent to clients to report fault conditions on-site. Downtime 1 day - 1 week
				2	The GSM Network is faulty	No or partial alarm SMS reports can be sent to clients to report fault conditions on-site. Downtime 1 day - 1 week

				3	The Internet connection is faulty	No or partial email alarm reports can be sent to clients to report fault conditions on-site. Downtime 1 day - 1 week
				4	Incorrect alarm set up	No or partial alarm reports can be sent to clients to report fault conditions on-site. Downtime 1 day
				5	Too many alarms to be sent from single server	No or partial alarm reports will be sent to clients to report fault conditions on-site. Alarms might not be sent due to the bottleneck condition. Downtime 1 day - 2 days
5	To publish all data on the Internet for a client to inspect & analyse within 10 minutes of data capture	A	No data is published on the internet	1	Internet application server is faulty or down	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 1 week
				2	Internet application server's internet connection is faulty or down	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 1 week
				3	Internet App server's link to database server is faulty or down	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 2 days
				4	Data in database is corrupted and unreadable	No data will be available to clients on their operations on-site. Downtime 1 day - 2 days
				5	Incorrect set up of data account	No or incorrect data will be displayed or reported on client on site operations. Downtime 1 day - 2 days
		B	Faulty or Partial data is published	1	Internet application server is faulty	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 1 week
				2	Internet application server's internet connection is faulty	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 1 week
				3	Internet App server's link to database server is faulty	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 2 days
				4	Data in database is corrupted and partially unreadable	No or partial data will be available to clients on their operations on-site. Downtime 1 day - 2 days
				5	Incorrect set up of data account	No or incorrect data will be displayed or reported on client on site operations. Downtime 1 day - 2 days
		C	Data is not published on time	1	Internet application server is faulty	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 1 week
				2	Internet application server's internet connection is faulty	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 1 week
				3	Internet App server's link to database server is faulty	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 2 days
				4	Data in database is corrupted and partially unreadable	No or partial data will be available to clients on their operations on-site. Downtime 1 day - 2 days

				5	Incorrect set up of data account	No or incorrect data will be displayed or reported on client on site operations. Downtime 1 day - 2 days
				6	Too much data to be displayed in the amount of time available	Incorrect or partial data will be displayed in the reports provided to the client. Downtime 1 day - 3 days
6	To analyse data of clients and compile reports to send to clients via email weekly	A	Data cannot be analysed	1	Internet application server's internet connection is faulty	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 1 week
				2	Internet App server's link to database server is faulty	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 2 days
				3	Operator or client not competent in system	Incorrect data might be shown to the client in the report due to personnel who are not yet competent. No downtime
				4	Operator or client terminal is faulty or down	Incorrect or no data will be displayed in a client report due to the operator terminal not working properly. Downtime 1 day - 2 days.
				5	Station is faulty or down	Incorrect or no data can be sent from the control station on-site at the client resulting in incorrect or no data being displayed in the client reports. Downtime 1 day - 1 week
		B	Data is analysed wrongfully	1	Operator or client not competent in system	Incorrect data might be shown to the client in the report due to personnel who are not yet competent. No downtime
				2	Operator or client terminal is faulty or down	Incorrect or no data will be displayed in a client report due to the operator terminal not working properly. Downtime 1 day - 2 days.
				3	Station is faulty or down	Incorrect or no data can be sent from the control station on-site at the client resulting in incorrect or no data being displayed in the client reports. Downtime 1 day - 1 week
				4	Report is compiled wrongfully	Incorrect data might be shown to the client in the report due to personnel who are not yet competent. No downtime
		C	Report cannot be sent to client	1	Internet application server's internet connection is faulty	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 1 week
				2	Internet App server's link to database server is faulty	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 2 days
				3	Operator or client not competent in system	Incorrect data might be shown to the client in the report due to personnel who are not yet competent. No downtime
				4	Operator or client terminal is faulty or down	Incorrect or no data will be displayed in a client report due to the operator terminal not working properly. Downtime 1 day - 2 days.

		D	Reports are not sent out on time	1	Operator or client not competent in system	Incorrect data might be shown to the client in the report due to personnel who are not yet competent. No downtime
				2	Operator or client terminal is faulty or down	Incorrect or no data will be displayed in a client report due to the operator terminal not working properly. Downtime 1 day - 2 days.
				3	Internet application server's internet connection is faulty	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 1 week
				4	Internet App server's link to database server is faulty	No or partial data will be reported to clients on their operations on-site. Downtime 1 day - 2 days
7	To inspect & manipulate data in the database	A	Database is not available	1	Database server is faulty or down	Captured data cannot be processed and displayed or reported to clients in an understandable format. Downtime 1 day - 2 day
				2	Link to database server is faulty or down	Data cannot be read from database resulting in data not being available for client reports. Downtime 1 day
				3	Operator does not have necessary rights to change data	Data cannot be accessed by the operator in the database and no changes to data can be made. Downtime 1 day
		B	Cannot operator database facility	1	Operator not trained properly	Data might be changed incorrectly or removed/added incorrectly by an operator. Downtime 1 day
				2	Database server is faulty or down	Captured data cannot be stored on the central management system and clients will not be able to receive any new data, alarms and production reports on operations. Downtime 1 day
		C	Wrongfully change data	1	Operator not trained properly	Data might be changed incorrectly or removed/added incorrectly by an operator. Downtime 1 day

System	Newcom FMS		System No	NFM_FMS_SE_00			Facilitator		F.O.		Date	2012/03/07	Sheet No	6		
Sub-System	Off-Site Management System		Sub System No	NFM_FMS_SE_02			Auditor		N.O.		Date	2012/03/08	of			
Information Reference			Consequence Evaluation				H1	H2	H3	Default Action			PROPOSED TASK		INITIAL INTERVAL	CAN BE DONE BY
							S1	S2	S3							
F	FF	FM	H	S	E	O	O1	O2	O3	H4	H5	S4				
							N1	N2	N3							
1	A	1	N	N	N	Y	N	N	Y				Inspect & reboot if required field equipment to establish a new GPRS connection. If it does not work, wait for GPRS connection to restore on its own.		Weekly	Operator or Technician
1	A	2	N	N	N	Y	N	N	Y				Inspect & reboot the GPRS gateway if required to establish a new GPRS connection. If it does not work, wait for GPRS connection to restore on its own.		Daily	Operator or Technician
1	A	3	N	N	N	Y	N	Y					Inspect & reboot the field control station if required to establish a new connection to the server. If it does not work, proceed to change control station.		Daily	Operator or Technician
1	A	4	N	N	N	Y	N	Y					Perform routine inspections & reboot actions on the data collector server & keep up to date all required software on the computer incl. AV, system updates, etc.		Monthly	Newcom software engineer
1	A	5	N	N	N	Y	N	Y					Inspect the data collector computer & perform hardware check incl. physical clean up, hardware scans and other action which is required to maintain the computer		Monthly	Newcom software engineer
1	B	1	N	N	N	Y	N	N	N				If data can be captured in the following download cycle, which is acceptable. If this happens constantly - redesign of the collection mechanism is necessary		On occurrence	Technician

1	B	2	N	N	N	Y	N	N	N				Upon installation verify signal strength. Verify the consistency of collected data quality and frequency. If signal quality is in general poor, then redesign antenna of field control station.	On occurrence	Technician
1	B	3	N	N	N	Y	N	N	N				Upon installation verify signal strength. Verify the consistency of collected data quality and frequency. If signal quality is in general poor, then redesign antenna of server station.	On occurrence	System Engineer
1	B	4	N	N	N	Y	N	N	N				Wait for next download cycle. If unit responds, the all is o.k. If unit does not respond, proceed to reboot field unit. If unit responds, all is o.k. If unit does not respond, proceed to change field control station.	On occurrence	Technician
1	B	5	N	N	N	Y	N	Y					Inspect data collector data capture interface to verify data which was not captured. Rectify by inspecting data availability & signal quality.	Daily	Newcom software engineer
1	B	6	N	N	N	Y	N	Y					Inspect data collector data capture interface to verify data which was not captured. Rectify by allowing another capture cycle. If the same problem exists, reboot data collector computer. Of same problem exists, switch to backup computer.	Daily	Newcom software engineer
1	C	1	N	N	N	Y	N	N	N				Contact on-site responsible personnel to switch on the system. Verify all is working fine by forcing a data download cycle.	Daily	Data clerk
1	C	2	N	N	N	Y	Y						Verify correct set-up with account creation by testing the set up with the live system and creating a test report.	Installation	Technician

2	A	1	N	N	N	Y	Y						Perform routine inspections & reboot actions on the data processing server & keep up to date all required software on the computer incl. AV, system updates, etc.	Monthly	Software engineer
2	A	2	N	N	N	Y	Y						Perform routine inspections & reboot actions on the database server & keep up to date all required software on the computer incl. AV, system updates, etc.	Monthly	Software engineer
2	A	3	N	N	N	Y	Y						Execute programs verifying quality of communications between servers	Monthly	SW Engineer
2	A	4	N	N	N	Y	Y						Verify correct set-up with account creation by testing the set up with the live system and creating a test report.	Installation	Technician
2	B	1	N	N	N	Y	N	N	N				In this event, it would justify to install a new server		
2	B	2	N	N	N	Y	Y						Perform routine inspections & reboot actions on the database server & keep up to date all required software on the computer incl. AV, system updates, etc.	Monthly	SW Engineer
2	B	3	N	N	N	Y	Y						Perform regular inspections on communication channels and speed of data processed to determine if system adheres to specification	Monthly	SW Engineer
2	C	1	N	N	N	Y	Y						Verify correct set-up with account creation by testing the set up with the live system and creating a test report.	Installation	Technician
2	C	2	N	N	N	Y	Y						Perform routine inspections & reboot actions on the server & keep up to date all required software on the computer incl. AV, system updates, etc.	Monthly	SW Engineer

2	C	3	N	N	N	Y	Y						Perform routine inspections & reboot actions on the server & keep up to date all required software on the computer incl. AV, system updates, etc.	Monthly	SW Engineer
3	A	1	N	N	N	Y	Y						Perform routine inspections & reboot actions on the database server & keep up to date all required software on the computer incl. AV, system updates, etc.	Monthly	SW Engineer
3	A	2	N	N	N	Y	Y						Visual inspection to verify all servers are up and running	Daily	clerk
3	A	3	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer
3	A	4	N	N	N	Y	Y						Review database size and project time to saturation	Monthly	SW Engineer
3	B	1	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer
3	B	2	N	N	N	Y	Y						Execute programs verifying quality of communications between servers	Weekly	SW Engineer
3	B	3	N	N	N	Y	Y						Review database size and project time to saturation	Monthly	SW Engineer
3	C	1	N	N	N	Y	Y						Execute programs verifying quality of communications between servers	Weekly	SW Engineer

3	C	2	N	N	N	Y	Y						Perform routine inspections & reboot actions on the database server & keep up to date all required software on the computer incl. AV, system updates, etc.	Monthly	SW Engineer
3	C	3	N	N	N	Y	Y						Perform routine inspections & reboot actions on the database server & keep up to date all required software on the computer incl. AV, system updates, etc.	Monthly	SW Engineer
3	C	4	N	N	N	Y	Y						Ensure all clerks, technician and engineers have recent training and are competent with system. Software Engineer can have random work assessments of clerk & technicians work.	Monthly	Clerk, Technician, Engineers
3	D	1	N	N	N	Y	Y						Execute programs verifying quality of communications between servers	Weekly	SW Engineer
3	D	2	N	N	N	Y	Y						Perform routine inspections & reboot actions on the database server & keep up to date all required software on the computer incl. AV, system updates, etc.	Monthly	SW Engineer
3	D	3	N	N	N	Y	N	N	N				In this event, it would justify to install a new server		
3	E	1	N	N	N	Y	Y						Execute programs verifying quality of communications between servers	Monthly	SW Engineer
3	E	2	N	N	N	Y	N	N	N				Wait for new data to be captured or ask client to perform a test transaction	Occurrence	
3	E	3	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer

4	A	1	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer
4	A	2	N	N	N	Y	Y						Execute programs verifying quality of communications between servers	Weekly	SW Engineer
4	A	3	N	N	N	Y	Y						Get routine updates from GSM service provider to enquire about possible problems with GSM network. In such an event, switch over to email alarms or alternative mechanisms incl. informing the client about situation	Weekly	Clerk
4	A	4	N	N	N	Y	Y						Execute programs verifying quality of communications of server publishing data on internet	Daily	SW Engineer
4	A	5	N	N	N	Y	Y						Verify correct set-up with account creation by testing the set up with the live system and creating a test report.	Installation	Technician
4	B	1	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer
4	B	2	N	N	N	Y	Y						Get routine updates from GSM service provider to enquire about possible problems with GSM network. In such an event, switch over to email alarms or alternative mechanisms incl. informing the client about situation	Weekly	Clerk
4	B	3	N	N	N	Y	Y						Execute programs verifying quality of communications of server publishing data on internet	Daily	SW Engineer

4	B	4	N	N	N	Y	Y						Verify correct set-up with account creation by testing the set up with the live system and creating a test report.	Installation	Technician
4	C	1	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer
4	C	2	N	N	N	Y	Y						Get routine updates from GSM service provider to enquire about possible problems with GSM network. In such an event, switch over to email alarms or alternative mechanisms incl. informing the client about situation	Weekly	Clerk
4	C	3	N	N	N	Y	Y						Execute programs verifying quality of communications of server publishing data on internet	Daily	SW Engineer
4	C	4	N	N	N	Y	Y						Verify correct set-up with account creation by testing the set up with the live system and creating a test report.	Installation	Technician
4	C	5	N	N	N	Y	Y						Review alarm database to estimate saturation point.	Monthly	SW Engineer
5	A	1	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer
5	A	2	N	N	N	Y	Y						Execute programs verifying quality of communications of server publishing data on internet	Daily	SW Engineer
5	A	3	N	N	N	Y	Y						Execute programs verifying quality of communications between servers	Weekly	SW Engineer

5	A	4	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer
5	A	5	N	N	N	Y	Y						Verify correct set-up with account creation by testing the set up with the live system and creating a test report.	Installation	Technician
5	B	1	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer
5	B	2	N	N	N	Y	Y						Execute programs verifying quality of communications of server publishing data on internet	Daily	SW Engineer
5	B	3	N	N	N	Y	Y						Execute programs verifying quality of communications between servers	Weekly	SW Engineer
5	B	4	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer
5	B	5	N	N	N	Y	Y						Verify correct set-up with account creation by testing the set up with the live system and creating a test report.	Installation	Technician
5	C	1	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer

5	C	2	N	N	N	Y	Y						Execute programs verifying quality of communications of server publishing data on internet	Daily	SW Engineer
5	C	3	N	N	N	Y	Y						Execute programs verifying quality of communications between servers	Weekly	SW Engineer
5	C	4	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer
5	C	5	N	N	N	Y	Y						Verify correct set-up with account creation by testing the set up with the live system and creating a test report.	Installation	Technician
5	C	6	N	N	N	Y	Y						Run diagnostic program or procedure to verify the amount of data captured to be processed and published can be done in the allocated time.	Monthly	SW Engineer
6	A	1	N	N	N	Y	Y						Execute programs verifying quality of communications of server publishing data on internet	Daily	SW Engineer
6	A	2	N	N	N	Y	Y						Execute programs verifying quality of communications between servers	Weekly	SW Engineer
6	A	3	N	N	N	Y	Y						Training user of system to be competent and provide standard set of operational procedures.	6-Months	All users
6	A	4	N	N	N	Y	Y						Perform routine inspections & reboot actions on the client computer & keep up to date all required software on the computer incl. AV, system updates, etc.	Monthly	Client
6	A	5	N	N	N	Y	N	Y					Inspect & reboot the field control station if required to establish a new connection to the server. If it does not work, proceed to change control station.	Daily	Operator or Technician

6	B	1	N	N	N	Y	Y						Training user of system to be competent and provide standard set of operational procedures.	6-Months	All users
6	B	2	N	N	N	Y	Y						Perform routine inspections & reboot actions on the client computer & keep up to date all required software on the computer incl. AV, system updates, etc.	Monthly	Client
6	B	3	N	N	N	Y	N	Y					Inspect & reboot the field control station if required to establish a new connection to the server. If it does not work, proceed to change control station.	Daily	Operator or Technician
6	B	4	N	N	N	Y	Y						Training user of system to be competent and provide standard set of operational procedures.	6-Months	Clerk & Client
6	C	1	N	N	N	Y	Y						Execute programs verifying quality of communications of server publishing data on internet	Daily	SW Engineer
6	C	2	N	N	N	Y	Y						Execute programs verifying quality of communications between servers	Weekly	SW Engineer
6	C	3	N	N	N	Y	Y						Training user of system to be competent and provide standard set of operational procedures.	6-Months	Client
6	C	4	N	N	N	Y	Y						Perform routine inspections & reboot actions on the client computer & keep up to date all required software on the computer incl. AV, system updates, etc.	Monthly	Client
6	D	1	N	N	N	Y	Y						Training user of system to be competent and provide standard set of operational procedures.	6-Months	Client

6	D	2	N	N	N	Y	Y						Perform routine inspections & reboot actions on the client computer & keep up to date all required software on the computer incl. AV, system updates, etc.	Monthly	Client
6	D	3	N	N	N	Y	Y						Execute programs verifying quality of communications of server publishing data on internet	Daily	SW Engineer
6	D	4	N	N	N	Y	Y						Execute programs verifying quality of communications between servers	Weekly	SW Engineer
7	A	1	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer
		2	N	N	N	Y	Y						Execute programs verifying quality of communications between servers	Weekly	SW Engineer
		3	N	N	N	Y	N	N	Y				Inform personnel with necessary rights to perform changes	Occurrence	Clerk
7	B	1	N	N	N	Y	Y						Training user of system to be competent and provide standard set of operational procedures.	6-Months	Client
		2	N	N	N	Y	Y						1) Visual inspection to verify all servers are up and running. 2) Perform routine inspections & reboot actions on the servers & keep up to date all required software on the computer incl. AV, system updates, etc.	1) Daily & 2) Monthly	1) clerk & 2) SW Engineer
7	C	1	N	N	N	Y	Y						Training user of system to be competent and provide standard set of operational procedures.	6-Months	Client

System: Newcom FMS		System No: NFM_FMS_SE_00		Facilitator: F. Oosthuizen		Date 2012/02/21 Sheet No 3
Sub-System: Newcom Management System		Sub System No: NFM_FMS_SE_03		Auditor: N. Oosthuizen		Date 2012/02/22 of
Function		**Functional Failure**		**Failure Mode**		**Failure Effect**
1	To operate the FMS Data Management System	A	Unable to use the DMS system	1	DMS Functional Failure	See Sheet 2 for DMS analysis
				2	Operator not competent with system	Manual data reports can be compiled wrongfully & incorrect. Downtime 1 day
				3	No operator available	No manual reports can be compiled and sent to a client. Supervision. Downtime 1 day
		B	Unable to use the system at least once per day per client	1	DMS Functional Failure	See Sheet 2 for DMS analysis
				2	Operator not competent with system	Manual data reports can be compiled wrongfully & incorrect. Downtime 1 day
				3	No operator available	No manual reports can be compiled and sent to a client. Supervision. Downtime 1 day
		C	DMS system is not functioning	1	DMS Functional Failure	See Sheet 2 for DMS analysis
2	To coordinate and control maintenance activities	A	Cannot coordinate & control activities	1	Staff not competent	System maintenance activities will be conducted poorly as well as the inspection of client data services might be incorrect with poor recommendations. Downtime 1 week
				2	No resources available	System maintenance activities will not be done at all as well as there will be no inspection of client data services and no recommendations provided to clients. Downtime 1 day.
				3	Technical failure on operational equipment	See Sheet 2 for DMS analysis
				4	No work-schedule or procedure in place	A crisis will be managed as they occur and system will not be properly maintained. Expenditure on maintenance related activities will be very high. Downtime 1 week
		B	Poor coordination & control of activities	1	Staff not competent	System maintenance activities will be conducted poorly as well as the inspection of client data services might be incorrect with poor recommendations. Downtime 1 week

				2	No resources available	System maintenance activities will not be done and there will be no inspection of client data services and no recommendations provided to clients. Downtime 1 day.
				3	Technical failure on operational equipment	See Sheet 2 for DMS analysis
				4	Poor work-schedule or procedure in place	A crisis will be managed as they occur and system will not be properly maintained. Expenditure on maintenance related activities will be very high. Downtime 1 week
3	To continuously improve overall processes	A	No improvement activities done	1	No improvement strategy or plan	Maintenance activities will periodically increase in frequency and costs due to the deterioration in equipment without a continuously evolving approach to the maintenance.
				2	No resources allocated	Maintenance activities will periodically increase in frequency and costs due to the deterioration in equipment without a continuously evolving approach to the maintenance.
				3	Staff not competent perform activities	Maintenance activities will periodically increase in frequency and costs due to the deterioration in equipment without a continuously evolving approach to the maintenance.
		B	Insufficient data captured for process improvement	1	No resources allocated	Maintenance activities will periodically increase in frequency and costs due to the deterioration in equipment without a continuously evolving approach to the maintenance.
				2	No procedure on proper data capture in place	Maintenance activities will periodically increase in frequency and costs due to the deterioration in equipment without a continuously evolving approach to the maintenance.
				3	Data not available to be captured	Maintenance activities will periodically increase in frequency and costs due to the deterioration in equipment without a continuously evolving approach to the maintenance.

System	Newcom FMS	System No	NFM_FMS_SE_00	Facilitator	F.O.	Date	2012/03/07	Sheet No	7
Sub-System	Newcom Management System	Sub System No	NFM_FMS_SE_02	Auditor	N.O.	Date	2012/03/08	of	

Information Reference			Consequence Evaluation				H1	H2	H3	Default Action			PROPOSED TASK	INITIAL INTERVAL	CAN BE DONE BY
							S1	S2	S3						
F	FF	FM	H	S	E	O	O1	O2	O3	H4	H5	S4			
							N1	N2	N3						
1	A	1	N	N	N	Y	Y						See Sheet 6 on DMS proposed tasks on the DMS system	Sheet 6	Sheet 6
1	A	2	N	N	N	Y	Y						Train operators & users of system in regular intervals. Provide training documentation which must include operational procedures	6 Months	Technician or Clerk
1	A	3	N	N	N	Y	Y						Train other staff as clerks & technicians to serve as backup when primary clerks & technicians are unavailable	6 Months	Technician or Clerk
1	B	1	N	N	N	Y	Y						See Sheet 6 on DMS proposed tasks on the DMS system	Sheet 6	Sheet 6
1	B	2	N	N	N	Y	Y						Train operators & users of system in regular intervals. Provide training documentation which must include operational procedures	6 Months	Technician or Clerk
1	B	3	N	N	N	Y	Y						Train other staff as clerks & technicians to serve as backup when primary clerks & technicians are unavailable	6 Months	Technician or Clerk
1	C	1	N	N	N	Y	Y						See Sheet 6 on DMS proposed tasks on the DMS system	Sheet 6	Sheet 6
2	A	1	N	N	N	Y	N	Y					Review maintenance operations to determine improvements & train staff on improvements	3 Months	System Engineer

2	A	2	N	N	N	Y	N	Y					Review resource usage of maintenance operations as well as expenditure versus income. Plan with & train staff with improvements	3 Months	System Engineer
2	A	3	N	N	N	Y	Y						See Sheet 5 on proposed tasks for failures on system equipment	Sheet 6	Sheet 6
2	A	4	N	N	N	Y	Y						Create, implement & improve maintenance work schedule. Include all relevant stakeholders	3 Months	System Engineer, Technician, Operator
2	B	1	N	N	N	Y	N	Y					Review maintenance operations to determine improvements & train staff on improvements	3 Months	System Engineer
2	B	2	N	N	N	Y	N	Y					Review resource usage of maintenance operations as well as expenditure versus income. Plan with & train staff with improvements	3 Months	System Engineer
2	B	3	N	N	N	Y	Y						See Sheet 5 on proposed tasks for failures on system equipment	Sheet 6	Sheet 6
2	B	4	N	N	N	N	N	Y					Develop of proper maintenance strategy and allocate resources. Monitor operations and improve on short comings.	Start-Up, 3 Month & 1 year reviews	Newcom company
3	A	1	N	N	N	N	Y						Develop & implement a maintenance strategy which makes provision for continuous improvements to be implemented. Create a company culture of continuous improvement	All the time	Newcom company

3	A	2	N	N	N	Y	N	Y					Review resource usage of maintenance operations as well as expenditure versus income. Plan with & train staff with improvements	3 Months	System Engineer
3	A	3	N	N	N	Y	N	Y					Review maintenance operations to determine improvements & train staff on improvements	3 Months	System Engineer
3	B	1	N	N	N	Y	N	Y					Review resource usage of maintenance operations as well as expenditure versus income. Plan with & train staff with improvements	3 Months	System Engineer
3	B	2	N	N	N	Y	Y						Create & implement a proper data capture procedure specifying the capturing, storage and back functions.	Yearly	SW & System Engineer
3	B	3	N	N	N	Y	Y						Create data capture system (forms, questionnaires, etc.) to allow data to be effectively captured in order to improve maintenance	Monthly	Newcom company

System: Newcom FMS	System No: NFM_FMS_SE_00	Facilitator: F. Oosthuizen	Date 2012/02/13 Sheet No 4
Sub-System: Client System	Sub System No: NFM_FMS_SE_04	Auditor: D van Huyssteen	Date 2012/02/19 of
Function	**Functional Failure**	**Failure Mode**	**Failure Effect**

	Function		Functional Failure		Failure Mode	Failure Effect
1	To send correct reports to clients every week and every month	A	Reports are incorrect	1	Incompetent personnel performing the function	Reports will be of poor quality and not satisfy the needs of the client. Downtime 1 week
				2	DMS failure - No or Partial data available	See Sheet 2 for DMS analysis
				3	No contact details of client captured	Unable to communicate and correspond with client. Unable to send and obtain any information from client. Downtime 1 day
		B	Reports are not sent	1	DMS failure - No or Partial data available	See Sheet 2 for DMS analysis
				2	No resources available	Unable to provide clients with optimal services and provide clients with poor or no services. Downtime 1 day
				3	No contact details of client captured	Unable to communicate and correspond with client. Unable to send and obtain any information from client. Downtime 1 day
				4	Incompetent personnel performing the function	Reports will not be sent to the client and the client will have no data of his/her fluid usages. Downtime 1 week
		C	Reports are not sent on time	1	DMS failure - No or Partial data available	See Sheet 2 for DMS analysis
				2	Too little resources available	Unable to communicate and correspond with client. Unable to send and obtain any information from client. Downtime 1 day
				3	No contact details of client captured	Unable to communicate and correspond with client. Unable to send and obtain any information from client. Downtime 1 day
				4	Incompetent personnel performing the function	Reports will not be sent on time to the client and the client will obtain data on his/her fluid usages too late. Downtime 1 week
		D	DMS Failure	1	DMS failure - No or Partial data available	See Sheet 2 for DMS analysis
2	To contact clients at least once a month to discuss the system feedback and determine any possible failures	A	Clients are not contacted	1	Incompetent personnel performing the function	No communication with the client will increase maintenance costs as there will be no idea what the current status of the equipment on-site is and therefore unnecessary resources will be spent.

						Downtime 1 day
				2	Too little resources available	Unable to communicate and correspond with client. Unable to send and obtain any information from client. Downtime 1 day
				3	No contact details of client captured	Unable to communicate and correspond with client. Unable to send and obtain any information from client. Downtime 1 day
				4	No fixed procedure to follow to contact clients and obtain the proper information	Poor information & information quality will be gathered thereby increasing the maintenance tasks because of the lack of knowledge of what the current status of the field equipment really is. Downtime 1 day.
		B	Clients are not contacted once a month	1	Incompetent personnel performing the function	Poor communication with the client will increase maintenance costs as there will be no idea what the current status of the equipment on-site is and therefore unnecessary resources will be spent. Downtime 1 day
				2	Too little resources available	Unable to communicate and correspond with client. Unable to send and obtain any information from client. Downtime 1 day
				3	No contact details of client captured	Unable to communicate and correspond with client. Unable to send and obtain any information from client. Downtime 1 day
				4	No fixed procedure to follow to contact clients and obtain the proper information	Poor information & information quality will be gathered thereby increasing the maintenance tasks because of the lack of knowledge of what the current status of the field equipment really is. Downtime 1 day.
		C	Feedback is not obtained from clients	1	Incompetent personnel performing the function	When no feedback is obtained and given to clients, they become frustrated. Also, due to the lack of knowledge on the client system, maintenance costs increases. Downtime 1 day
				2	Too little resources available	Unable to communicate and correspond with client. Unable to send and obtain any information from client. Downtime 1 day
				3	No contact details of client captured	Unable to communicate and correspond with client. Unable to send and obtain any information from client. Downtime 1 day
				4	No fixed procedure to follow to contact clients and obtain the proper information	Poor information & information quality will be gathered thereby increasing the maintenance tasks because of the lack of

					knowledge of what the current status of the field equipment really is. Downtime 1 day.
3	To continuously educate clients on the system to perform basic system check and maintenance tasks	A	Clients are not educated or trained on the system	1	Incompetent personnel performing the function	Clients do not take ownership of the "black-box" system and therefore maintenance costs of Newcom are increased due to the little to no support from the client. Downtime 1 week
				2	No fixed training procedure or training & system documentation available	Poor information & information quality will be gathered thereby increasing the maintenance tasks because of the lack of knowledge of what the current status of the field equipment really is. Downtime 1 day.
				3	Too little resources available	Unable to communicate and correspond with client. Unable to send and obtain any information from client. Downtime 1 day
		B	Poor training is provided	1	Incompetent personnel performing the function	Clients do not take ownership of the "black-box" system and therefore maintenance costs of Newcom are increased due to the little to no support from the client. Downtime 1 week
				2	No fixed training procedure or training & system documentation available	Poor information & information quality will be gathered thereby increasing the maintenance tasks because of the lack of knowledge of what the current status of the field equipment really is. Downtime 1 day.
				3	Too little resources available	Unable to communicate and correspond with client. Unable to send and obtain any information from client. Downtime 1 day

System	Newcom FMS	System No	NFM_FMS_SE_00	Facilitator	F.O.	Date	2012/03/07	Sheet No	8
Sub-System	Client System	Sub System No	NFM_FMS_SE_02	Auditor	N.O.	Date	2012/03/08	of	8

Information Reference			Consequence Evaluation				H1	H2	H3	Default Action			PROPOSED TASK	INITIAL INTERVAL	CAN BE DONE BY
							S1	S2	S3						
F	FF	FM	H	S	E	O	O1	O2	O3	H4	H5	S4			
							N1	N2	N3						
1	A	1	N	N	N	Y	Y						Regular training and feedback of personnel on training effectiveness.	Quarterly	Systems Engineer
1	A	2	N	N	N	Y	Y						See Sheet 6 on DMS proposed tasks on the DMS system	Sheet 6	Sheet 6
1	A	3	N	N	N	Y	N	N	Y				Obtain contact details from client	Occurrence	Data Clerk
1	B	1	N	N	N	Y	Y						See Sheet 6 on DMS proposed tasks on the DMS system	Sheet 6	Sheet 6
1	B	2	N	N	N	Y	N	N	Y				Investigate resource shortage and resolve problem with appropriate action.	Occurrence	System Engineer
1	B	3	N	N	N	Y	N	N	Y				Obtain contact details from client	Occurrence	Data Clerk
1	B	4	N	N	N	Y	Y						Regular training and feedback of personnel on training effectiveness.	Quarterly	Systems Engineer
1	C	1	N	N	N	Y	Y						See Sheet 6 on DMS proposed tasks on the DMS system	Sheet 6	Sheet 6

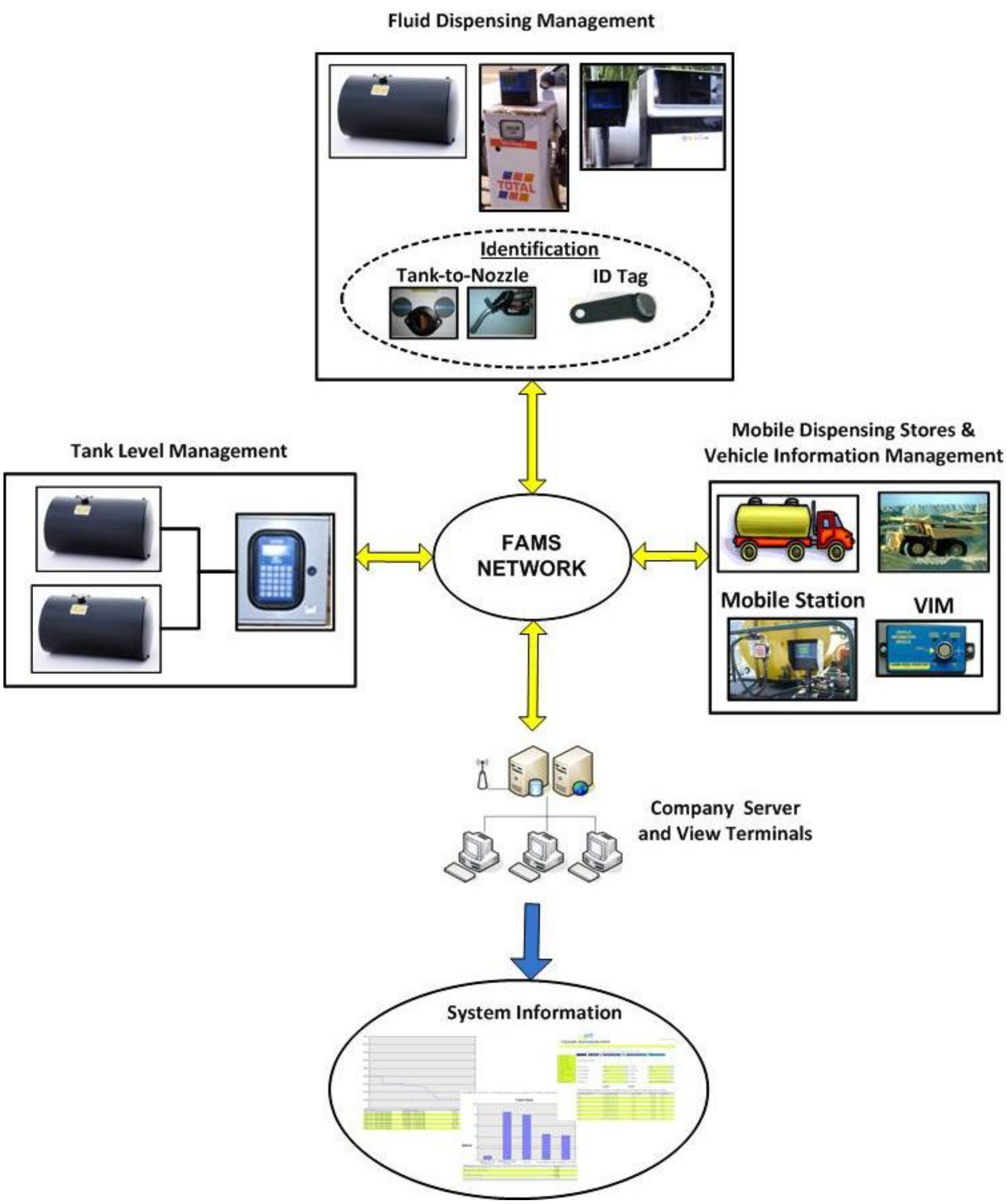
1	C	2	N	N	N	Y	N	N	Y				Investigate resource shortage and resolve problem with appropriate action.	Occurrence	System Engineer
1	C	3	N	N	N	Y	N	N	Y				Obtain contact details from client	Occurrence	Data Clerk
1	C	4	N	N	N	Y	Y						Regular training and feedback of personnel on training effectiveness.	Quarterly	Systems Engineer
1	D	1	N	N	N	Y	Y						See Sheet 6 on DMS proposed tasks on the DMS system	Sheet 6	Sheet 6
2	A	1	N	N	N	Y	Y						Regular training and feedback of personnel on training effectiveness.	Quarterly	Systems Engineer
2	A	2	N	N	N	Y	N	N	Y				Investigate resource shortage and resolve problem with appropriate action.	Occurrence	System Engineer
2	A	3	N	N	N	Y	N	N	Y				Obtain contact details from client	Occurrence	Data Clerk
2	A	4	N	N	N	Y	N	N	Y				Create standard procedure and implement.	Occurrence	Data Clerk Supervisor

2	B	1	N	N	N	Y	Y						Regular training and feedback of personnel on training effectiveness.	Quarterly	Systems Engineer
2	B	2	N	N	N	Y	N	N	Y				Investigate resource shortage and resolve problem with appropriate action.	Occurrence	System Engineer
2	B	3	N	N	N	Y	N	N	Y				Obtain contact details from client	Occurrence	Data Clerk
2	B	4	N	N	N	Y	N	N	Y				Create standard procedure and implement.	Occurrence	Data Clerk Supervisor
2	C	1	N	N	N	Y	Y						Regular training and feedback of personnel on training effectiveness.	Quarterly	Systems Engineer
2	C	2	N	N	N	Y	N	N	Y				Investigate resource shortage and resolve problem with appropriate action.	Occurrence	System Engineer
2	C	3	N	N	N	Y	N	N	Y				Obtain contact details from client	Occurrence	Data Clerk
2	C	4	N	N	N	Y	N	N	Y				Create standard procedure and implement.	Occurrence	Data Clerk Supervisor

3	A	1	N	N	N	Y	Y						Regular training and feedback of personnel on training effectiveness.	Quarterly	Systems Engineer
3	A	2	N	N	N	Y	N	N	Y				Create standard procedure and implement.	Occurrence	Data Clerk Supervisor
3	A	3	N	N	N	Y	N	N	Y				Investigate resource shortage and resolve problem with appropriate action.	Occurrence	System Engineer
3	B	1	N	N	N	Y	Y						Regular training and feedback of personnel on training effectiveness.	Quarterly	Systems Engineer
3	B	2	N	N	N	Y	N	N	Y				Create standard procedure and implement.	Occurrence	Data Clerk Supervisor
3	B	3	N	N	N	Y	N	N	Y				Investigate resource shortage and resolve problem with appropriate action.	Occurrence	System Engineer

APPENDIX B: FMS OVERVIEW

The Fluid Management Solution or FMS solution is the system used by Newcom to render a complete fluid management solution and consists of different system components as illustrated below. The component functionality will be discussed briefly:



Level Management System (LMS)

This system element has everything to do with managing fluids stored in bulk storage tanks. Applications can range from single tank installations to vast remote tank farms. The LMS includes:

- Automatically & electronically capture tank level readings at scheduled intervals
- Any amount of tanks, any size tanks and any product can be managed
- All tank data is communicated to the central data management software
- Alarms and Exception Reports created for fault-conditions according to client needs
- 24/7 Reports available on all current and historical tank level data
- Real Time tank levels via management platform interface & local LMS controller display
- Reports on tank level behavior over customized time periods
- Product Re-Order alarms can be configured to a user defined tank level

Fluid Dispensing Management (FDM)

This system element has to do with the management of fluid - fuel or lubricants - dispensed. The module includes the following:

- Manages the dispensing of all fluids to any and all personnel, vehicles & equipment
- FDM controls pump - No transaction will be started without the necessary authorization
- FDM can manage single product dispensing points and multi-product dispensing points
- FDM solutions can be installed on fixed or mobile dispensing stores
- FDM communicates wired or wirelessly to Data Management Software
- FDM Equipment is very robust and was designed to operate in harsh conditions
- FDM interface provides audiovisual feedback on actions to simplify operations
- Multiple Identification & Verification of methodologies or configurations
- User definable dispensing volumes

- Time & Date stamp transactions as well as person, place, volume, product and reason.

Data Management Software (DMS)

The DMS system elements provides the central platform from where all data can be viewed, analysed and exported to another platform or software system. The DMS includes:

- DMS is available 24/7 via an internet or relevant network connection
- Client data is Username and Password protected – Different levels can be configured
- Various standard and customized reports available
    - **Specific Product Usage Overview** – Usage information on specific product
    - **Specific Vehicle Usage –** Usage of a Specific Vehicle
    - **Transaction Type** – If have different types of transactions
    - **Cost Centers** – Create own Costs Centers; Usage on Cost Centers
    - **Fuel Usage –** Fuel Usage of Group/Cost Centre/Vehicle/etc.
    - **Store Usage –** Usage of a dispensing point i.e. Specific Pump Station
    - **Allocations** – Reasons for dispensing. Reports on usage per Allocation reason
    - **Stock Level Reports –** Real time tank dips, trend tank level history, re-order levels.
    - **Statistics Reports –** Usage and production Statistics on Vehicles/Equipment
    - **Exception Reports** – Flagged users on over-usage or poor-consumption

Support & Training

Newcom can provide the following services as part of the fuel management solution to ensure that a client obtains a real value adding system to his organisation:

- Continuous training to all client personnel utilizing and operating the FMS
- Data inspection and consultations services on client FMS data from Newcom
- On-site repair and maintenance of all FMS equipment performed by Newcom
- Repair & Replacement agreement will always be available on FMS
- Telephonic and remote support services are always available

Newcom will also continuously provide training on-site and off-site for all client personnel. Special training sessions can be provided upon client request at no additional charges.

A standard set of documentation on the system operation can also be supplied to a client in a hardcopy and a soft copy format to ensure sustainable operations by operators and improve user friendliness. Instructions sets can be mounted against dispensing stations to enable effective operations.

APPENDIX C: CORRECTIVE STRATEGY OUTLINE

The current maintenance strategy deployed by Newcom was not formally developed, but it evolved over time. What follows is a basic idea of how the maintenance was managed.

Newcom Fluid Management Corrective Maintenance Strategy Overview:

i. Inspect data on the data management system to identify faults or potential faults
ii. Phone clients and identify faults or potential faults
iii. If fault is identified, schedule corrective tasks to be completed
iv. Schedule a maintenance site visit to all clients within a 50km-100km radius from the client with a fault.
v. Prepare all the spare equipment required for all possible scenarios
vi. Ensure the system support engineer is available via telephone on the day maintenance work is being done – enable telephonic support
vii. If the frequency of faults of a client's equipment rises above 1 fault per 8x week cycle due to equipment faults, the equipment should be replaced
viii. If traveling more than 300km to a client, than technician must spend the night

APPENDIX D: NEWCOM INTERVIEWS

The section will provide a quick summary on the notes of the various interviews with Newcom.

Newcom Interview 1: 5th February 2011 – Newcom Vdpk Offices

De la Rey van Huyssteen – Company Founder Operations Directors

Nico Oosthuizen – System Engineer

- Newcom - company develop electronic products & systems for RSA and African markets.
- Specialize in fuel and fluid management systems and additional equipment around the general fuel industry
- Rental business model primary business model
- No formal maintenance strategy – reactive maintenance approach
- No data on current system availability – desire levels of 0.9 and higher
- Possible reduce current expenditure by 20% if possible
- FMS system composition (Mr. Oosthuizen)
- Proper maintenance plan – less expenditure on unplanned tasks. Also, if 1 x client is lost, it can equate to huge financial losses.
- All clients business operations are directly related to the successful availability of fuels and lubricants

Newcom Interview 2: 9th October 2011 – Newcom Potchefstroom Offices

De la Rey van Huyssteen – Company Founder Operations Directors

Nico Oosthuizen – System Engineer

- Discuss RCM process
- Baseline data for RCM process – not formally available
- Request information from clients if possible, use historical baselines as specified by Newcom

Newcom Interview 3: 1st April 2012 – Newcom Vdpk Offices

De la Rey van Huyssteen – Company Founder Operations Directors

Nico Oosthuizen – System Engineer

- Discuss the feedback from the different maintenance strategy analysis
- Considered the advantages and disadvantages of each strategy and ran practical scenarios
- Based on the needs of Newcom, the RCM was selected as the most appropriate maintenance strategy to continue to research
- Data to be used in physical experiment was discussed – Available data was determined and estimated data was determined which would be used in experimental analysis