AN INVESTIGATION OF THE MAINTENANCE PROCESS OF COMMERCIAL VEHICLES IN THE DEPARTMENT OF DEFENCE

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DECLARATION

I, the undersigned hereby declare that the work contained in this document is my own work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature: ______________ Date: 20/04/2005

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Lastly and importantly, I thank God for the blessings of talent and virtues I needed to have to successfully complete this thesis. I thank Thee for the guidance and love bestowed upon me.

ABSTRACT

The purpose of this investigation was the development of a holistic solution to problems of high cost and long turn around times in the maintenance process of D-vehicles (commercial vehicles) in the Department of Defence (DOD).

The investigation was focussed on the technical functions of the process, but also explored direct interfaces with the process, namely the financial, procurement and transport sections. During the research phase, benchmarking was done at various Government Departments to enquire about best maintenance practices in a similar environment.

As a result of this investigation, an improved process has been designed based on modern maintenance practices. Results have shown that the implementation of the proposed solution would lead to a substantial improvement in the present state of affairs.

A representative group of Defence Force units were visited during the investigation. The DOD managed approximately 17 500 D-vehicles at the time of the investigation. Problems relating to the maintenance process started surfacing during the last few years after the change of policy, in that non-core functions in the DOD should be outsourced. These vehicles were subsequently not considered to be a core function.

The importance of this investigation was underlined by the enormous financial impact that the maintenance of this large commodity has on the Defence Force budget, and more importantly, the capability of ensuring a high ratio of availability of these vehicles as essential support equipment.

The completed report is currently being scrutinised by the responsible DOD authorities. A decision whether the recommendations of this study will be implemented or not, has unfortunately not yet been reached.

SAMEVATTING

Hierdie ondersoek het gelei tot die voorstel van 'n holistiese oplossing vir die instandhoudings proses van D-voertuie (kommersiële voertuie) in die Departement van Verdediging (DVV). Die Departement het gedurende die laaste paar jare groot frustrasies beleef met uitermatige lang omdraai tye in die instandhoudingsproses van hierdie voertuie.

Die ondersoek was hoofsaaklik gefokus op die tegniese gedeelte van die proses, alhoewel raakvlakke met ander funksies soos die finansiële, aanskaffings en voertuig administratiewe funksies ook ondersoek is. Verskeie Staatsdepartemente is ook ondersoek as deel van die navorsing, om meer kennis op te bou omtrent voertuig instandhouding in 'n soortgelyke omgewing.

Die analise van die ondersoek fase het 'n verbeterde prosesontwerp tot gevolg gehad, en belowe om noemenswaardige verbeteringe in die huidige praktyk teweeg te bring.

'n Verteenwoordigende groep DVV eenhede is besoek gedurende die ondersoek en dit is bepaal dat die Departement nagenoeg 17500 D-voertuie bestuur. Probleme was ondervind kort na die uitvoer van die instruksie dat nie-kern besigheids funksies uitgekontrakteer moes word. Aangesien D-voertuie as ondersteuningsuitrusting, eerder as 'n kernbesigheidsfunksie bestempel word, is die instandhouding daarvan uitgekontrakteer.

Die belangrikheid van hierdie ondersoek is onderstreep deur die omvangryke finansiële impak wat die instandhouding van hierdie kommoditeit gehad het op die Departement van Verdediging, asook die kritiese vermoë om 'n hoë beskikbaarheid van hierdie belangrike ondersteunings uitrusting te kan verskaf.

Hierdie verslag word tans deur die DVV owerhede bestudeer. Ongelukkig is daar nog geen besluit oor die implementering van die aanbevelings geneem nie.

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ABBREVIATIONS

AFB	Air Force Base
AFP	Air Force Publication
ASU	Air Servicing Unit
BEE	Black Economic Empowerment
CALMIS	Computer Aided Logistics Management Information System
C Fin	Chief of Finance
C Log	Chief of Logistics
COTS	Commercial of the Shelf
DESS	Directorate Engineering Support Services
DNL	Directorate Naval Logistics
DOD	Department of Defence
DODI(s)	Department of Defence Instruction(s)
DPSS	Directorate Product Systems Support
D-vehicles	Category Delta Vehicles - commercial
Eng	Engineering
FA	Financial Authority
FMN	Formation
FSE	Force Structure Element
GOC	General Officer Commanding
GSB	General Support Base
Ind	Industrial
LSF	Logistics Support Formation
Max	Maximum
Min	Minimum
MOD	Ministry of Defence
OSIS	Operational Support Information System
PDI(s)	Previously Disadvantaged Individual(s)
RCM	Reliability Centred Maintenance
SAAF	South African Air Force
SANDF	South African National Defence Force
SG	Surgeon General

SMME(s)	Small, Medium and Micro Enterprise(s)
SSTC	Sub Standard Tender Committee
SSO	Senior Staff Officer
TSU	Technical Service Unit
URS	User Requirement Statement

ACRONYMS

D-vehicle	Commercial off-the-shelf (COTS) vehicles for commercial and domestic transport needs [17, 38].
In-house maintenance	Own capability of maintaining vehicles.
Operational Availability (vehicle)	The percentage of time that a vehicle is available for intended use by the owner. The vehicle must be in such a condition that the vehicle will at least not have any predicted failure during the successful accomplishment of the required task.
Financial Authority	Financial Authority from authorised persons (the budget manager and budget holder of a unit) to spend Government funds.
Consensus	Collective opinion or concord; general agreement or accord. [Latin, from *consentire*, to agree]

1 INTRODUCTION AND LITERATURE STUDY

1.1 BACKGROUND

The Department of Defense (DOD) experiences excessive turn around times in the maintenance of D-vehicles (original off-the-shelf sedan vehicles). This leads to low productivity and tremendous frustration amongst employees dependent on transport for the execution of tasks.

Over the years, but particularly since 1995, the D-vehicle maintenance process has changed drastically. These changes were imposed as a result of a policy decision to outsource non-core functions [32, 33, and 35], in this case the repair of category-2 equipment (non-combat vehicles), which includes D-vehicles.

At the time of the study there were approximately 17 500 D-vehicles in the DOD. The operational availability of these vehicles at any given time was found to be poor and consequently efficiency and productivity were forfeited.

This investigation originated from the realization by Director Engineering Support Services (DESS) that problems are being experienced in the D-vehicle maintenance process, which was indicated by numerous complaints. It became clear that the problem extended to all Services; DESS requested that the problem be investigated and that a possible holistic solution be proposed.

The project briefing and formal letters of complaints [11 and 22] created a clear picture of the frustration, which users suffered with the current D-vehicle maintenance process in the DOD. It was evident that something needed to be done in order to improve this situation. According to the Public Finance Management Act [9 and 23-28], public and donor funds should be managed in an accountable, responsible and transparent manner. This fact emphasised that the management of this costly commodity should be regarded as extremely important.

The objective was thus to inform the Chief of Logistics in the DOD (C Log) of modern maintenance management techniques that could acceptably improve the turn-around-times of the maintenance of D-vehicles in the DOD. It was then required to recommend those techniques that are feasible for implementation in a non-profitable governmental organisation, such as the National Defence Force.

1.2 VEHICLE FLEET MAINTENANCE

Vehicle Fleet Maintenance was investigated to enlarge the knowledge regarding the problem. Modern maintenance management techniques described by various specialists [3, 4, 8, 12, 15 and 18], formed part of the technical perspective from which this maintenance project is conducted.

Some research indicated that few companies have a formal approach to preventive maintenance. Consultants are mostly used to provide training, facilitation, to collect and analyse data and to make recommendations regarding preventive maintenance tasks. The most important success factors were considered to be management involvement.

The use of information systems seemed to be an advantage, as it made the maintenance process much easier to manage. It ensures an effective maintenance system, which remarkably reduces maintenance costs. The use of computers further simplifies statistical analysis from which important management information could be obtained. Based on these advantages, computers have become a critical success factor in Modern Fleet Maintenance.

Vehicle failures have negative effects on the organisation. Depending on the impact of a failure on the organisation and the severity thereof, a decision needs to be made whether to prevent such a failure or to handle it on occurrence. The familiar Pareto Principle could be applied to aid in decision-making. It states according to Kolarik [15] that roughly 20% of the causes account for about 80% of the failures. If the vital few causes could thus be eliminated, many of the failures will be reduced.

One of the best maintenance approaches available is Reliability Centred Maintenance (RCM). The result of RCM is a maintenance plan for an organisation. RCM stratifies maintenance into design-out of failure modes, the prevention of failures or the correction thereof [3]. **Figure 1.1** illustrates these strategies.

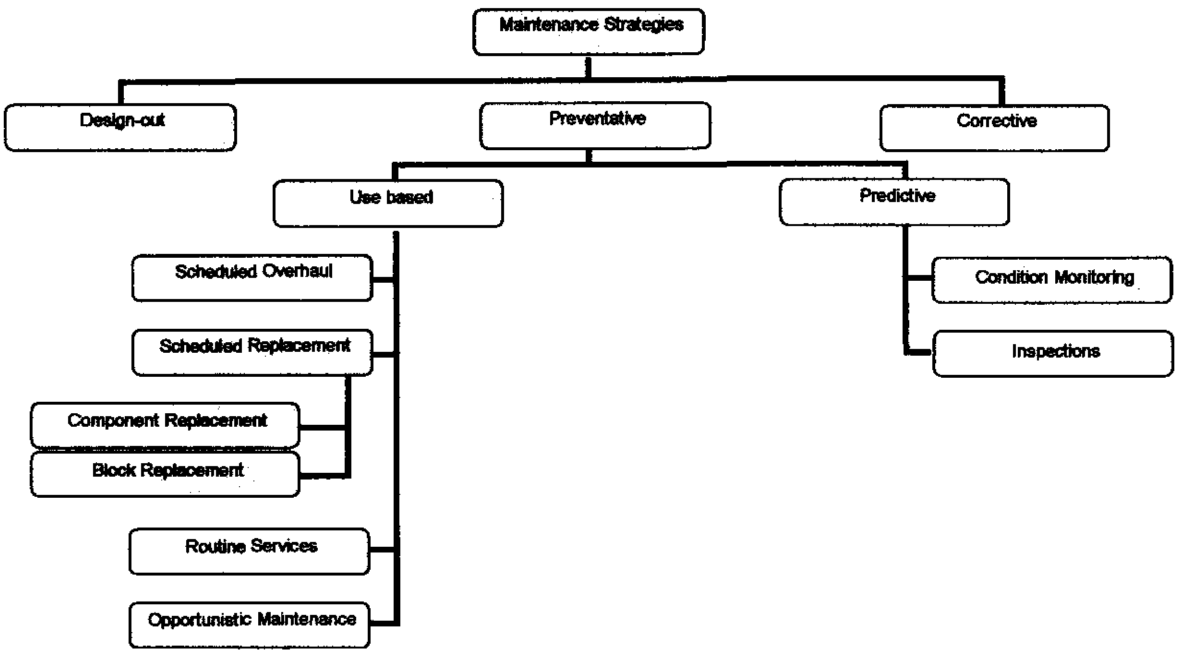

Figure 1.1: Maintenance Strategies

Further research was done on maintenance planning and management. The research was broken down into setting-up and the maintenance of a Maintenance Policy that steers the maintenance of the vehicles in a common determined direction. The Maintenance Policy, however, is a limited document that only serves as a guide to clarify, and not to describe in detail.

Maintenance Procedures followed the policy, to provide exact direction in the execution of different tasks. It ensures that the job is done in accordance with the vision of the Maintenance Policy. Maintenance objectives were determined on which the procedures and processes should focus to ensure an effective maintenance plan. The overall objective of maintenance according to Coetzee [3], is to support the production process with adequate levels of availability, reliability, operability and safety at an acceptable cost.

In order to find the optimal solution to any problem, one needs to find a point of balance at which the interaction of all parameters gives the most feasible solution. Maintenance Measurement thus forms an integral part of the process. It gives feedback on the performance of the system in order to adjust strategies for the desired or improved output. **Figure 1.2** illustrates the closed loop feedback system.

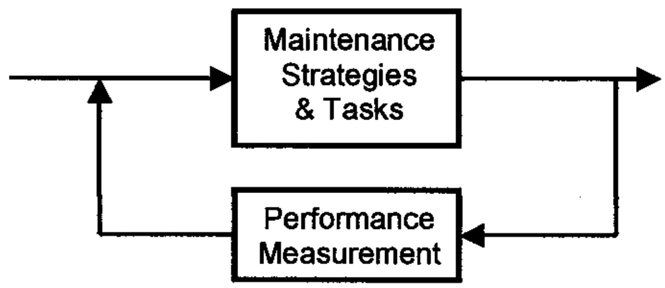

Figure 1.2: Maintenance Feedback System

Modern Maintenance is focussed on the prevention of failures and reduction in maintenance costs. This is achieved by setting up a Maintenance Policy supported by maintenance procedures that is based on certain reachable maintenance objectives. In order for this process to be improved and to function optimally, Maintenance Performance Measurement is done and fed back as input. This approach of maintenance management ensures an effective and modern maintenance process.

Compared with the present maintenance approach of the DOD, a preventive approach would ensure fewer failures and increase the operational availability of vehicles by reducing unexpected breakdowns. This approach would have a considerable impact on maintenance management in the DOD, since all maintenance has to be planned and scheduled.

In conclusion of modern fleet maintenance techniques, RCM has proved to be a very successful maintenance philosophy in terms of productivity, availability and cost. RCM involves most of the success factors mentioned in this paragraph through statistical analysis by means of computer, maintenance and management information ensuring better management involvement and a holistic paradigm shift towards prevention rather than correction.

1.3 VEHICLE COST LIFE-CYCLE

The cost of a vehicle is a very important consideration in the maintenance plan of an organisation. At what point does a particular vehicle become a liability? When does the maintenance of a vehicle cost more than what it is worth to the organisation?

Many studies have been done in this area and attempts have been made to calculate the optimal point disposal. According to Coetzee [3] the probability of failure of an item against time follows a Bathtub Curve as illustrated in **Figure 1.3**. It is clear that in due time, failures would become more frequent; hence the maintenance and costs increase.

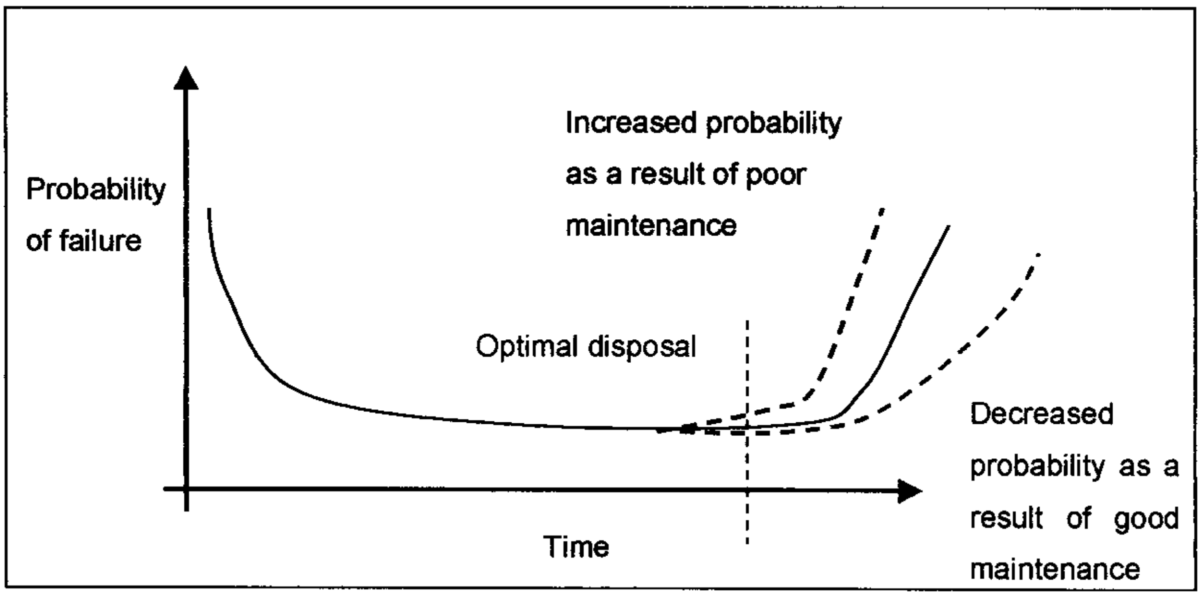

Figure 1.3: Bathtub Curve

The Bathtub Curve is dependent on the degree of maintenance of a particular item. Note in **Figure 1.3** that the probability of failure increases with less maintenance and decreases with proper maintenance. Calculating the optimal disposal point in this regard becomes somewhat complex, as it changes as the degree of maintenance changes, which cannot be predicted unless proper maintenance planning is done.

Since most new vehicles are sold with a maintenance plan, various South African motor manufacturers (Nissan - Hansie Roodt Vereeniging, Volkswagen - Dutton Motors Sasolburg, and Boulevard Delta Vanderbijlpark) could not give a pertinent best disposal point for vehicles. Vehicles are sold according to a national value of the vehicle based on its age and distance travelled. If the vehicle is well maintained, the possibility for a higher resale value is assured.

This establishes a philosophy on maintenance that costs could be decreased and the value of the vehicle increased with good maintenance. The optimal disposal point is largely dependent on the degree of maintenance and therefore has become a personal preference.

1.4 RELATIONSHIP TO OTHER ACTIVITIES

It was important to firstly understand the extent of the project before the investigation could commence. Other related projects were identified and had to be considered throughout the project, so that duplication and other consequences could be avoided.

The DOD D-vehicle fleet management has been investigated and analysed since 2002 to evaluate and redesign the entire DOD transport management system. A detailed investigation was also done at the TSU to improve their effectiveness. This project entailed the investigation of the D-vehicle Maintenance Process that forms part of the Fleet Management System. The investigation however, was done on this process level throughout the DOD. **Figure 1.4** illustrates the relationship to other investigations.

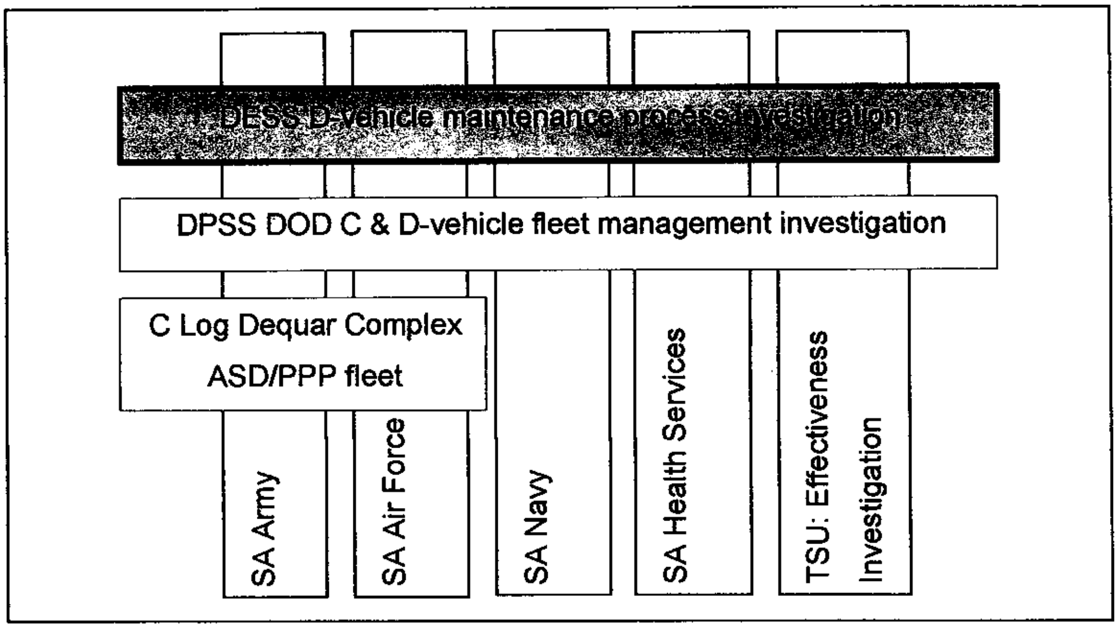

Figure 1.4: Relationship of Project to Other Investigations

Although the primary focus was on the maintenance process, it was important to maintain a holistic view of the system, since various other factors and functions influence the maintenance process. These factors and functions include the procurement, finance, transport, technical, motor vehicle accident, damage and loss sections. Since these sections form part of both the maintenance process and of fleet management, a clear boundary had to be considered throughout the investigation.

In the DOD D-vehicle Product System Management Investigation, a top-down approach is followed, where as a bottom-up approach was followed in the D-vehicle Maintenance Process investigation. The bottom-up approach enabled the investigation to consider, and more practically, experience the problems and frustration of the people involved in the maintenance process. The organisational levels for D-vehicles can be seen in **figure 1.5**.

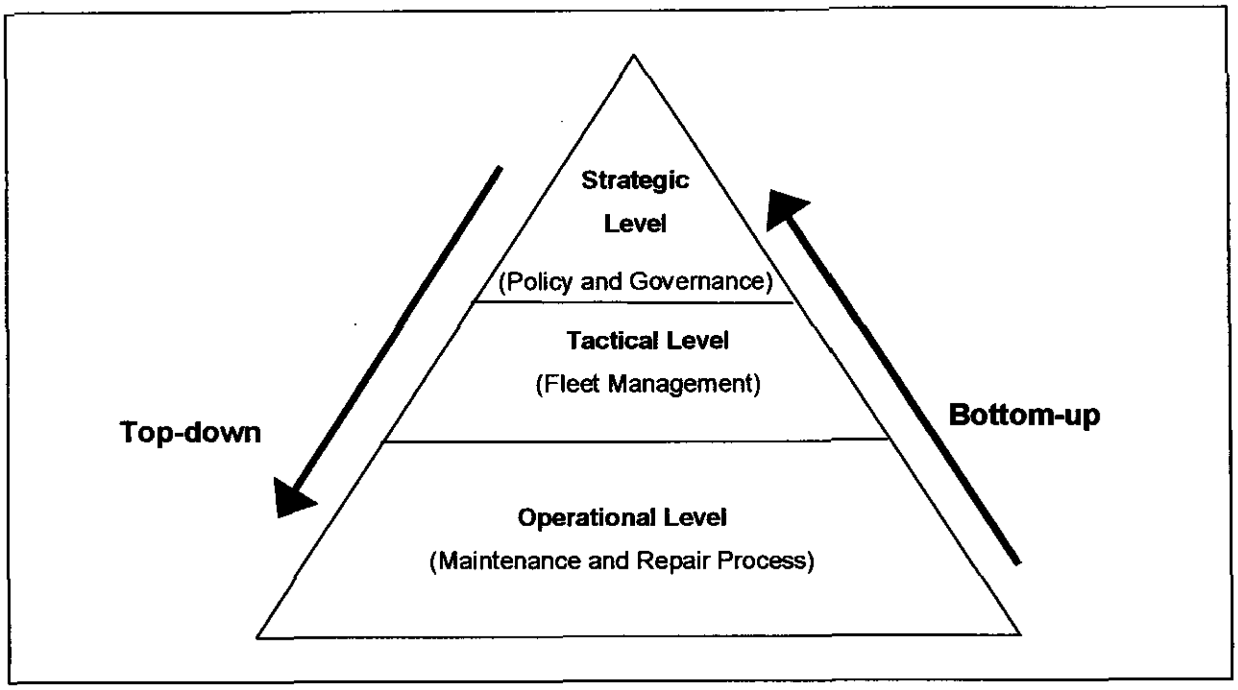

Figure 1.5: Organisational Levels for D-vehicles

1.5 BENCHMARKING

It was important to consider the fact that the DOD is a governmental body. This implied certain constraining factors in terms of finance, politics and governing bodies outside the Defence Force that have binding policies to abide by. The DOD working environment is explicitly militaristic, which alone has other constraining factors on the solution framework. In reflection on the latter, research was conducted at the following organisations: South African Police Service (SAPS) Silverton, City of Tshwane Metropolitan Municipality (METRO) and Department of Water Affairs and Forestry (DWAF).

1.5.1 South African Police Service

The Police Garage at Silverton Police Station was visited. The SAPS is also a government body regulated by mostly the same policies as the DOD. Several interesting maintenance and business practices were identified.

The Silverton Police Garage is managed as a business. Although it is a non-profitable organisation, it measures its profit margins and important financial ratios to ensure survival. A production bonus scheme is in place to reward outstanding performance and dedication. This style of management enables the Garage to be optimally productive and improve continuously.

Owing to the fact that the Garage is also run as a continuous and on-the-job training centre, the technical personnel are highly capable and qualified to perform maintenance and repair on all types of vehicles, if economically feasible. They undergo training at various agents to be able to maintain even the most technologically advanced vehicles in the fleet.

The business processes are customer focused and therefore ensure a quick response and service time. Vehicles are only outsourced when the Garage does not have the capacity to maintain the amount of vehicles on request, or when equipment is not available due to economical feasibility.

Making use of an on-site spares contractor (Auto Zone Pty Ltd) enables the Garage to perform normal scheduled services within a waiting time of two to three hours. SAPS has made a storeroom available for the contractor in the Garage. The contractor is obliged under the contract to supply parts being kept in stock at all its branches, within 48 hours. If the parts are not kept in stock, the supplier has three days to supply the specific part.

An interesting and useful procedure, which portrays the good fleet management of the clients (Police stations), is that all clients allow for pre-approved Financial Authority (FA) (R10 000 for mechanical repairs and R20 000 for panel beating). It is evident that the client performs some actions in advance before the actual repairing or servicing starts, which could only be a result of proper planning.

More proof of good fleet management, is the implementation of a proper phase-out policy. The vehicles' have a high utilisation of 40 000 km p.a. They also implemented a policy of 80% disposal. This means that when 80% of the vehicle's initial cost is spent on maintenance, the vehicle is disposed of. This procedure requires careful monitoring and record keeping of maintenance history, which is accurately done.

In the SA National Defence Force, every soldier has a responsibility to partake in parades, regimental duties, deployment, etc. This does not occur in the Police Service, since the technical personnel are only dedicated for functional utilisation, and have no other responsibilities.

1.5.2 City of Tshwane Metropolitan Municipality

The visit to the Tshwane Metropolitan Municipality revealed some interesting facts. Similar to the SAPS, they repair all the vehicles themselves. Repair and servicing are only outsourced to civilian companies when the workload is excessive or when they do not have the necessary specialised equipment.

METRO also makes use of an on-site single-source spares contract (in the workshop). The availability of spares in the workshop drastically improves the process in terms of parts management and procurement. The normal parts management and procurement process, where all parts are assigned certain equipment numbers according to accountability classes, is entirely eliminated.

Maintenance contracts are awarded for three years. Experience has shown that this is the most effective period for awarding a contract.

They work on a system where FA delegations are based on a percentage of the person with the highest authority. If the General Manager has financial authority for example, R100 000.00, then a Workshop Manager for example would have a delegation of 50% thereof, hence R50 000.00. This delegation ensures that certain types of work could still be performed in the absence of the General Manager.

1.5.3 Department of Water Affairs and Forestry

The following best practises were identified during the visit to the Department of Water affairs and Forestry (DWAF).

DWAF outsource their normal use of vehicles to a vehicle leasing company. When involved in projects that require vehicles at the construction sites, vehicles are bought and managed by DWAF as part of project equipment. These vehicles are then managed and maintained for the duration of the project. On completion of the project, these vehicles are disposed of.

For the maintenance of the construction vehicles, DWAF makes use of contractors. The vehicles are outsourced to contract holders only. The contracts are renewed every two years.

There is also a Fleet Card System where each vehicle has its own card for urgent repairs and services to a vehicle, or for fuel. These cards have limits and certain levels of authority. For example, a sedan type vehicle may make use of, R1000.00 for urgent repairs, whereas a bigger vehicle may use R2500.00 for repairs before authority has to be given to spend more than the specified amount.

1.6 PROBLEMS REPORTED IN OFFICIAL DOCUMENTATION

Other literature sources also gave insight into the problem as well as some solutions. Problems were identified through official documents [22] addressed to relevant directors in the DOD. This gave an initial steer towards the approach of the investigation.

These policies [1, 32, 33 and 35] were merely judicial guidelines rather than useful modern vehicle maintenance techniques. However the policies are fairly rigid and changes could be proposed to improve the process.

The following endless list of problems was identified from official documents addressed to the higher levels of authority concerned with the support of D-vehicles.

1.6.1 Maintenance Process

The following list of problems was received through formal complaints regarding the maintenance process:

- The maintenance and repair process of the DOD is *ineffective*.

- The Technical community experiences *frustration* with the maintenance process of military vehicles as a result of an ineffective and time-consuming process.

- The various Department of Defence Instructions (DODIs) applicable to all Arms of Services are contradicting, unclear and not implemented properly. This creates *confusion and inconsistency* within the process.

- The *absence of an authoritative institution* (Product System Management for vehicles in the DOD) on level two/three (tactical level, refer to **Figure 1.5**) to direct, support and enforce maintenance principles to all Services in the Pretoria region, results in inconsistent actions.

- Absence of client agreement (where the DOD is the client of suppliers) regarding the execution principles and product requirements, result in *sub-standard work*.

- Absence of a D-vehicle maintenance concept and *phase-out plan* creates fruitless efforts.

- Technical Service Unit (TSU) members are not competent and to some extent not adequate to execute their task. Insufficient effort is put into teaching or training technical personnel on the relevant technical policies and procedures, resulting in *ignorance*.

- Indifferent attitude of users and maintenance community (internal and external) towards an *ageing fleet* of vehicles requiring consistent maintenance to keep them roadworthy.

- *Scheduled repairs* (a transport responsibility whereby vehicles are inspected and attended to at specific intervals) are not planned for at most units.

- Spares are purchased and supplied to vehicle maintenance companies through the transport and financial system for the repair of vehicles. The *accounting* of these spares and proof that the spares were actually fitted to vehicles can be questioned, because no technician was involved in the process certifying (in terms of Treasury Instructions) that work was done to standards.

- *Purchased materials/parts lost.*

- *Small, Medium and Micro Enterprises (SMMEs) and Previously Disadvantage Individuals* (PDIs), which should receive preference as part of the Government's upliftment strategy, do not always have the infrastructure to ensure quality of work, nor have sound administration and accounting systems, and cannot adequately guarantee workmanship of an acceptable standard.

- Stringent *checks and balances are required* to ensure accountability and transparency of these funds and have to be adhered to by all parties concerned, ensuring proper governance of public funds.

1.6.2 Financial Approval

The following list of problems was received regarding the financial approval of maintenance tasks.

- Validity of *quotations expires* before repair authority to purchase parts/spares is granted. This implies that companies are requested to update their quotations, knowing that it is only for SANDF administrative purposes, causing frustration and conflict.

- Turnaround times of six months and more are experienced due to obtaining repair authority through the *tender process* [10 and 14] for repairs.

- The Chief Director Accounting instructed on 28 May 2003 that no cash purchase exceeding R5000.00 per case or per person would be granted irrespective of rank [14]. According to personnel responsible for payment of maintenance tasks, this *petty cash amount is not feasible.*

- Only Chief of Finance (C Fin) can authorise repair of damaged vehicles [2 and 14], resulting in *delays in the process*.

- Various Services and Divisions have their own unique standing operating procedures when applying for *Financial Authorities* (FAs) or FA extensions. This creates an unnecessary delay in administration and additional costs to fax and copy documentation.

1.6.3 Procurement

The following list of problems was received regarding the procurement function within the maintenance process.

- An approved database is managed to give the public equal opportunity to tender for service to be rendered to the DOD. The suppliers' facilities may not be inspected nor may work standards be investigated before a complaint has been received. Consequently, there are *questionable suppliers* of parts and services on the database.

- Far too much time is spent on *administration* and the obtaining of *authority to repair vehicles*.

- The *Procurement Policy [10]* does not enhance the D-vehicle maintenance procedure.

2 RESEARCH METHODOLOGY

The object of this study was an investigation into the Maintenance Process of D-vehicles in the DOD and the need for a holistic solution. The research methodology is further explained below.

The research was divided into two phases as illustrated in **figure 2.1**. Firstly an assessment of the current maintenance process was done. This included a problem analysis, process analysis and a process evaluation.

After assessment of the current situation, the design phase followed. It included the identification of system improvement objectives, a requirement analysis, decision analysis and a final process design.

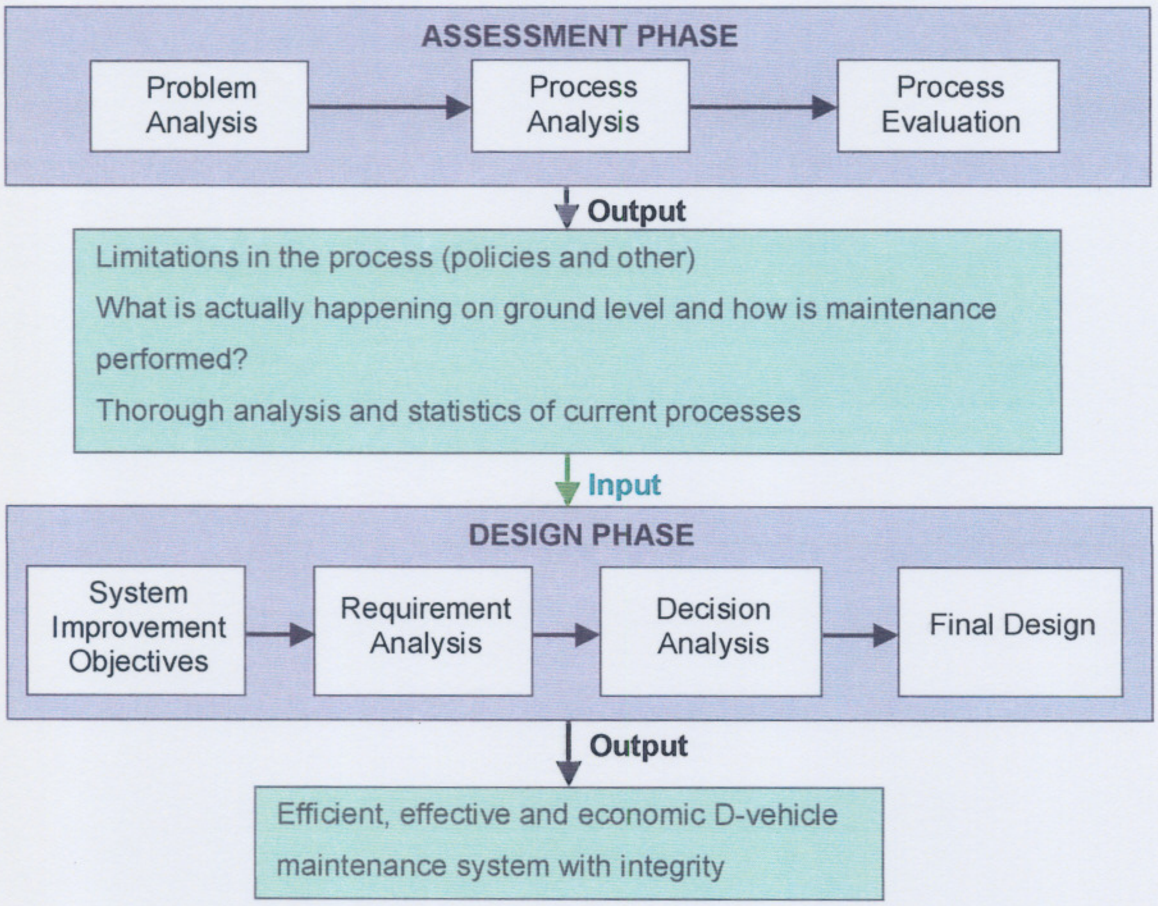

Figure 2.1: Research Methodology

2.1 ASSESSMENT PHASE

The first part of the requirement was to investigate the current maintenance process. Different Air Force, Army, Navy and Military Health Units were visited to investigate and evaluate the current D-vehicle Maintenance Process. The information obtained from these units was used to complete the assessment phase of the project. Most of the information during the investigation was obtained by discussions with important role players [39-58] in the process. **Table 2.1** shows the different units visited during the investigation.

Table 2.1: Investigation Visit Schedule

Unit	City
GSB MOD	Pretoria
SAMHS LWT	Pretoria
ASB Dequar Road	Pretoria
AFB Waterkloof	Pretoria
MDW (Snake Valley)	Pretoria
GSB Simonstown	Cape Town
ASB Youngsfield	Cape Town

2.1.1 Problem analysis

The problem analysis specifically focussed on the problems involved in different areas of the Maintenance Process. These problems are discussed below:

2.1.1.1 Introduction

During the investigation, the Maintenance Process of each unit was documented. Problems were identified at all levels in each of the Services that were investigated. Background information was obtained and an assessment was done on the current state of affairs. The results are to be used for the improvement and development of the maintenance process.

Commercial or domestic road transport in the SANDF is regarded as a non-core function, in other words, transport is not considered to be a major contributor towards achieving the vision of the different Services within the SANDF. According to policy [32 and 33], the maintenance and repair of these vehicles are to be outsourced. The DOD is therefore not structured to do in-house (own capability of maintaining D-vehicles) maintenance on these vehicles.

Appendix A shows a flow diagram of the prescribed process. This process is basically followed at the various units; however, certain unique processes occur at the various units because of different interpretations of the promulgated policies. Note the interaction of the different role-players throughout the process.

Role players can be seen as all the different functions involved in the maintenance of D-vehicles. This implies that not only a technical environment is involved in the process, but also procurement, finances, clients of the technical centre (internal units dependent on one repair authority), agents and suppliers of vehicle parts, services and repairs as well as governing bodies to authorise certain actions within the process. **Figure 2.2** shows the interaction between the different role players.

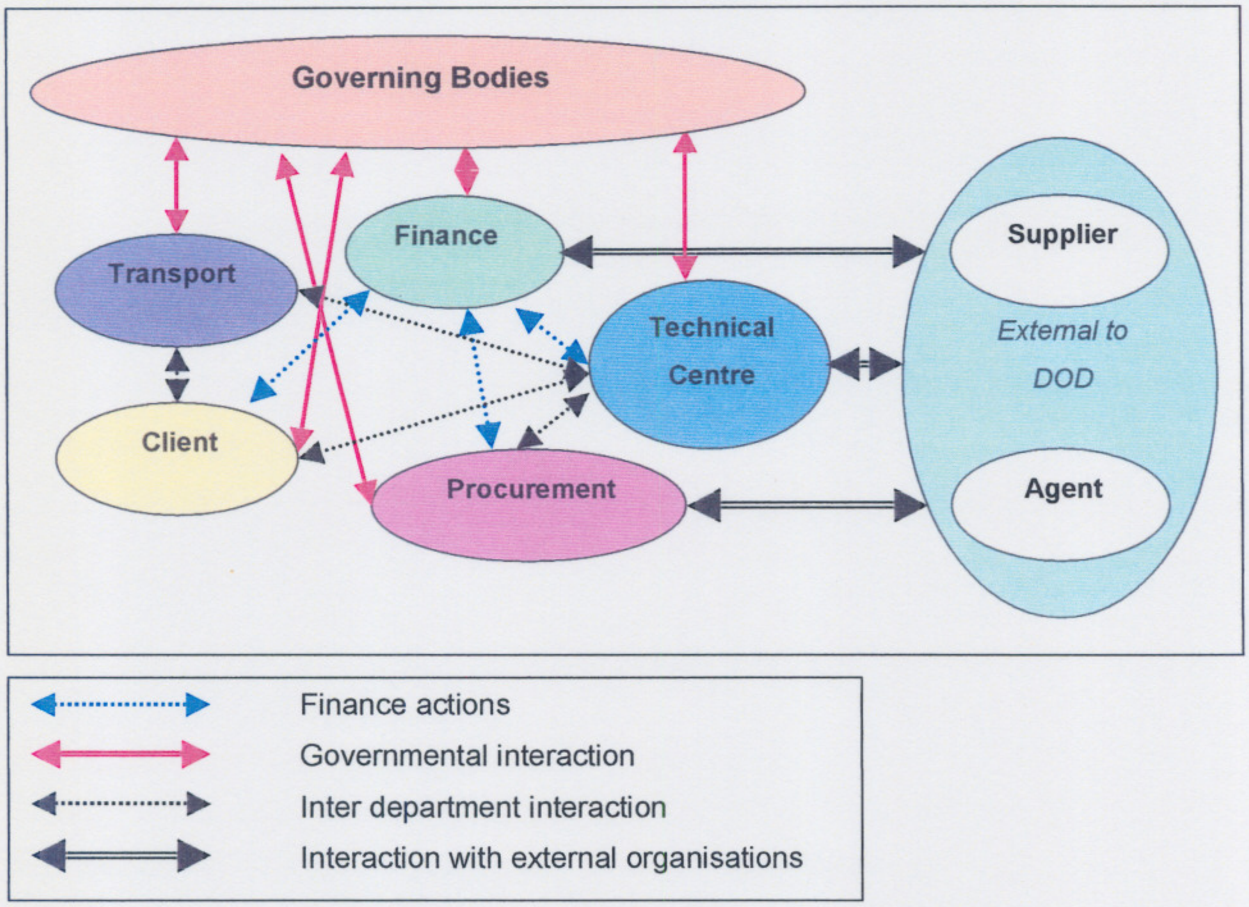

Figure 2.2: Interaction between Role Players in the Maintenance Process

The process starts when a request for a vehicle repair is submitted by the client (sections within a unit who has their own budget for vehicle maintenance) to the transport section. They ensure that the vehicle is not reserved during the time a vehicle has to undergo repair or service. This function is facilitated in the Operational Information Support System (OSIS) and the Computer Aided Logistics Information System (CALMIS), the computer programs of the different Services in the SANDF [20]. The transport section also keeps the history files of the vehicles up to date. A work request form (DD 1836) is submitted to the technical section, which then schedules a technical inspector to do an out-inspection task on the vehicle.

The inspector assesses the required maintenance or repair tasks to be done upon which three quotations are obtained from suppliers. The procurement section is responsible for obtaining quotes and keeping a database for different suppliers who all need to get an equal opportunity to do work for the government. A comparative list is compiled and the best quote is authorised. The Sub-Standard Tender Committee also verifies the process followed up to this point, before the process continues.

When a supplier has been identified, the client is notified and a request for funds to be made available to the technical centre or directly to the supplier is initiated. After financial authority is granted, the vehicle is taken in for repairs. The vehicle is repaired where after the technical inspector will conduct a full in-inspection (inspection after the vehicle is received back from the supplier) to ensure the requested tasks were satisfactorily performed on the vehicle.

All the relevant documentation accompanies the vehicle and it is delivered to the transport section. Upon completion of the relevant administration and the updating of the vehicle history file, the client is notified to collect the vehicle.

The process takes longer when a vehicle is damaged in an accident or by other means. In such a case, special authority is needed by the Chief of Finance (C Fin) [10] before a vehicle may be repaired. Under such circumstances, C Fin requires various documentation [2] to be completed, which includes amongst others, accident reports in case of an accident, trip authority forms, driver's licence and identification document, etc. This documentation is seldom complete because of various reasons, which results in a long waiting period for special authority.

It is evident that the Maintenance Process involves more than just technical personnel, but is interfaced with certain other functions as well. The Maintenance Process not only comprises of the servicing or repairs of vehicles and other technical functions, but also includes finance, procurement, various administration and management functions. The following problems were identified and grouped into appropriate sections:

2.1.1.2 *Transport*

All vehicle activities start within the transport section. If this section does not function properly, the maintenance process succeeds. Different problems were identified in this environment and are listed below:

Most of the transport personnel are not *formally trained or qualified* in Transport Management. Transport courses are available, but the application for, or attendance of the courses are very low.

The information systems *OSIS and CALMIS are not fully understood, implemented and utilised*, by the users.

Management of the Transport Parks presents a problem. A Transport Park usually consists not only of pool vehicles, but also of satellite Transport Parks. The central Transport Park needs to manage the maintenance process of the pool vehicles as well as the satellite Transport Parks' vehicles.

The basic *transport procedures* [1, 2, 5-7, 16, 30-32, 34 and 35] (e.g. first and last parades, accident or damage and loss reporting and follow-up) are *not followed* and differ from unit to unit.

The *Transport Courses* presented *[5-7, 20 and 21] are inadequate* with regard to management of *scheduled maintenance*. Scheduled services are addressed incorrectely and leads to misunderstanding on the part of the students implementing and managing it at their units.

2.1.1.3 *Technical Centre*

Technical work is considered a very important function in this process. Several problems were identified and are listed below:

The *Technical Centre is understaffed* (claimed by most of the Technical Centre Managers). In general the technical personnel are not only responsible for the maintenance of the vehicles, but also for database [38] administration (the suppliers are managed according to a database thus ensuring equal opportunities for all), in- and out-inspections and supplier management.

Security at the Technical Centres and Transport Parks is poor and theft of vehicles and vehicle spares causes unnecessary expenses in the maintenance of vehicles.

The *database* is, according to policy [10], a procurement function for system integrity purposes. It is however in most cases managed and administered by the Technical Centre as it reduces the process time and induces a certain degree of technical expertise to this task.

Most of the Technical Centres have *poor facilities, equipment and security.* This is mainly due to fact that DOD units are not structured for in-house D-vehicle maintenance as set out in the relevant policy.

The concept of outsourcing leads to technical personnel not being nominated to attend any new product information courses, which will ensure *competency.* This results in uncertainty of inspector competency, especially regarding newer vehicles, that are electronically advanced.

The computer systems *OSIS and CALMIS are not fully understood by the users and not fully implemented and utilised.* An effort is however, initiated to implement VMS (Vehicle Maintenance System on OSIS) at all units in the SAAF (South African Air Force).

Virtually no competency *inspections of the suppliers* on the database are occurring. This results in sub-standard repair and servicing of military vehicles, which in turn could lead to catastrophic consequences.

2.1.1.4 Procurement

Different procurement problems were identified.

The procurement personnel responsible for the necessary vehicle procurement functions are *not situated in close proximity of the Transport* Parks and Technical Centre. This causes a time delay since the documentation needs to be transported between the different sections.

The Sub Standard Tender Committee (*SSTC) meetings are not held frequently enough,* causing vehicles to wait for SSTC approval for more than one week. The SSTC approves the process of obtaining comparative quotes, before financial approval can be requested.

The *responsibility of maintaining the suppliers' database* lies with Procurement. Obtaining quotes is however delegated to the Technical Centre to utilise their technical expertise and ensuring that government funds are spent wisely.

2.1.1.5 Finance Control System

This section is responsible for giving authorisation to repair damaged vehicles. No vehicle is to be repaired before this authority is given. One of the most important reasons for this delay in the process, is that in the case of a vehicle accident where death of a person occurred, certain boards of enquires have to take place. This is an investigation on the accident and such enquiries can take up to three years, which is the time a civilian has to submit a claim against the DOD.

Certain procedures have to be followed when a vehicle was involved in an accident. An accident is defined as damage incurred by a vehicle whilst in motion. Damage and losses are dents or scratches to the body and theft of vehicle parts when the vehicle is not in motion. The problems were:

The drivers of vehicles do not *report vehicle accidents, damage or losses* due to either a lack of knowledge on the correct procedure [2 and 29] or a lack of co-operation, or indifference on supervisory level.

Transport personnel are not certain when a *Board of Inquiry (BOI)* must be convened. If a BOI is convened, the entire maintenance process is delayed further as explained earlier.

Transport personnel are unclear regarding the correct *accident, damage or loss procedure*, the documentation required and how reporting should occur.

Transport personnel are uncertain of the correct procedure regarding *reporting accidents to Chief of Finance* (C Fin). Once accidents are reported, the time needed to obtain a repair authority is laboriously long. Sometimes the authorisation is not received at all.

A *communication problem exists between C Fin and the different units*. The responsible technical personnel do not necessarily receive feedback on the status of their damages and losses documentation. Consequently, some units have begun to repair damaged vehicles without the necessary authorisation.

2.1.1.6 Financial

The finance function in the process is very important and was found to be one of the biggest concerns and one causing unduly delays.

The procedure to grant *Financial Authority (FA) [14] takes too long.* The Budget Manager and Holder are the required and only authorised persons to give the necessary authority. If one or both of them are unavailable, approval is delayed. The process of financial delegations [9, 14 and 23] to OCs and subordinates is inadequate.

The Financial Governing Function discourages bulk FAs and the Budget Managers are wary of bulk FAs. Bulk FAs are a way of granting a lump sum of money to a unit for a certain type of transaction. It can be seen as a credited account from which vehicles can be maintained. Budget managers feel that they do not have the desired control over the spending of money.

Suppliers are generally more ready to accept government work when being paid in *cash*, since government *orders sometimes take months* to be paid. The fact that the technical personnel want to have the vehicles repaired as quickly as possible, forces them to use the Cash Advanced System (CAS) where a cash amount of R5000.00 per person is allowed to be drawn from the petty cash per case according to [14].

The *financial year change over* causes FA approvals to take longer than usual because of funds not being available, or only made available in the next financial year. Consequently the maintenance of D-vehicles during this, two-month period comes to a virtual standstill.

2.1.1.7 Summary of Most Important Problems

The most important problems were identified and are discussed below:

D-vehicle *Product System Management* does not have the necessary funds and supportive structure to effectively, efficiently and economically manage the system.

Inadequate information capturing, processing and analysis results in poor management information [8]. This leads to ineffective fleet management and various data integrity issues.

Policies and procedures governing the maintenance process restrict the personnel involved to a great extent. These policies are dictated from all the relevant interfacing functions in the process, and therefore affect the spectrum of people involved. The result of this '*bureaucratic red tape*' is a process which requires an *enormous administrative effort*. People therefore start to ignore procedures and seek loopholes to satisfy their requirements.

The *Phase-Out Policy* of the specific distance or age limit is interpreted differently at various units. The result is that vehicles are not phased out. With an old vehicle fleet, the reliability reduces because the probability of failure of components increases with age, as shown in the bathtub curve in chapter one. A back-up vehicle is being maintained for this reason for each vehicle assigned to a client. This causes the accumulation of to a very large fleet to manage with limited funds. The fleet age sampled during the investigation was calculated and is shown in **figure 2.3**.

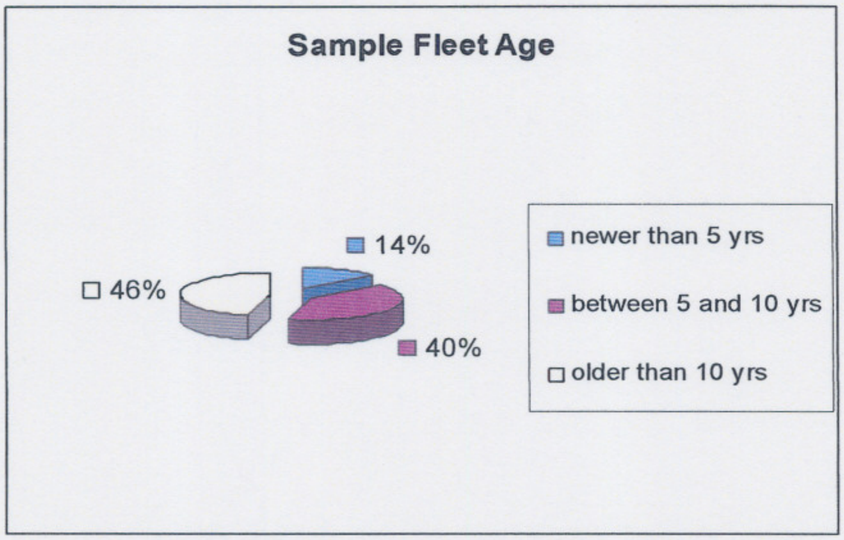

Figure 2.3: Sample Fleet Age

The *security and safety* of vehicles in general are extremely poor. Vehicles and parts are lost due to theft and improper parts control.

There are *not sufficient funds* to repair all the vehicles. The DOD has a limited budget allocated to it and maintenance does not receive adequate financial support to ensure an acceptable availability of functional D-vehicles.

2.1.2 Process analysis

This analysis is specifically focussed on the maintenance process and its aspects. The process is analysed by means of a process analysis framework, collecting and calculating applicable statistics (as far as possibly obtainable) and simulating the present process using a simulation computer programme. The generic process as obtained from the various site visits is identified in order to address the similarities between the different practical processes implemented. **Appendix A** shows a flow diagram of the current generic D-vehicle Maintenance Process as explained earlier.

2.1.2.1 Process Analysis Framework - PIECES

This Process Analysis Framework (**see Appendix B**) allows one to evaluate a process on different aspects, namely: **P**erformance, **I**nformation, **E**conomics, **C**ontrol, **E**fficiency and **S**ervice. The result of the PIECES evaluation is included in **Appendix C**. The following important problems were identified according to the PIECES analysis:

The computer system Vehicle Management System (VMS) on OSIS is not adequately utilised to store data and retrieve the necessary information. Personnel have a resistance to these systems and use their own defined informal systems.

The current data has little integrity, is inaccurate, unorganised and unreliable. The data is also often based on guesswork, is inconsistent and flooded by errors. This causes a lack of data to determine accurate maintenance expenditures, utilisation and maintenance history of D-vehicles. The users are aware of this and therefore do not trust the information or any deduction based on it.

The process requires excessive administration effort to complete a task because of inconvenient control measures and bureaucratic red tape that slows the process.

Documentation is transported to and fro different sections within the process and adds to the total process time.

2.1.2.2 Statistics

Statistics are not only useful but indeed essential in understanding one's working environment. It provides ways of gaining insight into the behaviour of systems, equipment, people and/or processes. The objective of acquiring and calculating statistics on the process is to identify bottlenecks (a point in the process that causes work to pile up), trends and areas for improvement.

Statistical analyses and the storing of data are identified as a major problem in the process. Necessary information for statistical analysis could therefore not always be obtained, at least not sufficient or reliable information. However, certain basic process time measurements could be established to analyse and simulate the current process. A statistical analysis was done and is summarised in **Appendix D.**

2.1.2.3 Simulation

A generic representative simulation model of the current process was built with the computer program, ARENA. Simulation is the imitation of the operation of a real-world process or system. It involves the generation of an artificial history of the system, and the observation thereof to draw inferences concerning the operating characteristics of the real system that is examined.

The model was used to simulate the generic process in order to identify problem areas and to enable later development and evaluation of alternative solutions. The accuracy level of the simulation was measured against actual time studies and obtained maintenance history, at a minimum of 85%. The objectives of the simulation were:

- To build a simulation model that represents and predicts the events of the real system.

- Identify problems and areas of concern in the maintenance process through visual inspection.

- Obtain and evaluate statistical information from the simulation to identify problems and areas of concern.

- Use the statistical and other information as guidelines when developing the new process.

The following summarised results were obtained from the simulation of the Generic Maintenance Process:

- An average of 62.6 % of all requests was completed per year. This figure illustrates that only 63 vehicles out of a 100 sent in for repairs within a period of one year, are repaired.

- 82 % of the time spent in the process was non-value adding time. Delays within the system mostly contributed to the non-value adding time spent in the process.

- The average total process time was 626.27 hours, roughly 15 weeks, to maintain a vehicle. This includes the servicing or repairing of the vehicle. Included are vehicles that have been in an accident for which repairing authority must be obtained. Sorting of the vehicles to obtain a more accurate figure of the maintenance process time was impossible due to negligence, which results in inaccurate vehicle maintenance history.

- There are many delays in the process, mostly caused by the involvement of role-players that do not add value to the maintenance process but are involved purely because of obligation under government policy. Some of the role-players are not easily accessible and some are simply adding to the delay caused by their own negligence.

- Personnel sometimes cause many entities to queue for a long time. This is due to the over-utilisation of some personnel, making it difficult for them to attend to all tasks in a reasonable time.

A more detailed discussion on the simulation of the current process appears in **Appendix E**.

2.1.3 Process Evaluation

Maintenance can be seen as a closed loop *feedback system*. Throughout the process within the life-cycle of a vehicle, all history but more specifically, maintenance data like defects, servicing schedules and maintenance tasks have to be fed back into the process. This enables one to retrieve useful management information and establish trends and failure patterns. Consequently preventive maintenance can be done to prevent failures in the future. This feedback system ensures proper maintenance of a vehicle and is illustrated in **figure 2.4**.

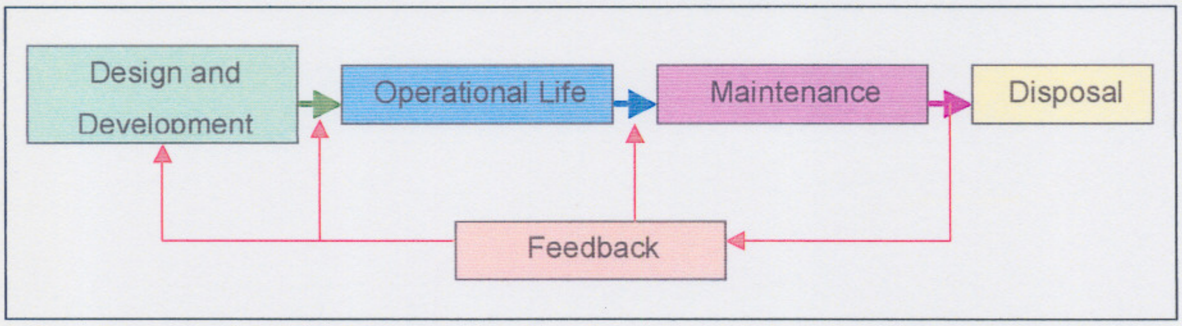

Figure 2.4: Maintenance Feedback System

It is evident from **figure 2.4** that *communication* plays an important role in any process. Communication includes verbal, telecommunications, electronic and paper documentation. All these forms of communication need to be in place and functioning for the feedback system to operate properly. This communication includes operative channels between all the different role players in the process, i.e. contractors or SANDF personnel. Once these channels are operative, planning and management can be done.

DOD personnel make use of vehicles mostly on an ad-hoc basis or at short notice. Vehicles are assigned to a group of people or kept in a transport pool (a fleet of vehicles not assigned to someone particular, but available to use by anyone) except for subsidiary vehicles assigned to specific persons (normally Col's or higher in rank). This type of usage requires a maintenance system that provides optimal availability of serviceable vehicles.

It is also very important to consider and establish disposal policies of vehicles at certain time intervals. Disposal is necessary because of increasing maintenance costs over time and vehicles becoming uneconomical or difficult to maintain due to the difficulty in obtaining parts for older vehicles.

For the requirement of having sufficient functional vehicles for random demand, *Preventive Maintenance* would be the best maintenance strategy. This strategy would reduce the risk of unexpected breakdowns of vehicles. By constantly reducing this risk of unexpected vehicle breakdown, optimal availability and reliability would be ensured and costs reduced.

Preventive Maintenance requires proper planning and management. Maintenance plans are compiled from the *support requirements* in accordance with the organisational objectives. The requirements include support equipment (such as commercial vehicles) usage for a financial year according to which funds is allocated for maintenance.

Fleet managers plan their maintenance tasks according to the allocated budget in order to satisfy the requirement. For maintenance personnel to effectively comply with the required standard and maintenance tasks, certain *maintenance procedures and policies* need to be properly enforced. This would ensure maintenance tasks to be done correctly, as planned and prescribed.

Management is remarkably more effective when the necessary management information is available. Management information is filtered in an organised manner from all the maintenance and equipment specific data. In order to obtain this required information, proper *information management* is necessary to guide the maintenance process. The most accurate and accessible information for management is obtained by means of computers and preferably an *information system* designed for vehicle maintenance management information (i.e. the Vehicle Management System on OSIS).

A maintenance process in theory could be most successful, and vehicles maintained as efficient as possible, but if drivers do not have a sense of *ownership and responsibility*, the vehicles would still be utilised carelessly resulting in damaged and unreliable vehicles. This aspect includes both parties in the process, the driver and the maintainer. A mutually beneficial relationship needs to be established to ensure that the vehicles are properly maintained.

The above discussion stated various success factors in effective vehicle maintenance concluded from literature studies. The process evaluation entailed a comparison of a desired level of maintenance (that could be described by certain determined objectives according to proper maintenance and a specific Defence Force requirement) with the observed maintenance process (as described during the assessment phase).

Closely evaluating the assessment phase and mapping (Gap Analysis) it onto the success factors described, many shortcomings and improvement areas were identified. Apart from the primary problem being the solution to the low availability of vehicles, a gap was identified that portrayed several shortcomings and areas for improvement. This analysis creates the possibility of not only solving the low level of serviceability of D-vehicles, but to also develop an effective and proper maintenance process that includes internationally proven maintenance practices. **Figure 2.5** illustrates the process evaluation.

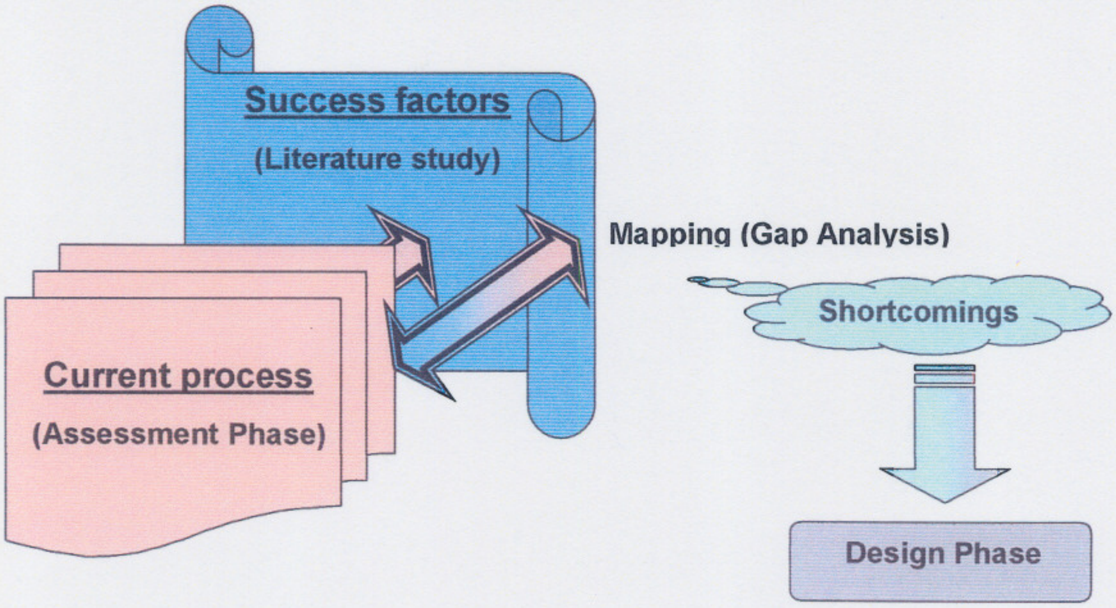

Figure 2.5: Process Evaluation

In order to establish an efficient maintenance process with all the necessary attributes as explained by the literature and requirement, it is essential to determine certain actions that will result in improvements on the current situation. A design phase is followed to derive improvement criteria that would ensure movement towards the desired level of vehicle operational availability.

2.2 DESIGN PHASE

The assessment phase sets a clear picture of the current situation at all levels throughout the SANDF. It also reveals the constraining and enabling factors that influence the performance of the process. The next phase is to consider these shortcomings and problems as well as the recommendations and best practices, to design an effective maintenance process that has specific outcomes. Another important fact to consider is that the designed process should be flexible adaptable and not be susceptible to failure when the organisational needs change, and should operate without loss of integrity.

Consequently, a new process is designed to eliminate undue redundancy and excessive bureaucracy, and to increase efficiency and service. The design phase can be explained according to **Figure 2.6**. Certain steps have to be followed in designing a new or improved process to ensure that all the problems are addressed and to make use of the most feasible practices.

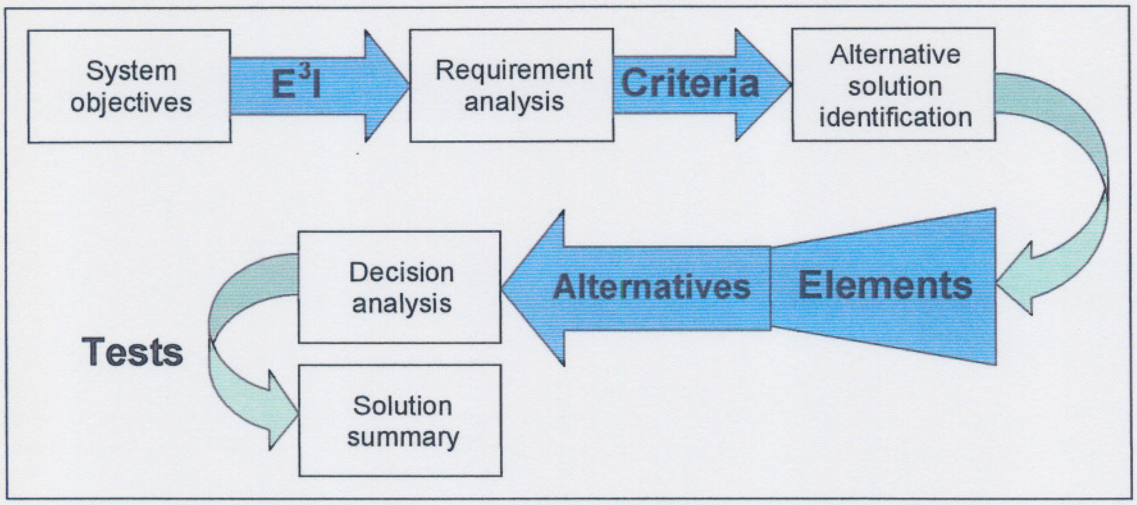

Figure 2.6: Process Design Phase

These steps include determining the exact objectives to be met; hence the goal of the process, which denotes the vision of the project. A requirement analysis followed in order to determine improvement criteria that can align the process towards achieving the determined objectives.

Improvement criteria alone cannot be of much value if they cannot be realised in executable actions. In determining alternative solutions, solution elements are identified as these single actions, which address most of the criteria from the requirement analysis.

These elements each have different maintenance strategies linked to them and it will not make sense to implement all of them. It is therefore necessary to determine alternative solutions by combining certain elements denoting certain maintenance strategies. The set of alternatives is then compared to each other in terms of their conformity to all the determined improvement criteria, in order to determine the solution that satisfies the most of these criteria, thus optimally satisfying the system objectives.

2.2.1 System Objectives

On completion of the process evaluation, where a solution framework was established, specific system improvement objectives were established on which the new processes should focus. The goal of the investigation was to improve the turnaround time of the maintenance process. Time reduction itself, can however not be a sufficient solution, for there are other important aspects of the process to consider. An improvement in one area of the process could negatively influence another area.

The PFMA (Public Finance Management Act) requires certain financial management measures to ensure accountability in the spending of public funds. These measures should be adhered to in the financial management process, which is an integral part of the maintenance process. These measures were adopted as the system objectives. It provides for the maintenance process to be as thorough, accountable and lean (short process time whilst utilising the least resources) as possible. The objectives were therefore defined as:

<u>Effective</u>

Effectiveness, as defined by Chase [4], means doing the correct things to create the most value for the company. In this case it means that the correct things must be done to ensure the highest possible availability of D-vehicles, which is of high value to the process. An effective maintenance process would thus ensure that vehicles are optimally available according to the operational requirement.

The specific effectiveness objective of the process is consequently determined and agreed upon by stakeholders to be a turnaround time of an average of one day for services, and a maximum of two days for minor repairs.

Efficient

Efficiency is defined by Chase [4] as doing the correct thing at the lowest possible cost. For the process to be efficient, it must achieve the successful maintenance of D-vehicles in the DOD, in the shortest time possible with the least amount of resources (money and man-hours). A balanced process in terms of resources means that an optimum level is reached in terms of supporting the vehicles.

Economic

The process should be economically feasible. Economic feasibility could be measured in terms of the monetary value of the process. Value is defined by Chase [4] as quality divided by price. The quality of the maintenance performed on these vehicles should thus be as high as possible within a constrained budget.

According to the Department of Defence Instruction (DODI) on financial management and the PFMA [9, 14 and 23-28], the DOD is responsible for the accountable use of public funds. Establishing an economic process as defined here would mean that the DOD complies with the applicable statutory requirements.

Integrity

System Integrity should be as high as possible, addressing security, fraud, theft, data manipulation and other system integrity issues. Integrity is of a very high importance for an effective maintenance process. As literature states, maintenance can become a fairly complex technical exercise.

Statistics for the implementation of preventive maintenance is very much dependent on data capturing done by the operator. If data is manipulated, as has been uncovered during this investigation, it results in inaccurate statistics.

Making use of faulty statistics can have serious consequences, which could lead to ill motivated decisions having catastrophic results.

2.2.2 Requirement Analysis

After setting the system objectives, actions need to be taken to achieve these objectives. It is therefore necessary to acquire specific criteria that could align the process towards achieving the objectives. These criteria have to be carefully selected as to effectively address the problem. The Lewin Force Field Analysis [13] is used to exactly determine these criteria.

The Lewin Force Field Analysis technique has been found very effective in analysing a problem and breaking it down into its basic components. It helps identifying the key elements of the problem situation. This technique also helps developing a systematic and significant strategy for problem solving which minimizes fruitless efforts. It then creates a set of criteria for the evaluation of steps to be taken.

Lewin proposes that any problem situation may be thought of as constituting a level of activity that differs from the desired level. Any problem situation, defined as a certain level of activity, may then be thought of as resulting from a number of pressures and influences acting upon the factors creating the problem (individual, group or organisation). These influences are called *forces* and may be internal (inside) or external (outside). Lewin identified two forces, namely driving and restraining forces.

Driving forces promotes or encourages the occurrence of the particular activity of concern, and *restraining forces* inhibits or opposes the occurrence of the same activity. The activity level is the resultant of the simultaneous operation of both the driving and restraining forces. Solving a problem would thus mean to affect the forces in such a way that the activity level weighs towards the desired result. These forces each have to be defined as thorough as possible in terms of contribution or relative strengths to aid in the effective problem solving.

The problem is defined in terms of activity level (low or high) and activity type (good or bad). Change strategies are then planned accordingly. **Table 2.1** shows the change strategies according to the particular situation.

Table 2.1: Planning Change Strategies

		Activity Level	
		Low	**High**
Activity Type	**Bad**	No Problem	Weaken Driving Force
	Good	Weaken Restraining Force	No Problem

The Activity has been identified by the problem statement as long turnaround times for the service and repair of D-vehicles. The assessment phase aided in the identification of the driving and restraining forces and the force field can be drawn as in **Figure 2.7**.

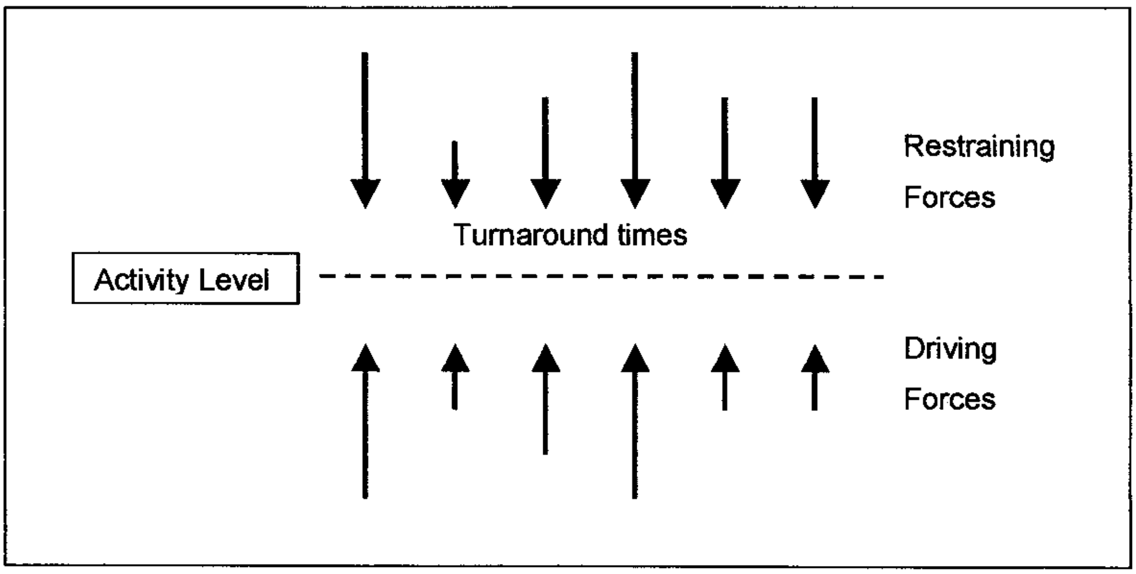

Figure 2.7: Force Field Analysis for Long Turnaround Times

The Force Field Analysis was conducted with the inputs of role players, other engineers and managers, commanding officers and relevant role players. They all gave valuable information regarding the impact of the different forces.

This analysis helped identify which forces influence the turnaround times and to what degree.

A strategy was developed from the analysis, which takes into account the reasons for the problem as well as the probable consequences of the proposed solution. The strategy resulted in a set of improvement criteria against which the process can be measured in order to achieve the determined system objectives, ultimately solving the problem.

The array of criteria could further be divided into five measurable and functional areas. These areas are:

Principles

Criteria are identified in terms of the system itself, logistical principles and the performance of the system as a whole to which the process should conform in general and are grouped under principles.

Feasibility

The feasibility of the proposed solutions is important and can be measured in terms of certain identified criteria, namely technical, operational, economic, schedule and risk feasibility.

Time

The problem state that time is the main concern; therefore certain time criteria were set.

Cost

For any proposed solution, the cost of implementation is of considerable importance therefore cost criteria were defined.

Management

Certain management criteria were identified in terms of data management, scheduling, process management and communication.

These areas each consists of a set of determined criteria to be met in order to solve the problem effectively. The improvement criteria are given in **Table 2.2.**

Table 2.2: Improvement Criteria

Criteria				
Principles	**Feasibility**	**Time**	**Cost**	**Management**
System	**Technical**	**Total**	**Utilisation**	**Data management**
Accountable	**Operational**	**Value adding**	**Maintenance**	**Scheduling**
Affordable	**Economic**	**Non-value adding**		Workshop
Transparent	**Schedule**	**Waiting/lead**		Resources
User-friendly	**Risk**			Maintenance
Safety				**Process**
Self-sustainable				**Communication**
Logistic				
Foresight				
Simplicity				
Operation				
Sustainable				
Flexibility				
Performance				
Reliability				
Operable				
Maintainable				
Available				
Feasible				

If a solution could be determined, it would have been necessary to test it against the determined criteria. In order to qualify the degree to which a proposed solution complies with each criterion, certain compliance levels had to be defined. The levels were defined accordingly.

Each criterion is weighted according to the degree of compliance by the solution. The levels of compliance were determined to be:

Fully compliant, if a proposal complies 86 – 100% with a criterion.
Largely compliant, if a proposal complies 51 – 85% with of the criterion.
Partially compliant, if a proposal complies 16 – 50% with a criterion.
Non-compliant, if a proposal complies 0 – 15% with a criterion.

The compliance levels were determined on the basis of having at least near-perfect compliance to all criteria, illustrated by the right hand side of an exponential distribution curve. The required level is that the majority of compliance at least lie in the 51 – 85% level or better. The compliance levels were accordingly structured as shown in **Figure 2.8**.

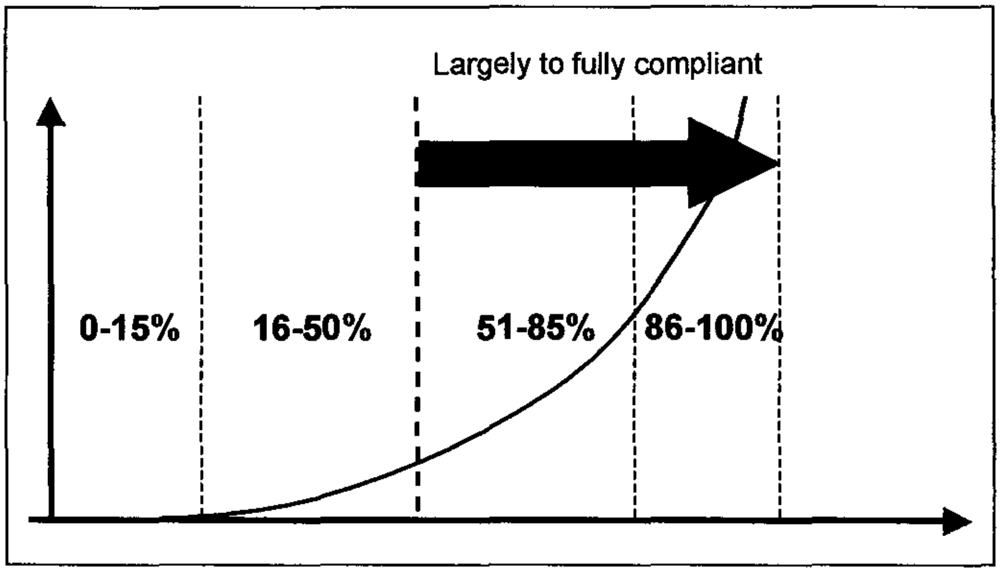

Figure 2.8: Compliance Levels Distribution

Specific outcomes were identified for each individual criterion in terms of every compliance level. The compliance levels were then subjectively defined, based on the obtained information about the maintenance process. The compliance levels are explained in **Appendix F**.

In order to satisfy the process objectives, these criteria needed to be met as best possible. The way to achieve this was to determine what actions should be taken that would ensure the process to perform well in the five focus areas.

2.2.3 Element Identification

Actions that could result in good process performance in terms of the criteria were identified as solution elements. Care should be taken when determining solution elements, because of the impact it has on the process. It might be positive in one way while simultaneously forfeiting performance in another way. In order to make the correct decision on what actions to implement, one must be familiar with the process and all the various aspects thereof. These improvement elements were identified by:

- Documenting and evaluating problems experienced with the current process obtained during the investigation phase.

- Suggestions obtained during the investigation phase, for the most fruitful information would come from respondents with hands-on experience of the process.

- Visually identifying improvement possibilities by analysing the simulation of the generic process and altering the process in order to test various scenarios and possibilities.

- Considering best practices during the investigation and benchmarking phase. Meaningful information was obtained from this exercise and gave positive solutions towards solving the problem.

The exercise of determining the solution elements were done subjectively, based on the inputs from the different role-players and the experience gained from the investigation.

The elements were compared to the improvement criteria. This is a verification to ensure that each chosen element would indeed improve the system in such a way that the objectives are certain to be met and that it does not influence other criteria negatively. **Appendix G** shows a table of the chosen solution elements and which improvement criteria element is addressed.

The identified elements are discussed in the following paragraph. Advantages, disadvantages and risks of each element are described in **Appendix H**. The extent of the different elements is:

Full Computerisation

Make full use of the computer systems OSIS or CALMIS. The computer systems OSIS and CALMIS are in most cases not fully utilised or implemented. By making use of the systems, delays between the Transport and the Technical Centre can be reduced considerably since the electronic data transfer between the sections happens instantly (compare electronic vs. paper).

These systems were implemented in correlation to SANDF policy. It is thus the automation of DOD procedures. All the transport administration theory taught in the Transport courses [5-7, 20 and 21] are thus facilitated by these information systems and should be utilised. Furthermore, certain additional actions can be performed on these systems that aid in properly managing the vehicle fleet.

These include a degree of service scheduling that automatically blocks the issuing of a vehicle before it has to undergo a service [20]. One of the most valuable and useful advantages is that management reports can be drawn from the data captured by using the system, by means of the Management Reporting Function of OSIS [21] also taught at 68 Air School and General Support Base (GSB) Youngsfield.

Dedicate Procurement Personnel to the Technical Centre

Procurement Personnel must be dedicated (assigned, or staffed) to or at the Technical Centre for all technical procurement functions. If Procurement

Personnel are dedicated to the Technical Centre, they can perform procurement functions that are currently performed by the technical personnel. The Procurement Personnel will be responsible for allocating the three suppliers, requesting quotes from the suppliers, compiling the comparison list and FA request and printing and signing the Government Order (GO).

The most important advantage of having Procurement Personnel in the technical environment is a remarkable reduction in process time. Normally the procurement office and the technical centre are geographically separated and make the communication and documentation flow a burden, and due to the fact that a large amount of procurement functions take place each day regarding the maintenance of vehicles. This element would thus improve one of the biggest delays in the process.

Bulk Financial Authority (FA)

The biggest delay in the maintenance process is caused by the financial interfaces. A possible reason could be the many governing policies [9, 10, 14, 23-28, 36 and 37] regarding the procedures and control of funds within the Government. For each cent spent, specific persons are officially delegated by means of government instructions [14], to authorise the accountable use thereof.

For safety reasons, the maximum amount of cash drawn at once by any individual in the DOD according to the JDP [14] is R5 000.00. This amount becomes unfeasible especially when the cost of services of repairs to a vehicle regularly exceeds the amount granted per case. It implies that for each vehicle repaired, a new transaction has to be negotiated. Reconsolidating petty cash in each case slows down the.

A bulk FA is a single authority for placement of multiple orders. More than one vehicle can then be paid for by using the same FA. In essence, a certain amount of money is authorised against which many transactions can be done.

The delay time caused by such and related governances in the maintenance process can be eliminated.

Scheduled Maintenance

Another big contributor to the long turnaround time in the maintenance process is the interfacing of the procurement and financial functions. When the servicing of a vehicle is not planned, all these functions have to take place after the stopwatch has started i.e., it forms part of the whole process time.

Effectively managing the service times of vehicles, hence scheduling the services, the exact time for a service will be known and the interfacing or preceding actions in the process are pre-determined. This would ensure all the necessary administration is completed and the total process time from the perspective of the client would be only the time the vehicle is being serviced and exclude the lead-time (time it takes for the administration and preceding actions before a vehicle could be serviced).

The information systems OSIS and CALMIS provide for a degree of scheduling [7 and 20] to be done. Scheduling is also taught in the Transport courses [5-7] available. By utilising this capability to the full and by developing a sense of responsibility, proper planning could be done and the process time would improve remarkably.

Maintenance Contracts

The existing policy regarding maintenance of non-combat vehicles (which includes D-vehicles) in the DOD clearly states that the DOD will not be responsible for the execution of these tasks, but that it should be outsourced [33]. Furthermore, the DOD is governed by the PFMA, stating that the DOD is responsible for the accountable management of public funds. This implies that certain measures have to be instated to ensure this integrity and accountability.

The measures include that three quotations be collected, as explained earlier in the document, before a service can be outsourced. The whole authorisation process [10] and financial management [9 and 14] adds to this process. If however a maintenance contract could be agreed on with a manufacturing agent or certified supplier, only one quotation is required for the financial approval of every maintenance task to be carried out. This implies that the contractor does the work at a certain acceptable standard and that the price and procedures are negotiated beforehand.

Setting up a maintenance contract according to Treasury Regulations [36 and 37] could remarkably reduce the process time and ensure a high standard of work done on the vehicles. The standard of work is necessarily of high importance, because of the accountable management of funds that makes re-work unacceptable, as well as the fact that a lower standard of work might involve safety risks that the DOD cannot accept.

In-house repair with on-site parts contract

The capability of performing maintenance by the DOD itself, is contradicting to the existing policy. Certain advantageous factors have been identified, which lead to the decision of making this option a solution.

Due to the fact that maintenance is outsourced, a very time-consuming procedure had to be put in place to ensure accountability, as explained in the previous section. By performing in-house maintenance, with the existing workforce (a study could be initiated to investigate the existing workforce against the required workforce), the whole procedure could be drastically improved.

The following issue immediately comes to mind; that stock and parts management is needed. It is well known that the management of any item in the military environment can become a cumbersome responsibility. Each item has to be accounted for, which means that item numbers have to be assigned and storage procedures have to be followed, with the parts taking up a lot of space and management time. Therefore, this element is proposed with the condition that parts be supplied by a contractor (as learnt from the benchmarking phase), which is situated in close proximity of the technical workshop for quick access to parts.

The contractor should necessarily be pressured under contract, to supply any part within a given time period. Personnel could thus plan their work according to the lead-time necessary for the required parts to be available. The disadvantageous factors could be that more personnel need to be trained for competent work on all makes and models as required. This could be costly. Facilities and the necessary equipment also need to be made available that would have certain cost implications.

Re-establishing the in-house capability of maintaining commercial vehicles within the Department of Defence, could certainly improve the turnaround time of repairing and servicing vehicles. Consider a case where only a light bulb needs to be repaired or exchanged. It would be much quicker and effective to do this task in-house, than obtaining three quotes and financial authority for getting it repaired or replaced by a supplier.

The argument could be raised that qualified planners would exploit the opportunity and assess any other damages to the vehicle to be repaired at the same time. This will be taken care of in-house, in a much quicker way.

Lastly, the morale of the technical personnel would drastically improve. They would be involved with tasks they are trained for and not only inspections and technical advice anymore. Their motivation should improve (according to Maslow's hierarchy of human needs [13]) because of the challenge they would regain by maintaining the vehicles themselves.

2.2.4 Alternative Solution Identification

Solution elements were defined to execute in order to improve the process. These elements are actions that lead to measurable results. Results that could be compared against the performance criteria. Different elements however, imply different maintenance strategies (preventive or corrective). It is thus logical to not simply implement each individual element, but selectively choose elements to be implemented.

Different combinations of elements were grouped and tested in various ways to determine the improvement impact and the feasibility thereof. The most important consideration of which elements to group together, was that the resultant consequence of a group would ensure the optimal improvement of the process, in terms of the defined criteria.

According to **Appendix I**, the groups of elements that address the most of the improvement criteria were considered. Eventually six sets of elements were formed and these sets constitute the solution alternatives. **Table 2.3** shows the different elements that each alternative comprises of.

Table 2.3: Alternative Solutions

	Alternatives					
Elements	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Full Computerisation			X	X	X	
Dedicated Procurement Personnel	X		X			
Bulk FA			X	X	X	
Scheduled Maintenance			X	X	X	X
Maintenance Contract		X		X		X
In-house Capability					X	

From the list of alternatives, a most suitable solution must be identified. Any of the alternatives, however, would result in an improved process, but not necessarily the best. In order to make the correct decision a decision analysis was necessary.

2.2.5 Decision Analysis

The decision analysis is a structured method of decision-making, based on facts and ensures confidence. The final decision on what alternative to implement or recommend, was to choose the alternative that best addresses the defined improvement criteria.

By comparing the alternatives in terms of the improvement criteria, an analytical best solution could be chosen. Some criteria in fact, were more important to be satisfied in terms of the system objectives. It was therefore decided that a weighted test methodology be used in the decision analysis.

This methodology provides the ability to let the compliance to more important test criteria weigh more than compliance to less important criteria. The focus areas and test criteria within these areas were consequently assigned weights (as explained in **Appendix J**) in accordance with the importance of compliance.

It must be emphasised that the weight assignment of the criteria has a considerable influence on the result of the decision. The test results were quite sensitive for changes in the weights. It was therefore necessary to correctly and confidently assign these weights and keep it static.

The assignment was therefore based on the inputs of role players directly involved in the process, managers, professional engineers and analysts and strategists with higher-level management experience who understand the medium and long-term strategy of the larger organisation. The difficulty of getting all these role players together at the same time, led to smaller discussion groups where the weights were determined and ultimately agreed upon.

The weight assignment was done by ranking the criteria of each area in order of significance. Then it was determined to what degree each criterion is more important than the other by assigning an appropriate rate to the particular criterion. The weights are determined by dividing the individual rates by the total of the weights for a focus area, which results in a normalised factor for each criterion within a focus area. Normalised factors for the different focus areas were determined in the same manner.

As explained earlier, compliance levels were determined and defined for each individual criterion. The degree to which an alternative complies with a criterion is worth a certain compliance value according to the compliance level table in **Appendix J**. This value was multiplied by the weight of the criterion and in this manner the alternatives scored against each criterion.

Ultimately the scores were added and multiplied again by the weight of the focus areas, because of the importance of an area in terms of the other areas as well. The scores were then added and the best alternative could be determined. **Appendix J** includes a table of the alternative solutions with the specific criteria each individually addresses. The Following tests were conducted:

<u>Principle Test</u>

A principles test was conducted in terms of logistics, performance and system principles.

<u>Feasibility Test</u>

A feasibility test was conducted in terms of technical, operational, economic, schedule and risk feasibility criteria to determine the most feasible solution.

<u>Time Test</u>

All identified elements and alternatives were simulated. The results of these simulations were evaluated and compared.

Cost Test

The cost of implementing a solution was of particular importance. A cost test was conducted in terms of utilisation and maintenance cost.

Management Test

A management test was conducted in terms of data management, scheduling, process management and communication.

The test results in **Appendix K** show the different weights of the criteria and how each of the alternatives scored in terms of the different tests and the related criteria.

3 RESULTS

The project objective was to propose a holistic solution to the long turnaround times in the maintenance process of D-vehicles in the SANDF. To ensure that all facts are considered in the solution a thorough investigation was conducted in accordance with the assessment phase. Thereafter a well-structured design phase was followed to design the optimal solution. The expected outcome was a solution in the form of a maintenance plan or strategy to be implemented throughout the Defence Force.

With the detailed information obtained from the assessment phase, alternative solutions were formed from where a decision analyses was conducted to determine the optimal solution.

The weighted tests resulted in a well-founded and analytical outcome on which confident decisions could be made. **Table 3.1** shows a summary of the ranked test results for each alternative (a rank of 1 equals the best and higher equals worse). It is evident that alternative four scored the best and is accordingly ranked first out of the possible six alternatives. **Appendix K** shows the test results of all the tests as well as the test summary.

Table 3.1: Test Rankings of Alternatives

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Principles	4	2	3	1	4	6
Feasibility	5	3	2	1	5	3
Time	6	5	3	2	1	4
Management	6	5	1	2	4	3
Cost	5	1	1	1	6	1
Ranking	6	5	2	1	3	4

Some interesting remarks could be made from the tests with particular interest and focus on the time reduction. The simulation discussed earlier and in **Appendix E** helped establishing the percentage time reduction in the process. The best three alternatives produced the following **(Table 3.2)** time reduction in the total process time.

Table 3.2: Process Time Reduction

Alternative	% Time Reduction
Alt 5	70.35
Alt 4	42.34
Alt 3	35.16

The focus of the investigation was to reduce the turnaround time of the maintenance process without loss of integrity and efficiency. This statement immediately creates doubt in the fact that Alternative Four proved to be the best solution, since it does not give the best time reduction. If one carefully evaluates the test results, it could be seen that Alternative Five, although remarkably improving the turnaround time, is the most expensive to implement therefore not chosen, proving another objective, namely economic.

The reason for this extremely high cost determinant for Alternative Five is that the capability of maintaining vehicles in-house needs to be re-established. This option includes provision of maintenance and repair facilities, necessary equipment and special tools, re-structuring organisational manpower, providing training of personnel to ensure competent and high quality work and lastly, to review DOD policy and procedures regarding the in-house maintenance of commercial type vehicles.

In this way the alternatives compared to each other and the most feasible solution that could improve or best satisfy the system objectives was Alternative Four.

4 RECOMMENDATIONS

The results of the design phase indicate that Alternative Four is the best solution to implement and it is therefore recommended that Alternative Four be implemented throughout the Department of Defence. Alternative Four entails the following.

Alternative Four

- The *full utilisation of the computer packages OSIS and CALMIS*. This would include the adequate training of users and clerks to correctly use these systems. OSIS and transport courses [5-7, 16, 20 and 21] need to be used as functional promotion courses to ensure the staffing of qualified personnel in the correct positions.

  This would also ensure people performing their work with passion, because it is what they want to do and not only for money or status by receiving a higher rank. Adequate training and passion for the work would also increase data integrity as knowledge of the system improves and the understanding level is higher of how important each step in the process is, especially input of data.

- The use of *bulk Financial Authorisation* (FAs) would cause a remarkable improvement of process time. The methodology of the SAPS can be followed to improve the process, by making use of pre-approved FAs. This means that when a client sends a vehicle to the technical section to be repaired, a certain amount of money is already allocated for that maintenance tasks required.

- Implement *scheduled maintenance.* As emphasised in the previous chapter, the biggest delay in the process is caused by the financial and procurement functions. By making use of scheduled servicing including preventive maintenance tasks, the time for next service of vehicles could be determined and timely administration could be done. This could enable the achievement of the objective being one-day services.

- Set up *maintenance contracts* with manufacturing agents to perform the maintenance on the vehicles. This includes maintenance contracts when buying new vehicles. By doing this, the process is also shortened because only one or no quotation (when standard pricing is agreed on for certain tasks) is necessary instead of three. The standard of service delivered by the agents is also a guarantee of acceptable or better quality, lacking in the current maintenance process.

Irrespective of the alternative being implemented, certain general implementation guidelines are also recommended. These guidelines have to be followed and could also improve the system and ensure a proper functioning maintenance process without implementing any alternative.

General Implementation Guidelines

It is found that the DOD experiences extreme frustration in the maintenance process of D-vehicles. Holistically the maintenance process of D-vehicles in the DOD is failing. It does not provide the capability of ensuring a high level of availability of vehicles. This frustration is caused by various factors.

Many problems have been discussed and all contribute towards the ineffective and insufficient process. The biggest problems identified are mostly policy and people-driven. It means that something can be done to rectify the situation.

The financial and procurement functions both contribute to the biggest delays in the process. If these functions could be eliminated from the turnaround time of the vehicles, it would cause a remarkable improvement in process time.

It would however not optimally solve the problem by simply eliminating these functions, because it is irremovably part of the process. Whether it is done before-hand by proper planning, it would also still be time consuming. An attempt must be made to improve these functions in the future as it affects other business processes as well and the DOD would benefit from it in more than one way.

- In a first attempt to remove the procurement and financial functions from the process, maintenance management needs to be improved. It would mean a paradigm shift towards preventing failures, thus *planning the maintenance tasks.* This focus and proper planning would cause the effect that certain administration actions are performed before a vehicle is sent for repair or a service, resulting in increased operational availability of the vehicles.

- Proper planning can become a very complex task if managed by hand and even more complex when the fleet is large. It will be essential to make use of the available information systems. This cannot be done by simply guessing time intervals and task types; it needs to be based on vehicle specific data and history. The data and history therefore needs to be fed into the information system for the effective planning of services and preventive maintenance tasks. It is recommended that *data management* be improved at all levels and functions.

- *Co-ordinate and manage the activities and relationships* between: Transport, Technical Maintenance, Procurement and the Financial section. Proper data and communication flow is a necessity for the success of any process.

- Furthermore, management can make valuable decisions regarding the fleet maintenance if they could have access to relevant fleet maintenance and *management information* and statistics. This can only be done if data is captured correctly and then making good use of the reports of the information systems.

- The investigation proves that the level of qualification and necessary training of all people involved in the maintenance process is not at all at the required standard. It is recommended that *competency* levels be improved through training and evaluation of personnel required to achieve the effective utilisation of the information systems.

- *Maintenance plans* should be considered when buying new vehicles, to make vehicles more attractive to sell at the end of their calculated life (in this case, the best time to sell a vehicle was found to be just before the maintenance plan expires). It cannot be guaranteed that vehicles will be less expensive to maintain when new vehicles are bought with a maintenance plan. It would at least not cost more than maintaining older vehicles without maintenance plans and the process would certainly be faster, since the financial function is eliminated.

- Establish and promulgate a *phase out plan* for old vehicles. Chapter 1 indicates that the probability of failure of a vehicle increases over its life cycle. It implies that more maintenance is required and therefore more funds are needed. It can therefore be recommended that a well-calculated phase out plan be compiled in order to schedule the phase out of vehicles at certain ages, odometer readings or maintenance cost levels.

- In general, the attitude of drivers needs to change to be more co-operative regarding procedures and prompt reporting of failures. They, and all personnel involved in the process need to accept *ownership and responsibility* of the vehicles.

- The morale of the technical personnel is unproductively low and needs to be addressed. *Empower and motivate* fleet managers, transport and technical personnel. A motivated workforce, according to [13] is one of the success factors of a high level of competence in the organisation.

- Improve or establish *Supplier Capability Inspection*. The so-called "Joe Soap" (any supplier of technical vehicle services 'around the corner') could not be chosen to service or repair DOD vehicles. Standards and capability or competencies are not questionable anymore, providing safe vehicles.

- Proper management and job requirement structures should be established to ensure the *correct staffing*. Make certain levels of training promotional requirements, to ensure people staffed in posts have the necessary competency and skills to do the work they are intended to successfully. This point leads to the most important general recommendation.

- *Vehicle System Management Structures* need to be clarified. The product can only be managed successful if the support structure is properly instigated and the necessary supporting policy and procedures are properly promulgated from top level to operational level.

The general guidelines discussed above would certainly set a sound base for a successful maintenance process. It is recommended that the planning of the guidelines be done at Product System Management level and be properly promulgated and implemented throughout the DOD.

5 CONCLUSION

The problem of the DOD experiencing excessive turnaround times in the maintenance of D-vehicles was investigated at all levels throughout the DOD. An assessment was done on the present situation and a clear insight was gained into all problems and areas of improvement in the process.

The current situation was compared with other Government Departments to find a golden thread that could ensure successful maintenance according to certain determined objectives. The process was improved accordingly and it could be said in confidence that the objectives would be achieved, if the recommendations were to be approved for implementation. In other words, the turnaround times for the maintenance of D-vehicles in the DOD would be acceptable, as stated in paragraph 2.2.1, and the availability of vehicles would increase to the operational requirement.

The value of the investigation was two-fold. Initiators of the project, DESS, obtained a thorough assessment sample on the D-vehicle maintenance process in the DOD, accompanied by all the necessary management information to be able to make well-informed decisions regarding the improvement of the maintenance process. They also received scientifically proven and educated recommendations on improvement actions that could and most certainly would remarkably improve the maintenance process.

At the end of the investigation, the findings and recommendations were presented to C Log. The implementation of any alternative, however, was not approved for two reasons: one being the search of a "quick fix" to the problem, and another the inability to make a decision pending the outcome of a fleet management investigation, where total fleet outsourcing were considered. The instruction followed that the general implementation guidelines be promulgated at targeted sites.

Consequently, a DODI was to be published, whereby the general implementation guidelines were to be implemented at the determined units. Hopefully an improvement in the maintenance process at these units could prove to the Log Staff Council that certain measures would not be fruitless. It is hoped that the decision would be made in the near future to implement the recommended solution, or at least authorise a team to compile a maintenance plan for D-vehicles in the DOD.

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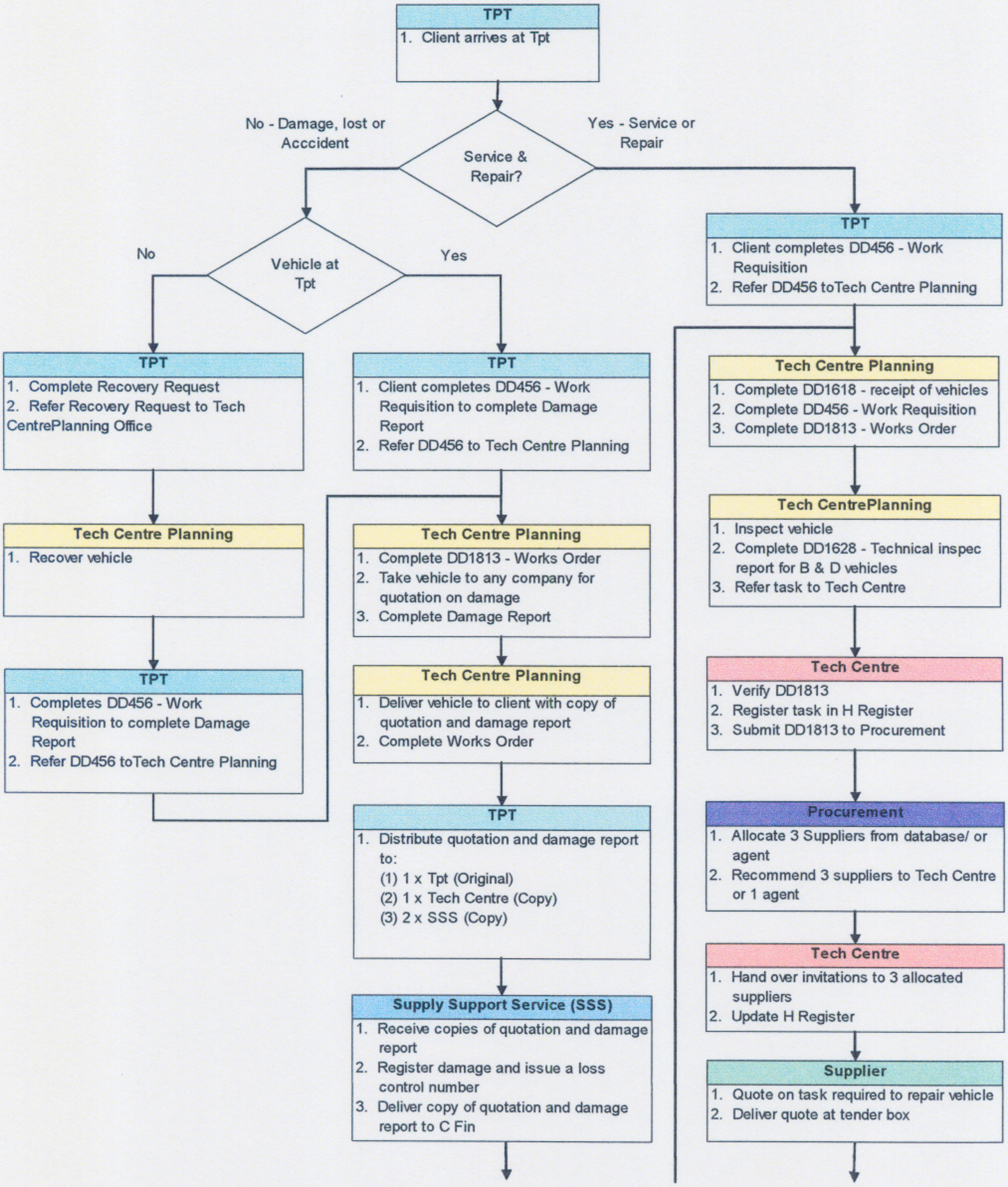
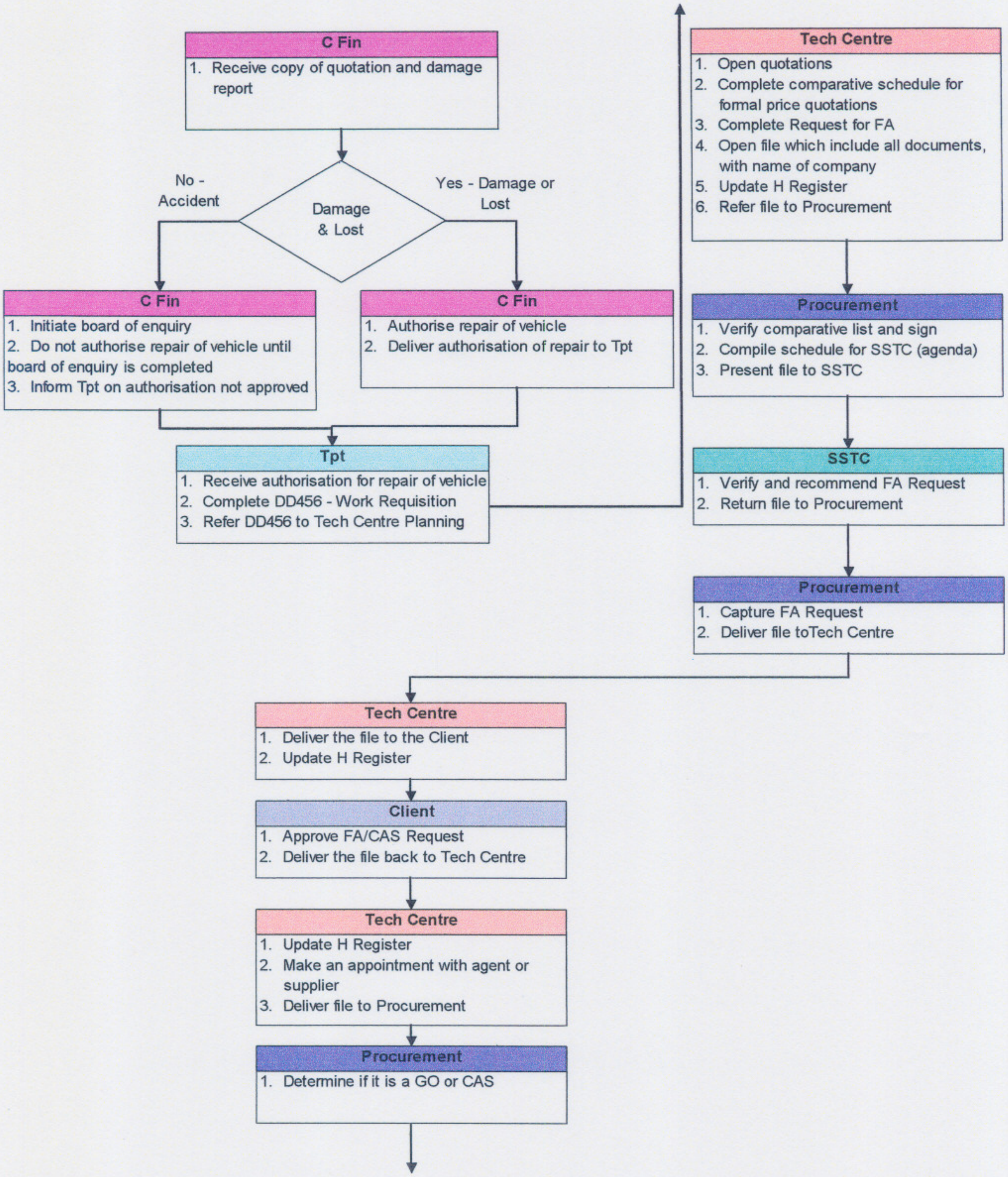
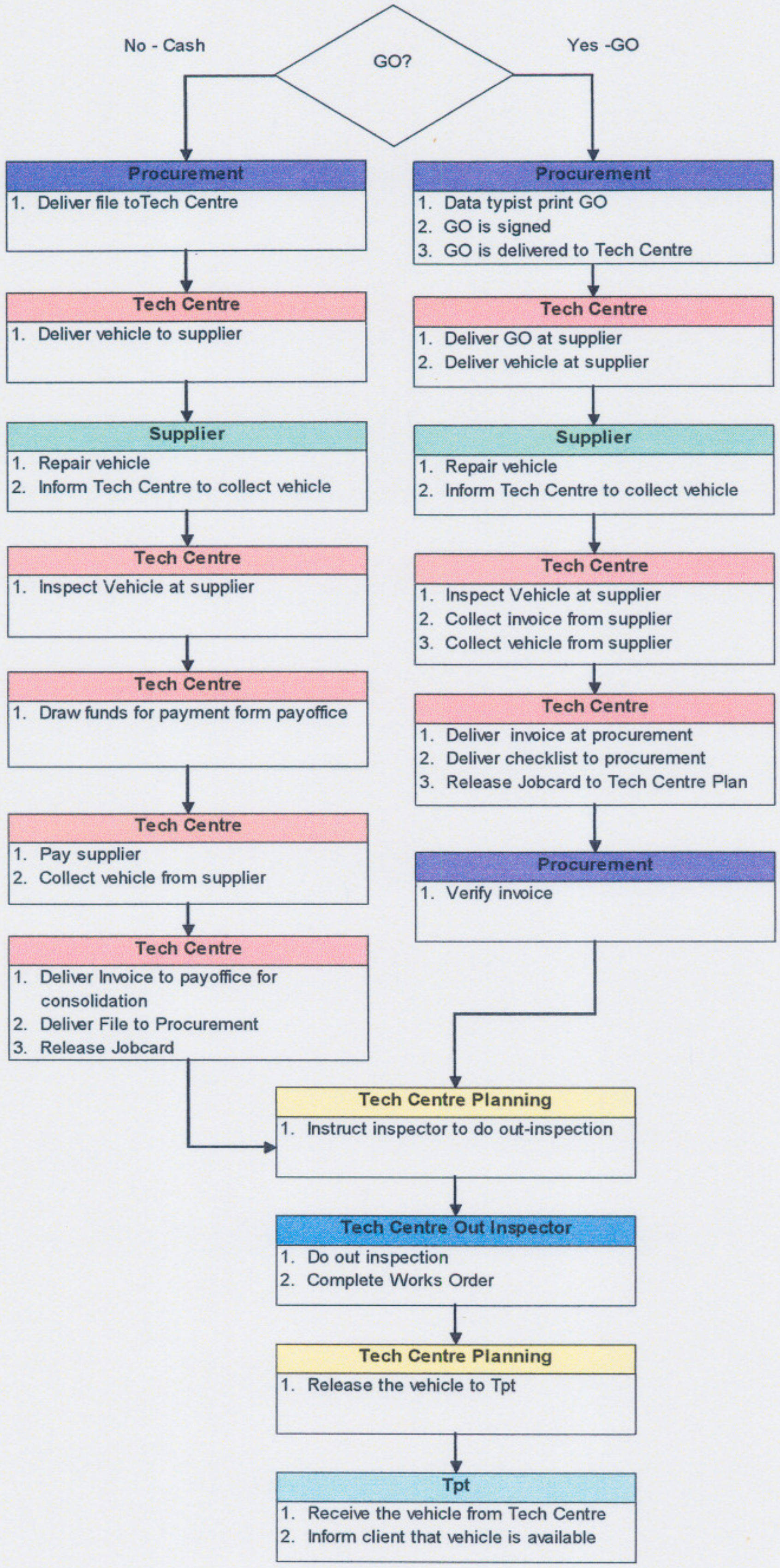
APPENDICES

Process Flow Diagram

Appendix A




C Fin
1. Receive copy of quotation and damage report
Damage & Lost
No - Accident
Yes - Damage or Lost
C Fin
1. Initiate board of enquiry
2. Do not authorise repair of vehicle until board of enquiry is completed
3. Inform Tpt on authorisation not approved
C Fin
1. Authorise repair of vehicle
2. Deliver authorisation of repair to Tpt
Tpt
1. Receive authorisation for repair of vehicle
2. Complete DD456 - Work Requisition
3. Refer DD456 to Tech Centre Planning
Tech Centre
1. Open quotations
2. Complete comparative schedule for formal price quotations
3. Complete Request for FA
4. Open file which include all documents, with name of company
5. Update H Register
6. Refer file to Procurement
Procurement
1. Verify comparative list and sign
2. Compile schedule for SSTC (agenda)
3. Present file to SSTC
SSTC
1. Verify and recommend FA Request
2. Return file to Procurement
Procurement
1. Capture FA Request
2. Deliver file toTech Centre
Tech Centre
1. Deliver the file to the Client
2. Update H Register
Client
1. Approve FA/CAS Request
2. Deliver the file back to Tech Centre
Tech Centre
1. Update H Register
2. Make an appointment with agent or supplier
3. Deliver file to Procurement
Procurement
1. Determine if it is a GO or CAS


GO?
No - Cash
Yes -GO
Procurement
1. Deliver file toTech Centre
Tech Centre
1. Deliver vehicle to supplier
Supplier
1. Repair vehicle
2. Inform Tech Centre to collect vehicle
Tech Centre
1. Inspect Vehicle at supplier
Tech Centre
1. Draw funds for payment form payoffice
Tech Centre
1. Pay supplier
2. Collect vehicle from supplier
Tech Centre
1. Deliver Invoice to payoffice for consolidation
2. Deliver File to Procurement
3. Release Jobcard
Procurement
1. Data typist print GO
2. GO is signed
3. GO is delivered to Tech Centre
Tech Centre
1. Deliver GO at supplier
2. Deliver vehicle at supplier
Supplier
1. Repair vehicle
2. Inform Tech Centre to collect vehicle
Tech Centre
1. Inspect Vehicle at supplier
2. Collect invoice from supplier
3. Collect vehicle from supplier
Tech Centre
1. Deliver invoice at procurement
2. Deliver checklist to procurement
3. Release Jobcard to Tech Centre Plan
Procurement
1. Verify invoice
Tech Centre Planning
1. Instruct inspector to do out-inspection
Tech Centre Out Inspector
1. Do out inspection
2. Complete Works Order
Tech Centre Planning
1. Release the vehicle to Tpt
Tpt
1. Receive the vehicle from Tech Centre
2. Inform client that vehicle is available

A3

PIECES ANALYSIS for the D-vehicle maintenance process in the DOD

1. PERFORMANCE

Throughput – the amount of work performed over some period of time

The throughput of the workshop depends on the facilities, capacity and capabilities thereof. Most of the units visited are not structured to repair D-vehicles, consequently the throughput of most of the units are far less than the amount of work received in a month creating tremendous backlogs.

Response times – the avg. delay between a transaction or request and a response to that transaction or request

Most of the units have a quick response to a repair request, although the process lags further downstream.

2. INFORMATION (and Data)

Outputs

- Lack of info
- There was a lack of relevant info right through the investigation.
- Too much info
- There was not too much info. The impression was that technical people don't particularly prioritise documentation as the important function that it is.
- Info not relevant or useful
- The info gathered was mostly not useful and sometimes not relevant.
- Incorrect info
- The info was also incorrect. The system is manipulated as a result of the ignorance or attitude against documentation and administration on the shop floor.

Inputs

- Data is not captured
- Data is captured, although not to the desired extent and not the correct or relevant data. Data is also unreliable because of the manipulation thereof.
- Data difficult to capture
- Data was mostly difficult to capture, since most of the units do not implement the computer systems available to its full potential. Computers make the capturing of data much easier and reliable.
- Too much data is captured or repeatedly captured
- Overall there was not too much info. Data is sometimes repeatedly captured.

Stored data

- Data stored redundantly in multiple files and/or databases
- Data is redundantly stored and repeatedly captured on more than one system. This is also a result of not making use of one general system where all data is captured.
- Stored data is inaccurate
- Data is not well organised
- Data is not flexible – not easy to meet new info needs from stored data
- Data is not accessible

3. ECONOMICS

Costs

- Costs are unknown
- Costs are untraceable to source
- Costs are too high

Profits

- Can new sources of maintenance suppliers/services be explored
- Can current sources of maintenance suppliers/services be improved

4. CONTROL (and Security)

- Too little security or control
- Input data not adequately edited
- Crimes committed against data
- Ethics are breached on data – data getting to unauthorised persons
- Redundantly stored data is Inconsistent and in different files or data basis
- Data privacy regulations are being violated
- Processing errors are occurring – by man, machine and interface
- Decision-making errors are occurring
- Too much control or security
- Bureaucratic red tape slows the system
- Controls inconvenience customers or employees
- Information is redundantly generated

5. EFFICIENCY

- People, machines or computers waste time
- Data is redundantly input or copied
- Data is redundantly generated
- People, machines or computers waste materials and supplies
- Effort required for tasks is excessive
- Materials required for tasks is excessive

6. SERVICE

- The system produces inaccurate results
- The system produces inconsistent results

- The system produces unreliable results
- The system is not user friendly and not easy to learn
- The system is not easy to use
- The system is awkward to use
- The system is inflexible to new or exceptional situations
- The system is inflexible to change
- The system is incompatible with other systems
- The system is not co-ordinated with other systems

PIECES Problem-Solving Framework and Checklist

	GSB MOD	SAMHS	SA ARMY	WKLF	MDW	NBS	YFLD	AVG
PERFORMANCE								
A. Throughput – the amount of work performed over some period of time (repairs per month)	120 repairs / mnth	21	30	20	44	75	32	49
B. Response times – the avg. delay between a transaction or request and a response to that transaction or request	1 day	1day	1day	1day	1day	1day	1day	1day
INFORMATION (and Data)								
A. Outputs								
1. Lack of info	1	1	1	1	0	0	0	1
2. Too much info	0	0	0	0	0	0	0	0
3. Info not relevant or useful	0	0	0	0	0	0	0	0
4. Incorrect info	0	1	1	1	1	0	1	1
B. Inputs	0	0	0	0	0	0	0	0
1. Data is not captured	0	0	0	0	1	0	0	0
2. Data difficult to capture	1	1	1	0	0	0	1	1
3. Too much data is captured or repeatedly captured	1	0	0	0	0	1	0	0
C. Stored data	0	0	0	0	0	0	0	0
1. Data stored redundantly in multiple files &/ databases	1	1	1	0	0	1	0	1
2. Stored data is inaccurate	1	1	1	1	0	0	0	1
3. Data is not well organised	1	1	1	1	0	1	0	1
4. Data is not flexible – not easy to meet new info needs from stored dat	0	0	0	0	0	0	0	0
5. Data is not accessible	1	1	1	0	0	0	0	0

	GSB MOD	SAMHS	SA ARMY	WKLF	MDW	NBS	YFLD	AVG
ECONOMICS								
A. Costs	0	0	0	0	0	0	0	0
1. Costs are unknown	0	0	0	0	0	0	0	0
2. Costs are untraceable to source	0	1	1	1	0	0	0	1
3. Costs are too high	1	1	1	1	1	1	1	1
B. Profits	0	0	0	0	0	0	0	0
1. Can new sources of maint suppliers/services be explored	1	1	1	1	1	1	1	1
2. Can current sources of maint suppliers/services be improved	1	1	1	1	1	0	1	1
CONTROL (and Security)								
A. Too little security or control	0	0	0	0	0	0	0	0
1. Input data not adequately edited	1	1	1	1	0	1	0	1
2. Crimes committed against data	1	1	1	0	0	1	0	1
3. Ethics are breached on data – data getting to unauthorised persons	1	1	1	0	0	0	0	0
4. Redundantly stored data is Inconsistent and in different files or	1	1	1	0	1	1	0	1
data basis	0	0	0	0	0	0	0	0
5. Data privacy regulations are being violated	1	1	1	0	1	0	0	1
6. Processing errors are occurring – by man, machine and interface.	1	1	1	1	1	0	0	1
7. Decision making errors are occurring	1	1	1	1	1	0	0	1
B. Too much control or security	0	0	0	0	0	0	0	0
1. Bureaucratic red tape slows the system	1	1	1	1	1	1	1	1
2. Controls inconvenience customers or employees	1	1	1	1	1	1	1	1
3. Information is redundantly generated	1	1	1	0	0	0	0	0

	GSB MOD	SAMHS	SA ARMY	WKLF	MDW	NBS	YFLD	AVG
EFFICIENCY								
A. People, machines or computers waste time	0	0	0	0	0	0	0	0
1. Data is redundantly input or copied	1	1	1	0	0	0	0	0
2. Data is redundantly generated	1	1	1	0	0	0	0	0
B. People, machines or computers waste materials and supplies	1	1	1	0	0	0	0	0
C. Effort required for tasks is excessive	1	1	1	1	1	1	1	1
D. Materials required for tasks is excessive	1	1	1	1	0	0	0	1
SERVICE								
A. The system produces inaccurate results	1	1	1	1	0	0	0	1
B. The system produces inconsistent results	1	1	1	1	0	0	0	1
C. The system produces unreliable results	1	1	1	1	0	0	0	1
D. The system is not user friendly and not easy to learn	1	1	1	0	0	0	0	0
E. The system is not easy to use	1	1	1	1	0	0	0	1
F. The system is awkward to use	1	1	1	1	0	0	0	1
G. The system is inflexible to new or exceptional situations	0	1	1	0	0	0	0	0
H. The system is inflexible to change	0	0	0	0	0	0	1	0
I. The system is incompatible with other systems	1	1	0	0	0	0	1	0
J. The system is not coordinated with other systems	1	1	1	1	1	0	1	1

STATISTICS

For a certain level of confidence in statistical data, the size of the sample needs to be determined. The value x_i denotes the number of maintenance requests for a particular month i. The number of observations was determined accordingly.

Sample size calculation				
	x value			**(xi - x Avg)^2**
x1 =	100	Apr '02		838.480
x2 =	115	May '02		1932.176
x3 =	54	June '02		290.480
x4 =	85	July '02		194.784
x5 =	116	Aug '02		2021.089
x6 =	61	Sep '02		100.871
x7 =	65	Oct '02		36.524
x8 =	96	Nov '02		622.828
x9 =	60	Des '02		121.958
x10 =	70	Jan '03		1.089
x11 =	67	Feb '03		16.350
x12 =	15	Mrt '03		3140.871
x13 =	82	Apr '03		120.045
x14 =	74	May '03		8.741
x15 =	86	June '03		223.698
x16 =	83	July '03		142.958
x17 =	69	Aug '03		4.176
x18 =	71	Sep '03		0.002
x19 =	92	Oct '03		439.176
x20 =	51	Nov '03		401.741
x21 =	25	Dec '03		2120.002
x22 =	87	Jan '04		254.611
x23 =	10	Feb '04		3726.306
x Avg =	71.04348		Total =	16758.957
			n =	23
			k =	0.1
			t =	1.721
			s =	27.600
Number of observations =			**44.703**	

For a confidence level of 90%, it was determined that at least 45 observations be made. The analysis was done and is shown in the tables below.

INDEX	M-nr	NH/nr	DD456 (TPT)	DD1813 (LWT Plan)	DD1628 Inspected	Receive DATABASE	Receive Quotes	Print GO (PROC)	Complete repair	Invoice to PROC	Out Inspect	Complete DD1813	Release vehicle
1	BLL867	979	2003/01/14	2003/01/30	2003/01/28		2003/02/07	2003/06/12	2003/06/20	2003/06/25	2003/06/26	2003/06/26	2003/06/28
2	BLC760	776	2002/10/21	2002/11/04	2002/10/23		2002/11/11	2002/11/18	2002/11/29	2003/11/29	2002/12/03	2002/12/02	2002/12/03
3	BLC199	571	2002/08/14	2002/08/21	2002/08/21	2002/08/23	2002/09/23	2002/11/11	2002/12/02	2002/12/02	2002/12/06	2002/12/02	2002/12/06
4	BLB696	407	2002/07/09	2002/07/10	2002/07/10		2003/05/22	2003/06/13	2003/06/19	2003/06/24	2003/06/25	2003/06/24	2003/06/25
5	BLB171	562	2003/08/25	2003/08/26	2003/09/23		2003/10/06	2003/10/30	2003/11/05	2003/11/06	2003/11/07	2003/11/05	2003/11/07
6	BLK994	187	2003/06/03	2003/06/03	2003/06/03		2003/06/04		2003/06/25	2003/06/25	2003/06/26	2003/06/25	2003/06/26
7	BLL472	17	2003/03/17	2003/04/07	2003/03/28		2003/05/27		2003/05/29	2003/05/29	2003/05/30	2003/05/30	2003/05/30
8	BLM791	994	2003/01/31	2003/02/04	2003/01/31		2003/02/07		2003/02/25	2003/02/25	2003/02/25	2003/02/26	2003/02/26
9	BLL348	962	2003/01/23	2003/01/23	2003/01/23		2003/01/31	2003/02/19	2003/02/27	2003/03/03	2003/03/04	2003/03/03	2003/03/04
10	BLG644	603	2003/09/30	2003/09/30	2003/10/06		2003/10/14		2003/11/17	2003/11/17	2003/12/03	2003/11/17	2003/12/03
11	BKW170	72	2003/04/07	2003/04/22	2003/04/24		2003/05/08		2003/06/02	2003/06/02	2003/06/09	2003/06/03	2003/06/09
12	BKP010	420	2002/07/04	2002/07/15	2002/07/09		2002/07/26	2002/08/22	2002/09/03	2002/09/03	2002/09/12	2002/09/12	2002/09/12
13	BLJ842	550	2003/09/10	2003/09/15	2003/09/17		2003/09/25	2003/11/21	2003/11/24	2003/11/27	2003/12/01	2003/11/27	2003/12/01
14	BKV526	369	2003/07/10	2003/07/11	2003/07/15		2003/07/25		2003/09/25	2003/09/25	2003/10/30	2003/10/30	2003/10/30
15	BKP143	65	2003/04/14	2003/04/15	2003/04/16		2003/05/09		2003/06/17	2003/06/17	2003/06/19	2003/06/19	2003/06/19
16	BLL347	394	2003/07/22	2003/07/23	2003/07/25		2003/08/04		2003/08/27	2003/08/27	2003/08/29	2003/08/27	2003/09/02
17	BKN735	671	2003/10/21	2003/10/21	2003/10/21		2003/11/04	2003/11/20	2003/12/05	2003/12/07	2004/01/28	2003/12/07	2004/01/28
18	BLG975	674	2003/10/13	2003/10/14	2003/10/27		2003/12/04	2003/11/27	2003/12/11	2003/12/12	2004/01/21	2003/12/12	2004/01/21
19	BLL820	372	2002/06/24	2002/06/28	2002/06/26		2002/07/04	2002/07/16	2002/07/19	2002/07/19	2002/07/22	2002/07/20	2002/07/22
20	BKZ914	397	2003/07/03	2003/07/23	2003/07/28		2003/08/04		2003/08/15	2003/08/15	2003/08/15	2003/08/15	2003/08/18
21	BKW150	1082	2003/02/28	2003/03/05	2003/03/03		2003/04/07		2003/06/03	2003/06/03	2003/06/10	2003/06/03	2003/06/10
22	BLL261	128	2003/05/06	2003/05/06	2003/05/06		2003/05/14		2003/07/07	2003/07/09	2003/07/10	2003/07/09	2003/07/10
23	BLM089	989	2003/01/29	2003/01/31	2003/01/30		2003/02/07		2003/03/12	2003/03/12	2003/03/12	2003/03/12	2003/03/12
24	BKT471	636	2002/08/27	2002/09/18	2002/09/13		2002/09/26	2002/10/09	2002/10/30	2002/11/01	2002/11/28	2002/11/01	2002/11/28
25	BLM955	549	2003/09/16	2003/09/16	2003/09/17		2003/09/25		2003/10/09	2003/10/09	2003/10/10	2003/10/09	2003/10/10
26	BLL608	730	2003/11/04	2003/11/06	2003/11/10		2003/11/13		2003/11/19	2003/11/18	2003/11/19	2003/11/19	2003/11/19
27	BLL154	1101	2003/03/20	2003/03/24	2003/03/24		2003/04/04		2003/06/02	2003/06/04	2003/06/05	2003/06/04	2003/06/05
28	BLL139	356	2003/07/14	2003/07/14	2003/07/14		2003/08/01		2003/09/15	2003/09/15	2003/09/22	2003/09/21	2003/09/22
29	BLL768	704	2003/10/29	2003/10/30	2003/11/03		2003/11/11		2003/11/26	2003/11/26	2003/11/27	2003/11/26	2003/11/27
30	BLB593	248	2003/04/11	2003/06/12	2003/06/17		2003/08/27		2003/09/04	2003/09/04	2003/09/29	2003/09/23	2003/09/29
31	BLL485	700	2003/10/22	2003/10/23	2003/11/03		2003/11/12		2003/11/20	2003/11/20	2003/11/21	2003/11/21	2003/11/24
32	BLB604	767	2002/10/24	2002/10/25	2002/10/25		2003/06/27		2003/07/11	2003/07/11	2003/07/14	2003/07/15	2003/07/15
33	BLH877	283	2003/06/23	2003/06/27	2003/06/30		2003/07/22	2003/08/28	2003/09/10	2003/09/12	2003/09/12	2003/09/12	2003/09/12
34	BLM096	602	2003/07/21	2003/07/21	2003/07/21		2003/07/28		2003/08/15	2003/08/15	2003/08/25	2003/08/15	2003/08/26
35	BLH767	1088	2003/03/05	2003/03/07	2003/03/06		2003/03/31	2003/05/08	2003/05/16	2003/05/20	2003/06/02	2003/06/04	2003/06/04
36	BGP079	959	2003/01/13	2003/01/24	2003/01/22		2003/04/10	2003/05/29	2003/05/26	2003/06/12	2003/06/18	2003/06/17	2003/06/19
37	BLF010	134	2003/05/06	2003/05/07	2003/05/09		2003/05/21		2003/09/16	2003/09/16	2004/01/16	2003/09/16	2004/01/20
38	BLH872	167	2003/05/13	2003/05/20	2003/05/20		2003/05/27		2003/06/17	2003/06/17	2003/06/19	2003/07/14	2003/07/14
39	BLH620	11	2003/03/24	2003/04/07	2003/03/27		2003/04/17	2003/05/15	2003/05/22	2003/05/22	2003/05/22	2003/05/22	2003/05/22
40	BLH768	511	2003/08/25	2003/08/26	2003/09/08		2003/09/23		2003/10/20	2003/10/20	2003/10/23	2003/10/20	2003/10/23
41	BLH713	848	2002/11/13	2002/11/21	2002/11/20		2002/12/03	2003/01/21	2003/01/31	2003/01/31	2003/02/07	2003/02/07	2003/02/07
42	BLL104	211	2003/06/06	2003/06/06	2003/06/09		2003/06/24		2003/07/25	2003/07/25	2003/07/29	2003/07/30	2003/08/01
43	BLG796	1070	2003/02/26	2003/02/26	2003/02/26		2003/03/04	2003/05/20	2003/05/23	2003/05/26	2003/05/28	2003/05/26	2003/05/29
44	BLL656	629	2003/10/03	2003/10/09	2003/10/09		2003/10/24	2003/12/08	2003/12/17	2003/12/18	2003/12/22	2003/12/18	2003/12/22
45	BLD462	186	2003/05/28	2003/05/29	2003/05/29		2003/10/02		2003/10/15	2003/10/14	2003/10/27	2003/10/15	2003/10/28

DURATIONS

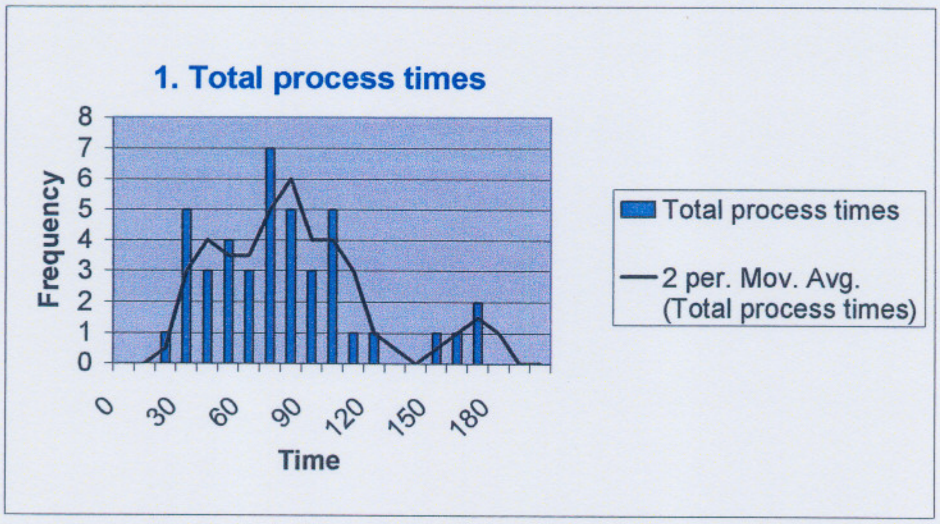
1. Total Process Time	2. TPT to LWT Planning	3. Plan to 1st Inspect	4. 1st Inspect to quote received	5. Quote received to Repair done	6. Repair done to Out Inspect	7. Repair done to vehicle receive	8. Jobcard complete to Out Inspect
164	16	-2	9	133	6	8	0
42	13	-11	18	18	4	4	1
112	7	0	32	69	4	4	4
346	1	0	312	27	6	6	1
72	1	27	13	29	2	2	2
23	0	0	1	21	1	1	1
73	20	-9	59	2	1	1	0
26	4	-3	7	18	0	1	-1
41	0	0	8	27	7	7	1
63	0	6	8	33	16	16	16
62	15	2	14	24	7	7	6
68	11	-6	17	37	9	9	0
81	5	2	8	59	7	7	4
110	1	4	10	60	35	35	0
65	1	1	23	38	2	2	0
40	1	2	9	23	2	5	2
97	0	0	13	31	53	53	51
98	1	13	37	7	40	40	39
28	4	-2	8	15	3	3	2
45	20	5	6	11	0	3	0
100	5	-2	34	56	7	7	7
64	0	0	8	53	3	3	1
43	2	0	7	35	0	0	0
91	21	-5	13	34	28	28	27
24	0	1	8	14	1	1	1
15	2	4	3	6	0	0	0
75	4	0	10	58	3	3	1
68	0	0	17	44	7	7	1
28	1	3	8	15	1	1	1
168	61	5	70	7	25	25	6
32	1	10	9	8	1	4	0
261	1	0	242	14	3	4	-1
79	4	3	22	48	2	2	0
35	0	0	7	17	10	11	10
89	2	-1	25	46	16	18	-2
156	11	-2	78	46	22	23	1
254	1	2	12	115	120	124	120
61	7	0	7	20	2	27	-25
58	13	-10	20	35	0	0	0
58	1	12	15	27	3	3	3
84	8	-1	13	58	7	7	0
55	0	3	15	31	4	6	-1
93	0	0	8	79	5	6	2

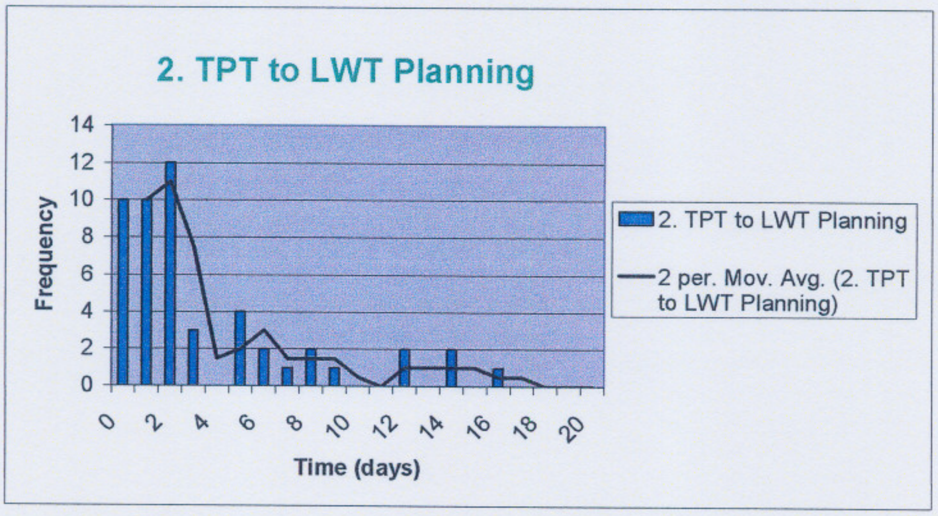
GRAPH INFORMATION

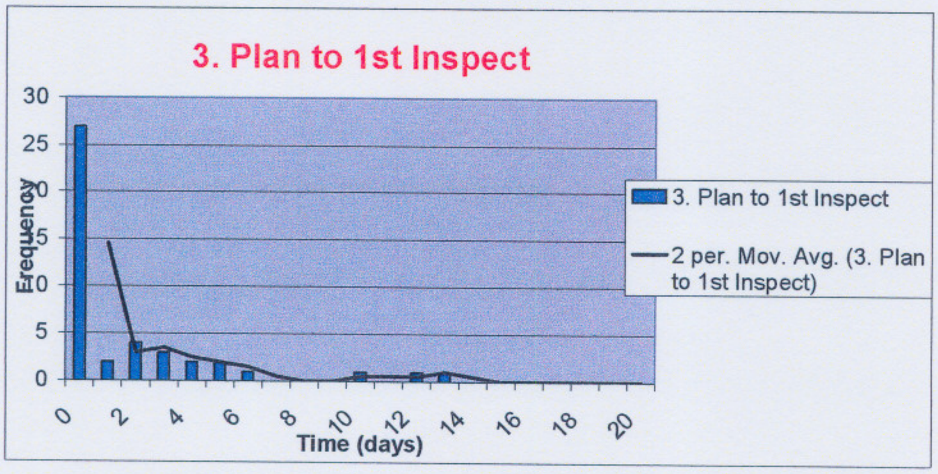
Graph intervals (10's)	Graph intervals (5's)	Graph intervals (1's)	1. Total process times	2. TPT to LWT Planning	3. Plan to 1st Inspect	4. 1st Inspect to quote received	5. Quote received to Repair done	6. Repair done to Out Inspect
0	0	0	0	10	27	0	0	5
10	5	1	0	10	2	20	5	20
20	10	2	1	12	4	13	10	10
30	15	3	5	3	3	3	7	1
40	20	4	3	0	2	3	8	2
50	25	5	4	4	2	0	4	2
60	30	6	3	2	1	1	7	1
70	35	7	7	1	0	1	1	1
80	40	8	5	2	0	1	1	1
90	45	9	3	1	0	0	0	0
100	50	10	5	0	1	0	0	0
110	55	11	1	0	0	0	0	1
120	60	12	1	2	1	0	1	0
130	65	13	0	0	1	1	0	0
140	70	14	0	2	0	0	1	0
150	75	15	1	0	0	0	0	0
160	80	16	1	1	0	0	0	0
170	85	17	2	0	0	0	0	0
180	90	18	0	0	0	0	0	0
190	95	19	0	0	0	0	0	0
200	100	20	0	0	0	0	0	0

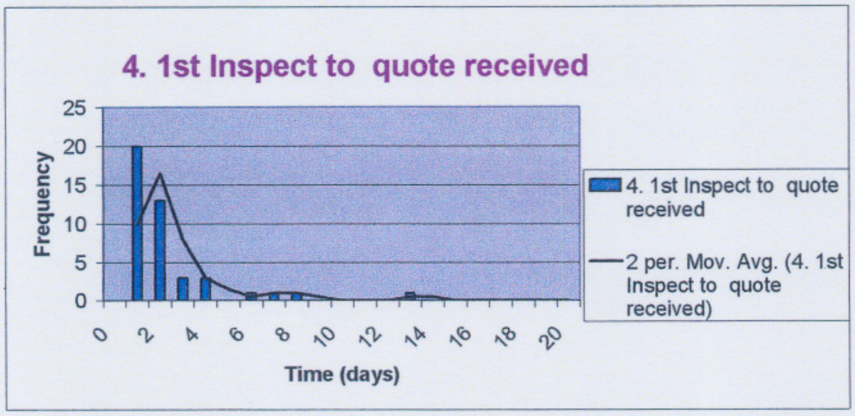
AVG	AVG	AVG	AVG	AVG	AVG
86.13333	6.066667	1.133333	31.13333	35.86667	10.93333
STDEV	STDEV	STDEV	STDEV	STDEV	STDEV
66.53762	10.33837	6.099925	58.63237	26.85703	20.18032
VAR	VAR	VAR	VAR	VAR	VAR
4427.255	106.8818	37.20909	3437.755	721.3	407.2455

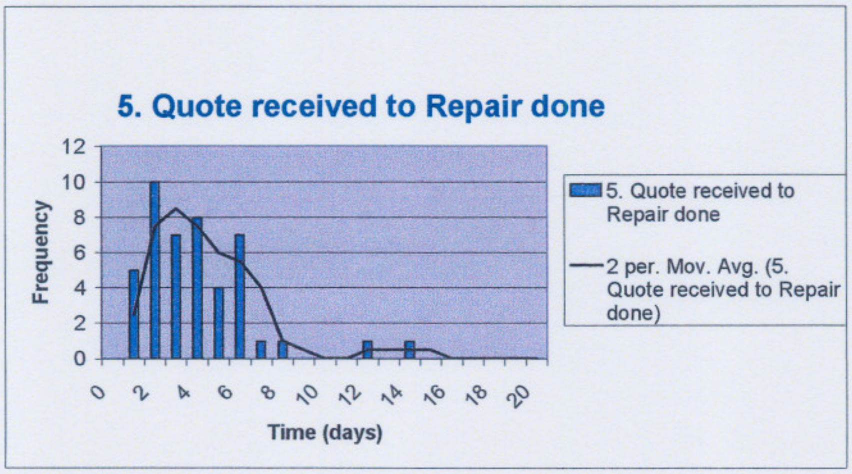
Graphs (Histograms) of evaluated times during maintenance process

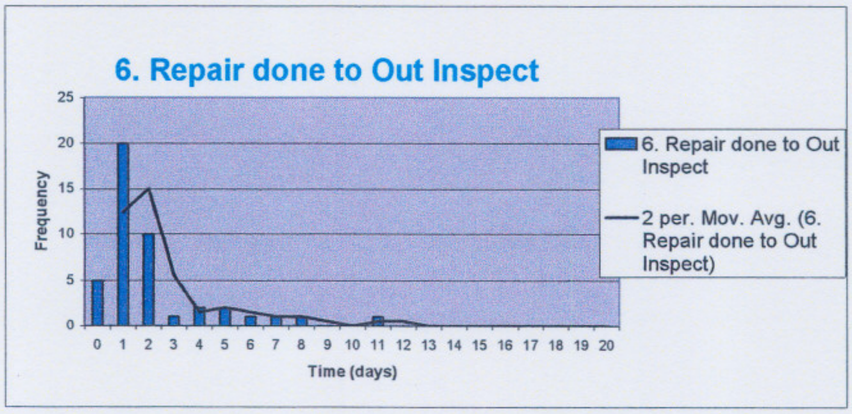


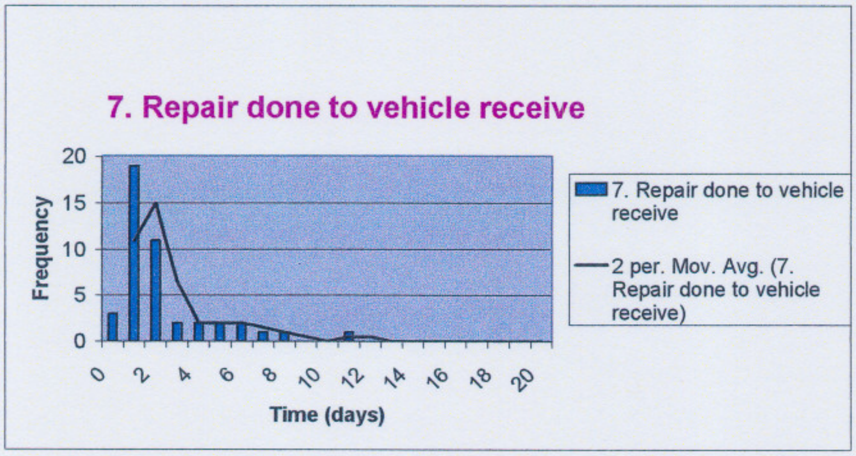


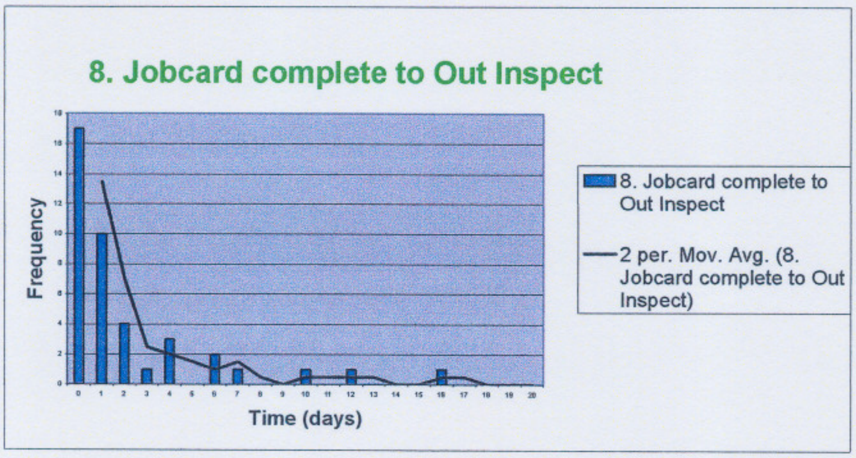



4. 1st Inspect to quote received
25
20
15
10
5
0
Frequency
0
2
4
6
8
10
12
14
16
18
20
Time (days)
4. 1st Inspect to quote received
2 per. Mov. Avg. (4. 1st Inspect to quote received)


5. Quote received to Repair done
12
10
8
6
4
2
0
Frequency
0
2
4
6
8
10
12
14
16
18
20
Time (days)
5. Quote received to Repair done
2 per. Mov. Avg. (5. Quote received to Repair done)


6. Repair done to Out Inspect
25
20
15
10
5
0
Frequency
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time (days)
6. Repair done to Out Inspect
2 per. Mov. Avg. (6. Repair done to Out Inspect)





The process was divided into sub-processes in order to do interval time measurements. The above analysis and graphs shows certain delays within the process denoting time distribution of each of the sub-processes. This type of analysis was particularly important in determining exact steps within the process that causes delays and result in a poor total process time.

The average total process time was calculated to be 86.1 days. Interesting observations were the average time it took to obtain three quotes, it was 31.1 days. And the time to repair a vehicle by a supplier was 36.9 days. These two observations alone revealed some improvement options to take into account in proposing a new process. Other observations were taken into account in the design phase to optimise the proposed process.

SIMULATION NOTES

A generic simulation model of the current process was built on the computer package ARENA. The model was used to simulate the current process to identify problem areas in the process.

The statistical information used in the model was mostly obtained from the General Support Base at the Minister of Defence (GSB MOD). This information was used since it was the most accurate and complete information gathered from the investigation. The statistics is based on a 90% confidence level.

Statistics were gathered from the model. These statistics were also used in the process analysis discussed earlier.

1. MODEL DESCRIPTION

The D-vehicle maintenance process was simulated. The process starts when a client arrives at the Transport Park and completes a work requisition to repair or service a vehicle. The work requisition is then referred to the Technical Centre (TC), which starts the maintenance process making use of resources such as procurement, finance and the client. In the model the TC responsibility is divided into two sections namely the Technical Centre Administration and Technical Centre Inspectors.

1.1 Conceptual Translation of Model

The conceptual translation of the model describes the logic, assumptions, entities, attributes, resources, queues and statistics of the model.

1.2 Logic

The logic of the model can be described in the following steps. The information in brackets is the distributions used. The first distribution is an exponential distribution that is used to represent the process, defined in the model as: Exp (exponential distribution characteristic). The second distribution is a triangular distribution that is used to represent a delay, defined in the model as: Tri (min, mean, max). These distributions fitted the data best and gave reliable statistical information.

- Create work requisition (Exp (0.153) days, Tri (0,4,7.8) days).
- Open works order to do in-inspection (Exp (15) minutes, Tri (0,1.12,4.9) days).
- Inspector does in-inspection (Exp (1) hour, Tri (0,5.49,19.9) days).
- Procurement allocates three suppliers from database (Exp (10) minutes, Tri (0,5.65,9.3) days).
- Technical Centre clerk request for quotations from suppliers (Exp (1) hour).
- Supplier's quotes on tasks (Tri (0,8.166,24.3) days).
- Technical Centre clerk completes comparative list and FA request (Exp (1) hour, Tri (0,4,6.918) days).
- SSTC checks for procedural correctness of quotation process (Exp (1) hour, Tri (0,5,7.35) days).
- Client approves FA (Exp (1) hour, Tri (0,5,7.168) days).
- Procurement decides if it is a GO or CAS payment (50-50 two way by chance).
- Procurement prints and signs the GO (Exp (1) hour, Tri (0,5,7.618) days).
- Inspector deliver vehicle to supplier (Exp (1) hour, Tri (0,1.5,4.3511) days).
- The supplier repairs the vehicle (Exp (2) hour, Tri (0,5,8.99) days).
- Inspector does inspection at supplier and collect vehicle (Exp (2) hour, Tri (0,4.655,6.1585) days).
- Inspector does out-inspection (Exp (2) hour, Tri (0,1.6875,3.2809) days).

- Technical Centre clerk completes work order (Exp (15) minutes, Tri (0,1.5625,3.19375 days).
- Vehicle is released to Transport, disposing of the initial work requisition (Exp (10) min, Tri (0,3.893,7.2729) days).

1.3 Assumptions

The following assumptions were made:

- A works requisition arrives individually – only one at a time.
- Clients complete only one requisition at a time.
- Only one vehicle is serviced at a time at a supplier.
- Only one vehicle is released at a time to transport.
- Grouping of work requisitions, works orders, comparative list and FA requests are done. To accommodate for the grouping or batching, delays are build into the model.
- A works requisition is transformed into a works order, then a quote, FA request, FA approval and then finally a vehicle. This is how the status of the request changes throughout the system.
- All process distributions are exponential. An exponential distribution is used to model intervened times in random arrival and breakdown processes. For the processes in the model, the exponential distribution was the most appropriate approach.
- All delay distributions are triangular. A triangular distribution is used to represent the minimum, maximum and most likely values. The triangular distribution best fitted the delays in the process since the most likely values were known from the information obtained from the investigation.

1.4 Entities

Entities are the dynamic objects in the simulation – they usually are created, move around for a while and then are disposed of as they leave. Some entities may never leave the system, but float around or keep circulating in the system. In the process, only a works requisition is created.

1.5 Attributes

Attributes individualise entities. It is a common characteristic of an entity. The status of the works requisition changes throughout the process. It could therefore be thought of the attributes of the entity, works requisition.

1.6 Resources

The following resources were identified:

- Technical Centre clerk (capacity = 3).
- Inspector (capacity = 7).
- SSTC (capacity = 1).
- Client (capacity = 20).
- Procurement personnel (capacity = 1).
- Supplier (capacity = 30).

1.7 Queues

The following queues are used in the model:

- Create works order queue.
- In-inspection queue.
- Allocate three suppliers queue.

- Request quotations queue.
- Complete comparative list and FA request queue.
- SSTC queue.
- Client approves FA or CAS queue.
- Print and sign GO queue.
- Deliver GO and vehicle to supplier queue.
- Supplier repair vehicle queue.
- Inspector inspect vehicle and collect invoice and vehicle queue.
- Deliver vehicle to supplier queue.
- Inspector inspects vehicle queue.
- Inspector draw cash queue.
- Inspector pay supplier and collect vehicle queue.
- Inspector consolidate cash queue.
- Out-inspection queue.
- Complete works order queue.
- Release vehicle to the Transport Park queue.

1.8 Statistics

The following statistics were gathered from the simulation:

- The value, non-value adding and total time of an entity in the system.
- Total number of entities in, out of and being processed in the system.
- Queuing time of entities.
- Queuing quantity of entities.
- Resource utilisation.
- Average total time of an entity in the system.

2. SIMULATION TIME

For the model to produce reliable results, the simulation runtime had to be determined. Striving for a confidence significance of at least 90%, the moving average and batch means methods were used to determine this run length. The simulation was run and set to produce the average total process times of the replications done. As the replications increased, it was concluded that the system is stable from the first replication and it was thus not necessary to determine an ultimate simulation run length. The simulation was done for 250 replications of 254 working days in a year. It was found to be significant as the results obtained were more than 90% reliable. This was tested using the moving average method to determine how many runs should suffice to produce reliable enough results, as can be seen from the moving average plot of the total process times of 250 replications. From this it is evident that the information obtained from the model and simulation is highly reliable and a true representation of the real world system. Analysis was done on the statistical output of this simulation and will be addressed later in the report.

3. INPUT PARAMETERS

Mostly task or action times were used as inputs to the system. Notably, delays were deliberately designed into the system as to recognise the exact bottlenecks and problem areas in the process. The following input parameters were used to build the simulation model:

- Number of works orders per year.
- Time to create a works order.
- Time to do an In-inspection.
- Time to allocate three suppliers.
- Time to request for quotations.
- Time to complete a comparative list and FA request.

- Time to complete a SSTC meeting.
- Time the client takes to approve a FA or CAS.
- Time to print and sign a GO.
- Time to deliver the vehicle to the supplier.
- Time the supplier takes to repair a vehicle.
- Time to do an inspection at the supplier.
- Time to draw cash.
- Time to collect the vehicle from the supplier.
- Time to consolidate the cash.
- Time to do an Out-inspection.
- Time to complete a works order.
- Time to release a vehicle to the Transport Park.

4. VERIFICATION AND VALIDATION

4.1 Verification

The task of ensuring that the model behaves as you intended – also debugging. The following verification criteria were identified:

- Debug model and ensure that it works correctly.
- Verify that the computer representation represents the conceptual model.
- Walk through logic and ensure it is correct and complies with information gathered.
- Ensure that the right things are happening.

4.2 Validation

Validation is the task of ensuring that the model behaves the same as the real system. The following verification criteria were identified:

- Ensure that input distributions match observations.
- Ensure that the output match with those from reality.
- Ensure that model capture and predict the events of the real system.

5. SUMMARY RESULTS

The results could be evaluated from the overview as follows:

System - *The system output was 1040 completed requests out of 1661 requests.* That is a throughput percentage of 62.6 %of all requests are completed per year.

Entity time - Process times during the process are defined as value adding or not. Mostly all delays are non-value adding tasks and tasks adding value to the completion of the process obviously are defined as value adding tasks. Out of the total average process time of 626.27 hours, only 14.69 hours were value-adding tasks. 93.55 Hours were waiting times and enormously 518.03 hours were spent on non-value adding tasks such as delays.

Entity other - As concluded, only 1040 of the 1661 requests were completed in a year's time and on average, 437.96 tasks were in progress.

Resource usage - The utilisation of the different resources was as follows:

Resource	Max Utilisation (%)	Ave Utilisation (%)
Client	40	3
Inspector	100	70
TC Clerk	100	83
Procurement Pers	100	42
SSTC Pers	100	62
Supplier	43	4

From the table, which contains the values obtained from the categorised overview output, it can be seen that the suppliers and clients are not utilised very much in the process. However these two resources are not utilised very much, their involvement could still produce timely delays and should be addressed. The rest of the resources have much higher utilisation rates that are more acceptable, as one needs to make enough use of one resources as not to have them sitting around (if it is people) and getting paid for doing nothing. This will not be cost effective, thus one have to use resources optimally to be economical.

Resource	**Appointed**	**Max usage**	**Ave Usage**
Client	20	8	0.6
Inspector	7	7	4.9
TC Clerk	3	3	2.5
Procurement Pers	1	1	0.4
SSTC Pers	1	1	0.6
Supplier	30	13	1.1

From the above table it is evident that the resources are mostly used to a near maximum availability, except for the clients and suppliers who are more than enough. The high resource usage supports the complaints of understaffing, as documented from the investigation and addressed later on in the report.

Resource	**Max number seized**	**Ave number seized**
Client	1344	1240
Inspector	8307	7933
TC Clerk	7706	7372
Procurement Pers	2245	2096
SSTC Pers	1362	1268
Supplier	1253	1168

The values from the above table provide an indication of the allocation of resources throughout the process. These values are the number of times an individual resource was used throughout the year respectively.

Output - The average total process time was 626.27 hours. That is roughly 15 weeks, to maintain a vehicle. This includes the servicing or repair of the vehicle, being scheduled for service or repaired after being damaged in an accident for example.

Visually, there seems to be a lot of bottlenecks in the process. Identified bottlenecks are primarily at inspections and approval committees. Supplier and client involvement also slows the process to a great extent and overall too many delays between actions are occurring. The delays are mostly caused by a lack of personnel taking responsibility, lack of enthusiasm, education and training and importantly a lack of communication. Lastly the involvement of important higher authorities and managers are low. There are also a lot of delays in the process as a result of physical distance between and the presence of different involved parties (role players) in a feasible proximity from each other. The fact that some role players are not easily accessible complicates and delays the process.

Possible solutions to these visual evaluations could be to ensure better or optimum accessibility and involvement of role players and managers on different levels. Delegation of duties, when a role player is not accessible, could decrease process delays remarkably. The overall commitment and acceptance of responsibility of all players involved in the process could also make a positive difference. Re-evaluation of staffing numbers and the support structure for the maintenance of D-vehicles, could drastically improve the total process time.

REQUIREMENT ANALYSIS

1 PRINCIPLES

1.1 System

1.1.1 Accountable

The process will be accountable if it is possible to explain and trace all process actions.

Fully – each action in the process is clearly defined and explained and the outcome of each action is traceable.
Largely – each action in the process is defined and traceable.
Partial – each action in the process is defined, but not traceable.
Non-compliance – the actions are not defined and traceable.

1.1.2 Affordable

The process will be affordable if the money, means and time to implement and operate the process are reasonable and inexpensive.

Fully – The execution and operation of the process is inexpensive, not resource intensive and do not require excessive time commitment.
Largely – The execution and operation of the process is inexpensive, not resource intensive, but time consuming.
Partial – The execution and operation of the process is inexpensive, resource intensive and time consuming.
Non-compliance – the execution and operation of the process is expensive, resource intensive and time consuming.

1.1.3 Transparent

The process will be transparent if the process actions are easily perceived and understood, clear and unmistakable.

Fully – The process actions are clearly understood by all users, leaving no room for errors and misperception.
Largely – The process actions are clearly understood by all users.
Partial – Al users understand the process actions, but are not clear and confident on the actions to be taken.
Non-compliance – The users do not understand the process, leaving room for errors and misperception

1.1.4 User-friendly

The process will be user-friendly if the system users have no difficulty in understanding and completing the process actions.

Fully – The process users have no difficulty in understanding and completing the process actions without assistance.
Largely – The process users understand the process actions and are able to complete the process actions.
Partial – The process users do understand the process, but may have difficulty in completing the process actions.
Non-compliance – The process users do not understand the process and have difficulty in completing the process actions.

1.1.5 Safety

The process will be safe if it is free from risk and all the ways to operate the process unauthorised is reduced.

Fully – The process is free from the risk of accidental or dangerous operation.
Largely – The risk of accidental or dangerous operation of the process are reduced.
Partial – There is a possibility for accidental or dangerous operation of the process.
Non-compliance – There is a high risk for accidental or dangerous operation of the process.

1.1.6 Self-sustainable

The process will be self-sustainable if the process itself has the capability of using a resource without depleting or totally damaging that resource.

Fully – The process has the capability of using resources without depleting or totally damaging the resources.
Largely – The process has the capability of using resources effectively.
Partial – The process makes extensive use of resources without damaging the resource.
Non-compliance – The process do not have the capability to use resources without depleting or totally damaging the resource.

1.2 Logistic

1.2.1 Foresight

The process will have foresight if it has the ability to foresee and prepare for future needs.

Fully – The process has the capability to fully foresee future needs.
Largely – The process has the capability foresee future needs to a large extent.
Partial – The process has the capability to foresee some future needs.

Non-compliance – The process do not have the capability to foresee future needs.

1.2.2 Simplicity

The process will have simplicity if the process is not complicated or elaborated, if it is easy to understand, use and maintain.

Fully – The process is not complicated or elaborated and easy to understand and maintain.
Largely – The process is not complicated or elaborated and is understandable and maintainable.
Partial – The process is fairly complicated and elaborated and is fairly understandable and maintainable.
Non-compliance – The process is complicated and elaborated and is not is to understand and maintain.

1.2.3 Operation

The process will be operational if it as the ability to function as specified.

Fully – The process has the ability to fully function as specified.
Largely – The process has the ability to function as specified.
Partial – The process have the ability to fairly function as specified.
Non-compliance – The process do not have the ability to function as specified.

1.2.4 Sustainable

The process will be sustainable if it has the capability of using a resource so that the resource is not depleted or permanently damaged.

Fully – The process has the capability of using resources without depleting or totally damaging the resources.
Largely – The process has the capability of using resources effectively.
Partial – The process has the capability of using resources without damaging the resource.
Non-compliance – The process do not have the capability to use resources without depleting or totally damaging the resource.

1.2.5 Flexibility

The process will be flexible if it has the ability to adapt or change to suit circumstances.

Fully – The process has the ability to predict and adapt or change to suit circumstances.
Largely – The process has the ability to adapt or change to suit circumstances.
Partial – The process has the ability to adapt to some predefined circumstances.
Non-compliance – The process do not have the ability to adapt or change to suit circumstances.

1.3 Performance

1.3.1 Reliability

The process will be reliable if it is consistent in performance and quality.

Fully – The process is consistent in performance and quality.
Largely – The process is consistent in either performance or quality.
Partial – The process delivers an output.
Non-compliance – The process is not consistent in performance and quality.

1.3.2 Operable

The process will be operable if it is able to operate and produce an effect.

Fully – The process is fully operable and produces an effect.
Largely – The process is operable and produces an effect.
Partial – The process fairly operable and produces an effect.
Non-compliance – The process is not operable and do not produce an effect.

1.3.3 Maintainable

The process will be maintainable if the process can be supported and provided for.

Fully – The process can be fully supported and provided for.
Largely – The process can be supported and provided for.
Partial – The process can be fairly supported and provided for.
Non-compliance – The process cannot be supported and provided for.

1.3.4 Available

The process will be available if the process is ready or able to be used.

Fully – The process is always ready or able to be used.
Largely – The process is mostly ready or able to be used.
Partial – The process is sometimes ready or able to be used.
Non-compliance – The process is never ready or able to be used.

1.3.5 Feasible

The process will be feasible if it is likely, plausible and possible to execute.

Fully – The process is totally plausible and possible to execute.
Largely – The process is plausible and possible to execute.
Partial – The process is fairly plausible and possible to execute.
Non-compliance – The process is not plausible and possible to execute.

2 Feasibility

2.1 Technical Feasibility

The process will be technically feasible if it is technically practical and the staff has the technical expertise to implement and use the system.

Fully – The process is practical and the staff has the technical expertise to implement and use the system.
Largely – The process is practical and the staff has most of the required technical expertise to implement and use the system.
Partial – The process is fairly practical and the staff has most of the required technical expertise to implement and use the system.
Non-compliance – The process is not practical and the staff does not have the technical expertise to implement and use the system.

2.2 Operational Feasibility

The process will be operationally feasible if the solution fulfil the users' requirements, if it will have a positive impact on the users work environment and perception.

Fully – The process definitely fulfills the user requirement and has a positive impact on the user's work environment and perception.
Largely – The process fulfills the user requirement and has some positive impacts on the user's work environment and perception.

Partial – The process partially fulfills the user requirement and influences the user's work environment and perception.
Non-compliance – The process does not fulfill the user requirement and does not positively impact the user's work environment and perception.

2.3 Economic Feasibility

The process will be economic feasible if the solution is cost effective.

Fully – The process is totally cost effective.
Largely – The process is mostly cost effective.
Partial – The process is fairly cost effective.
Non-compliance – The process is not cost effective.

2.4 Schedule Feasibility

The process will be schedule feasible if the solution can be designed and implemented within an acceptable time period.

Fully – The process can be designed and implemented within the desired time period.
Largely – The process can be designed and implemented within an acceptable time period.
Partial – The process can be designed and implemented within a fairly reasonable time period.
Non-compliance – The process cannot be designed and implemented within the desired time period.

2.5 Risk Feasibility

The process will be risk feasible if the process can be successfully implemented using the technology and approach.

Fully – The process is successfully implemented using the specified technology and approach.
Largely – The process is fairly successfully implemented using specified technology and approach.
Partial – Some aspects of the process is successfully implemented using the technology and approach.
Non-compliance – The process is not successfully implemented.

3 Time

3.1 Total

The total average time it takes an entity to go through the entire maintenance process.

Fully – The total process is completed in a desired time period.
Largely – The total process is completed in an acceptable time period.
Partial – The total process is completed in a fairly reasonable time period.
Non-compliance – The total process is completed in an unacceptable time period.

3.2 Value Adding

The average cumulated time in which work is performed on an entity.

Fully – The average cumulated time work is performed on an entity is desired.

Largely – The average cumulated time work is performed on an entity is acceptable.
Partial – The average cumulated time work is performed on an entity is fairly reasonable.
Non-compliance – The average cumulated time work is performed on an entity is unacceptable.

3.3 Non-value Adding

The average cumulated time the entity is in the system and not being worked on.

Fully – The average cumulated time the entity is in the system and not being worked on is desired.
Largely – The average cumulated time the entity is in the system and not being worked on is acceptable.
Partial – The average cumulated time the entity is in the system and not being worked on is fairly reasonable.
Non-compliance – The average cumulated time the entity is in the system and not being worked on is unacceptable.

3.4 Waiting / Lead Time

The average cumulated time an entity is in a queue waiting to be worked on.

Fully – The average cumulated time the entity is in a queue waiting to be worked on is desired.
Largely – The average cumulated time the entity is in a queue waiting to be worked on is acceptable.
Partial – The average cumulated time the entity is in a queue waiting to be worked on is fairly reasonable.

Non-compliance – The average cumulated time the entity is in a queue waiting to be worked on is unacceptable.

4 Cost

4.1 Utilisation

Utilisation cost will be optimised if resource utilisation to complete the maintenance process is minimal.

Fully – Resource Utilisation cost to complete the maintenance process is minimal.
Largely – Resource Utilisation cost to complete the maintenance process is acceptable.
Partial – Resource Utilisation cost to complete the maintenance process is reasonable.
Non-compliance – Resource Utilisation cost to complete the maintenance process is high.

4.2 Maintenance

Maintenance cost will be optimised if the cost to maintain vehicles is a minimum.

Fully – The cost to maintain vehicles is a minimum.
Largely – The cost to maintain vehicles is acceptable.
Partial – The cost to maintain vehicles is reasonable.
Non-compliance – The cost to maintain vehicles is high.

5 Management

5.1 Data Capturing, Storage and Measurement

Data capturing, storage and measurement will be managed if data is captured and stored effectively and measurements are done from stored data to improve the system.

Fully – Data is captured and stored effectively and improvement measurements are done from stored data.
Largely – Data is captured and stored and some measurements are done from stored data.
Partial – Data is captured and stored redundantly and no useful improvement measurements are taken from stored data.
Non-compliance – Data is not captured and stored and no improvement measurements are taken from stored data.

5.2 Scheduling

Scheduling will be managed if a program or timetable of planned events or work is developed to optimise the utilisation of facilities, resources and time.

5.2.1 Workshop

The scheduling of workshop facilities is managed.

Fully – The scheduling of workshop is totally managed and automated.
Largely – The scheduling of workshop is well managed and automated.
Partial – The scheduling of workshop is managed.
Non-compliance – The scheduling of workshop is not managed.

5.2.2 Resources

The scheduling of resources i.e. manpower, material, etc. is managed.

Fully – The scheduling of resources is totally managed and automated.
Largely – The scheduling of resources is managed and automated.
Partial – The scheduling of resources is managed.
Non-compliance – The scheduling of resources is not managed.

5.2.3 Maintenance

The scheduling of maintenance tasks is managed.

Fully – The scheduling of maintenance is totally managed and automated.
Largely – The scheduling of maintenance is managed and automated.
Partial – The scheduling of maintenance is managed.
Non-compliance – The scheduling of maintenance is not managed.

5.3 Process

The process will be managed if the action(s) that transforms input to output under certain process governance (control) and enablers (mechanisms) over a time period are defined, monitored, measured and controlled.

Fully – The processes is fully defined, monitored, measured and controlled.
Largely – The processes is defined, monitored, measured and controlled.
Partial – The processes is partially defined, monitored, measured and controlled.
Non-compliance – The processes is not defined, monitored, measured and controlled.

5.4 Communication

Communication will be managed if information flow and data between personnel are:

- Known
- Transferred or transmitted
- Successfully conveyed
- Connected

Fully – The information flow and data are always known, transferred, conveyed and connected.
Largely – The information flow and data are mostly known, transferred, conveyed and connected.
Partial – The information flow and data are sometimes known, transferred, conveyed and connected.
Non-compliance – The information flow and data are not known, transferred, conveyed and connected

Element Identification

	Element					
	1	2	3	4	5	6
Criteria	Full Comp	Proc at TMSC	Bulk FAs	Sched Maint	Maint Cont	In-house
System						
Accountable	x	x			x	
Affordable		x	x			
Transparent	x	x		x	x	x
User-friendly		x	x	x	x	x
Safety	x	x		x	x	
Self-sustainable	x	x	x		X	
Logistic						
Foresight	x			x		
Simplicity	x	x	x			
Operation	x	x	x	x	x	x
Sustainable	x	x	x		x	
Flexibility		x	x	x	x	x
Performance						
Reliability	x				x	
Operable	x	x	x	x	x	x
Maintainable	x	x	x	x	x	
Available	x	x		x	x	x
Feasible	x	x	x	x	x	x
Technical	x	x	x	x	x	x
Operational		x	x		x	x
Economic		x	x	x	x	
Schedule		x	x			
Risk	x	x	x	x	x	x
Total	x	x	x	x	x	x
Value adding		x	x	x	x	x
Non-value adding	x	x	x	x	x	x
Waiting/lead	x				x	
Utilisation	x		x		x	
Maintenance				x		x
Data management	x		x	x	x	
Scheduling						
Workshop				x	x	x
Resources				x	x	x
Maintenance	x			x	x	x
Process	x	x	x	x	x	
Communication	x	x	x	x	x	
	23	**24**	**22**	**23**	**28**	**17**
33	69.70%	72.73%	66.67%	69.70%	84.85%	51.52%

Comparison of Alternatives

		Full computerisation	Proc personnel at TMSC	Bulk FAs	Scheduled maintenance	Maint Contract	In-house Repair & Parts contractor
	Advantages	**Alt 1**	**Alt 2**	**Alt 3**	**Alt 4**	**Alt 5**	**Alt 6**
1	Reduced transfer times between TPT and TMSC	x					
2	Improved data storage, retrieval and integrity	x					
3	Improved performance measurements	x					
4	Reduced transfer times between TMSC and Procurement		x				
5	Improved availability of Industrial Inspectors		x				
6	Improved integrity on quoting system		x				
7	The client is not involved in the maintenance process			x			
8	Administration between the TMSC and client is reduced			x			
9	Improved fund management			x			
10	Client can plan vehicle utilisation				x		x
11	Better supplier management and communication				x		x
12	Improved fleet management				x		x
13	Improved proactive maintenance				x		x
14	Reduced quoting time					x	
15	Higher quality of suppliers					x	
16	No spare parts storage, control and management	x	x	x	x	x	x
17	No quotes are required						x

		Full computerisation	Proc personnel at TMSC	Bulk FAs	Scheduled maintenance	Maint Contract	In-house Repair & Parts contractor
	Disadvantages	**Alt 1**	**Alt 2**	**Alt 3**	**Alt 4**	**Alt 6**	**Alt 9**
1	Implementation of OSIS and CALMIS is time consuming	x					
2	Cost related to the implementation of OSIS and CALMIS	x					
3	Slow learning curve	x					
4	Procurement personnel not in normal working environment		x				
5	Control and consolidation of funds can be difficult			x			x
6	Proper use of computer systems is necessary				x	x	
7	Regular revision of contract					x	
8	Restructuring of Technical Centre						x
9	Training of technical workforce						x

	Risks	**Alt 1**	**Alt 2**	**Alt 3**	**Alt 4**	**Alt 6**	**Alt 9**
1	Fewer Technical Centre personnel required	x					
2	Non-technical personnel request quotes with no technical experience		x				
3	Client do not have as much control over spending of money			x			
4	Supplier not delivering the required level of quality service					x	
5	Identification of minor repairs						x

Alternative Solution Identification

	Alternatives / Elements					
	1	2	3	4	5	6
Criteria	2	5	1,2,3,4	1,3,4,5	1,3,4 6	4,5
Principles						
System						
Accountable	1	1	1	1	1	1
Affordable	1	0	1	1	1	0
Transparent	1	1	1	1	1	1
User-friendly	1	1	1	1	1	1
Safety	1	1	1	1	1	1
Self-sustainable	1	1	1	1	1	1
Logistic						
Foresight	0	0	1	1	1	1
Simplicity	1	0	1	1	1	0
Operation	1	1	1	1	1	1
Sustainable	1	1	1	1	1	1
Flexibility	1	1	1	1	1	1
Performance						
Reliability	0	1	1	1	1	1
Operable	1	1	1	1	1	1
Maintainable	1	1	1	1	1	1
Available	1	1	1	1	1	1
Feasible	1	1	1	1	1	1
Feasibility						
Technical	1	1	1	1	1	1
Operational	1	1	1	1	1	1
Economic	1	1	1	1	1	1
Schedule	1	0	1	1	1	0
Risk	1	1	1	1	1	1
Time						
Total	1	1	1	1	1	1
Value adding	0	1	1	1	1	1
Non-value adding	1	1	1	1	1	1
Wainting/lead	1	1	1	1	1	0
Cost						
Utilisation	0	1	1	1	1	1
Maintenance	0	0	1	1	1	1
Management						
Data management	0	1	1	1	1	1
Scheduling						
Workshop	0	1	1	1	1	1
Resources	0	1	1	1	1	1
Maintenance	0	1	1	1	1	1
Process	1	1	1	1	1	1
Communication	1	1	1	1	1	1
	24	**28**	**33**	**33**	**33**	**29**
	72.73%	84.85%	100.00%	100.00%	100.00%	87.88%

Where, 1 – satisfy and 0 – not satisfy.

ASSIGNMENT OF TEST WEIGHTS

Weighted tests are comparative tests conducted when one needs to decide amongst different options. Criteria are identified according to which these options are compared with each other. Since some criteria may be more important than others, weights are assigned to each criterion.

This importance was established through the determination of the criteria that had the biggest impact on the process, in other words could cause the biggest improvement with the least amount of effort. Also, meetings with users, managers, role players and strategists together with the background of the whole assessment phase, resulted in useful inputs to determine the importance in terms of achieving the system objectives.

The different options were then evaluated individually against these criteria and given a compliance score that indicates how well the option comply with each criterion. After all the options have been scored it is multiplied by the criteria weights and added to get an overall test result for each option. The option with the highest score is then the winning option and it could be recommended. The compliance scores and weight assignment for the different tests are discussed below.

1 Compliance Scores

The compliance scores are determined according to how well an option complies with the test criteria. All the criteria to be satisfied have certain conditions to comply to and are explained in the document that contains the different improvement criteria. The compliance table is given below.

Table 1: Compliance score table

Compliance Level	Extent %	Value
Fully (F)	86 - 100	3
Largely (L)	51 - 85	2
Partially (P)	16 - 50	1
None (N)	0 - 15	0

2 Weight Assignment

Different test criteria are identified according to which the options are compared. These criteria differ in importance and are consequently ranked. Another dimension is added to this difference to emphasise the degree by which the criteria differ from one another. Rates are assigned according to this degree and the criterion's rank. By dividing the rate into the sum of all the rates, these rates are normalized and represent the respective weights for the criteria.

2.1 Principle Test

The principle test compared the alternative solutions against three criteria areas, namely logistic, performance and system principles. The weights were determined according to the importance of each criterion. Table 2 shows the weights for the principles test.

2.1.1 System Principles

It was decided that system principles were the most important since system reliability; operability, maintainability, availability and feasibility were the most important aspects an alternative could contribute to the system. System principles were assigned a rate of 100.

2.1.2 Logistic Principles

Secondly logistic principles were assigned a rate of 80 and were considered to be second most important. It addresses the accountability, affordability, transparency, user-friendliness, safety and self-sustainability of the system.

2.1.3 Performance Principles

Lastly the performance principles were considered least important and were assigned a rate of 60. It addresses the foresight, simplicity, operational, sustainability and feasibility of the system.

Table 2: Principles Test Criteria Weights

Principles Criteria	Rank	Rate	Weight
Logistic	2	80	**0.333**
Performance	3	60	**0.250**
System	1	100	**0.417**
		240	

2.2 Feasibility Test

The feasibility test compared the alternative solutions against five criteria, namely technical, operational, economic, schedule and risk feasibility. The weights were determined according to the importance of each criterion. Table 3 shows the weights for the feasibility test.

2.2.1 Risk Feasibility

The probability of successful implementation is of very high importance, since the need is to effectively solve the problem. This criterion serves then as a first filter of comparing the different alternatives. It was considered to be the most important criterion and was assigned a rate of 100.

2.2.2 Operational Feasibility

The solution should definitely fulfil the user's requirement. The user should also feel comfortable with the solution and be fully motivated to implement the recommended solution. Therefore operational feasibility was considered to be the second most important criterion and assigned a rate of 85.

2.2.3 Technical Feasibility

It is very important for the solution to be technically practical. It is however possible to propose a solution which could presently not be as technically feasible as one would have wished for, but it could be managed to make it technically feasible by implementing the necessary system or process for example. A rate of 65 was assigned to the technical feasibility of the alternative.

2.2.4 Economic Feasibility

Throughout the design of different alternative solutions, cost effectiveness was continuously considered. According to the user requirement, it is however more important to reduce the turn-around time of the maintenance process than it being cost effective. Therefore economic feasibility was assigned a rate of 45.

2.2.5 Schedule Feasibility

Schedule feasibility is the ability to design and implement the solution within an acceptable time period. Since most of the alternatives are more or less implemented at various units, no major problems are foreseen regarding this criterion. It is also justifiable to think that implementation should take a while and cannot happen over night. This criterion was therefore considered the least important and assigned a rate of 15.

Table 3: Feasibility Test Criteria Weights

Feasibility Criteria	Rank	Rate	Weight
Technical	3	65	**0.210**
Operational	2	85	**0.274**
Economic	4	45	**0.145**
Schedule	5	15	**0.048**
Risk	1	100	**0.323**
		310	

2.3 Time Test

The time test compared different time measurements of the alternative solutions. The criteria were total process time, value adding and non-value adding time as well as waiting time for the simulated processes. The weights were determined according to the importance of each criterion. Table 4 shows the weights for the time test.

2.3.1 Total time

The most important user requirement was to reduce turn-around time. For this reason the total process time for the alternatives were considered to be the most important criterion and was assigned a rate of 100.

2.3.2 Non-value Adding Time

Non-value adding times in a process are unnecessary and could improve total process time significantly if reduced. Non-value adding time was thus considered to be second most important criterion and was assigned a rate of 80.

2.3.3 Value Adding Time

Another way to improve total process times is to reduce the value adding time of the process. This is time that contributes positively to the result of the process. It was considered to be the third most important criterion and assigned a rate of 50.

2.3.4 Waiting Time

Wait time also increases total process time, but could not always be accounted for since some functions are performed outside the control of the DOD. Wait time was thus considered to be the least important and assigned a rate of 25.

Table 4: Time Test Criteria Weights

Time criteria	Rank	Rate	Weight
Total	1	100	**0.392**
Value adding	3	50	**0.196**
Non value adding	2	80	**0.314**
Wait	4	25	**0.098**
		255	

2.4 Management Test

The feasibility test compared the alternative solutions against four criteria, namely data capturing, storage and measurement, scheduling, process and communication management. The weights were determined according to the importance of each criterion. Table 5 shows the weights for the management test.

2.4.1 Scheduling

Scheduling management was considered to be the most important management criterion because of the enormous improvement effect it has on the process. It was assigned a rate of a 100.

2.4.2 Data Capturing, Storage and Measurement

Data capturing, storage and measurement was considered to be second most important since it equips fleet managers with a handy tool to better manage and control the vehicle fleet. It was assigned a rate of 90.

2.4.3 Communication

Communication management was considered the third most important criterion since it is the medium by which management is channeled through all levels of operation. It was assigned a weight of 80.

2.4.4 Process

Process management was also considered important as to better holistically monitor and control the flow of data throughout the process and was assigned a rate of 70.

Table 5: Management Test Criteria Weights

Management Criteria	Rank	Rate	Weight
Data capturing, storage and measurement	2	90	**0.265**
Scheduling	1	100	**0.294**
Process	4	70	**0.206**
Communication	3	80	**0.235**
		340	

2.5 Cost Test

The cost test compared the alternative solutions against two criteria, namely utilisation and maintenance cost. The weights were determined according to the importance of each criterion. Table 6 shows the weights for the cost test.

2.5.1 Maintenance Cost

Maintenance cost was considered to be the most important criterion to ensure an economic maintenance process. It was assigned a rate of 100.

2.5.2 Utilisation Cost

Utilisation cost was also considered to be an important cost-reducing criterion and was assigned a rate of 80.

Table 6: Cost Test Criteria Weights

Cost Criteria	Rank	Rate	Weight
Utilisation	2	80	**0.444**
Maintenance	1	100	**0.556**
		180	

APPENDIX K

TESTS

Principles Test

Principles Criteria	Rank	Rate	Weight
Logistic	2	80	**0.333**
Performance	3	60	**0.250**
System	1	100	**0.417**
		240	

Compliance	Extent %	Value
Fully (F)	**86 - 100**	**3**
Largely (L)	**51 - 85**	**2**
Partially (P)	**16 - 50**	**1**
None (N)	**0 - 15**	**0**

		ALTERNATIVE SOLUTIONS					
Principle Criteria	**Weight**	**ALT 1**	**ALT 2**	**ALT 3**	**ALT 4**	**ALT 5**	**ALT 6**
Elements		**2**	**5**	**1,2,3,4**	**1,3,4,5**	**1,3,4,6**	**4,5**
1. Logistic Principles:	**0.333**	**13**	**11**	**12**	**12**	**11**	**9**
a. Accountable		2	2	3	2	2	2
b. Affordable		3	1	2	2	2	1
c. Transparent		2	2	2	2	2	2
d. User-friendly		2	2	1	2	1	1
f. Safety		2	1	2	1	2	1
g. Self sustainable		2	3	2	3	2	2
2. Performance principles:	**0.250**	**8**	**8**	**9**	**10**	**9**	**8**
a. Foresight		1	1	2	2	2	1
b. Simplicity		2	1	1	1	1	1
c. Operation		2	2	2	2	2	2
d. Sustainable		2	3	2	3	2	2
e. Flexible		1	1	2	2	2	2
3. System Principles:	**0.417**	**10**	**13**	**11**	**12**	**11**	**11**
a. Reliable		1	2	2	3	2	2
b. Operable		2	3	2	2	2	2
c. Maintainable		2	2	2	2	2	2
d. Available		2	3	2	2	2	2
e. Feasible		3	3	3	3	3	3
	Total	**10.5**	**11.08333**	**10.83333**	**11.5**	**10.5**	**9.583333**
	N~Total	**0.65625**	**0.692708**	**0.677083**	**0.71875**	**0.65625**	**0.598958**
	Rank	**4**	**2**	**3**	**1**	**4**	**6**

Feasibility Test

Feasibility Criteria	Rank	Rate	Weight
Technical	3	65	**0.210**
Operational	2	85	**0.274**
Economic	4	45	**0.145**
Schedule	5	15	**0.048**
Risk	1	100	**0.323**
		310	

Compliance	Extent %	Value
Fully (F)	**86 - 100**	**3**
Largely (L)	**51 - 85**	**2**
Partially (P)	**16 - 50**	**1**
None (N)	**0 - 15**	**0**

		ALTERNATIVE SOLUTIONS					
Feasibility Criteria	**Weight**	**ALT 1**	**ALT 2**	**ALT 3**	**ALT 4**	**ALT 5**	**ALT 6**
Elements		**2**	**5**	**1,2,3,4**	**1,3,4,5**	**1,3,4,6**	**4,5**
1. Technical	**0.210**	**2**	**2**	**2**	**2**	**1**	**2**
2. Operational	**0.274**	**1**	**2**	**3**	**3**	**3**	**2**
3. Economic	**0.145**	**3**	**2**	**2**	**3**	**1**	**2**
4. Schedule	**0.048**	**2**	**1**	**2**	**1**	**1**	**1**
5. Risk	**0.323**	**2**	**2**	**2**	**2**	**2**	**2**
	Total	**1.870968**	**1.951613**	**2.274194**	**2.370968**	**1.870968**	**1.951613**
	N~Total	**0.623656**	**0.650538**	**0.758065**	**0.790323**	**0.623656**	**0.650538**
	Rank	**5**	**3**	**2**	**1**	**5**	**3**

Time Test

Time criteria	Rank	Rate	Weight
Total	1	100	**0.392**
Value adding	3	50	**0.196**
Non value adding	2	80	**0.314**
Wait	4	25	**0.098**
		255	

		Elements						Current	Alternatives					
Time Criteria	**Weight**	**ELE 1**	**ELE 2**	**ELE 3**	**ELE 4**	**ELE 5**	**ELE 6**		**ALT 1**	**ALT 2**	**ALT 3**	**ALT 4**	**ALT 5**	**ALT 6**
1. Total	**0.392**	578.00	491.70	600.04	523.48	476.67	282.24	**626.27**	491.70	476.67	406.09	361.13	185.67	439.79
2. Value adding	**0.196**	14.69	14.73	13.70	14.48	12.69	5.84	**14.69**	14.73	12.69	14.13	11.31	4.92	12.41
3. Non value adding	**0.314**	456.71	392.24	484.98	385.93	361.46	271.47	**518.03**	392.24	361.46	223.50	173.94	176.89	282.34
4. Wait	**0.098**	106.60	84.73	101.36	123.07	102.51	4.92	**93.55**	84.73	102.51	168.47	175.88	3.86	145.04
								% improvement	**21%**	**30%**	**35%**	**42%**	**70%**	**24%**

		Alternatives					
Time Criteria	**Weight**	**ALT 1**	**ALT 2**	**ALT 3**	**ALT 4**	**ALT 5**	**ALT 6**
1. Total	**0.392**	0.00	0.03	0.17	0.27	0.62	0.11
2. Value adding	**0.196**	0.00	0.14	0.04	0.23	0.67	0.16
3. Non value adding	**0.314**	0.00	0.08	0.43	0.56	0.55	0.28
4. Wait	**0.098**	0.52	0.42	0.04	0.00	0.98	0.18
	Total	**0.050809**	**0.104685**	**0.215456**	**0.324281**	**0.642791**	**0.177399**
	N~Total	**0.050809**	**0.104685**	**0.215456**	**0.324281**	**0.642791**	**0.177399**
	Rank	**6**	**5**	**3**	**2**	**1**	**4**

Cost Test

Cost criteria	Rank	Rate	Weight
Utilisation	2	80	**0.444**
Maintenance	1	100	**0.556**
		180	

Compliance	Extent %	Value
Fully (F)	**86 - 100**	**3**
Largely (L)	**51 - 85**	**2**
Partially (P)	**16 - 50**	**1**
None (N)	**0 - 15**	**0**

		ALTERNATIVE SOLUTIONS					
Cost Criteria	**Weight**	**ALT 1**	**ALT 2**	**ALT 3**	**ALT 4**	**ALT 5**	**ALT 6**
Elements		**2**	**5**	**1,2,3,4**	**1,3,4,5**	**1,3,4,6**	**4,5**
1. Utilisation	**0.444**	3	2	2	2	2	2
2. Maintenance	**0.556**	0	2	2	2	0	2
	Total	**1.333333**	**2**	**2**	**2**	**0.888889**	**2**
	N~Total	**0.444444**	**0.666667**	**0.666667**	**0.666667**	**0.296296**	**0.666667**
	Rank	**5**	**1**	**1**	**1**	**6**	**1**

Management Tests

Management Criteria	Rank	Rate	Weight
Data capturing, storage and measurement	2	90	**0.265**
Scheduling	1	100	**0.294**
Process	4	70	**0.206**
Communication	3	80	**0.235**
		340	

Compliance	Extent %	Value
Fully (F)	**86 - 100**	**3**
Largely (L)	**51 - 85**	**2**
Partially (P)	**16 - 50**	**1**
None (N)	**0 - 15**	**0**

		ALTERNATIVE SOLUTIONS					
Management Criteria	**Weight**	**ALT 1**	**ALT 2**	**ALT 3**	**ALT 4**	**ALT 5**	**ALT 6**
Elements		**2**	**5**	**1,2,3,4**	**1,3,4,5**	**1,3,4,6**	**4,5**
1. Data capturing, storage and measurement	**0.265**	1	1	3	2	3	1
2. Scheduling	**0.294**	0	3	9	9	6	9
a. Workshop.		0	1	3	3	2	3
b. Resources		0	1	3	3	2	3
c. Maintenance		0	1	3	3	2	3
3. Process	**0.206**	1	2	2	2	2	2
4. Communication	**0.235**	2	2	2	2	2	2
	Total	0.941176	2.029412	4.323529	4.058824	3.441176	3.794118
	N~Total	0.197531	0.425926	0.907407	0.851852	0.722222	0.796296
	Rank	6	5	1	2	4	3

SOLUTION SUMMARY

Tests	Rank	Rate	Weight
Principles	1	95	**0.216**
Feasibility	3	90	**0.205**
Time	2	100	**0.227**
Management	4	80	**0.182**
Cost	5	75	**0.170**
		440	

	Weight	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Principles	0.216	0.65625	0.692708	0.67708333	0.71875	0.65625	0.598958
Feasibility	0.205	0.62365591	0.650538	0.75806452	0.790323	0.623656	0.650538
Time	0.227	0.05080882	0.104685	0.21545594	0.324281	0.642791	0.177399
Management	0.182	0.19753086	0.425926	0.90740741	0.851852	0.722222	0.796296
Cost	0.170	0.44444444	0.666667	0.66666667	0.666667	0.296296	0.666667
Total		**0.39247606**	**0.497496**	**0.62883389**	**0.65906**	**0.597163**	**0.561121**
N~Total		**0.39247606**	**0.497496**	**0.62883389**	**0.65906**	**0.597163**	**0.561121**
Rank		**6**	**5**	**2**	**1**	**3**	**4**

APPENDIX K

TESTS

Principles Test

Principles Criteria	[illegible]	[illegible]	Weight
Logistic	2	80	**0.333**
Performance	3	60	**0.250**
System	1	100	**0.417**
		240	

Compliance	[illegible]	Value
Fully (F)	**86 - 100**	**3**
Largely (L)	**51 - 85**	**2**
Partially (P)	**16 - 50**	**1**
None (N)	**0 - 15**	**0**

		ALTERNATIVE SOLUTIONS					
Principle Criteria / Element	Weight	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6
1. Logistic Principles:	**0.333**	**13**	**11**	**12**	**12**	**11**	**9**
a. Accountable		2	2	3	2	2	2
b. Affordable		3	1	2	2	2	1
c. Transparent		2	2	2	2	2	2
d. User-friendly		2	2	1	2	1	1
f. Safety		2	1	2	1	2	1
g. Self sustainable		2	3	2	3	2	2
2. Performance principles:	**0.250**	**8**	**8**	**9**	**10**	**9**	**8**
a. Foresight		1	1	2	2	2	1
b. Simplicity		2	1	1	1	1	1
c. Operation		2	2	2	2	2	2
d. Sustainable		2	3	2	3	2	2
e. Flexible		1	1	2	2	2	2
3. System Principles:	**0.417**	**10**	**13**	**11**	**12**	**11**	**11**
a. Reliable		1	2	2	3	2	2
b. Operable		2	3	2	2	2	2
c. Maintainable		2	2	2	2	2	2
d. Available		2	3	2	2	2	2
e. Feasible		3	3	3	3	3	3
	Total	**10.5**	**11.08333**	**10.83333**	**11.5**	**10.5**	**9.583333**
	N~Total	**0.65625**	**0.692708**	**0.677083**	**0.71875**	**0.65625**	**0.598958**
	Rank	**4**	**2**	**3**	**1**	**4**	**6**

Feasibility Test

Feasibility Criteria	Rank	[illegible]	Weight
Technical	3	65	0.210
Operational	2	85	0.274
Economic	4	45	0.145
Schedule	5	15	0.048
Risk	1	100	0.323
		310	

Compliance	Extent %	Value
Fully (F)	86 - 100	3
Largely (L)	51 - 85	2
Partially (P)	16 - 50	1
None (N)	0 - 15	0

		ALTERNATIVE SOLUTIONS					
Feasibility Criteria Elements	Weight	ALT 1 2	ALT 2 5	ALT 3 1,2,3,4	ALT 4 1,3,4,6	ALT 5 1,3,4,6	ALT 6 4,5
1. Technical	0.210	2	2	2	2	1	2
2. Operational	0.274	1	2	3	3	3	2
3. Economic	0.145	3	2	2	3	1	2
4. Schedule	0.048	2	1	2	1	1	1
5. Risk	0.323	2	2	2	2	2	2
	Total	1.870968	1.951613	2.274194	2.370968	1.870968	1.951613
	N~Total	0.623656	0.650538	0.758065	0.790323	0.623656	0.650538
	Rank	5	3	2	1	5	3

Time Test

Time criteria	Rank	Rate	Weight
Total	1	100	**0.392**
Value adding	3	50	**0.196**
Non value adding	2	80	**0.314**
Wait	4	25	**0.098**
		255	

		Elements						[illegible]	Alternatives					
Time Criteria	Weight	ELE 1	ELE 2	ELE 3	ELE 4	ELE 5	ELE 6		ALT 1	ALT 2	ALT 3	ALT 4	ALT 5	ALT 6
1. Total	**0.392**	578.00	491.70	600.04	523.48	476.67	282.24	**626.27**	491.70	476.67	406.09	361.13	185.67	439.79
2. Value adding	**0.196**	14.69	14.73	13.70	14.48	12.69	5.84	**14.69**	14.73	12.69	14.13	11.31	4.92	12.41
3. Non value adding	**0.314**	456.71	392.24	484.98	385.93	361.46	271.47	**518.03**	392.24	361.46	223.50	173.94	176.89	282.34
4. Wait	**0.098**	106.60	84.73	101.36	123.07	102.51	4.92	**93.55**	84.73	102.51	168.47	175.88	3.86	145.04
								% improvement	**21%**	**30%**	**35%**	**42%**	**70%**	**24%**

		Alternatives					
Time Criteria	Weight	ALT 1	ALT 2	ALT 3	ALT 4	ALT 5	ALT 6
1. Total	**0.392**	0.00	0.03	0.17	0.27	0.62	0.11
2. Value adding	**0.196**	0.00	0.14	0.04	0.23	0.67	0.16
3. Non value adding	**0.314**	0.00	0.08	0.43	0.56	0.55	0.28
4. Wait	**0.098**	0.52	0.42	0.04	0.00	0.98	0.18
	Total	**0.050809**	**0.104685**	**0.215456**	**0.324281**	**0.642791**	**0.177399**
	N~Total	**0.050809**	**0.104685**	**0.215456**	**0.324281**	**0.642791**	**0.177399**
	Rank	**6**	**5**	**3**	**2**	**1**	**4**

Cost Test

Cost Criteria	Rank	Rate	Weight
Utilisation	2	80	**0.444**
Maintenance	1	100	**0.556**
		180	

Compliance	Extent %	Value
Fully (F)	**86 - 100**	**3**
Largely (L)	**51 - 85**	**2**
Partially (P)	**16 - 50**	**1**
None (N)	**0 - 15**	**0**

		ALTERNATIVE SOLUTIONS					
Cost Criteria Elements	Weight	ALT 1 2	ALT 2 5	ALT 3 1,2,3,5	ALT 4 1,2,4,5	ALT 5 1,3,4,5	ALT 6 4,5
1. Utilisation	**0.444**	3	2	2	2	2	2
2. Maintenance	**0.556**	0	2	2	2	0	2
	Total	**1.333333**	**2**	**2**	**2**	**0.888889**	**2**
	N~Total	**0.444444**	**0.666667**	**0.666667**	**0.666667**	**0.296296**	**0.666667**
	Rank	**5**	**1**	**1**	**1**	**6**	**1**

Management Tests

Management Criteria	Rank	[illegible]	Weight
Data capturing, storage and measurement	2	90	**0.265**
Scheduling	1	100	**0.294**
Process	4	70	**0.206**
Communication	3	80	**0.235**
		340	

Compliance	Extent %	Value
Fully (F)	**86 - 100**	**3**
Largely (L)	**51 - 85**	**2**
Partially (P)	**16 - 50**	**1**
None (N)	**0 - 15**	**0**

		ALTERNATIVE SOLUTIONS					
Management Criteria	Weight	ALT 1	ALT 2	ALT 3	ALT 4	ALT 5	ALT 6
Elements		2	5	[illegible]	[illegible]	[illegible]	4, 5
1. Data capturing, storage and measurement	**0.265**	**1**	**1**	**3**	**2**	**3**	**1**
2. Scheduling	**0.294**	**0**	**3**	**9**	**9**	**6**	**9**
a. Workshop.		0	1	3	3	2	3
b. Resources		0	1	3	3	2	3
c. Maintenance		0	1	3	3	2	3
3. Process	**0.206**	**1**	**2**	**2**	**2**	**2**	**2**
4. Communication	**0.235**	**2**	**2**	**2**	**2**	**2**	**2**
	Total	**0.941176**	**2.029412**	**4.323529**	**4.058824**	**3.441176**	**3.794118**
	N~Total	**0.197531**	**0.425926**	**0.907407**	**0.851852**	**0.722222**	**0.796296**
	Rank	**6**	**5**	**1**	**2**	**4**	**3**

SOLUTION SUMMARY

Tests	Rank	Rate	Weight
Principles	1	95	**0.216**
Feasibility	3	90	**0.205**
Time	2	100	**0.227**
Management	4	80	**0.182**
Cost	5	75	**0.170**
		440	

	Weight	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Principles	0.216	0.65625	0.692708	0.67708333	0.71875	0.65625	0.598958
Feasibility	0.205	0.62365591	0.650538	0.75806452	0.790323	0.623656	0.650538
Time	0.227	0.05080882	0.104685	0.21545594	0.324281	0.642791	0.177399
Management	0.182	0.19753086	0.425926	0.90740741	0.851852	0.722222	0.796296
Cost	0.170	0.44444444	0.666667	0.66666667	0.666667	0.296296	0.666667
Total		**0.39247606**	**0.497496**	**0.62883389**	**0.65906**	**0.597163**	**0.561121**
N~Total		**0.39247606**	**0.497496**	**0.62883389**	**0.65906**	**0.597163**	**0.561121**
Rank		**6**	**5**	**2**	**1**	**3**	**4**