“A case-study is an intensive analysis of an individual unit (as a person or community) stressing developmental factors in relation to environment.”
Merriam-Webster’s dictionary (2009)

Chapter 5 CASE-STUDY

The case-study will provide the PRACA data which will be analysed using the Narrative Inquiry research method. The phenomena observed during the case-study project will be analysed using the DSR research method. Using this approach will enable the achievement of the research objectives and provide answers to the research questions posed in chapter 1.

This chapter discusses the case-study for the upgrade of the ZT3 Anti-Tank Weapons System to a third generation anti-tank weapons system.

5.1 Purpose and Outline of the Chapter

The purpose of this chapter is to describe the application of the systems engineering process and the development model used for the case-study anti-tank weapons system project. The IPS development model was the model of choice by the case-study contractor for system development projects. The IPS development model is shown in figure 16 and follows the systems engineering process (Mil-Std-499B, 1994) and technical reviews described in Mil-Std 1621 (1995). In essence it follows a top-down development process until system industrialisation.
Figure 16: IPS development model
Source: Roos, (2001)
According to Roos (2001), development consists of six phases:

- **Management aspects of development (phase 0).**
  
  This is the initiation phase of any project and the development model is tailored during this phase.

- **Concept, exploration and definition phase (phase 1).**
  
  This phase is represented by the transition from the User Requirement Specification (URS) to the System Specification (SS), this phase is called the Concept Evaluation Phase (CEP).

- **A demonstration and validation phase (phase 2).**
  
  This phase of the development is shown in figure 16 as the Demonstration and Evaluation phase (DVAL). The typical activities during phase 2 are one or more of the following:
  
  - Detailed simulation and analysis of building blocks of the design.
  - Rapid prototyping of critical parts or high risk circuits where applicable.
  - Building of evaluation test beds and breadboards of part of the design that cannot be simulated.
  - Designing and building of man-machine interfaces that need to be evaluated.

- **Engineering and manufacturing phase (phase 3).**
  
  This phase is shown in figure 16 as the transition from a System Specification (SS) to an Item Development Specification (IDS), called the Full Scale Engineering Development phase (FSED). During this phase the hardware development starts. The trade-off studies and the simulations should have been completed.

- **A production phase (phase 4).**
  
  “The primary objective of the production phase is to produce and deliver an effective, fully supported system to the client at an optimal cost” (Roos, 2001).
• Commissioning and support phase (phase 5).

Production items are delivered to the client and support begins with the commissioning of the product and continues throughout the usable life of the product (Roos, 2001).

According to Roos (2001), the IPS model deals with the first four phases of the development since no development should take place during the last two phases. One of the aims of this model was to ensure that no development is necessary during the last two phases (Roos 2001).

This is a convenient model since the client has structured the contract payment milestones according to Mil-Std 1621 (1995) technical review points. The logistics package for the anti-tank weapons system was developed in parallel with the system development process. The logistic system is required to operate and support the new system in the client’s environment. This approach necessitated the incorporation into the IPS development model of not only the systems engineering process, but also the logistics engineering process, as well as the interactions between the two processes and finally the development of the logistics infrastructure to support the new system.

The case-study therefore also enables the evaluation of the IPS model and provides enough data to determine whether an adaptation of the IPS model or another model would perhaps have been more successful.

Since the case-study is a large complex multi-discipline system, in order to keep the size within acceptable limits, the focus of the case-study will primarily be on the overall process followed rather than the technical detail. Where applicable, further detail information has been provided in the appendices.

5.2 Development Model and Development Process

The case-study company has very well established infrastructures for the development of complex multi-discipline systems and is equipped with the latest information systems and tools.

Since both the system and the logistic system had to be developed taking full cognisance of the TRAMP criteria, it was decided to follow the IPS model (refer to fig 16) recommended by Roos (2001), as the better model for the development of the 3rd generation anti-tank weapons system. According to Roos, (2001), the IPS development model is a model for development in a multi-disciplinary environment for complex products. It can be tailored for different disciplines. The implementation of small design steps is a contribution towards the
development of a new product in a multi-disciplinary development environment. This model underwrites the principles of concurrent engineering but avoids some of the disadvantages, (Roos, 2001).

5.3 Development Project Objectives

Budget and time-scale constraints for the development of the anti-tank weapons system necessitated a development strategy with minimum risk and first time right results. The macro strategic planning by the client identified a requirements window for the anti-tank weapons system. To ensure project performance and schedule any unacceptable cost and schedule overruns could have resulted in the application of contractual penalties and subsequent contract termination, discussed in chapter 4.

The production contract was excluded from the development contract and would only be placed once the system has been fully qualified and accepted by the client, discussed in chapter 4.

5.4 Development Strategy

The system development followed the IPS process for the system and logistic system development. Design influencing was achieved by means of Success Domain (SD) and Failure Domain (FD) teams at all system hierarchy levels discussed in chapter 3. The design teams were divided into Success Domain (SD) and Failure Domain (FD) teams. The SD teams consisted primarily of design engineers and analysts whilst the FD teams consisted primarily of the logistic engineers analysing the “-ilities” of any proposed design from the SD team.

The FD teams specifically also investigated and analysed “out-of-specification” behaviour of a design and its influence on the overall system behaviour using fault tree analysis (FTA) and failure mode and criticality analysis (FMECA). The ensured system robustness and safety by orderly system behaviour under abnormal conditions.

5.5 Systems Engineering Process Selection

The system contractual boundaries and hierarchical interface with the client environment for the anti-tank weapons system are shown in fig 17.

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8 Any of the engineering “-ilities” (e.g., reliability, testability, producibility, supportability), (NASA, 2010).
The upgrade of the existing system and interfaces to the client operational and support environments are shown. The upgrade must also utilise the CFE and comply and constraints invoked by the client as discussed in chapter 4.

The system upgrade consists of:

- Upgrades to the missile system consisting of:
  - Upgrade to the existing ZT3 armoured vehicles
    - The Ratel weapons platform must be upgraded to accommodate the new weapons system.
o Upgrade to existing ZT3 turret

The Ratel turret must be upgraded to accommodate the new weapons system.

o Upgrade to the missile weapons system

The existing anti-tank weapons system must be replaced with the new 3rd generation anti-tank weapons in the existing CFE turret.

- Upgrade to the existing training system

The existing training and simulator system must be replaced and a new training and simulator for the new anti-tank weapons system must be developed.

- Upgrade to missile system’s maintenance and repair vehicles.

The existing anti-tank missile system maintenance and repair vehicles must be adapted for the new anti-tank weapons system.

5.5.1 Applied Systems Engineering Process

The IPS development model (Roos, 2001) discussed above was used as guide for the systems engineering process for the development of the 3rd generation anti-tank weapons system and associated logistics infrastructure. The specific systems engineering process is shown in figure 18.
Figure 18: Case-study Systems Engineering process
The first 4 phases of the IPS development model discussed above applied to the case-study are shown in figure 18. Separate development tracks for the electronic design, mechanical and software design are shown to depict their fundamental differences. Each track starts with a development specification review. The aim of this review is to set the requirements and constraints to the design team. A formal design review follows a completed design before acceptance to the next level of integration. This is followed by the development of a production data pack as part of the systems engineering output discussed in chapter 3. This data pack is also subjected to a formal review before acceptance.

To ensure standardisation and design quality, a project specific set of checklists and design guidelines have been developed to be discussed in the next paragraph.

5.5.2 Design Reviews and Baseline Management

A structured design review format was followed to ensure an orderly and structured method of evaluating subsystem designs against applicable specifications; standards, project value system and that all TRAMP parameters and requirements have been addressed. The aim of TRAMP is to influence the design of the system from as early in the design process as possible to improve the Testability, Reliability, Affordability (unit cost as well as life cycle cost), Maintainability and Producibility. This concurs with the research findings of Maylor et al, (1998) on new product development and the research findings of Lu et al, (2006) with the early inclusion of process design for manufacture.

Design reviews had the following generic format:

- Summary of design requirements and constraints of the applicable system/subsystem or component.
- Applicable standards.
- Trade-off studies and value system used.
- Final design implementation.

To assure quality and uniformity of design standards, the following checklists and guidelines have been developed from past experience and implemented:

- Components identified by the International Traffic in Arms Regulations (ITAR, 2011)
- Mechanical design
• Electronic design
• Digital design
• Printed circuit board design
• Design reliability
• Software requirements
• Safety
• Standardisation guideline
• Built-in Test (BIT) coverage guideline
• Production Readiness review

Once a design has been approved at the critical design review (CDR), all further changes had to be formal by means of Engineering Change proposal (ECP) and approval process by the Project Configuration Management Board (PCMB).

5.5.3 Engineering Change Management

Regular project configuration board meetings were held to evaluate and approve all ECPs. All the stakeholders were represented at the PCMB meetings so that the impact and ripple effect of a change was thoroughly discussed and investigated before final approval.

5.5.4 PRACAS Management

In Chapter 2 the closed loop Problem Reporting and Corrective Action System (PRACAS) was discussed. The case-study development project PRACA was captured on the company’s integrated SAP® management system and provided a database for the subsequent RCA for resolution of the problems encountered on the project. The outcome of the PRACAS is also used to update the design review checklists. This ensures a continuous development process improvement and provides a guide for the new design engineers.
5.5.5 Overview of the Final Evolved System

The anti-tank missile system was completely integrated into the vehicle turret, source: Denel Dynamics Ingwe Missile brochure, (2009). The vehicle platform was kept standard in compliance with the user requirements. Figure 19 shows the basic principle of operation of the beam rider system. The camera system also incorporates a third generation thermal imager camera for night target acquisition.

![Figure 19: Anti-tank missile system integrated into the ZT3 turret](source: Denel Dynamics Ingwe Missile brochure, (2009)).

5.6 Development Project Logistics Engineering Process

The URS provided the main input driver for the logistics engineering process. The Use study in accordance with Mil-Std-1388 1A, (1990) complemented the URS to provide sufficient resolution of the operational environment for the system. The Integrated Logistic Support Plan (ILSP), provide the strategy (“WHAT”) to be followed for the logistics engineering and logistics product development. From the ILSP, the Integrated Support Plan was developed to specify “HOW” for the logistics engineering process. From the ILSP, the Logistics Support Analysis Plan using Mil-Std 1388 2B, (1993), as a guide was developed followed by the Product Support Plan detailing how the system has to be supported during the operational phase.

The logistic engineering process used the Mil-Std-1369 (1988) and Mil-Std-1388 (1990) as well as Jones, (1987) as guides. Figure 20 shows the interrelationship between the systems engineering and the logistics systems engineering.
The outcomes of the logistics engineering process included:

- Design influencing with specific focus on for all the “ilities”.

- Logistic products development.

The system development team were the SD team whilst the logistics engineering team were the FD design influencing team described above.

As the system architecture and functional breakdown structures (FBS) became available, it was modelled in RELEX®. From the FBS the Reliability Block Diagram (RBD) was developed followed by reliability modelling. The top down Fault Tree analysis was followed by the bottom-up FMECA process, source: Reliability Practitioner’s Guide, (2003).

Maintainability was analysed using Mil-Hdbk-472, (1966), as a guide. The relatively low technical skill levels of the operators and first line maintenance personnel required that extensive Built-in Test Equipment (BITE) be developed. The requirements was for a Built-in Test (BIT) coverage >80% with a better than 90% confidence level.

The logistics engineering team established and maintained a standardised terminology list under configuration control to ensure
terminology standardisation amongst all development and logistic products documentation. Any additions to this list also had to be approved by the client. The logistics engineering team also focussed on availability optimisation, level of repair analysis (LORA), Interchangeability and standardisation, Bill of materials (BOM), obsolescence, human engineering and life cycle cost (LCC).

The logistics products development project was responsible for:

- The requirements specifications for the development of support test equipment at the different levels of support in accordance with the LORA.

- Operating and support documentation development.

  The logistic support technical writers were responsible for the development of the support documentation suite.

- Training simulator and training material development.

  The logistics-training specialists were responsible for the requirements specification of the training simulator, the development of the training curricula and training material as well as the initial training of the client’s training instructor personnel.

- The logistic support analysis record (LSAR) development and subsequent integration into the client’s management information system (MIS).

The administrative support team consisted of:

- Quality assurance (QA)

  The QA manager is responsible for all project QA activities in accordance with the QA plan and liaison with the client QA manager.

- Configuration management (CM)

  The CM is responsible for the administration of all engineering change proposals ECPs and scheduling of project configuration management board (PCMB) meetings in accordance with the project configuration management plan.

- Procurement

  The procurement manager is responsible for parts and material procurement as well as sub contracting of
component manufactures, the administrative BOM and procurement specification management.

- Safety

The safety manager is responsible for corporate and client safety compliance and liaison with the client safety manager.

Summarising, the logistics engineering process follows the systems engineering process described by the IPS model (figure 16), since analysing a design from a logistics engineering perspective can only occur once a coherent design is available. The logistics engineering process to support the system first analysed the designs with two objectives:

- Design influencing

- Establish the requirements for the development of the logistic products.

From the logistic product requirements, the logistic products such as operator- and maintenance manuals as well as training courses were then developed using the IPS model discussed above.

5.7 System Hand-Over

The final system hand over and Integration into the Client’s Inventory prior to the closure of the contract was done in phases:

- Engineering Test and Evaluation (ET&E) performed by the development engineering team with the client personnel observing.

- Operational Test and Evaluation (OT&E) performed by contractor personnel with the client personnel observing.

- Qualification Test and Evaluation performed by fully trained client personnel with the contractor observing and providing limited technical support.

Once these phases have been successfully completed and all outstanding items closed will the system be formally incorporated into the client’s inventory and the project closed.
5.8 Chapter Summary

This chapter provided a description of the systems engineering process, followed in the development of the ZT3 Anti-Tank weapons system, using the IPS development model recommended from the research by Roos (2001) for the development of a full-scale complex multi-discipline weapons system, (figure 16). The logistic products were also developed using the IPS development model described above.

The size and multi-discipline nature of the project necessitated further refinements, to ensure efficient and effective group interaction during design reviews, by dividing the development team into a Success Domain (SD) team with the objective of getting the system working in accordance with the specifications, and a Failure Domain (FD) team with the objective of finding and eliminating weaknesses in the evolved designs, and to ensure that all the “-ility” objectives and requirements have been achieved.

Logistic engineering analysis of the designs was used to firstly influence the design and once the design is accepted, as requirement for development of logistic products. The logistic there functioned as the FD team for design influencing. This will be further discussed in chapter 7.

The extensive use of checklists completed by the individual design engineers, and distributed as part of their design review documentation prior to a design review substantially facilitated the design review effectiveness and time management. These checklists were continually updated from PRACAS database to prevent recurrence of a problem and to provide a learning curve for the other design teams. This closed the corrective action loop by preventing recurrence of a problem discussed in chapter 2. The checklists also served as a very effective guide for the lesser-experienced design engineers on the team.

In the next chapter the problems experienced with the development process and lessons learned will be discussed.
Chapter 6 PROBLEMS EXPERIENCED AND LESSONS LEARNED

The purpose of this chapter is to evaluate the case-study project and identify the fundamental root causes for the problems experienced. The objective being to find answers to the research questions posed in chapter 1. Discussed in Chapter 2, applying the DSR research methodology, the PRACA data collected will first be analysed using the Narrative Inquiry research method to reveal the symptoms of the problems observed. According to Clandinin et al. (2000), the Narrative Inquiry is a powerful tool in the transfer and sharing of knowledge in a work group environment. Since the primary research objective was to get a better understanding of the project failure phenomena as well as the factors at play, the Narrative Inquiry qualitative research approach was performed on the project PRACA data. On completion of the project, the team unanimously agreed to invest time for a project review work session to review the problems experienced applying the Narrative Inquiry research methodology. The results from this work session will then be further analysed using RCA to identify the fundamental root causes of the phenomena observed in accordance with the DSR research methodology.

It is a general fact that projects often over-spend and deliver late. Steyn, (2009), shows by means of a simplistic cause-and-effect diagram some of the factors at play that may result in a project schedule over-run. Steyn (2009) points out that corporate politics and hidden agendas have a detrimental influence on project performance. Corporate political factors, quite often, have a negative influence on the results produced by case studies, disturbing the parameters to be analysed. This makes analysing the results difficult and in a lot of cases makes the isolation of the real root causes of cost and schedule over-runs very difficult.

The long standing trust between team members and management negated the negative influence of corporate politics facilitating more accurate isolation and analysis of the root causes of the problems experienced on the project.
6.1 Review of the Case-study

In chapter 5 the background to the case-study for the development of the ZT3 Anti-Tank weapons system and the systems engineering process using the IPS development model was discussed. This specific case-study was chosen in that the development project ran continuously from start to finish with the same team. The author was a major player on the team from the beginning and familiar with the background issues of the project and could provide invaluable DSR inputs.

Another factor for selecting this specific case-study was that the major team players, the client, the procurement agency and the contractor were very experienced. They have been involved in past projects as a team. They were keen cyclists belonging to the same team and often went as a team to cycling events. There was a strong camaraderie and trust between all players, very seldom found on commercial projects. This was evident at project meetings where honest reporting was done without any attempts to move the blame but rather a strong focus on how to correct and overcome problems. When a team member slipped up there was no witch hunting, rather support was given to assist and prevent a recurrence. Open and honest reporting had a very positive effect on the team resulting in a positive work culture as well as mitigating the negative influence of corporate politics.

The case-study had all the ingredients of being a successful project using the IPS development model recommended by Roos, (2001). There was total commitment and co-operation between all the players. Additionally, the different subsystem development teams were divided into SD and FD teams discussed in chapter 3. The Success Domain and Failure Domain participants at design reviews proved to be very effective and productive. It was particularly at preliminary design reviews (PDR) that system and subsystem behaviour during out-of-specification conditions was thrashed out and agreed upon. The out-of-specification behaviour, also sometimes referred to in the literature as negative scenarios, (Alexander et al, 2009), added to the robustness of the design. These conditions were incorporated into the development-, test- and qualification specifications. Qualification tests also involved TAAF testing for reliability growth in accordance with the guidelines of Mil-Hdbk-189, (1981).

Client specialist operational personnel were actively involved in work groups with the contractor development personnel addressing specialists’ areas such as ergonomics, munitions and Command and Control, (Alberts et al, 2006). The client operational personnel valued the new anti-tank weapons system as being very successful, complying with all their requirements and expectations. Yet as a
project, the project failed since the project was over cost and schedule.

At the Production Readiness Review, the disappointed team felt that there must be deeper fundamental factors at play resulting in the cost and schedule overruns.

Since all the project resource data as well as the PRACAS were integrated into the contractor’s SAP3® management information system and available on the company Intranet, a full day work session was held in a conference room, complete with laptop PC, LAN connection and overhead projector with all the major stakeholders present, enabling instant access to any project and system data during the discussions.

Discussed in chapter 1, the objectives of this research are:

- Optimisation of design influencing by dividing the design teams into two different mindset groups.
- Evaluate the impact of design changes in terms of cost and schedule overruns in a concurrent engineering development environment.

The first step of achieving the research objectives was to hold a narrative inquiry discussed in chapter 2. The participants of this team formed a structured focus group. The outcomes of this work session were then verified using the Delphi Technique, (Hsu, 2007), and triangulation, (Greene, 2007), to confirm the research facts and data until consensus between all the participants were reached.

The group consisted of the following participants:

- System and subsystem engineers (8)
- Logistic and reliability engineers (6)
- Technical authors (4)
- Procurement (1)
- Configuration (1)
- Quality assurance (1)
- Project management (1)

Most of the engineers and project team members had post graduate qualifications in their respective fields. The technical authors were
specially trained technologists with years of shop floor and field experience. The author was the facilitator.

All participants were emailed a copy of NAVSO P-6071, (1986), in preparation for the work session to review the traps applicable to their specific area and to what extent these have been mitigated and avoided.

6.2 Grouping and Quantification of the Problems Experienced

The PRACA items were analysed during the structured focus group work session using qualitative research methods, (Morgan, 1997), getting as many points of view, as possible, from all members of the group. The grouping and quantification of the PRACA items were then cross examined using triangulation methodology, (Greene, 2007), to ensure confidence in the findings. The PRACA items relating to specific PM-SE engineering problems were further investigated by the iterative Delphi Technique, (Hsu, 2007). A number of problems impacted in more than one category. In that case the value allocated would be the impact to that specific category. In other words it is possible that the same problem be allocated different values under different categories.

The problems experienced on the project were quantified using a five-point Likert scale (Likert, 1932) to determine the impact on the project:

- 0 = no effect/not applicable
- 1 = not important
- 2 = slightly important
- 3 = important
- 4 = very important
- 5 = crucial for project success

Guided by the research objectives and research questions, the work group categorized problems experienced into the following categories:

- Management related problems
- Systems Engineering related problems
- Quality Assurance (QA) related problems
• Configuration management (CM) related problems

6.3 Evaluation of the Analysis Results

The Narrative Inquiry structured focus group was unanimous that the IPS model was a very effective development model. The recorded PRACA items were then subjected to critical review by the structured focus group applying the Narrative Inquiry methodology. It was found that in total 61 recorded PRACA items relevant to this research were identified and analysed and subsequently quantified. Those PRACA items not relevant to this research were ignored. The total Likert scale value of the 61 analysed PRACA items was 176. A breakdown and summary of the problems experienced and allocated Likert scale values have been provided in Appendix B. The summary of the findings are shown in the table 21:

<table>
<thead>
<tr>
<th>Problem area</th>
<th>Consolidated incidents</th>
<th>Total impact</th>
<th>average %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management related project problems</td>
<td>32</td>
<td>100</td>
<td>56.8%</td>
</tr>
<tr>
<td>System Engineering design related project problems</td>
<td>12</td>
<td>35</td>
<td>19.9%</td>
</tr>
<tr>
<td>Quality Assurance (QA) related project problems</td>
<td>7</td>
<td>15</td>
<td>8.5%</td>
</tr>
<tr>
<td>Configuration management (CM) related project problems</td>
<td>10</td>
<td>26</td>
<td>14.8%</td>
</tr>
<tr>
<td>Total</td>
<td>61</td>
<td>176</td>
<td></td>
</tr>
</tbody>
</table>

Figure 21: Summary of problems experienced in the case-study

In general more problems were reported by team members further downstream in the systems engineering process, such as the logistics product development personnel and in particular the technical authors responsible for the development of the operational manuals, support manuals and training material. This was to be expected since deficiencies upstream in the systems engineering process are generally more likely to manifest themselves further downstream.

A detailed problem summary obtained from this research has been provided in appendix B.

6.3.1 Management Related Project Problems

From the analysis, it was found that 32 PRACA items with a total impact value of 100, equating to 56.8% of the problems experienced on the project, was apportioned to management.
The management related project problems were primarily due to:

- Client requirements - baseline shift.
- Matrix organisational structure – unavailability of resources and fragmented indirect project functions.
- Project management and schedule – unexpected post CDR design changes.

Detail problems encountered and explanations are discussed in the next paragraphs.

**6.3.1.1 Client Requirements – baseline shift**

The client requirements baseline changed during the project due to miss interpretation of requirements and client requested change.

The procurement agency systems engineer has drawn up a very comprehensive client requirements specification. This was augmented with a number of comprehensive associated documents in specialists’ areas such as logistic support environment and training. The contractor at the planning and contracting phase mistakenly assumed that the existing ZT3 operational and support manuals as well as the training material could be adapted for the newly developed system in order to achieve a cost and schedule saving.

This has proven to be wrong since the client has revised his technical manual and training standards in the interim. This oversight resulted in a costly re-development of these documents. This problem was further exacerbated by the lack of internal detail knowledge of the new standards. This resulted in an unusually large number of problems reported by the technical authors.

Also as the system evolved the client subtly exploited opportunities to include additional changes to existing requirements. The ripple effects of these were sometimes underestimated leading to cost and schedule overruns on the affected elements of the project.

In conclusion, the lesson learned is that missing a requirement or a constraint (non-functional requirement, (Sommerville, 1996), invariably leads to re-work and wasted resource effort.
This often impact negatively on the overall project schedule and cost. Also it is important that any uncertainties and assumptions are tested with the client up-front prior to the start of the project.

6.3.1.2 Matrix Organisational Structure Related Problems
(Unavailability of resources and fragmented indirect functions)

In a matrix organisational structure (Blanchard, 1998), development resources are not available on-demand since they are re-allocated to other projects on completion of their specific milestone on the project. Also indirect functions that are not directly coupled to project milestones are considered as part of the company overhead and fall under the relevant facility structures resulting in fragmentation of these functions. The detailed consequences are discussed in the next paragraphs.

- **Unavailability of on-demand resources**

Under the Matrix organisational structure, once a specialist resource has completed his task on the weapons system development project, the resource is allocated to new tasks on other projects. The consequence is that the resource is not immediately available should his expertise be required later to solve latent problems.

Developing a complex weapons system demands a large number of multi-disciplined specialists’ skills. These expert skilled resources are only required for relatively short periods of time in the total development project schedule. As discussed in chapter 3, the downside of the matrix organisational structure, apart for the large internal subcontracting workload for the project manager, is the unavailability of on-demand expert specialist resources.

These scarce resources are immediately re-deployed by the facilities to other projects. This places a severe handicap on the schedules of a development project should an expert resource be required for say the identifying and analysis of a root cause failure and the subsequent development of an engineering change to correct the problem.

- **Fragmented indirect project functions**

The internal company rule mandated that only direct personnel could work on project structures since all resource expenditure must be coupled to payment milestones.

The company management information system SAP3® is so structured to enforce this rule. The consequence of this rule
is that the project’s indirect functions such as configuration management, procurement and quality assurance at subsystem level are performed by facilities and as such becomes fragmented from a project point of view.

The PRACAS identified this problem fairly early in the project resulting in top management amending this rule. To alleviate the problem, configuration, quality assurance and procurement personnel were seconded to the project. Particularly the seconded procurement personnel enabled bypassing the corporate production procurement organisation expediting the procurement and delivery of small quantities of critical engineering components for development models.

Facilities in a matrix organisation generally provide resources for a number of projects, making it impractical to cater for the individual requirements of a specific project. This is a fundament impediment particularly with larger facilities. On the other hand workload variations cannot be handled effectively by smaller facilities.

The matrix organisation resulted in:

- Fragmented indirect functions such as QA, CM and procurement.
- Lack of specialist design expertise availability after the CDR of a specific configuration item.
- Large internal subcontracting workload.

In general very good interpersonal relations between project managers and facility managers can mitigate these deficiencies of the matrix organisational structure. However when it comes to subcontracting to other business units and outside subcontractors this may not always be possible.

6.3.1.3 Project Management and Schedules
(Unexpected post CDR design changes)

Project management decided to implement the critical chain principles and provision of schedule buffers to prevent bottlenecks (Goldratt, 1997). This project management approach was selected due to the large number of internal and external subcontracting on the project. The large number of internal and external subcontracting was primarily as a result of the diverse nature of all the disciplines required for the development of the weapons system.
It was anticipated that the critical chain approach with its inherent buffers would reduce the project bottleneck risks that could result in schedule and cost overruns. Fundamentally this worked very well right up to the CDRs of the individual configuration items for the weapons system. In general at that stage the individual elements of the project were on schedule and within cost and no project schedule and cost risk was foreseen until the integration level of the items.

The project cost and schedule problems started to manifest themselves at the integration level where unforeseen problems forced post CDR modifications on certain configuration items. The unforeseen problems continued at each subsequent level of integration. Although the problems reported were relatively few given the complexity and multi-disciplined nature of the weapons system the effect on cost and schedule proved to be detrimental on the project since they were not planned for.

The contractor organisation configuration management system uses three categories to control the status of configuration items by using Mil-Hdbk 61, (1997) as a guide. To facilitate service-life tracking, these components normally have their own serial and revision numbers and are referred to as Configuration Items (CI) in the military industry.

At subsystem level the classifications are defined as follows:

- **Class I**

  A class I modification is a modification where the Form-Fit-and-Function (FFF) of the configuration item is affected. In other words an interface or performance characteristic of the affected configuration item is changed. This also results in part number and/or revision number changes and interchangeability is affected, (Mil-Hdbk 61, 1997).

- **Class II**

  A class II modification is one that does not affect the FFF and performance and is contained in its entirety internal to the configuration item. Generally this only results in a revision change, (Mil-Hdbk 61, 1997).

- **Rework**

  A rework is not a modification issue but rather a quality issue where an item during test did not conform to specification and had to be reworked to bring it back to
specification. The part number or revision of the affected item is not changed. Rework manifests mostly during pre-CDR in the development phase and during production although sometimes items also fail during integration testing.

Class I and Class II changes apply to the data pack of the affected configuration item and rework applies to a physical hardware item. Modifications and rework are unplanned activities and consume resources and as such have a detrimental impact on cost and schedule of a project.

During development particularly at integration level, most of the changes were generally class I where the FFF of an item is affected. This causes a ripple effect throughout the system structure mainly due to functional couplings and emergent properties of the different levels in the system hierarchy. This is further exacerbated in a concurrent engineering environment due to other system components that are concurrently under development. This generally has a negative effect on cost and schedule since not only the affected item but also the functionally related items in the system hierarchy must be modified.

To reduce this ripple effect it was sometimes decided during the Project Configuration Board (PCMB) reviews to overcome a problem that the root cause item itself is not modified but rather a lesser impact item is modified provided the overall system dynamic performance as described by Viljoen, (2007), is not affected. This is sometimes called a “band-aid” fix. The technical authors being further downstream in the systems engineering process developing the operating, support and training material were mostly affected by these changes. It is also in this area where most of the schedule and cost overruns occurred.

In conclusion, the integration problems experienced on this development project generally occurred on the interfaces between configuration items and was seldom due to the configuration item itself. This may be attributed to the extensive pre-CDR qualification testing of configuration items making it highly unlikely for latent design defects remaining in the configuration item itself.

The cost and schedule overrun on the project, can to a very large extent, be ascribed in order of priority to:

- Modification ripple effects of functionally coupled configurations items in the system structure.
Specialist expert resource availability as a result of the matrix organization structure.

6.3.2 Systems Engineering Related Problems

The systems engineering related problems were grouped and collated to 12 events with an average impact value of 2.92 (19.9%).

The systems engineering problems can be summarised into:

- Specialist and subsystem expert resource availability after the CDR of the relevant configuration item.
- System and CFE data integrity and availability.
- Standardized terminology.

6.3.2.1 Specialist Resource Availability

Discussed in chapter 3, the matrix organisation structure resulted in resource unavailability after completion of the design and CDR.

To overcome this problem, a small percentage of specialist time was contracted with facility managements and subcontractors for consultation and technical assistance purposes during the integration and testing phases at system level. On paper this sounded like a good solution but in practice proved to be almost unworkable because of the pressure of work by other projects for the specialists’ resources.

6.3.2.2 System Data Availability and Data Integrity

The customer’s furnished items and associated data packs were accepted at face value from the client. Subsequent audits further downstream in the project revealed a number of deficiencies that resulted in avoidable engineering changes and rework particularly by the technical authors.

The main problem that stood out however was that the current established systems engineering process described by INCOSE, (2010), NASA System Engineering Manual, (2007) and Mil-Std-499B, (1994) focuses from the Customer Needs through all the specification levels to the final product specifications on the “WHAT”. In other words “what” is the system/subsystem required to do to the final confirmation after
qualification testing that the envisaged system indeed does “what” it is required to do. The total focus for the system data pack development is on the requirements and requirements traceability.

The processes described by Alexander et al, (2009), how to discover and specify requirements have been used on this project. In complex multi-functional systems such as the ZT3 weapons system upgrade, requirements traceability tools such as DOORS® have been used to ensure that all requirements trace down to the lowest level specifications and documents in the systems hierarchy to finally facilitate system qualification and handing over to the client.

Nowhere is there a requirement for the system, subsystem and design engineers to produce formal documents that describes “HOW” the particular design works. It can be seen in figures 18 and 20 chapter 5, the formal document structure as part of the systems engineering process followed only specifies the “WHAT”. Informally the “HOW” information was generally provided during the design reviews as part of the particular design engineer’s presentations but then at a relatively high level unless forced to provide more details by the questions and answers of the attending participants.

The attending participants at design reviews were stakeholders actively involved at that particular phase of the systems engineering process. Stakeholders further downstream of the systems engineering process such as the technical authors were not represented and this impacted negatively on early design influencing.

The technical authors developing the operational and support manuals and training material had access via the company intranet to the project configuration system and full system data pack. However they found that they still could not perform their tasks since the vitally needed “HOW” information for the development of the technical manuals and training material were not available. This problem was further exacerbated by the fact that they generally did not have the detail engineering skills and knowledge to analyse the designs and deduce “HOW” the designs work without assistance from the experts. Also the unavailability of engineering expertise for consultation and redlining of the draft manuals aggravated the situation. The Failure Domain team to a large extent assisted the technical authors since they had already analysed the designs and had a good grasp of the “HOW” a specific design worked.

In order to provide a more formal work around the lack of “HOW” data, project management contracted design engineers
to produce formal Storyboard Descriptions describing how their particular designs worked, (Wikipedia 2009). This worked very well but since it was unforeseen and unplanned, it impacted negatively on the project cost and schedule.

### 6.3.2.3 Standardised Terminology

Lack of early and initial terminology standardisation resulted in a lot of rework particularly by the technical authors. As the project progressed, new items were identified and named initially by the designer. These names were later amended or changed as other stakeholders became involved and felt that their naming of a particular item was more appropriate. This naming evolution was carried through further down the systems engineering process. Finally the shop floor personnel and client operational and support personnel, who have to live with the name for the product lifecycle, decided on more practical names from their point of view. The stores personnel on the other hand had their own unique naming nomenclature and standards prescribed in Standard No. 5F, (1982), and the Cataloguing Handbook, (1988), adding to the problem.

This item name evolution process during the total system design, apart from the confusion in understanding the different level of documents, resulted in a lot of rework by the technical authors particularly in documents such as the illustrated parts catalogue (IPC).

This problem was identified by the PRACAS fairly early in the project and it was decided to initiate a standardised terminology list that also had to be approved by the client.

This reduced the problem to certain extent but did not completely resolve it, since ideas of what a specific item should be called changed as the development process progressed, and different levels of people became involved and more familiar with the specific item. This resulted in a number of ECPs and their associated ripple effects.

From this experience it was agreed by the team that a terminology list, instead of being a dictionary of names, should be a thesaurus of synonym names that also identifies the final name to be used in the bill of materials (BOM) and Illustrated Parts Catalogue (IPC).
6.3.3 QA and CM Related Problems

The Quality Assurance (QA) and Configuration Management (CM) related problems were grouped and collated to 7 events with an average impact value of 2.14 (8.5%) and 10 (14.8%) respectively.

The main problems in these two areas originated from the fragmented functions as a result of the company management rule that QA and CM are considered indirect functions. Discussed above under matrix organisational structure related problems, these functions fall under the different facilities of the matrix organisational structure.

The seconding of QA and CM personnel to the project to a large extent mitigated this problem.

6.3.4 Development Process

The Integrated Product Support (IPS) model was used for the development of the upgrade of the ZT3 anti-tank weapons system. Key goals of the IPS design model according to Roos, (2001), are design maturity at the end of the development phase, design verification, low risk transition from development to production, and high production quality.

From past design review experience in the company, the author introduced a formal design review guideline to ensure keeping focus on the big picture and to prevent the very common side tracking on detailed technical issues. It was found that generally, depending on the designer’s experience, primarily due to their Success Domain mindset, they very often did not fully understand the full extent of the design problems and requirements. To facilitate and ensure consistent standards and quality, the use of checklists, discussed earlier, was introduced. This gave the designers a better idea of what was required.

Design reviews were held in two stages. A preliminary design review (PDR) and a critical design review (CDR). The purpose of the PDR was to ensure that the requirements of the particular development specification were fully understood by the tasked design team whilst the purpose of the CDR is to ensure compliance with all the requirements.

With the focus on design influencing early on in the project, the Failure Domain team’s presentations of the development specifications at the PDR design reviews highlighted and emphasized what was really required from a particular design. The primary objective of the CDR was to ensure that the particular final
design complied with all the requirements. The design review
guideline can be summarized into the following main categories:

- Specification and associated documents.
- Requirements and constraints.
- Value systems of both the client and company.
- Trade-offs.
- Technical solutions.
- Design review checklists.

The opposing mindsets of the SD and FD design teams proved to
be very effective and efficient as predicted by Kuhn et al. (2006).
The opposing viewpoints from the SD and FD design review team
members led to very constructive and thorough discussion with
optimal outcome of the final solution.

The ECP database in SAP3® confirmed not a single design, apart
from interface design changes during integration, had to be
extensively modified or redesigned. This process also proved to be
particularly valuable for software requirements document (SRD)
and software design document (SDD).

6.4 The Causes of the Problems Encountered

The observation, analysis, understanding and finding of a solution to
a phenomenon observed is the objective of DSR discussed in chapter
2. The Narrative Inquiry research findings show that the two main
problem areas are Management and Systems Engineering. Unplanned design changes appear to cause conflict with project
management and lack of suitable data in the design data packs
appear to cause problems with the logistic system development team.
Appendix B provides a detailed breakdown of the problems
experienced.

The Project Management and Systems Engineering categories are
not independent. It can be simplistically argued that without project
management there would not have been systems engineering and
system development. Likewise without systems engineering there
would not have been a system development project. It can therefore
be construed that the findings in table 21 are the symptoms of deeper
underlying problems.

The question that remains now is “why” were these problems
experienced on the case-study project? What are the fundamental
underlying causes? The approach taken on the case-study project was analysing the problems experienced and then asking the question “why” these manifested. This approach is also supported by Seusy, (1988). The causes of the problems experienced can be grouped into the following two categories:

- **Project management and the systems engineering processes have areas of incompatibility**

Project management is in essence a structured sequential milestone driven process with a beginning and an end, definitions abound. The PMBOK, (2008) definition has been discussed in chapter 3. The most appropriate definition applicable to this research can be found by Rasmussen, (2009) “Project Management is a formalised and structured method of managing change in a rigorous manner. It focuses on achieving specifically defined outputs that are to be achieved by a certain time, to a defined quality and with a given level of resources so that planned outcomes are achieved” Project management is in essence a rigidly structured sequential milestone driven process until the end goal is achieved and the project completed.

Systems engineering on the other hand is defined by Eisner as: “Systems engineering is an **iterative** process of top-down **synthesis**, development, and **operation** of a real-world system that satisfies, in a **near optimal** manner, the full range of requirements for the system,” (Eisner, 2002). Eisner (2002), places specific emphasis on “iterative”, “**synthesis**”, “**operation**”, “**near optimal**” and “satisfies the system requirements”. Eisner, (2002), further states that the design and building of a system involves several loops of iteration such as “synthesis-to-analysis”, “concept-to-development” and “architecting-to-detailed design”.

The project manager is measured against project performance primarily in terms of cost and schedule. The systems engineer on the other hand is measured in terms of system performance and compliance with requirements. The project manager and the systems engineer are measured differently and are subjected to different performance metrics. As such the project manager and the systems engineer have conflicting value systems.

Indeterminate events such as iterations, re-work etc. are classed as risks in project management and a certain amount of resources are normally allocated to a project risk pool based primarily on the project manager’s previous experience.

The systems engineer and his design team (Success Domain) iterate from concept to design in order to find the optimum solution. Once a coherent design is available can this design be analysed by the logistics engineering team (Failure Domain),
(Eisner, 2002). The outcome of this process invariably will result in another iteration loop of design. The number of design loops is in relation to the technological complexity and risk of the design. State-of-the-art designs invariably involve high technological risks. The systems engineer is forced by the client’s requirements into these high risk areas particularly if his system solution is to be effective and competitive.

In conclusion, the structured “milestone-by-milestone” project management process cannot effectively accommodate the indeterminate iterations of the systems engineering process. Once a milestone has been completed, project management cannot accommodate a revisit to that milestone unless it was anticipated and planned for under a new milestone. The proposal by Grundy (1998) for PM to implement cycles of deliberate and emergent change as opposed to linear strategy development has the potential to alleviate some of the problems experienced.

According to Goldratt, (1997), a manager behaves in accordance with how he is measured. Since the project manager and the systems engineer are measured against different and opposing performance criteria, it can be deduced that areas of project management and systems engineering processes are in conflict. For the smooth and efficient running of a complex systems development project, soft systems methodology must be used as described by Checkland, (2001). Such a process is difficult to quantify and measure and depends to a large extent on the cooperation and team spirit of the individual members of the development team, (Checkland, 2001).

- **Systems Engineering primarily develop “WHAT” data and insufficient “HOW” data**

The current systems engineering process and data pack development primarily focuses on the “What” and generally does not provide sufficient data on “How” the system, subsystems and designs work.

The systems engineering process is entirely requirements driven from the customer’s needs right through to the final product specification, (INCOSE, 2010), (Mil-Std 499B, 1994) and (Military Standard 1521, 1995). All the formal documentation produced addresses and describes the “WHAT” and how to build and test the particular configuration item. No formal system documentation as part of the development model describes “HOW” a particular design works.

This qualitative “HOW” data is not available from the formal configuration controlled design data pack. The “HOW” design information is crucial for the following reasons:
• Development of operational and maintenance manuals and associated training material

Operational and maintenance personnel must have a clear understanding how the system and the particular subsystem work in order to be able to optimally operate, deploy and apply the system. This information is a requirement for the operator and maintenance manuals. This is also a vital input for the development of the training systems. In essence the “How” data becomes part of the URS for the training system development.

• System diagnostics and maintenance

In order to be able to efficiently and effectively identify, diagnose and localize system malfunctions, maintenance personnel must have a deeper level of understanding of the system architecture, interfaces and in particular “How” a subsystem and component performs their functions.

• Through-life engineering support

Military systems typically have an operational life of 20 years. During this time the system may need modifications and upgrades of subsystems and components for various reasons such as field problems experienced, obsolescence etc. A different design engineer must be able to analyze and develop a modification for the affected subsystem or component. To this effect apart from the “WHAT” data, he also needs the “HOW” information, in particular the classification of characteristics (CoC) and rationale of the design as described in DoD-Std-2101, (1979).

6.5 Chapter Summary

In this chapter the problems experienced and the identification of the root causes in the IPS development model used in the case-study project have been discussed. The summary of the research findings are that management accounted for 57% of all the problems experienced on the project whilst systems engineering accounted for 20%. The remainder of the problems fell into the specialised categories of QA and CM.

Discussed earlier, most of the engineers and project team members had post graduate qualifications in their respective fields and practical field experience. Therefore the project team focus group was qualified and experienced in research. Applying the Narrative Inquiry,
Clandinin et al, (2000), two fundamental causes for the problems experienced have been identified:

- Project management and the systems engineering processes have areas of incompatibility.

- Systems Engineering primarily develop “WHAT” data and insufficient “HOW” data.

Both these factors have a significant detrimental effect on development project performance and accounted primarily for the cost and schedule overruns on the case-study project.

It is significant that management related problems overshadowed the other problems on the case-study project. The results reflected in table 1, however are misleading in that they reflect the symptoms of the incompatible interactions between the SE and PM processes. As discussed in Chapter 3, the one process cannot function without the other. What is observed is an apparent paradox in that the very team that wants the project to be on schedule and within cost are apparently the cause for the cost and schedule overruns! The competence of management has been ruled out and the fundamental root causes for project failure for being over-schedule and over-cost must now be identified.

In the next chapter the performance of the IPS model and whether there is a theoretical ground for the case-study findings will be discussed.