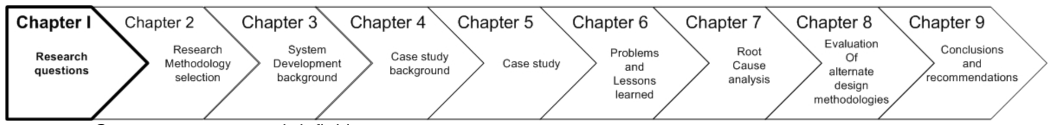
"Design is directed toward human beings. To design is to solve human problems by identifying them and executing the best solution."
Ivan Chermayeff



System concepts and definitions
Research objectives
Research contributions
Problems statement
Research questions
Research roadmap

In this chapter the researcher discusses the rationale of this research. A synopsis of system concepts and definitions are provided followed by a discussion on research objectives, research contributions and research questions. A brief introduction on the preferred development model and structured design is provided. These will be discussed in detail later in this dissertation.

Chapter 1 INTRODUCTION

Modern systems comprise many subsystems and components. INCOSE, (2010), coins the term "system-of-systems". System-of-systems are systems whose subsystems are themselves self contained systems. These subsystems in turn comprise lower level subsystems down to components. The self contained systems or subsystems can be multi-disciplinary and may be of varied technologies (INCOSE, 2010).

A system is more than a collection subsystems and components. The interactions or functional couplings between the different subsystems and their components provide the emergent properties of the system, (Sparrius, 2008), (Johnson, 2006). Modern systems therefore can entail a multi-dimensional hierarchy consisting of many levels with a myriad of functional couplings between the system components. A system therefore does not live in isolation but is always part of a larger system. These characteristics will be taken into account when studying the behaviour of a system.

One of the research objectives is to determine and assess the factors that often result in the poor performance of development projects of integrated complex[1] multi-component systems. The particular focus will be to provide better insight into the design process. The constraints placed on the development process by other processes such as project management will be investigated. The mechanism of the design influencing process, in particular the influence of project management, on this process will also be looked into. This will

[1] The meaning of complex in the context of this research is defined in par 1.2. below.

facilitate the identification of factors that may increase the risk of a design change later in the development process.

The main aim of this research is to identify and analyze the impact of a design change on the rest of the system hierarchy and to make proposals on how to minimize the impact on the development project's performance.

1.1 Development Projects Problem areas

The literature contains many references to the fact that system development projects, particularly in the defence industry, very often suffer from cost and schedule overruns, (Christensen 1998), (Smirnoff 2006). To date, not all the causes for these overruns have been identified. It is commonly presumed that a "***rubber***" baseline is the main cause for project cost and schedule overruns. However, studies by Christensen et al, (1998), on the performance of development projects for military systems, found that other factors must also be influencing development project cost and schedule overruns.

Design as part of systems engineering is an iterative and dynamic process. The history of the iterative and incremental development process is discussed by Larman et al, (2003). Although the systems engineering process has been very well structured and refined over the years, it still remains to a certain extent an unpredictable process. A consequence of this is that changes to a subsystem or component of the system can occur at any stage of the process, often during the system integration stages. During the system integration phases, very often a latent design defect of a system component surfaces. This may force a corrective design change to the affected component to overcome the problem.

In order to reduce development time, integrated complex multi-component systems are developed in a concurrent engineering environment. This entails components and subsystems being developed in parallel, and subsequently integrated into higher level subsystems until the final system integration. The development of a multi-component, multi-disciplinary system generally entails the development of individual system components by different development teams. The development teams may be in-house or outside companies depending on the skills and facilities required.

The accepted process for the development of new systems is the documented Systems Engineering process by INCOSE, (2010) and NASA (2007). Both state that a design is successively refined until it is mature and acceptable for further integration into the system.

The impact of an unexpected design change is exacerbated in a concurrent engineering environment where system components are being developed concurrently during the development of multi-component systems.

Browning et al, (2000), developed models that modelled some of the important characteristics of the development process. They found that design iteration is a fundamental but an often under estimated characteristic of the product development process. The design change impact is mediated by the activity structure or architecture of the process. Models were developed that allow simulation of the process architecture to minimise design change impact thereby reducing development project risk. To demonstrate their model, they used a case-study for the development of an uninhabited aerial vehicle (UAV). Their research, however, was aimed at the managerial system development process and it does not address the influence of the detail design process on development project risk.

In this research a case-study for the development of an anti-tank weapons system project is investigated and then subjected to Root Cause Analysis (RCA), with the objective of determining and analysing the actual factors resulting in project cost and schedule overruns.

The main research objective is to determine and assess the factors that often result in the poor performance of development projects of integrated complex multi-component systems. The particular focus will be to provide better insight into the design process. The constraints placed on the development process by other processes such as project management will be investigated. In particular, the influence of project management on the design influencing process will also be investigated. This will facilitate the identification of factors that may increase the risk of a design change later in the development process.

A generic mathematical model will be developed to quantify the impact of design change on the rest of the system hierarchy. The model will enable optimisation of the system hierarchy to reduce design change impact on other components of the system. The combined effect of these cascaded design changes may have a profound effect on the development project performance. The findings of this research will enable the proposal of improved systems engineering, and design processes to mitigate development project cost and schedule overruns.

The benefits of structured design methodologies such as Axiomatic Design will also be investigated, with the objective of reducing design iterations and risk of later design changes, (Melvin et Al, 2002). Reduced design iterations and reduced unexpected design change risk will also reduce development project risk.

1.2 Concepts and Definitions

The following concepts and definitions are used in this research:

- **Complex systems**

  According to Joslyn et al, (2000) a complex system is a system composed of interconnected parts that as a whole exhibit one or more properties, (behaviour among the possible properties), not obvious from the properties of the individual parts.

  Complex systems in the context of this research will have the meaning of a multi-disciplinary, multi-component system in a multi-hierarchical system level structure.

- **Design**

  Design of a product is an activity to satisfy a consumer need, (Alexander, 2009). Design of a system composed of interconnected parts imposes interface requirements on the subsystems of that system.

  Garner, (1991) supported by Smith et al, (1997), claim that it is fundamentally incorrect to state that design is a problem solving activity, because, very rarely can a definitive answer to a design problem be provided. They also state that design problems do not lend themselves to being "***solved***". The result is that there is no universal definition for design but in general, design can be perceived as a process of compromise involving conflicting factors. The best a designer or design team can hope for is to resolve the conflicts by trading the conflicting factors or constraints off, against a value system. All these factors are, to a greater or lesser extent, in a state of flux and are resolved via a process of trade-off and optimization cycles of development and evaluation. As a result, design is not a one-time activity but a development process to grow the product to maturity.

  From the above arguments, it can be concluded that it is probably more correct to state that design is the art of compromise, since there is no unique design solution to satisfy a specific consumer need. Different designers may very well come up with different solutions, (Garner, 1991), (Smith et al, 1997).

- **System**

  Ludwig von Bertalanffy, (1968), describes a system as a set of mutually dependent variables, and states that a set of variables comprising a system is to hypothesize that each variable in the set is a function of every variable in the set, and uses the following definition: "*A system is a set of variables that maintain functional relations through time, where the present state of a given variable is dependent on its own past state as well as the other variables*". In other words a system can be described by a set of differential equations with time as the independent variable.

Another definition of a system is provided by Andrews et al, (1997) during a workshop on systems thinking. They state that "*A system is an arrangement (pattern, design) of parts which interact with each other within the system's boundaries (form, structure, organization) to function as a whole. The nature (purpose, operation) of the whole is always different from, and more than, the sum of its unassembled collection of parts*". From Andrew's definition it can be concluded that a system is not just a collection of building blocks, there must be some form of functional coupling between the different elements to comprise a system.

- **Systems Engineering**

  Systems engineering (SE) is defined by INCOSE, (2010) as follows: "*Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs*".

  From this definition it can be deduced, that the systems engineering process, includes not only the system but also the logistical system to operate and support the developed system.

- **Development model**

  The preferred product development process in the author's defence industry, is the Integrated Product Support (IPS) model, (Roos, 2001). The IPS development model is a concurrent engineering development model.

  According to Roos (2001, P196), the IPS model is divided into 6 phases shown in figure 16:

  - Management aspects of the development phase.
  - Concept, exploration and definition phase.
  - Demonstration and validation phase.

- Full scale engineering development phase.
- Production phase
- Commissioning and support phase.

The IPS model is discussed in more detail in paragraph 5.1 below. The IPS model ensures a structured concurrent systems engineering approach, at the macro system development project level. The detail design described by Roos (2001) is limited to high level design objectives. His discussions of the IPS model do not address the detail design processes, (Roos, 2001).

- **Project Management**

Project management is the discipline of planning, organizing, and managing resources to bring about the successful completion of specific project goals and objectives, (PMBOK, 2008). PMBOK defines a project as follows: - "*A project is a **temporary** endeavour undertaken to create a unique product or service. **Temporary** means that every project has a definite **beginning** and a definite **end**. Unique means that the product or service is different in some distinguishing way from all similar products or services* ", (PMBOK 1996).

Project management is a structured "*milestone-by-milestone"* process, PMBOK, (2008).

- **Development team member behaviour**

The behaviour of people in a project environment is aptly described by Goldratt, (2006), as follows: "*Tell me how you measure me, and I will tell you how I will behave. If you measure me in an illogical way … do not complain about illogical behaviour*".

Thus, according to Goldratt, (2006), workers in the work place, behave in accordance with how they are measured. This is logical since an employee's salary increases and career movements are dependent on their performance against the measurement metric.

Generally, the primary performance metric for systems and design engineers is technical performance and compliance to user requirements, of the systems and designs they have developed. As a consequence project performance is considered of secondary importance.

Project managers on the other hand are primarily measured on project performance, particularly in terms of cost and schedule, whilst system technical performance is of secondary importance to them (PMBOK, 2008).

The systems engineers and project managers are however, dependent on one another, for overall project success and as a team they need to take ownership for the overall success of the project, (INCOSE, 2010).

Team member interaction plays a pivotal role in the success of the system development project. According to Roach (2010) lack of vision, failure to take personal responsibility, personality conflict, power struggles, lack of clear identity of team member roles and lack of coaching, are the main reasons why teams fail. These pitfalls must be avoided when selecting and managing a design team.

The above concept discussions provides the reader with a clearer view of the limitations of design, the concept of a system, the systems engineering process to bring a system into being and the team members involved on the development project of a system.

1.3 Systems Engineering and Project Management Articles

A Google Scholar survey shows that since the early 1950s, 272,000 articles have been published discussing systems engineering topics. Over the same period, 886,700 articles have been published discussing project management topics, (refer to figure 1).

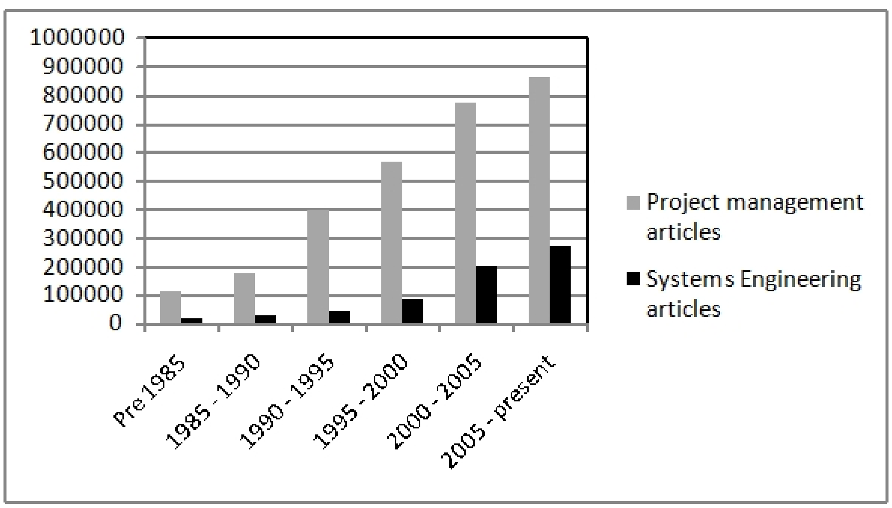


Figure 1: Published Articles

A further literature search indicates that there is a gap in the knowledge of the effects of design changes, during the development of complex systems, in a concurrent engineering environment.

In addition the consequences of design changes on the performance of a development project appear not to have been extensively researched.

This research will delve into the interactions between systems engineering and project management, in a development project environment. A multi-disciplinary development project for a 3rd generation anti-tank weapons system is used as a case-study. The objective being the identification of the root causes of project problems.

The analysis of the root causes of project problems will provide a better understanding of the fundamental mechanisms of the phenomena observed. This knowledge will allow the development and proposal of remedial and mitigating actions.

1.4 Problem Statement

This research is focussed on the concurrent development and integration of system products and the impact of a design change in a concurrent engineering environment. This research will also specifically focus on the influence and impact of project management on the design process.

According to Institute for Defence research Report R-338 (1988), "*Concurrent engineering is a systematic approach to the integrated, concurrent design of products and related processes, including manufacture and support. This approach is intended to cause developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements*".

System development in a concurrent engineering environment introduces new challenges for the system engineer. Sometimes, during integration, a problem is encountered with one component or subsystem, which requires a modification to overcome or correct the problem. If the correction affects an item's Form-Fit-and-Function (FFF), it can also force design changes to other components or related processes of the system, which are in various stages of their own development process.

A single design change of one component may result in design changes of a number of other components in the system. The problem is exacerbated for more complex systems with multi-layers of subsystems and components. The impact of these changes may ultimately have a detrimental effect on the system development project's cost and schedule performance.

Studies by Christensen et al, (1998), into the performance of 400 Defence acquisition projects, found that these often exhibit schedule and cost overrun problems. They also found that this phenomenon is not affected by baseline stability and contract type. They propose that other possible causal factors should be more closely examined, specifically management practices relative to change management.

Sanjay et al, (2000), studied 418 plants mainly in the motor industry and found that management has a profound effect on the quality of design.

Steyn (2009) proposes the compilation of a list of project cost and schedule overruns, and the identification of their causes. The interrelationships between them can then be identified.

Thunnissen, (2004), in his dissertation for mitigating uncertainty in the design of complex multidisciplinary systems, developed project sampling and modelling techniques in order to classify project uncertainty. He showed that the quantitative methods had benefits compared to the current heuristic-based methodology.

This research will focus on the interaction between systems engineering and project management and its influence on project quality. Problems have been identified, inter alia, by Christensen et al, (1998), and Sanjay et al, (2000), in the fundamental understanding of the mechanisms of design iterations and the influence of project management on design maturity.

1.5 Research Objectives

The objective of this research is to determine and assess the impact of design changes on the system, as well as on the development project, in a concurrent engineering environment, and to propose ways to mitigate the problems encountered.

The influence of project management as the encompassing process for system development will also be evaluated.

In this research the following research objectives will be addressed:

- Optimisation of design influencing by dividing the design teams into two complementary but opposing mind-set groups.

- Evaluate the impact of design changes in terms of cost and schedule overruns in a concurrent engineering development environment.

1.6 Research Contributions

The academic contribution of this research is the identification and detail analysis of the mechanisms and effects of design change, in a concurrent engineering environment, and their impact on the overall development project.

The primary body of knowledge for systems engineering, INCOSE (2010), and NASA (2007), focus on the systems engineering process. They, however, do not discuss the impact of design changes on the rest of the development project. The impact and influence of the project management process on system development is also not discussed.

The interaction between the systems engineering and the project management processes, as far as cost and schedule impact is concerned, have been investigated and a design influencing approach will be proposed to facilitate better overall project performance.

1.7 Research Questions

The following research questions are posed:

- Can design influencing models be established to depict the success/failure domain interactions in a dynamic project management environment?
- What is the impact of a design change, in terms of the functionally coupled items, on the development project?
- Can structured design methodologies reduce the number of design iterations, thereby reducing the project's cost and schedule? The Design Structure Matrix (DSM) approach ensures a direct link between the functional breakdown structure (FBS) and product breakdown structure (PBS), (Yassine et al, 2003).

1.8 Research Roadmap

The focus of this research is to determine and evaluate the effects of design changes on the performance of a complex, multi-disciplinary, system development project. Data from a case-study will be analysed to study the impact that design changes have on such development project. The case-study used for the research, is a fully fledged multi-disciplinary and multi-component system, developed in a concurrent engineering environment.

Design iterations are fundamental to the systems engineering process, primarily due to design influencing to drive the design to maturity, (INCOSE 2010), (NASA 2007). For this research it is important to first determine the fundamental mechanisms that give rise to design changes, before being able to determine the effects of these changes on a concurrent engineering system development project. Once these effects are fully understood, will it be possible to:

- Answer the research questions posed.
- Investigate alternative design methodologies to reduce development project risk, in terms of cost and schedule.

The roadmap followed by this research is illustrated in figure 2.

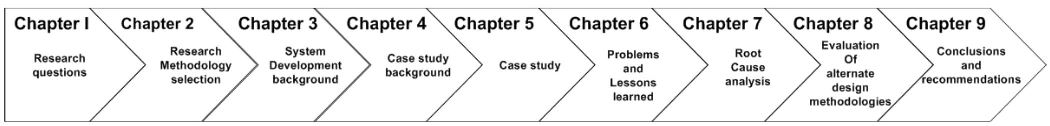


Figure 2: Research roadmap

Particular focus is given to the design influencing process and its impact on the development project as a whole.

System concepts and definitions will be discussed in chapter 1, this will provide the relevant background to systems engineering and project management. This chapter will present the research objectives, the research questions and the research contributions.

Research methodologies and their selection will be discussed in chapter 2. An overview of Root Cause Analysis will also be presented.

Systems, system engineering, project management and facility management, with specific focus on the research's objectives will be discussed in chapter 3. The design team structure, as well as the influence of project management will also be discussed.

The background of armour and anti-tank weapons and the evolution of anti-tank missile systems will be discussed in chapter 4. This will provide a better understanding of the case-study. This chapter will provide an overview of the contract, the top-level user requirements and the project management model.

The case-study for the development of a third generation anti-tank weapons system will be discussed in Chapter 5.

Chapter 6 will evaluate the case-study and present the problems experienced. The project Problem Reporting and Corrective Action System (PRACAS) data will be quantified and analysed.

The identification of the problems' root causes and their mitigating solutions will be discussed in chapter 7. The design influencing model and how the constraints, imposed by project management, can increase the system integration risk, will be discussed. A mathematical model will be developed to quantify the development project risk, and facilitate the optimisation of the system hierarchy.

Alternative design methodologies will be discussed in chapter 8, with the objective of improving project management process compatibility.

The research findings and the answers to the research questions will be discussed in chapter 9. This chapter will identify and make recommendations for further research.

1.9 Chapter Summary

The aim of this research is to identify and analyze the impact of a design change on the rest of the system, and to make proposals on how to minimize the impact of the change on the performance of the development project.

INCOSE, (2010), confirms that design iterations are fundamental to the systems engineering process, it does not, however, elaborate on the reasons for the iterations, or the impact of a design change on other components of the system under development. It also makes no mention of the influence that project management may have on the systems engineering process.

The novelty of this research lies in the identification of design influencing mechanisms, the impact of design changes on the concurrent development of other of the system components and the subsequent impact on the project.

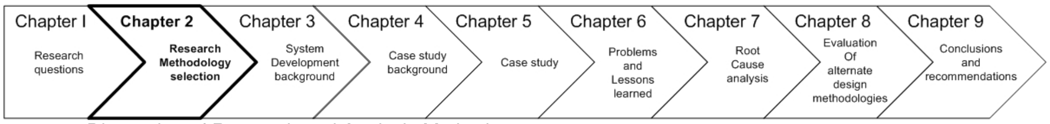
The systems engineering process does not place any constraints on either the activity time, or a resource requirement on the individual process steps. According to Kossiakoff et al, (2003), Systems Engineering must operate within the Project Management environment. This provides for the coordination and management of the schedule and the consumption of resources.

The project management process on the other hand, must function within the constraints of the organization's business process, which amongst others is cash flow and profit focused. It is therefore evident that the systems engineering process does not function in isolation, but functions within other processes. These other processes place constraints on the systems engineering process that may influence the system, under development, as well as the project's performance.

This research will determine the influence of project management on design influencing, and the effect on the overall project. The detrimental effects management has on the design quality, as highlighted by Sanjay et al, (2000) will also be explored.

In the next chapter, the selection of the research methodologies to identify the fundamental design process mechanisms, in a multi-level system hierarchy, will be discussed. As will the data collection and analysis approach to determining the root causes of problems experienced on the project.

"Dissertation Research Methodology is no doubt an important part of a dissertation project. Even it can make or break your project."
Lori Blake, 2008



Discussion of Research and Analysis Method
Selection of Research Methods
Root Cause Analysis (RCA)

In this chapter the researcher discusses the appropriate research and analysis methods, and the selection of the research methods. Also a background to root cause analysis is provided in preparation for the analysis of the case-study data.

Chapter 2 RESEARCH METHODOLOGY

2.1 Discussion of Research and Analysis Method

In the previous chapter the research objectives and research questions, in other words the "***what***" for this research have been discussed. In this chapter the "***how***", or the research methodologies and subsequent selection of the optimal or appropriate research method will be discussed.

First the research method to categorise and classify the problem, reporting and corrective action system data from the case-study will be discussed. This research method is generally limited to the identification of the symptoms of the problems observed. To provide a deeper understanding and subsequent finding of solutions to the problems observed, other research methods will also be investigated.

Research is in essence the search for knowledge by systematic investigation to establish the facts. The objective of research is to develop new or additional knowledge on a given subject. Generally research can broadly be classified into the following categories, Trochim, (2006):

- Exploratory research which identifies structures and quantifies new problems.

- Empirical research which tests the feasibility of a solution using empirical evidence.

- Constructive research which develops solutions to a problem.

Research may also build on previous research or knowledge which can be applied to a better understanding of a specific situation, (Trochim, 2006).

2.1.1 Exploratory Research

Exploratory research as the name implies, is a category of research also used if the problem has not been clearly defined. Its objective is to provide better insight and understanding of an observed phenomenon. Exploratory research will provide the "***why***", "***how***" and "***when***" of a specific observed phenomenon, but generally does not quantify the results. The outcome of exploratory research generally requires further research, Kotler et al, (2006).

2.1.2 Empirical Research

Empirical research in essence tests the feasibility of a solution using empirical evidence, that can be used to test a hypothesis. Empirical research according to **de Groot,** (1992), follows a cycle of Observation; Induction; Deduction; Testing and Evaluation as indicated in figure 3:

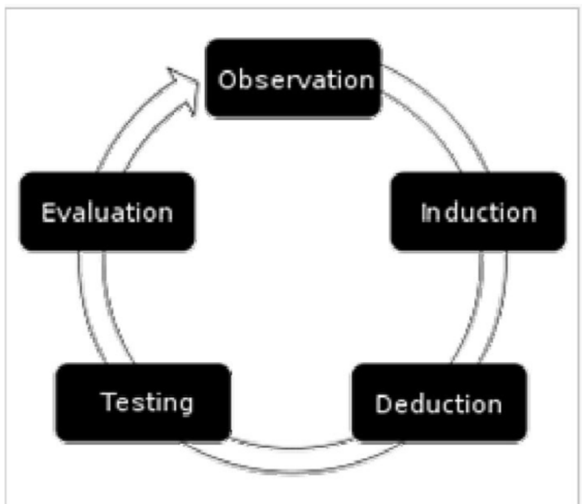


Figure 3: Empirical research cycle

Source: de Groot, (1992)

2.1.3 Constructive Research

The constructive research method evolved for finding and developing solutions to problems. The advantage apparently being that the approach demands a form of validation that does not need to be quite as empirically based as in other types of research, (Crnkovic, 2010).

Ryabov, (2009), states that constructive research aims at producing novel solutions to practically and theoretically relevant problems. According Ryabov, (2009), constructive research is widely used in software engineering and computer science. Constructive research method is building an artefact that solves a domain problem in order to create knowledge about how the problem can be solved, and if previous solutions exist, how the solution is new or better than previous ones.

A further development of Constructive Research is Action Research (AR). The literature is not clear as to the origins of AR but the concept started to appear in publications from the early 1990s with a primary focus in the computer science field. In 2004 van Aken defined the concept of Design Science Research with a more general focus, (van Aken, 2004). Livari et al, (2009) studied the similarities and differences between Action Research, and Design Science Research from several perspectives. They found that often AR does not share the paradigmatic assumptions and the research interests of DSR.

2.1.3.1 Design Science Research

The fundamental purpose of Design Science Research (DSR) is to develop general knowledge, which can be used by professionals in the field in question to design solutions to their specific problems, (van Aken, 2004). DSR is the observation, analysis, understanding and finding of a solution to a phenomenon observed in industry, (Venable et al, 1999) and (Gero et al, 2006). From the above discussions it can be concluded that DSR has evolved from Action Research which in turn has evolved from Constructive research.

2.1.3.2 Narrative Inquiry Research

Clandinin et al, (2000), describe the Narrative Inquiry as a method that uses field texts as data sources, such as stories, autobiography, journals, field notes, letters, conversations, interviews, family stories, photos (and other artefacts), and life experience. According to Clandinin et al, (2000), the narrative threads coalesce out of a past and emerge in the specific three-dimensional space called the inquiry field: "*Living, Telling, Retelling, And Reliving Stories".* The Narrative Inquiry emerged from the field of Knowledge Management under the sphere of Information Management. The Narrative Inquiry research method is a qualitative approach to understanding the behaviour of a process. According to Clandinin et al (2000), a Narrative Inquiry is an understanding of "*narrative as both phenomena under study and method of study.*"

Generally the Narrative Inquiry is a difficult and time consuming process. Since the Narrative Inquiry was limited to the registered

PRACA reports available on the company Local Area Network (LAN) it could be effectively employed by the expert group, discussed in 2.2 and 6.1 below.

2.2 Selection of Research Methods

There are relatively few large budget completed complex multi-component system development projects, particularly in a small country such as South Africa. Also most of the detail data required for in-depth research will generally be propriety company confidential information. Companies would be very reluctant to provide intimate large budget project performance data in an open survey. This eliminates the more generally adopted empirical research methodology due to inadequate detail data to provide an acceptable level of confidence on the findings.

According to Feagin et al, (1991), a case-study is an ideal methodology when a holistic, in-depth investigation is needed. In a case-study, the researcher collects extensive data on projects and events on which the investigation is focused. Leedy at al, (2001), states that the data often includes observations, interviews, documents, and past records. In many instances, the researcher may spend extended period of time on-site and interact regularly with people working on the systems that are being studied. Stake, (1995), states that the researcher must also record the details about the context in which the case is found, including information about the physical environment and any historical, economic, and social factors that have bearing on the situation. By identifying the context of the case, the researcher helps the reader to draw conclusions about the extent to which findings may be generalised for other applications, (Stake, 1995). Stake, (1995), also further suggests that the data generated by the case-study would often agree with the experience of a broad cross section of readers, thereby facilitating a greater understanding of the phenomenon. Yin, (1994), lists four applications for a case-study model:

- To explain complex causal links in real-life interventions.
- To describe the real-life context in which the intervention has occurred.
- To describe the intervention itself.
- To explore the situation in which the intervention, being evaluated has no clear set of outcomes.

A case-study research of a full scale multi-disciplinary complex weapons system development project using the concurrent engineering IPS development model, (Roos, 2001), within a project management environment will be used. A single case-study in depth research has also been successfully applied for doctoral studies by Gumus (2005), Thunnissen, (2004), and Melvin (2003).

Using the Problem Reporting and Corrective Action system (PRACAS) database as input, a Narrative Inquiry research method is used by a Design Review Board (DRB) comprising the key development team members. The team member responsible for the PRACA item under review provides the team with the detail and background to the problem. The team discusses all aspects of the problem before categorising and allocating a Likert scale value (Likert, 1932).

This will be a precursor in preparation for a subsequent root cause analysis of the project problems experienced. The project problems experienced data will be grouped, classified and quantified after completion of the project.

For further deeper analysis, understanding as well as finding of a solution to phenomena observed, the DSR methodology developed by van Aken, (2004), was selected.

Applying a Narrative Inquiry followed by a DSR approach to the case-study; it will be possible to find answers to the research questions by:

- Developing models to depict the success/failure domain interactions in a dynamic project management environment.

- Quantify the project impact as a result of a design change of one item, in terms of the total functionally coupled items in the system hierarchy to the affected item.

- Determine whether structured design can alleviate some of the project problems.

2.3 Root Cause Analysis (RCA)

The Narrative Inquiry into the case-study problems experienced will provide the basis for further detail RCA in preparation for subsequent DSR.

Literatures abound on RCA, (Wilson 1993), (Ammerman 1998), (Mobley 1999), Leszak et al, 2000), Latino 2010). NASA-HDBK, (2008), provides detailed guidelines for the management and resolution of problems on NASA projects most of which are also very applicable in the defence industry. The handbook by Mobley, (1999), provides in three parts detailed processes for failure and root cause analysis primarily with the focus on plant performance.

RCA is described as a thought process by Latino, (2010). NASA-HDBK, (2008), states that RCA aims at attempting to correct or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms. Literature agrees that corrective action is best aimed at root causes rather than symptoms to minimize the likelihood of problem recurrence, (Spolsky 2007), (Leszak et al, 2000).

In essence RCA is the in depth analysis of an undesirable phenomenon to allow a fundamental understanding of the mechanism causing the effect. The literature describes numerous ways and techniques to systematically arrive at the root cause of a problem, (Spolsky, 2007). The appropriate or best technique depends on the type of problem under investigation and the circumstances. The different techniques all boil down to making a series of measurements or observations under controlled conditions, followed by analysis of the results with the objective of isolating the undesirable effect or phenomenon. Once the phenomenon can be repeated, it can be studied and analysed until it is fully understood. Once the mechanism is fully understood, a solution to the problem can be developed to prevent recurrence of the problem. This is generally referred to in the literature as Corrective Action, (NASA, 2008). In practice RCA is generally an iterative process, and can be used as a tool for continuous improvement of a process or design. For instance design maturity and reliability growth, can most effectively be achieved by means of Test-Analyse-and-Fix (TAAF) testing, (DoD Hdbk-189, 1981). It is beyond the scope of this research to go into all aspects of RCA. For the purpose of this research, RCA will be focused on the system development environment.

If a process is not controlled, in other words the loop is not closed; no control or corrective improvement to the process can occur. For better understanding, the analogy of a closed loop process is similar to negative feedback in an analogue electronic signal amplifier to improve the output signal quality of the amplifier, (Langford-Smith 1960), (Terman, 1955).

By implementing a closed-loop Problem (or Failure) Reporting and Corrective Action System (PRACAS or FRACAS), feedback can be obtained about a development project performance, as well as details of any problems encountered, (NAVSO 1998). This is a system for recording problems and failures, and providing a management framework to analyse manage and eliminate the root causes of the problems and failures. The PRACAS term is used to widen the scope of addressing system and development process issues. During system development problems rather than failures are more likely to occur.

Since process problems can occur at any stage in a process and corrective action development takes time, it is generally impractical or impossible to stop the process until a solution is found, (Polsky, 2007). The exception is if the problem results in a safety hazard. In this case statutory regulations normally demand an immediate shut down of the process e.g. grounding of aircraft. However if the problem is not safety related, then generally the process is allowed to continue by implementing a temporary fix, or as is often called a band aid until a permanent solution to the problem can be found to prevent recurrence. Spolsky, (2007, calls this process improvement method "*Fix it twice or fix it two ways*".

Central to the success of PRACAS processes is the principle of a double feedback system as indicated in figure 4. An initial action is required to get the problem under control. A subsequent action is also required to ensure that the root cause of the problem is identified and eliminated. This will ensure that the problem will not recur, (Wessels, (1997).

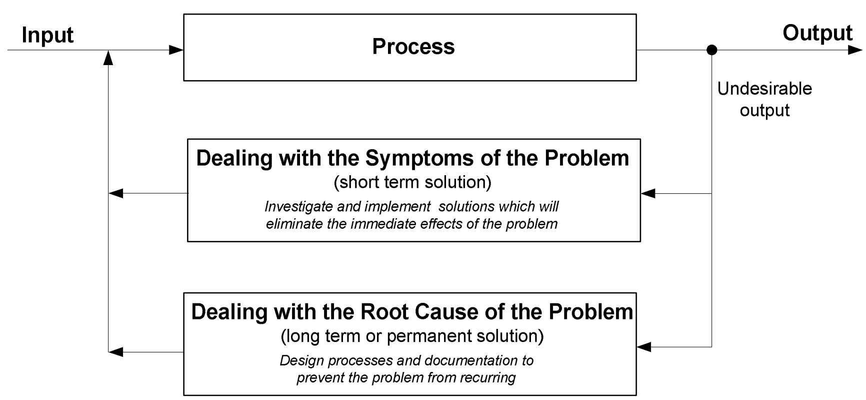


Figure 4: Double loop corrective action process

Source: Wessels, (1997).

NASA (2004), uses the closed loop PRACAS shown in figure 5.

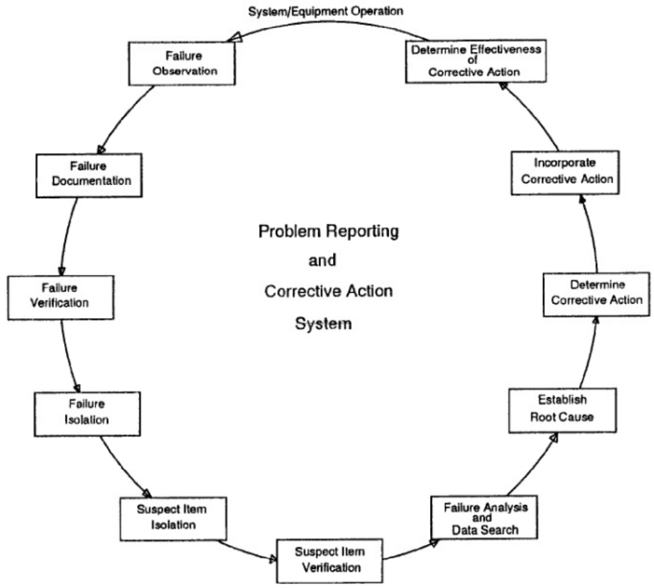


Figure 5: Closed-loop PRACAS

Source: NASA PD-ED-1255, (2004).

The information provided by PRACAS allows areas in possible need of improvement to be highlighted to engineering for development of a corrective action, if deemed necessary. With this system in place in the early phases of a project, means are provided for early identification and attention to eliminate the causes of problems/failures, (NAVSO, 1998). This contributes significantly to reliability growth and customer satisfaction. The system also allows trending data to be collected for systems that are in place. Trend analysis may show areas in need of design or operational changes, (NASA PD-ED-1255, 2004).

PRACAS addresses all problems experienced on a project and is not limited to only the system technical aspects, it includes external factors also, (NASA 2004), (NAVSO, 1998), (Wessels 1997).

In the next paragraph the research's primary focus is to find answers for the research questions and research road map will be discussed.

2.4 Chapter Summary

A literature investigation into research method and approaches has been made to enable selection of the most appropriate research method.

The PRACAS and closing the loop process were discussed to prevent recurrence of problems and to determine the root causes of these.

The Narrative Inquiry research method was selected for categorizing and grouping of the project PRACAS data. The Narrative Inquiry will provide a better background and insight of the context in which the development project problems occurred.

The Design Science Research (DSR) methodology was selected as the most appropriate methodology, for finding answers to the research objectives and research questions discussed in Chapter 1.

It is anticipated that by means of a better fundamental understanding of problems and their root causes, development of solutions to resolve or mitigate the problems can be found. To outline the approach, a research roadmap has been provided in chapter 1, figure 2.

In the next chapter the properties of a system, the systems engineering process, and the project management process to manage the system development project will be discussed. A design influencing approach and model will be proposed with the objective to effectively optimise a design.