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Lydall, Peter Wykeham

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Understanding the challenges of implementing an effective Requirements Analysis process within an engineering R&D environment

Peter Wykeham Lydall
(Student number: 9507552A)

School of Mechanical, Industrial and Aeronautic Engineering

University of the Witwatersrand

Johannesburg, South Africa.

Supervisor:
Professor Craig Law

A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in fulfilment of the requirements for the degree of Masters in Engineering.

Johannesburg, September 2024

DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the Degree of Master of Science in Systems Engineering to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.



……

(Signature of Candidate)

17th day of September, 2024

ABSTRACT

Requirements Analysis is widely regarded within the Systems Engineering community as an activity that has a significant impact on project outcomes. However, it is an activity that is often overlooked or poorly executed. This report details the application of Yin (2003)'s Case Study Method to a single case, involving an engineering research and development group at a South African science council. The case study attempted to gain insights into the perceptions and attitudes of engineers and managers towards Requirements Analysis, that might explain why it is performed inconsistently or less effectively than it could be. Key findings include: that there is a poor understanding of what Requirements Analysis is; the importance of assigning a Requirements Analyst, in a dedicated role, with the appropriate level of engineering experience and Systems Engineering training, and a desire to perform the activity; the necessity of having a cost effective and tailored process which evolves over time.

To my amazing wife and daughters without whose love, support and boundless patience, this report would not have been possible.

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1 INTRODUCTION

1.1 Introduction

Engineers and the organisations that employ them are constantly faced with the challenge of trying to produce complex systems on brief, on budget and on time. Systems Engineering is a discipline which suggests a practical approach towards addressing this issue through the application of managed processes and techniques at both the management and implementation levels. Requirements Engineering refers to the subset of Systems Engineering activities which deal with the requirements phase of projects (Sommerville and Sawyer, 1997). Requirements Analysis has been identified by many experts as one of the key activities which can have a significant impact on project success (Halligan, 1992, Kasser, 2012, etc).

Despite the known benefits of performing Requirements Analysis, there are still many engineering organisations which do not have an effective Requirements Analysis process in place (Kasser, 2012). This represents a significant opportunity for such organisations to improve on their ability to deliver successfully on projects. It is postulated that, if it can be understood why such organisations have not adopted effective Requirements Analysis processes, then organisations and their engineering teams would be in a better position to address this issue.

This qualitative case study examines a specialised group of teams, within a South African research and development organisation that operates within the defense and security cluster. Given that defense related projects are frequently requirements driven, this is a group which could potentially benefit from the adoption of a more effective Requirements Analysis process. Various factors, at both management and implementation levels, that aid or hinder achieving this are investigated, with the objective of identifying potential interventions that could lead to improved project outcomes. Specific attention is paid to the understanding of Requirements Analysis, the people expected to perform the associated activities, and the manner in which processes are adopted and followed.

1.2 Purpose of the Study

There is consensus within the Systems Engineering community (Halligan, 1992, Kasser, 2012, Sommerville and Sawyer, 1997, Van Buren and Cook 1998, Young, 2004) that a significant contributor to failed engineering projects is the problem of poor quality requirements. Similarly, they have recognised Requirements Analysis as the Systems Engineering activity suitable for assessing the quality of requirements and identify where and how they can be improved. However, it seems that while many engineers understand and accept the value of having a good set of requirements and how Requirements Analysis can be used to address the issue, in practice, the implementation of a formal Requirements Analysis process is often either under-utilised or overlooked entirely (Young, 2004). As a result, many opportunities to improve the quality of requirements are missed and systems are developed on the basis of these poor requirements. This translates into a greater probability of projects failing to meet deadlines, failing to stay within budget, and failing to address the need for which they are undertaken.

The purpose of this study is to explore some of the reasons for which an organisation may not have and/or practice an adequate Requirements Analysis process. The study attempts to gain insights into the role of the organisation, managers and implementers in the various stages of the execution of engineering projects, and how they affect the effective adoption of Requirements Analysis processes.

1.3 Study Context

The Radar Technology Area at the Defence and Security (D&S) cluster of the South African Council for Scientific and Industrial Research (CSIR) consists of several self-managed teams conducting research and development in various aspects of radar technology that have relevance in South Africa today. These teams regularly engage in the engineering of new, technologically advanced systems and subsystems for a wide variety of stakeholders, both in the public and private sectors, relating to defence,

safety and security. The teams include and rely heavily on a strong Science, Engineering and Technology (SET) base, required to implement projects, as well as the administrative staff required to perform associated management and support functions.

The organisational leadership has, for many years, recognised the applicability of Systems Engineering principles and practices to its operations and has an interest in supporting and expanding its existing capability therein to improve its ability to deliver successful projects. As such, resources have been allocated to equip staff, particularly at the SET level, with the necessary skills to implement these techniques. Despite this, in practice, it appears that Requirements Analysis is not being widely and effectively practised by the teams for the purposes of improving the quality of requirements. The reasons for this are not adequately understood.

Since the organisation is constantly looking for ways to improve its processes to deliver successfully on projects, reduce risk and save costs, gaining such an understanding could go some way towards achieving the broader business objectives of the organisation.

1.4 Problem Statement

System requirements are frequently used as the basis for creating an engineering solution to a problem. As such, the quality of these requirements is likely to have a significant impact on the success of the engineering effort that follows. Requirements Analysis is widely regarded, within the Systems Engineering field, as having the potential to make a positive impact on achieving successful engineering project outcomes by addressing the problem of poor requirements quality early in the project cycle. However, Requirements Analysis processes are not necessarily always implemented, or those that are implemented may prove to be ineffective.

There is, therefore, a need to acquire better insights into both how to ensure that Requirements Analysis processes are adopted consistently, and, also how to improve their effectiveness.

1.5 Research Questions

This study looks at three inter-related questions:

- How successful has the group been at implementing effective Requirements Analysis processes?
- What are the factors affecting the both the uptake and effectiveness of Requirements Analysis processes within projects undertaken by the group?
- What can be done to encourage that Requirement Analysis processes are implemented more consistently and more effectively?

1.6 Research Objectives

Three primary research objectives will be pursued:

- Perform a current state analysis of what Requirements Analysis activities are currently taking place within the teams and how effective they have been at improving the delivery of projects on brief, on budget and on time.
- Gain an understanding of how Requirements Analysis is perceived by members of the team in terms of what it is and the value it adds.
- Gain an understanding of what can be done to successfully introduce new Requirements Analysis processes or to improve the effectiveness of existing Requirements Analysis processes.

1.7 Hypotheses

- There is an inadequate understanding of what Requirements Analysis is and the mechanisms it employs to achieve more successful project outcomes. This not only undermines the benefits derived from the Requirements Analysis activities that are practiced, but also negatively impacts on the perceived value of performing such a process going forward.

- Requirements Analysis needs to be performed by people with the appropriate training and relevant project experience, who have an interest in doing this specific work, in a dedicated role.
- A Requirements Analysis process needs to be tailored appropriately to the ensure an alignment between the needs of the project and the goals and objectives of the team members expected to execute it.

1.8 Significance of the Study

Much of the literature about Requirements Analysis focuses on why it is important and argues the case for implementing such a process, what the process needs to do and how the process should be structured. Less emphasis is placed on understanding how the people, and the environment in which they operate, affect the adoption of the process and how successfully it is executed.

As such, this study aims to contribute, on a theoretical level, towards a better understanding of how to implement an effective Requirements Analysis process, by focussing on the people and the conditions within the organisation which affect this outcome. This has significance within the field of Systems Engineering and Requirements Engineering in that it provides a case study of a specific type of organisation. The lessons learned from this study may help in the broader understanding of the issues which tend to prevent the optimal use of Requirements Analysis and may provide useful insights for other similar organisations trying to achieve the same thing.

This has significance for the CSIR D&S Radar Technology Area teams in that it can serve as an aid to understanding how to improve their processes and achieve more successful and consistent outcomes in future engineering endeavours.

1.9 Research Scope

The research consists of a single case study, using the methods described by Yin (2003), of an engineering team within a larger research and

development organisation. The focus of the study was on a few key individuals in both management and implementation roles.

2 LITERATURE REVIEW

2.1 Overview

The literature review explores the following:

- Define project success in the engineering context.
- Define Requirements, Requirements Engineering and Requirements Analysis within the context of the Systems Engineering methodology.
- Establish the need for and value of Requirements Analysis and how it affects project success.
- Define what is meant by a good Requirements Analysis process:
    - What needs to happen.
    - What needs to be in place for that to happen.
- Examine the opinions of Requirements Analysis experts regarding:
    - Why Requirements Analysis is not always adopted.
    - Possible remedies.
- Examine what has been written about why organisations initiate changes in their processes and how the success of such initiatives are affected by the people in the organisation.

2.2 Defining "Project Success"

According to Bannerman (2008:1) "*there has been much discussion on the nature and definition of project success, but no consensus has emerged*". He goes on to explain that what defines success for a specific project depends largely on the context. Project success could be taken to mean *"on time, within budget, to specification"*. Alternatively success could refer to that of the product developed, or in achieving business objectives.

Cooke-Davies (2004:2) states that, despite the difficulty in defining project success, "*once the objectives of a project have been clearly defined and the constraints spelled out*" success can be defined as being able "*to deliver the*

project so that it meets the objectives within the constraints". Halligan (1992) takes the approach of looking at success as the absence of failure, and identifies "*loss of capability*", "*cost overruns*" and "*schedule slippages*" as three distinct areas of project failure. Accordingly, a project capable of performing according to its need, developed within budget and delivered on time can be defined as fully successful. Conversely, a project can be defined as not fully successful, or possibly only partially successful, when there is a failure to meet one or more of these three objectives, even if some of these objectives are achieved. While the degree of failure and the severity of the consequences may vary from project to project, it is by understanding how success is defined and measured that an organisation can identify failures and implement corrective actions to address them.

2.3 Requirements and Requirements Engineering

The concept of "Requirements" forms an important part of the Systems Engineering discipline. Buede (2009:151) goes so far as to state that "*Requirements are the cornerstone of the Systems Engineering process*". In trying to define what a requirement is, Harwell et al (1993:17-18) examine the characteristics and relationships of requirements. They state that "*all projects begin with a statement of requirements*" and go on to say that "*if it mandates that something must be accomplished, transformed, produced or provided, it is a requirement – period"*. Sheard (1996a:2) identifies the "*Requirements Owner*" as the first of twelve Systems Engineering roles. She states the first responsibility of the Requirements Owner as "*translating customer needs into specific, well-written requirements*". Sommerville (1996:6-7) looks at various viewpoints surrounding the area of Requirements Engineering. He notes that "*there is no such thing as a 'standard' requirements engineering process*". However, he does provide a generalised model of the four phases that most would tend to follow, shown in Figure 2.1.

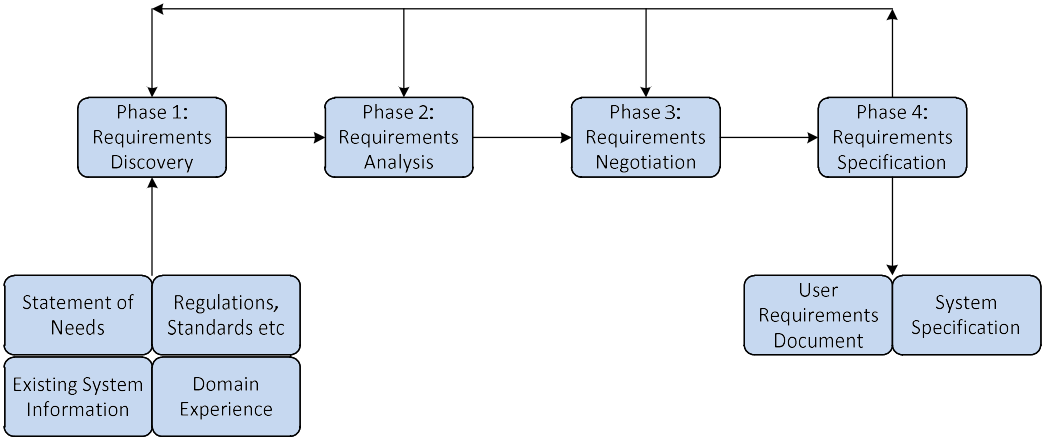


Figure 2.1: Generalised Requirements Engineering Process showing four phases (Sommerville, 1996:6)

He describes these four phases as follows:

1. Requirements Discovery

Various stakeholders are consulted in an effort to understand the need that is to be addressed and the context in which the system must operate. This need is expressed as a set of immature requirements that might be incomplete, ambiguous and not well structured.

2. Requirements Analysis

The set of immature requirements collected in the Discovery phase are analysed to assess how adequately they describe the characteristics of the system that is to be developed. The objective is to identify problems with the requirements, missing requirements, inconsistencies and conflicts between requirements. This often results in the Requirements Discovery phase being revisited.

3. Requirements Negotiation

The requirements that have been identified and refined in the previously phases are discussed with the stakeholders. During this phase, some requirements may be dismissed or modified to accommodate cost considerations.

4. Requirements Specification

The requirements that have been negotiated are formally documented as a user requirements document or a system specification (or both). Where a user requirements document is intended to be relatively easy for customers and end users to understand, a system specification contains detailed and accurate descriptions of what the system should do.

From this model, it can be established that the primary objective of the Requirements Engineering Process is to define, as accurately as possible, *what* a system must do to meet the need for which it is being created. This is achieved by breaking the problem, for which an engineering solution is being sought, down into a set of individual requirements. These are then presented in a requirements specification document. Collectively, these requirements describe, in detail, everything that the system must do. Ideally, if a system meets all its requirements, then the system should fulfil every need for which it is built.

2.4 Requirements Analysis

Requirements Analysis is identified by many authors (Young, 2004, Sawyer, Sommerville and Viller, 1998, Kasser, 2012, Halligan, 1992, Buede, 2009) as one the key activities within the field of Requirements Engineering. The Systems Engineering Body of Knowledge (Sebok) wiki page dealing with the subject (Faisandier et al, 2022), states the following: "*The purpose of the system requirements analysis process is to transform the stakeholder, user-oriented view of desired services and properties into a technical view of the product that meets the operational needs of the user*". As described by Sommerville (1996:6-7) in section 2.3, Requirements Analysis is an activity that happens once requirements have been discovered and before the requirements are finalised, in the form of a Requirements Specification, after further negotiation with stakeholders. It covers a group of activities and processes which are performed to better understand and improve the quality of a set of stakeholder requirements.

Halligan (1992:1) defines Requirements Analysis as a process of capturing and validating requirements "*through analysis of the problem domain*". This

is fundamentally different from simply gathering requirements from stakeholders. It is about taking those requirements and applying methods and techniques to refine and improve them. It is his assertion that, when it comes to requirements, Requirements Analysis "*provides the tools for transforming the inadequate to the adequate*". His paper goes on to identify and define the defects that are typically found in system requirements, before outlining suggested techniques that can be employed in correcting these defects.

Forsberg, Mooz and Cotterman (2005:140) note simply that user and customer requirements "*can be refined and developed by a structured process*". (Young (2004:2) observes that the need for such a process stems from the marked difference between stated requirements and "*real*" requirements. Stated requirements are typically provided directly by stakeholders. Real requirements "*reflect the verified needs*" that the system seeks to address. He goes on to say that "*Analysis of the stated requirements is required to determine and refine real customer and user needs and expectations of the delivered system*". In other words, Requirements Analysis is performed to transform stated requirements into real requirements.

Combining the terminology used by Halligan and Young, as discussed above, results in the depiction presented in Figure 2.2 in which a set of stated, inadequate requirements are transformed into a real and adequate set of requirements.



Figure 2.2: The Purpose of Requirements Analysis

It should be noted that there does not appear to be any singular, unified view among the Systems Engineering community of exactly what "Requirements Analysis" is, what it entails, and where its boundaries lie. The view presented above is merely one of several, but it is the view that

this study will focus on based on the activity it describes rather than the terminology used.

2.5 The Role of Requirements Analysis in Determining Project Success

Brooks (1986:1074) comments that *"The hardest single part of building a software system is deciding precisely what to build. No other part of the conceptual work is so difficult as establishing the detailed technical requirements, including all the interfaces to people, to machines, and to other software systems. No other part of the work so cripples the resulting system if done wrong. No other part is more difficult to rectify later"*. This speaks to the importance of establishing, in the form of requirements, an accurate understanding, which is shared between all stakeholders, of what to build before attempting to build it. This is true not just within the software environment to which Brooks specifically referred, but for the engineering of systems in general. As noted by Buede (2009:151), it is the responsibility of the System Engineer to engage with stakeholders to establish the system requirements and that "*Obtaining 'good' requirements is critical to the successful engineering of a system*". Achieving this shared understanding relies on the adequacy of the set of requirements, which is why many authors concur that the quality of the system requirements have a direct impact on project success and that poor requirements often lead to failed projects.

Sommerville and Sawyer (1996:3) state that "*It has been recognised for many years that problems with specifications are probably the principal reason for project failure where systems are delivered late, do not meet the real needs of their users, and perform in an unsatisfactory way*". According to Van Buren and Cook (1998:3) *"it has been known since as early as the 1950s that addressing requirements issues improves the chance of systems development success*". In the opinion of Young (2001:2) "*Reducing requirements errors is the single most effective action developers can take to improve project outcomes*". While Kasser (2007:288) notes that "*there is*

a consensus that good requirements are critical to the success of a project". Lastly, Halligan (1992:1) confirms that "*Innumerable studies have concluded that requirements problems are the single biggest contributor to cost overruns, schedule slippages and loss of capability in systems and software projects*".

The majority of these authors state explicitly that the earlier problems are identified, the easier, less costly and less time consuming they are to rectify. Thus, problems discovered during the requirements definition phase, which happens early in the lifecycle of a project, can be hundreds of times less impactful than those discovered after a product has been deployed. Halligan (1993:1) claims that "*studies have shown that the cost to correct an error typically increases by a factor of between 20 and 1000 over the life cycle of a system acquisition*". Van Buren and Cook (1998:9) assert that "*Requirements engineering is the systems development activity with the highest return on investment payoff. The cost savings that result from finding errors during verification and validation of requirements can be as high as 200-to-1*". Young (2001:2) goes on to say that "*There is as much as a 2000:1 cost savings from finding errors in the requirements stage vs. in the maintenance stage of the life-cycle*".

Given that poor requirements are known to increase the risk of reduced project success, and that the identification of problems during the requirements phase of a project leads to significant cost savings by correcting those problems early in the project lifecycle, improving the quality of requirements has the potential to significantly reduce risks to the success of a project. Thus, the objective of the type of Requirements Analysis effort that this report refers to should be the early identification of requirements related problems. This can be achieved by spending an appropriate amount of time and money during the requirements definition phase of a project on activities that can reasonably be expected to improve the quality of requirements.

2.6 Defining the "Right" Requirements Analysis Process

Pycraft et al (2010:38) define, from an Operations Management perspective, "*five basic 'performance objectives' that apply to all types of operation".* These include doing things right, fast, on time, cheaply and the ability to change what one does. The implication is that any process should aim to achieve improvements in some (or all) of these objectives, three of which correlate directly with the definition of project success (as defined in paragraph 2.2). The "right" process is one which contributes to project success, the more effectively, the better.

This section examines what constitutes a good Requirements Analysis process in terms of what it is trying to achieve. In other words, the characteristics of good requirements and the constraints within which it should be achieved, namely time and cost.

2.6.1 The Attributes of Good Requirements

As discussed in paragraph 2.6, a Requirements Analysis process improves the rate of project success by improving the quality of a set of requirements. Key to improving the quality of requirements is having a good understanding of what constitutes a "good" requirement and what differentiates good requirements from poor requirements.

Several authors have discussed what they consider to be attributes of good requirements. While some of these attributes pertain to each requirement individually, others pertain to the set of requirements viewed as a whole. These attributes form the basis for establishing a set of metrics which can be used to measure the quality of a set of requirements and used as part of a process designed to improve that quality. A summary of the characteristics identified by each of the authors is provided in Table 2.1.

Table 2.1: Attributes of Good Requirements commonly identified by various authors

	Buede	Halligan	Young	Harwell et al	Hooks
Clarity		X			X
Completeness	X	X	X	X	X
Conciseness	X		X		
Consistency	X	X	X		
Correctness	X	X	X		
Design Independence	X			X	X
Feasibility		X	X		X
Necessary			X		X
Traceability	X		X	X	X
Unambiguity	X	X	X	X	
Verifiability	X	X	X		X

The attributes identified in Table 2.1 are defined as:

Clarity

Halligan (1993:2) defines clarity of a requirement as the measure of how "*readily understandable*" it is. Hooks (1994:1248) states that a "*good requirement should be clearly stated*".

Completeness

Hooks (1994:1252), refers to the issue of missing requirements within a set to be problematic. Buede (2009:172) defines the completeness of a set of requirements according to how adequately it describes "*everything the system is required to do throughout the system's life cycle*". Halligan (1993:2) defines completeness of an individual requirement as it containing all of the necessary information to meet the need it is trying to satisfy within all the constraints and conditions under which it is expected to operate. Young (2004:8) echoes Halligan's definition, adding that the requirement should express a "*whole idea or statement*". Harwell et al (1993:22) define

completeness as providing all the information necessary to implement the next step in the design process.

Conciseness

Buede (2009:172) defines conciseness as not including any "*unnecessary information*" in a requirement. Young (2004:8) concurs, observing that the requirement should be "*stated simply*".

Consistency

Young (2004:8) defines consistency of a requirement as the absence of conflicts with other requirements. Halligan (1993:2) adds that requirements should furthermore not conflict with "*any element within its own structure*". Buede (2009:172) considers consistency across a set of requirements as well as the documents from which they are derived.

Correctness

Buede (2009:172) defines a correct requirement as one that "*states something required of the system, as judged by the stakeholders*". Halligan (1993:2) defines correctness as "*the absence of errors of fact*". Young (2004:8) agrees with Halligan's assertion, adding that the requirement should be "*technically and legally possible*".

Design Independence

Buede (2009:172) defines design independence as avoiding specifying part of the design solution within a requirement. Hooks (1994:1248) speaks about the importance of requirements stating "*what*" the system must do as opposed to "*how*" it should be implemented. Harwell et al (1993:20) express explicitly that requirements "*should state what is needed, not how it is to be provided*".

Feasibility

Young (2004:8) defines feasibility as the ability to realistically implement a requirement within the constraints of the schedule and budget of the project. Halligan (1993:2) and Hooks (1994:1248) add to this the constraints of

available technologies, the environment in which the system needs to operate and "*other*" constraints.

Necessary

Young (2004:8) asserts that a necessary requirement is one upon which the system depends to meet "*prioritized real needs*". Hooks (1994:1248) concurs that a requirement can only be considered necessary if its absence would result in some meaningful consequence.

Traceability

Buede (2009:172) defines traceability as the ability to link a derived requirement to the higher-level requirement from which it was derived "*via some unique name or number*". Young (2004:8) more broadly defines traceability as being to trace the source of a requirement, and that it should be able to be tracked throughout the system. Hooks (1994:1248) and Harwell et al (1993:18) simply state the need for the traceability without elaborating further.

Unambiguity

Buede (2009:172), Halligan (1993:2) and Young (2004:8) all define unambiguity as a requirement having only one interpretation, with Harwell et al (1993:22) explicitly stating that different users would interpret the requirement in the same way. Hooks (1994:1251), similarly defines unambiguous requirements as those that will not be misunderstood.

Verifiability

Young (2004:8) defines verifiability of a requirement as being able to prove that the requirement has been implemented in the system. Buede (2009:172) adds to this definition that it must be done within reasonable cost and time constraints. Halligan (1993:2) describes the same attribute, referring to it as "*testability*".

2.6.2 Cost and Time Constraints

While much has been written about the characteristics of good requirements should possess, for which there seems to be a lot of consensus, a lot less has been written about how much time and effort should be invested in requirements processes and, more specifically, the Requirements Analysis process. For any Requirements Analysis process to be worthwhile it must not only be able to successfully identify and correct poor requirements, but the time and cost invested in achieving the improvement in requirements quality must translate into an overall saving of time and cost to the project.

Halligan (1992:1) believes that cost overruns of between 10% and 80% could be addressed by implementing a Requirements Analysis process which, provided that adequate skills and methods are applied, could be achieved at a cost of less than 2% of the total project cost. Young (2004:197) does not speak specifically about how much time should be spent on Requirements Analysis, but notes that the industry average expenditure on requirements processes is in the order of 2% to 3% of total project cost. He goes on to state that NASA's experience demonstrates how projects which spent close to the industry average tended to suffer cost overruns of 80% to 200% while projects that allocated 8% to 14% fared significantly better at 0% to 50% overrun.

While Halligan (1992) and Young (2004) emphasise the need to spend more time on requirements processes, Sawyer, Sommerville and Viller (1998) caution against spending too much time. They consider the requirements process to be iterative in nature. Subsequent iterations achieve improvements in requirements quality but become increasingly costly and time consuming while yielding diminishing returns in terms of value added. As Sawyer, Sommerville and Viller (1998:3) put it: "*design activities cannot be deferred indefinitely while the requirements evolve slowly towards an elusive state of perfection*". In practice the process needs to be tuned to a point where the benefits still justify the cost. Sommerville and Sawyer (1997:16) are not prescriptive regarding how much time should be spent on requirements processes, but rather suggest that this point can be

discovered by actively pursuing process improvement within an organisation in an evolutionary manner. Their contention is that "*Revolutionary approaches to process improvement cost too much and are far too risky for most organisations. Rather, we are believers in an evolutionary approach to process improvement*". In so doing, organisations are able to discover how much time and effort is appropriate for their specific conditions to be spent on requirements processes, including Requirements Analysis.

2.7 Managing Change

While the previous sections have focused on issues directly related to Requirements Analysis, implementing new processes within an organisation involves a change in the way people do things. As stated by Cummings and Worley (2009:163) "*Change can vary in complexity from the introduction of relatively simple processes into a small work group to transforming the strategies and design features of the whole organization*". While this study is looking at the former, they contend that the same principles apply to all types of change. Cummings and Worley (2009:165) go on to state that "*organization members generally do not support change unless compelling reasons convince them to do so*". This section examines what motivates teams within organisations to implement new processes, why employees resist change and how organizations can affect the likelihood of success in such efforts.

2.7.1 Why Organisations Undertake Change

Burnes (2017:6) identifies one term that encompasses the multitude of potential reasons that organisations have for implementing change: "*Organisational Effectiveness*". However, he concedes to Rollinson's (2002:468) point that: "*There is no universally accepted theory of organisational effectiveness. Neither is there a universally accepted definition and set of criteria that allows the effectiveness of an organisation to be measured".* While the view of what makes an organisation effective may vary from organisation to organisation, the underlying point is that

organisations will undertake change according to what they perceive will make them more effective. Similarly, Cummings and Worley (2009:165) argue that change can be motivated by a dissatisfaction with the status quo that results in a desire to improve the organization.

2.7.2 Resistance to Change

Burnes (2017:13-14) notes that "*many see resistance as the main reason for the failure of so many change efforts*" and that the conventional view seems to be that "*for change to be successful, change agents have to anticipate and overcome employee resistance*". However, he goes on to argue that there is strong evidence that it is not only employees who resist change, but also the managers who are tasked with driving the change. Additionally, he notes that resistance to change is often indicative of flaws in the proposed changes. He concludes that most resistance to change stems from "*conflicting or incompatible objectives within the organisation*". As such, he argues that rather than trying to overcome employee resistance, organisations should seek to implement changes to which employees are more amenable.

Schermerhorn, Hunt and Osborn (2002:64) offer a similar view. They state that while change agents often view "*resistance as something that must be "overcome" in order for change to be successful*", such resistance should rather be used as helpful feedback and should be used in formulating a strategy to implement changes successfully. They go on to identify four important factors that typically influence people to resist the changes themselves – *Benefit, Compatibility, Complexity* and *Triability*. Specifically, the change itself should be: perceived as "*a better way*" of doing something; aligned with "*existing values and experiences*" of those directly affected; as easy and simple to execute as possible; and phased in incrementally over time, adapting to the changing environment as the impacts of the change become known.

Strebel (1996) argues that successful change initiatives are contingent on the acceptance of employees of the impact that such change will have on

what he refers to as the "*Personal Compact*" between the employee and the organisation. He describes this compact as an agreement consisting of both formal and informal elements that govern the relationship and mutual obligations and commitments to each other. He speaks about three "*dimensions*" of the personal compact – *Formal, Psychological* and *Social*. In other words, a personal compact consists of elements that: are explicitly agreed upon between the employer and employee; are implicitly understood, often arising from "*feelings like trust and dependence*"; and involve the differences between how a company purports to act and how it actually acts. He observes that companies that attempt to implement change by addressing only the formal dimension of the personal compact are unlikely to be particularly successful, and stresses the importance of ensuring that psychological and social dimensions are also considered. He argues the importance of not simply directing employees to implement change, but of convincing them of how the change will positively affect them personally. At the same time, it is not sufficient to simply convince employees of the value of accepting change, it remains important that organisation follow up on what is promised with action in order for the change to be successful.

2.7.3 Overcoming Resistance to Change

Worley and Cummings (2009:167) suggest three possible strategies for overcoming resistance to change:

1. *Empathy and Support:* This involves listening to the concerns of those who will be affected by the change and attempting to understand their concerns. Gaining such an understanding can help to formulate an effective strategy to successfully "*overcome barrier to change*".
2. *Communication:* This involves addressing the uncertainties of those who will be affected by the change by providing them with the information necessary to "*allay unfounded fears*".

3. *Participation and Involvement:* This involves giving those who will be affected by the change the opportunity to contribute to how the change will be effected. Not only is this effective at reducing resistance to change because people are more likely to buy into ideas that they themselves come up with, but it also tends to make the changes themselves more effective by drawing on a "*diversity of information and ideas*".

Strebel (1996) notes the importance of addressing the personal compact between the employer and the employee in getting people to accept change. He suggests three steps in revising the personal compact: Firstly drawing attention to the need for change and how this will affect the personal compact; then allowing employees the opportunity to "*revise and buy into*" a new personal compact; and lastly establishing a new set of both "*formal and informal rules*".

2.8 Factors Affecting the Successful Implementation of Requirements Analysis

The previous paragraphs have discussed why a Requirements Analysis process is desirable and what it should do. Kasser (2012) notes, however, that there is a consensus that despite an awareness of the importance of having good requirements and that methods of producing better requirements are known, organisations continue to produce poorly written requirements. Clearly it is not enough that the people within those organisations are aware of the need for Requirements Analysis. This implies that there are other factors that influence whether or not a Requirements Analysis process is adopted. These factors are divided into two categories: enablers are those factors that are considered important to the success of implementing a Requirements Analysis process; and barriers are factors that hinder that success. This section examines both as possible reasons as to why Requirements Analysis processes are not adopted.

2.8.1 Enablers

Management Support

Burnes (2017:20) notes that it is organisational leadership who are responsible for both accepting an identified need for change and driving that change. He states that "*change has to be managed*" by what he refers to as a "*change agent*" who is either in, or appointed by someone in a leadership position within the organisation. Cummings and Worley (2009:163) agree, stating the need for management involvement before implementing change. They go on to describe how it is leadership at a level appropriate to the scope of the change who are responsible for managing that change and ensuring that it persists and continues to improve over time.

Having a Dedicated Requirements Analyst Performing the Role

Sheard (1996a:1) notes that "*it is recognized that all engineers can and probably should adopt a Systems Engineering approach*". However, she draws a distinction between adopting the approach of Systems Engineering and performing a Systems Engineering role. In her companion paper, Sheard (1996b:5) states need for ensuring that people with specific Systems Engineering expertise are assigned to those roles, stating that "*If systems engineering is going to be done with teams, the teams need people who understand the systems engineering process*". Similarly, Young (2002:9-11) identifies the importance of ensuring that Requirements Analysis is performed by people with the appropriate training and experience. He states that "*it is crucial that training be required for requirements analysts and engineers*" as well as strongly recommending that "*the project involve people who have previously successfully used all methods and techniques that are to be employed*". Conversely, Kasser (2012:2) points to both "*Lack of training for writing good requirements*" and "*Lack of implementation and solution domain knowledge in the systems and software engineers eliciting and elucidating the requirements*" as two key factors that prevent getting requirements right.

Having a Formal, Documented Process

Somerville and Sawyer (1997:19-22) examine the idea of "*process maturity*" in requirements engineering. They consider the Capability Maturity Model (CMM), often used in software engineering, as the basis for defining their own, similar, definitions for requirements engineering process maturity levels. They note that the more mature the process is, the more likely it is to produce successful outcomes – in this case, high quality requirements documents. Identified among the necessary elements of achieving higher maturity levels is the formalisation of the process by means of defining it in a documented format. They explain that without this level of process maturity, the quality of a requirements tends to depend on the "*skills and experience of individual engineers*", leading, in many cases, to a failure to produce requirements documents of good quality.

Similarly, Young (2004:6) advocates for the use of what he calls a "*process approach*". He goes on to explain that one of the critical elements necessary to succeed in establishing such a process is that of creating and implementing a "*documented description*" thereof. This document provides the necessary information to adequately describe how to go about performing "*a set of activities that results in the accomplishment of a task or achievement of an outcome*". The important advantages of documenting a process he identifies include: that the knowledge and experience within the organisation can be captured; that there can be a common vision within an organisation and; that lessons learned during the implementation of the process can be captured and used to update the process in order to facilitate continuous improvement. He explains that unless a process is properly documented in a manner which is accessible and easy to understand by all who are required to follow the process, the successful adoption of the process remains unlikely.

Brace and Cheutet (2011:874) identify as one of the problems continuing to face Requirements Analysis is a lack of a uniform, formal process and see this as a motivation for establishing a framework to support Requirements Analysis.

2.8.2 Barriers

A Lack of Understanding of the Impact that Better Requirements have on Project Outcomes

Sheard (1996b:894) states that "*An unquestionable, rigorously defined, and measured value of systems engineering will probably never be developed*". This is because one can only observe a project outcome that was achieved given a certain Systems Engineering effort. One can only guess what the outcome would have been had a different Systems Engineering effort been committed. As with any such process, measuring the cost of implementing a Requirements Analysis process is visible and easily measurable, by simply assessing the amount of time spent by Systems Engineers on those activities. However, measuring the impact this has on final project costs is neither visible nor easily measurable. She goes on to argue that it's not the value of systems engineering activities that matters, so much as the "*perception of value*".

While the improvement of the *quality of requirements* may be measured using an appropriate set of metrics as suggested by Halligan (1993), demonstrating the benefit of that improvement on the final outcome of a project is often significantly more challenging because it is impossible to know how a project would have been affected had more, or in other cases, less time been devoted to this activity. Kasser (2012:2) notes too how a "*Fundamental lack of understanding of the need for, and the purpose served by, requirements, by management*" can lead to a failure in allocating sufficient time to produce good quality requirements.

Davis and Zowghi (2004) argue the point that, even though they are important, good requirements practices are "*neither necessary nor sufficient*" for project success. Their intent is not to refute that a good requirements practice will improve the likelihood of project success. Rather, they highlight that projects can succeed despite the absence of good requirements practices, while projects can also fail even with the inclusion of good requirements practices. If an organization can achieve project

success despite a lack of good requirements practices, those responsible for project delivery may be reluctant to invest time in a Requirements Analysis process because it is deemed unnecessary, and thus serve only to add extra time and cost to the project. Additionally, a bad experience on a project that implements a Requirements Analysis process could undermine confidence in using such a process in future endeavors. Davis and Zowghi strongly advise against such complacency and note that industry experience would suggest that long term results tend to favour organizations that do follow good requirements practices.

Unsuitable Processes

Halligan (1992) proposes a comprehensive Requirements Analysis process that looks at many aspects of poor requirements and how to address each of them. While there may indeed be merit in adopting the process in its entirely, other authors propose a more moderate approach of adopting a process that is focussed on addressing those issues that achieve the biggest positive impact on project outcomes.

Sommerville and Sawyer (1997:16) note that "*Getting started with process improvement is a daunting task*". Organisations tend to constantly be involved in the day-to-day tasks of delivering on projects and meeting deadlines. Convincing people to invest time in improving or developing new processes, even if those improvements will ultimately prove to be worthwhile, is challenging when there are more immediate pressing concerns. The bigger the time and cost investment required for the process, the more likely it is to be met with resistance. For this reason, they advocate avoiding revolutionary approaches to process improvement and rather support the pursuit of a more evolutionary approach. As they put it "*A continuous improvement cycle through a series of small steps is required. Small-scale improvements with a high benefit/cost ratio should be introduced before expensive new techniques*". Young (2002:12) agrees and states: "*Do not try to do everything at once. Rather encourage the project*

team to select and commit to a few improved practices that make sense in your environment".

A Lack of Understanding of the Difference Between Stated Requirements and Real Requirements

Young (2004:2) comments that "*There is a significant difference between "stated" requirements and "real requirements*". Unfortunately users and customers are not often particularly good at stating their requirements accurately and effectively. As Kasser (2012:2) puts it, it's not uncommon to experience a "*failure of the stakeholders to articulate the requirements, which results in incomplete and sometimes results in incorrect requirements*". Sawyer, Sommerville and Viller (1998:4) agree, stating that "*the customer may not have a clear view of what they need*". This could stem either from a poor understanding of what they need or from a lack of proficiency at writing good requirements, or a combination of both. Because there is a poor appreciation of this phenomenon, it is often incorrectly assumed that requirements obtained directly from users or customers are already adequate. As a result, engineers and developers are frequently unaware of the need for further Requirements Analysis. Ironically, this issue highlights both the importance of Requirements Analysis, as well as why it is often not performed.

Too Much Focus on Processes, Not Enough on People

Several authors have noted that more emphasis should be placed on the people who need to implement Requirements Engineering tasks. Van Buren and Cook (1998:9) state that "*At their heart, requirements skills are human based. Tools and technologies can only support requirements activities. When evaluating and adopting new RE technologies, focus on those technologies and adoption issues that support the human requirements engineer*". Kasser (2007:290) adds that "*Systems Engineering is perceived as a process (Hall, 1962) (MIL-STD-499B, 1992) and there is a major focus on process standards and Capability Maturity Models (CMM). The contribution of effective people and the difference they can make is*

generally overlooked". The point being made is that processes can fail even if *what* they are designed to do is correct unless attention is paid to *how* the people expected to implement the process are going to respond to it.

As noted by Sheard (1996a:1) "*There has been much discussion about whether INCOSE is about systems engineers or about systems engineering*". In identifying the twelve roles in Systems Engineering – roles that need to be performed by people – it is clear that Systems Engineering is a diverse discipline with many processes that would require specialists to perform.

Somerville and Sawyer (1997:23) also note that the maturity level of the process is only one of the factors affecting the quality of a requirements document, and identify that the "*abilities and experience of the people involved*" as another important factor.

Conflicting Priorities

Kasser (2012:2) identifies as another issue preventing getting requirements right, the "*Lack of time to write the requirements due to schedule constraints*". While he was not referring specifically to Requirements Analysis, the same principle could logically apply – that there might be sufficient time to write requirements, but not to analyse them due to schedule constraints. Young (2004:2) comments on the inclination to proceed directly to the "*real work*" of a project, to start with development processes, before sufficient time and effort have been committed to requirements activities, including Requirements Analysis. He suggests that this tendency is driven by a perception, particularly among customers and project managers, that the amount of work committed is an indication of "*progress being made*".

2.9 Theoretical Framework

Based upon the information gathered from the literature review, Figure 2.3 illustrates a theoretical framework of the various identified elements that contribute, directly or indirectly, to the effective use of Requirements

Analysis. Also illustrated in the diagram, as applicable, are attributes connected to some elements and the expected outcomes that are achieved when Requirements Analysis is used effectively.

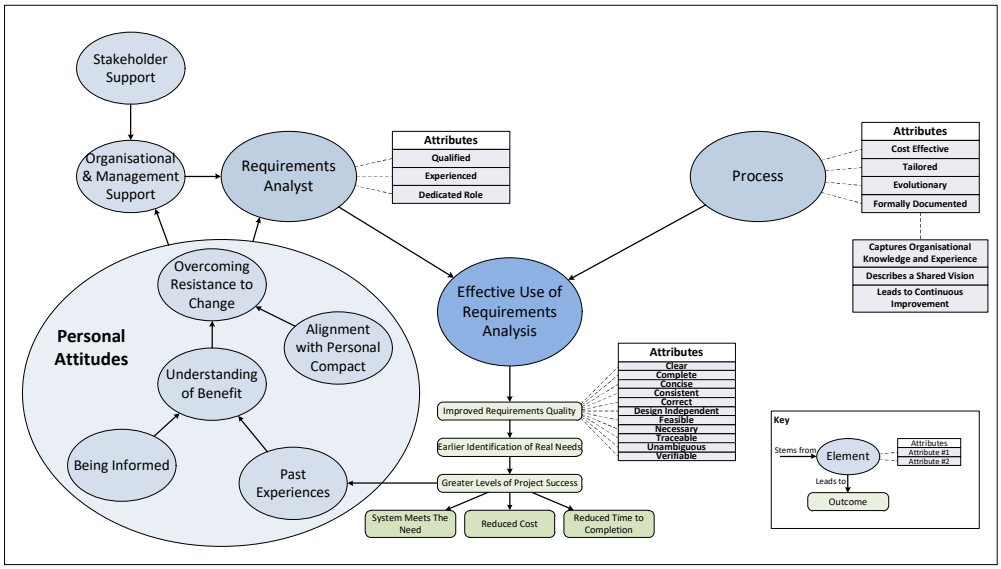


Figure 2.3: Theoretical Framework showing the various elements necessary to implement an Effective Requirements Analysis process

2.9.1 Element Descriptions

a) Effective use of Requirements Analysis

At the centre of the framework is a large bubble representing the *Effective use of Requirements Analysis*. This is the focus of the framework. It is achieved through the application of an effective process, implemented by a suitable requirements analyst. Effective use of Requirements Analysis is expected to lead to an outcome of improved requirements quality. This, in turn, leads to the earlier identification of "Real Needs" contributing to greater levels of project success.

Expressed as other bubbles in Figure 2.3 are the elements making up the framework. They represent the various things that contribute to the effectiveness of Requirements Analysis.

b) Process

The process is that of Requirements Analysis. It is the set of actions that the Requirements Analyst undertakes with the objective of achieving an

improvement in requirements quality. To be effective, the process should be characterised by the following attributes:

- Cost effective – Section 2.6.2 discusses the importance of ensuring that the process is effective at identifying requirements problems while not being overly time-consuming to perform;
- Tailored – Section 2.6.2 also highlights how the process should be focussed on what makes sense for the specific environment in which is being used; and
- Evolutionary – Section 2.8.2 describes how unsuitable processes are a barrier to implementation. As such, the process should be subject to a continuous series of incremental improvements over time based on the practical experiences gained from implementing it;
- Formally Documented – In section 2.8.1 it is discussed how the process should be defined formally by means of documentation focussed on three primary objectives:
    - Capture organisational knowledge and experience;
    - Create a shared vision of the process within the organisation; and
    - Provide a mechanism for continuous improvement.

c) Requirements Analyst

This is the person, or people, tasked with implementing the Requirements Analysis process. Suitable requirements analysts are characterised, in section 2.8.1, by the following attributes:

- They have appropriate qualifications acquired by means of formal training in the field of Systems Engineering with specialisation in Requirements Engineering; and

- They have an appropriate level of experience working on implementing systems within the domain of the system being developed.

To be successful at implementing a new Requirements Analysis process, or to improve an existing process, a Requirements Analysis needs management support and to overcome resistance to change.

d) Management and Organisational Support

Section 2.8.1 explores how organisational leadership is ultimately responsible for identifying the need for and driving change. Typically, such support is only given once issues that cause them to resist change have been overcome.

e) Stakeholder Support

The importance of getting stakeholders to support processes is touched upon in Section 2.8.2. Support from management is dependent on being able to convince clients of the necessity to commit the required time and money to the process.

f) Personal Attitudes

The importance of people involved in ensuring a process is successfully implemented is identified in section 2.8.2. Critical to the willingness of the requirements analyst to implement the process, as well as managers to provide the necessary support for the process, are their respective attitudes towards the process. Several factors contribute to such an attitude:

f.i) Being Informed

Section 2.8.2 highlights how the lack of understanding of the benefits of a process is a barrier to implementation. Being informed about these benefits is one method of gaining such an understanding. This could be achieved in

several ways, ranging from informal discussions with other people who have knowledge of the process, to formal training on the topic.

f.ii) Past Experiences

Following from point **f.i)**, past experiences involving the use of a process are likely to affect the understanding that people have of the effectiveness of a process. If past experiences have been positive, this could provide individuals with an innate understanding of the benefits. Conversely, if past experiences have been negative, this could result in individuals adopting a less positive attitude towards the process.

f.iii) Understanding the Benefit

Section 2.7.1 deals with why organisations undertake change. It is critical for any change initiative that the benefit of the change, both to the organisation and the individuals expected to drive and implement the change, is understood and accepted. The role that Requirements Analysis can play in achieving successful project outcomes is described in section 2.5. Two possible avenues by which employees in the organisation may acquire such an understanding include:

- By being informed by a third party, for example by way of training or obtaining of a qualification, as mentioned in point **f.i)**; or
- By experiencing it first hand through successful execution during a project, as mentioned in point **f.ii)**.

f.iv) Alignment with Personal Compact

The concept of a “Personal Compact” between an employee and the organisation for which they work is explored in section 2.7.2. A personal compact encompasses the understanding that the employee has of what is expected of them, and what they expect from the organisation in return. Typically, such a compact will comprise not only of agreements that are formally and explicitly agreed upon, but also of informal elements that are tacitly understood.

It is deemed important that any change initiatives within an organisation that affect an employee can be reconciled with their personal compact. This requires either ensuring that the change is acceptable within the existing compact or some degree of redefining of the personal compact to encompass the change.

f.v) Overcoming Resistance to Change

Section 2.7 examines managing change within an organisation. It is argued that the biggest reason for the failure of change initiatives like implementing new processes, or improvements to existing processes, stems from resistance by employees. Two key factors in overcoming this resistance are:

- Convincing the employee of the benefit of the change, as discussed in point **f.iii)**; and
- Ensuring that there is a strong alignment between what the change is trying to achieve and the personal compact that the employee has with the organisation, as discussed in point **f.iv)**.

Resistance to change can manifest both at the management level from which it is expected to drive the change, and at the implementation level where the change is expected to be executed. Therefore, it is important to ensure that the concerns of both management and implementors are addressed if resistance to change is to be overcome.

2.9.2 Outcomes

The objective of Requirements Analysis is to achieve greater levels of project success by improving the quality of system requirements. Requirements of high quality are characterised as clear, complete, concise, consistent, correct, design independent, feasible, necessary, traceable, unambiguous and verifiable.

An improvement in requirements quality is expected to lead to the identification of the real needs of a system earlier in the project cycle. This in turn leads to greater levels of project success in terms of being on brief, on budget and on time. Achieving greater levels of project success provides

a positive experience for the organisation and increases the level of confidence in persisting with the process.

3 RESEARCH METHODOLOGY

This section presents the research method used in this study.

Leedy and Ormrod (2015:97-98) explain how the research "*data and methodology are inextricably intertwined*", while Yin (2003:7) recognises that "*the most important condition for differentiating among the various research strategies is to identify the type of research question being asked*". The research questions thus inform both the research method employed as well as the type of data that needs to be acquired. The type of data, in turn, informs the research design.

3.1 Research Method

This study seeks to answer the research questions by describing and explaining the human attitudes and perceptions towards Requirements Analysis which drive behaviour. It is an explorative study, focussing on the *why* in order to explain the *what*. The data being sought is not objective, but rather the opinions and perspectives of individuals, each of whom have their own subjective realities and experiences. For this reason, a qualitative method was selected, with an emphasis on acquiring detailed data from individuals, who are actively involved in projects which would benefit from the use of Requirements Analysis and then attempting, through the process of thematic analysis, to find common threads. This work was conducted under the supervision of the school's ethics committee, ethics clearance number MIAEC 096/21.

3.2 Research Design

Yin (2003:6) suggests that a case study is useful, even preferred, when pursuing explanatory questions, questions that typically start with "*How*" or "*Why*". Since the research questions proposed focus on *why* individuals within an organisation make specific choices when it comes to Requirements Analysis, the use of a case study was considered appropriate for the research design.

The Radar Technology Area of the CSIR Defence and Security cluster was an ideal case study for this research due to the nature of the work that is done there and the people who are employed to do that work. Stakeholders include both government and private organisations involved in both military and civilian application areas. This leads to a varied portfolio of unique and interesting projects. These typically involve the creation of new systems which rely either on developing new technologies or the application and use of existing technologies in new and innovative ways. Development cycles can take many years and draw on many different engineering disciplines.

As stated in MIL-STD-499B (1994) which defines "*a total system approach to the development of defense systems*", "*the systems engineering process is applied iteratively throughout the system cycle to translate stated problems into design requirements*". Consequently, it is standard practice within the defence industry for projects to be requirements driven. As such, the engineers in the Radar Area teams are not only familiar with many of the concepts pertaining to requirements in Systems Engineering, but also have practical experience of working on projects of varying scope and complexity from inception to product delivery.

An additional benefit of using the CSIR in a case study is that the CSIR is mandated by the Scientific Research Councils Act of 1988 to be generally supportive of academic studies that seek to improve technical processes and methods that can be utilised in industry. Not only does CSIR management avail staff to participate in interviews for case studies, but it is also actively encouraged.

Since this case study was examining individuals within a specific research group of the CSIR, the number of potential participants from which to select a sample was deemed sufficient for the scope of the study. Adopting a single case study approach was also considered adequate given that the outcomes from the investigation will have direct benefit to the participants involved.

3.3 Sample

The selection of candidates attempted to include a mix of gender, age and ethnicity in order to ensure the inclusion of as many different perspectives as possible. As reflected in the research questions, it was also important to obtain the perspectives of people in both implementation and management roles. After the identification of possible candidates, emails were sent to ten selected individuals requesting voluntary participation in the study. Six candidates responded positively. The positive respondents comprised a group consisting of three male and three female respondents, two of whom were of Indian ethnicity and four of whom were white. Profiles of the six respondents based on roles and experience are presented in Table 3.1 below

Table 3.1: Respondent Profiles

Respondent	Respondent Profile
Respondent 1	Research Group Leader and Lead Technical Specialist
Respondent 2	Research Group Leader and Project Manager
Respondent 3	Principle Engineer and Lead Sub-Systems Developer
Respondent 4	Senior Engineer and Signal Analyst
Respondent 5	Senior Engineer and Sub-Systems Developer
Respondent 6	Junior Engineer and Sub-Systems Developer

3.4 Research Instrument

Yin (2003 p90) proposes three types of case study interviews. The "*focused interview*" (also referred to as a semi-structured interview) can be open-ended and takes on a conversational manner, while being loosely based on a set of prepared questions. Although it is more structured than a completely open-ended interview, it is less rigid than a formal survey. The focussed interview was selected because it provides a good opportunity to explore issues and follow where they lead, while remaining focussed on the specific questions at hand.

The primary tool used in extracting data from the interviews was thematic analysis. Guest et al. (2012 p10) summarises the process as follows:

"*Thematic analyses move beyond counting explicit words or phrases and focus on identifying and describing both implicit and explicit ideas within the data, that is, themes*". By identifying common themes, the hope was to answer the research questions and establish an understanding of *why* Requirements Analysis is not being used as effectively as it could be. This in turn would provide the insights necessary to achieve the final objective of study, that is, to gain an understanding of what can be done to successfully introduce new Requirements Analysis processes or to improve the effectiveness of existing Requirements Analysis processes.

3.5 Data Collection

Interviews were scheduled and conducted virtually using the medium of Microsoft Teams, being the software adopted by the CSIR during the Covid-19 pandemic to facilitate working remotely. This allowed interviews to be conducted safely as well as to ensure accuracy in the recording and transcription process. Respondents were asked a set of standard questions, but were given free rein to discuss their answers at length.

3.5.1 Case Study Questions

Yin (2003 p74-75) differentiates between case study questions and interview questions, explaining that asking the questions that need to be answered directly tends not to yield the desired results. He uses the example of a "*wily detective*" making sure that the questions asked of a witness or suspect do not betray what the detective is thinking. In order to investigate the hypotheses of this study, the interviews sought to acquire the data necessary to answer the following eight queries:

1. How do people within the group approach project work, specifically with regards to following processes and procedures?
2. Is there organisational support for ensuring that optimal processes are implemented?
3. What is understood by the term "Requirements Analysis" by members of the group?

4. To what extent have Requirements Analysis processes been used within the group?
5. How effective have the Requirements Analysis processes that the group has implemented in the past been?
6. To what have past successes/failures of Requirements Analysis within the group been attributed?
7. What would be the perceived value of including an ideal Requirements Analysis process within projects undertaken by the group?
8. How would people feel about implementing or supporting a more formal implementation of a Requirements Analysis process in future projects undertaken by the group?

3.5.2 Interview Questions

The interview questions were divided into two sections. The first section dealt with the respondent, their history with the organisation, their roles within their team, and their personal approach to working on projects. The second section dealt with the respondents' knowledge of, attitudes towards, and experiences with Systems Engineering and Requirements Analysis. Questions were tailored slightly according to whether the respondent was involved in a management role or an implementation role. The full questionnaire is provided in Appendix A.

3.5.3 Presentation of Interviewee Responses

Each case study question drew on answers provided in various interview questions. A summary of how the case study questions map to interview questions is provided in Table 3.2.

Table 3.2: Mapping of Case Study Questions to Interview Questions

Case Study Question	Relevant Interview Questions
Question 1	1.3a, 1.3b, 1.4a, 1.4b, 1.5a, 1.5b
Question 2	1.3a, 1.3b, 1.4a, 1.4b, 1.5a, 1.5b
Question 3	2.1, 2.2, 2.3b
Question 4	2.3a, 2.3b, 2.5b
Question 5	2.4a, 2.5a
Question 6	2.3a, 2.3b, 2.4b, 2.5b
Question 7	1.4a, 2.4c, 2.5c, 2.6
Question 8	1.4b, 2.2, 2.4c

Appendix B summarises the interviewee responses pertaining to each question, organised by interview respondent. These responses are then organised thematically in section 4 and discussed.

4 CASE STUDY FINDINGS AND DISCUSSION

This section assesses each of the eight case study questions in relation to the theoretical framework established in section 2.9. The relevant interview responses, as presented in Appendix B, pertaining to each question are summarised and organised thematically to identify common issues and compare the observations of the interviewees. This is followed by a discussion that attempts to answer the case study question based on the interview data.

4.1.1 Case Study Question 1

How do people within the group approach project work, specifically with regards to following processes and procedures?

Relevance to the Theoretical Framework

The Theoretical Framework suggests that effective use of Requirements Analysis is contingent on the application of a formally defined and documented process. Case Study Question 1 examines the willingness of the people in the group, both in management/leadership and implementation roles, to apply such a process.

Interview Outcomes

It was clear from the case study that the engineers tasked with executing on projects within the group, especially more senior engineers, are afforded a great deal of autonomy in terms of how they go about doing so and the processes they are expected to follow. Respondent 1 described how, in their team, senior engineers could be entrusted to operate unsupervised, but that more junior team members required more active supervision and guidance. This was verified by Respondents 5 and 6, who expressed having received more oversight by senior team members earlier in their careers, with a noticeable reduction thereof as they had matured into their roles. Respondent 2 described how they considered it to be "*more efficient*" to allow autonomy to those engineers who preferred it, rather than being prescriptive about how they perform their tasks – a perception supported by

Respondents 3 and 4, who spoke about their preference for being given autonomy and how they believe it enhances their effectiveness.

Even though it was evident that autonomy is highly valued by both managers and implementers within the team, it was also apparent that this kind of autonomy remains reliant on certain expectations being met. Providing autonomy is not equated with simply allowing engineers to ignore processes, but rather that engineers in the group are trusted to adopt the processes necessary to achieve the desired project outcomes in an optimal manner. Both Respondents 1 and 2, who are in leadership positions, seemed more interested in people being effective than having them follow specific processes. However, they still demonstrated an understanding of how applying appropriate processes can enhance effectiveness. Respondent 1 expressed this as an expectation that their team members perform "*proper engineering work*" and follow a "*correct process*". They went on to describe such a process as a personal process rather than a defined and documented process to be used by everyone. They stated the need for a consistent method of approaching and solving engineering problems, learned through both personal experience and from observing how more experienced engineers tackle engineering problems. Respondent 2 suggested that, for a process to be effective, it needs to be suited to the engineer seeking to implement it. They expressed an expectation that team members find and adopt suitable processes, and, similar to Respondent 1, suggested that such a process needed to be tailored to suit the individual. As an implementer, Respondent 3 acknowledged the potential benefits of having some degree of standardised processes but stressed the importance of those processes adding value, again, alluding to the importance of finding the right process.

Discussion

This case study reveals a team in which autonomy is highly valued. As such, the people tasked with executing on projects are given the freedom to choose how they approach their work and which processes to adopt.

Management are unlikely to interfere unless they perceive a risk to project outcomes.

Given that there was also an expressed desire from respondents within the group to deliver successfully on projects, this suggests that the approach most likely to be adopted would be dictated primarily by its suitability to the individual and potential to enhance the effectiveness of the individual in terms of being able to deliver successfully on projects.

This, in turn, suggests that the willingness of the group to adopt any process, including a formally defined Requirements Analysis process, is contingent upon the process satisfying these two criteria. It can be concluded that processes are more likely to both be supported by team leadership and practiced by implementors when such processes are both well suited to the people expected to implement them and have a demonstrable positive effect on peoples' work outputs and project outcomes.

4.1.2 Case Study Question 2

Is there organisational support for ensuring that optimal processes are implemented?

Relevance to the Theoretical Framework

Following on from Case Study Question 1, this question examines whether the organisation provides the necessary support to enable the implementation of a formally defined and documented process that the theoretical framework suggests is necessary for the effective use of Requirements Analysis.

Interview Outcomes

Both the Research Group Leader Respondents (1 and 2) described how they were mandated to give their team members the freedom to choose how to approach their project work, being more concerned about what was produced than how. They both also expressed a willingness to provide support, guidance and mentoring wherever necessary. This was backed up by the accounts given by respondents 3, 4, 5 and 6 who all described how

the team and project leaders afforded them freedom to choose how to do their work, as well as support when asked for.

It was, however, apparent that the group was generally lacking in terms of having formally documented processes that engineers could adopt and implement on projects. Respondent 2 described how, on larger projects, a "*framework*" would often be established. This framework would assign roles for activities like Systems Engineering. While these frameworks might often suggest that certain processes should be followed to produce specified outputs, for example standard Systems Engineering documentation, they tend not to define the processes to be followed. As such, the preference among engineers in the team was to follow the methods they each felt most comfortable with, with a focus on the outcome rather than the process. Respondent 2 went on to explain that, for smaller projects, time and budgetary constraints meant that no such framework was likely to be put in place. Respondent 1 also suggested that there is a lack of standard, documented processes that are followed, and reaffirmed the notion that budget constraints did not always allow for performing formally defined processes.

From the implementation side, Respondents 3, 5 and 6 all acknowledged that there was indeed a lack of mature, standard processes that they could utilise during implementation. While Respondent 3 suggested that even though they tended to get by without them, they stated that having more standard, documented processes could be useful, especially when working with clients who expected certain standards to be adhered to. Respondent 5 mentioned that in the limited instances where such processes did exist, they tended to be helpful. Respondent 6 stated that the lack of defined processes placed on them the need for "*self-discipline, self-management*" and, together with Respondent 5, expressed a desire to have more processes.

Discussion

While it seems that team leaders within the group are willing to support their team in terms of what processes its members choose to adopt and implement, it was generally acknowledged that there is a lack of formally defined, documented processes for the group to utilise. It was made clear that the group faced reluctance from clients and customers to pay for the outputs, typically in the form of documentation generated by Systems Engineering processes, including Requirements Analysis.

This would seem to indicate that there is a perception within the group that the primary objective of Systems Engineering processes is to produce outputs for the benefit of clients and customers who place value therein. While it makes sense that the group would not wish to commit effort to producing outputs that a customer is not willing to pay for, this should not prevent the group from supporting the implementation of processes that would help them to deliver on projects more effectively.

This suggests that the lack of understanding within the group of the potential benefit of utilising Requirements Analysis, as a means of reducing project risks and assisting in the successful delivery on projects, is an obstacle that needs to be addressed before management would be likely to drive such a process.

4.1.3 Case Study Question 3

What is understood by the term "Requirements Analysis" by members of the group?

Relevance to the Theoretical Framework

The theoretical framework identifies a need to overcome resistance to change when attempting to implement a new process. Key to achieving this is an understanding of the benefit of such a change. This is true of both the organisational leadership who are expected to drive that change and of the people expected to implement it. Understanding the benefit of such a

process is, in turn, contingent on an understanding of what the process is and what it is attempting to achieve.

Interview Outcomes

Of the six respondents, five have had some level of training in Systems Engineering. This training has ranged from a partially completed online course (Respondent 5), to a short course at a university (Respondents 4 and 6), to attending several short courses certified by the International Council on Systems Engineering (INCOSE) (Respondent 1), to extensive training with the intention of becoming a Systems Engineer (Respondent 2).

All the respondents have had exposure to Systems Engineering in the projects that they have worked on, to varying degrees. Respondent 1 has been performing a Systems Engineering role for over fifteen years, while the other manager in the group, Respondent 2, has been responsible for projects in which Systems Engineering activities happen. Respondent 3, although they have no Systems Engineering training, has worked on multiple projects where a Systems Engineering process has been used. Respondent 4 has worked, for several years, closely with experienced Systems Engineers and expressed an interest in growing their Systems Engineering capability. Respondents 5 and 6 have had very little direct exposure to Systems Engineering processes. However, they are aware of the fact that Systems Engineering activities happen on many projects undertaken by the team. They are also aware that many projects make use of a Requirements Specification document to which they do have exposure.

There was a general awareness of what Systems Engineering is about and many of the terms used. In particular, all of the respondents understood what requirements are and where they fit into the Systems Engineering process. Three of the respondents (1, 3, 4) specifically used the word “need”, while two other respondents (5 and 6) used the word “want” when defining what it is that requirements try to describe. Respondent 2 was clear in their understanding that requirements describe what the system should do, but did not link that to a stakeholder “need” or “want”.

Respondent 2 regarded Requirements Analysis as the process of converting a stated need into a set of requirements, thus conflating their understanding with that of requirements discovery as described by Sommerville (1996:6-7). Respondents 1, 3, 4 and 6 all described the analysis as a process of considering whether the requirements could be translated into a practically realisable system and, if so, how the problem could be broken down into subsystems with different requirements mapped to different subsystems. Respondent 1 also spoke about the need to ensure that all requirements were verifiable. Respondent 5 simply stated that requirements needed to be analysed to ensure that they "made sense".

Discussion

There is a clear distinction between what is understood by the term "Requirements Analysis" within the group and the activities and outcomes described in sections 2.4 and 2.5 from the literature.

There was no consistent and unified understanding within the group of what Requirements Analysis is. Interpretations varied from the analysis of stakeholder feedback with the intent of stating requirements, to an analysis of the requirements for the purpose of designing a system architecture. Although both these views are indeed consistent with the semantic meaning of "Requirements Analysis", in that they involve performing some sort of analysis pertaining to requirements, they do not represent the view presented in the literature review. That is, of an analysis process, performed on a set of systems requirements, for the purposes of improving the quality of that set of requirements.

This is not to say that the activities described by the respondents were necessarily wrong, or invalid as part of a system development process. Rather, this illustrates that there is a gap in awareness of the type of Requirements Analysis activities identified from the literature and, by extension, the potential benefits thereof. As such, attempts at remedying the situation should be focused not so much on convincing the group to start performing Requirements Analysis, an activity they already believe they are

performing, but rather on making the key members in the group aware of what Requirements Analysis is, as defined in this report.

4.1.4 Case Study Question 4

To what extent have Requirements Analysis processes been used within the group?

Relevance to the Theoretical Framework

Understanding the benefit of implementing a change is identified in the framework as a necessary criterion when trying to drive that change. This is frequently informed by past experiences. Positive experiences, for example projects that have been successful, encourage people to maintain the status quo and persist with what has worked in the past. Negative experiences are often necessary to force people to look for alternatives and adopt changes. This question examines what the group has been doing in terms of implementing the type of activities identified in Case Study Question 3, before Case Study Question 5 examines the outcomes thereof.

Interview Outcomes

While the respondents all stated that Requirements Analysis was being done to some extent, there was very little consistency between their accounts, either in terms of what was being done, or how much time was being devoted to the activity. In many cases, activities that were regarded as Requirements Analysis by respondents were being conflated with either requirements gathering (Respondent 2), or design activities (Respondents 1, 3, 4 and 6).

Consistently, Requirements Analysis was described as a process of thinking, discussion and collaborative problem solving that happens early in the project lifecycle. Respondent 1 used the phrase "*you need to apply your mind*". Respondent 3 described the process as "*just going through all the requirements logically, thinking about it, and writing them down and then seeing what impacts what*". They also noted that "*this is not normally done individually*", stating that typically this involved discussions between two or

more team members. Respondent 4 at one point used the phrase "*what can you dream of?*" when describing the process. Respondent 6, not being directly involved in any Requirements Analysis process, imagined the process as being one of senior team members sitting around a table discussing the issues, a view supported by Respondent 2 who described the process as "*a session of senior engineers sitting in a room together one afternoon*".

There were also differing accounts of when Requirements Analysis activities were being performed. In addition to the Requirements Analysis activities being performed during the definition phase of the project, it was also observed to be happening during the later phases of some projects. Respondent 6 alluded to experiences of requirements being changed even late into development. Respondent 4 confirmed this phenomenon, attributing it to the need to identify unknown problems through the experience of developing and working with a system, and then using that as the basis for performing analysis to come up with new requirements. Respondent 3 further supported this view when speaking about the need to revisit some of the thinking behind requirements "*as the project goes on*". Respondent 2 suggested that sometimes these activities were even ignored entirely during earlier project phases, quoting that "*this is literally something someone is thinking about as they are already in delivery mode*".

The level of effort and rigour being applied to Requirements Analysis activities across projects was described as being somewhat inconsistent. Respondent 2 believed that there was a notion within the group that Requirements Analysis did not require the kind of "*rigour*" that might apply to other activities. However, they did point to one specific project, referred to hereafter as "Project A"[1], in which a formal process had been followed to great success. Respondent 5 also referred to "Project A" as an example that stood out for having performed a rigorous Systems Engineering process

[1] "Project A" involved the development of a new prototype system intended to demonstrate technology that could address a gap in the local market. The budget for the project was in excess of R20 million, with development spanning over a 3 year period. Multiple team members, of differing disciplines, contributed to the engineering effort.

that they believed included Requirements Analysis. Respondents 2 and 5 both affirmed that this was notable because it was so unusual for a project to apply such a rigorous process. Respondent 3 stated outright that the group lacks a consistent process that is *"applied universally on all the projects*". Respondent 6 spoke about an inconsistency in terms of whether requirements documentation was available, suggesting that requirements processes were not always followed.

There were inconsistencies among the respondents regarding how much time is typically spent on Requirements Analysis activities. Respondent 1 mentioned that spending 5% of project time was ideal, but only achieved in some projects, Respondent 2 stated that projects tended to "*woefully underspend*", seldom reaching the 5% mark. Respondent 3 observed that some projects devoted a negligible effort to the activity, while others spent as much as 30% of their budget on it – in both cases to the detriment of the project. Respondents 4, 5 and 6 all mentioned how they had seen evidence of Requirements Analysis activities on some projects but not on others.

Discussion

Understandably, the types of Requirements Activities described to have been performed in the group tended to match what the respondents viewed Requirements Analysis to be, as outlined in section 4.1.3. However, it was clear that the amount of time and effort spent on these activities was not consistent across projects. As noted in section 4.1.2 this was often attributed to a lack of financial support for such activities from clients or customers.

The concerns raised that requirements issues often need to be revisited at later stages in the project could be indicative of problems with requirements quality. This highlights the potential to benefit from the application of the type of Requirements Analysis process focussed on addressing requirements quality, as outlined in section 2.4.

Not having a formal process likely also influences the inconsistent length of time that is spent on the activity. Having a standardised process would

provide a basis for estimating the amount of time needed for the activity and allow project planning for the process, ensuring that enough time is allocated without going overboard.

Importantly, “Project A” was identified as a project in which Requirements Analysis was implemented to its full extent and had a significantly positive outcome on the project delivering beyond expectations in terms of brief, budget and time.

4.1.5 Case Study Question 5

How effective have the Requirements Analysis processes that the group has implemented in the past been?

Relevance to the Theoretical Framework

Following on from Case Study Question 4, this question examines the perceptions of the effectiveness of the processes that have been used. This can be used as the basis for gauging the potential willingness of the group to explore the possibility of implementing changes to the process.

This question also looks indirectly at the people in the group that are tasked with performing a Requirements Analysis role.

Interview Outcomes

Respondent 1 was quite emphatic about the causal link between following good processes and achieving the desired results, talking about the need to execute “*proper engineering work*” as opposed to a more ad hoc, informal or non-structured approach to executing project work. Along with Respondent 4, they took the view that the group has been reasonably successful with using Requirements Analysis.

While Respondent 2 agreed on the importance of following Systems Engineering processes, they took the contrasting view that most, including Requirements Analysis, are not achieving their full potential impact on projects undertaken by the group.

Respondent 5 perceived that the application of Requirements Analysis was inconsistent across projects, but also noted that positive outcomes resulted where it was clear that significant effort was being devoted to it.

Respondent 3 was more sceptical of the value of the processes in use, citing that they tended to either fail to achieve the desired results, or were too time-consuming to be beneficial.

Respondent 6 did not have exposure to the Requirements Analysis activities that were happening on projects. However, they questioned the effectiveness of those activities based on their experience, as noted in section 4.1.4, of requirements changing during development.

Discussion

As discussed in section 4.1.4, most of the Requirements Analysis activities described by the respondents tended be informal rather than rigidly defined and documented. These activities involved engineers, typically those leading the system development, applying thought to system requirements already derived for the system and conversing collaboratively with other team members. “Project A” identified by Respondent 2, and mentioned by Respondent 5, was the sole example of where a formal and significant Systems Engineering effort had been applied.

Given the variety of perceptions that the respondents had previously expressed regarding w*hat is understood by the term “Requirements Analysis”*, discussed in section 4.1.3, as well as the inconsistencies in terms of the extent to which such activities are being performed, discussed in section 4.1.4, it should not be surprising that the observed impact of Requirements Analysis on projects was not very consistent.

In some cases, the activities that were being practiced were perceived to be adding value, but in other cases they were viewed as a waste of time. There was a sense among some of the respondents that such processes should be achieving better outcomes.

4.1.6 Case Study Question 6

To what have past successes/failures of Requirements Analysis and/or similar Systems Engineering activities within the group been attributed?

Relevance to the Theoretical Framework

This question seeks to explore factors identified by the interviewees that might have affected the effectiveness of the Requirements Activities discussed in sections 4.1.4 and 4.1.5. Two measures of success are considered:

- The group's success in ensuring that processes have been implemented; and
- The success of the processes themselves, where they been implemented.

The theoretical framework considers that the effectiveness of Requirement Analysis process is contingent primarily on the Requirements Analyst and the process. Interview data pertaining to either of these two elements, their attributes and those factors affecting them are examined.

Interview Outcomes

Factors Influencing Process Outcomes

Having a dedicated role

Respondent 2 took the view that a lot of the potential impact of using not just Requirements Analysis, but of most Systems Engineering processes, has been "*significantly eroded*" due to the lack of having dedicated specialists performing the role. They went on to explain how there tended be a conflation of the lead technical and Systems Engineering roles. They stressed the importance of keeping these roles separate so that projects can benefit from two distinct and critical viewpoints offered by these roles. While Respondents 1 and 4 did not necessarily share the view that this was problematic, they did refer to several projects in which Systems Engineering activities were being performed by technical leads, thus confirming the

phenomenon. Of the three notable “Systems Engineers” in the group identified by Respondent 4, only one was, in fact, formally qualified as a Systems Engineer.

Spending the right amount of time

Respondent 1 was emphatic about the need to understand requirements “properly” before commencing with design implementation, stressing that a failure to do so would result in greater loss of time down the line.

Respondent 3 believed the success of Requirements Analysis activities on project outcome hinged on the correct amount of time being spent on the activity. They had observed instances where too much time on projects was devoted to requirements activities, leading to delays in starting with development work which impacted negatively on project schedules. Similarly, they had observed instances where insufficient time was allocated to sorting out requirements properly, leading to development time being wasted on doing the wrong thing, necessitating rework that impacted negatively on project schedules. Their assessment was that spending too much time, or too little time on this activity could be equally detrimental.

Respondent 2 credited the fact that “Project A” achieved a significantly more successful outcome than was usual with projects undertaken within the group, to a Systems Engineering process being followed “*rigorously*” by a pair of engineers dedicated to the task and afforded the time – a lot more than they felt most people in the team are “*typically comfortable with*” – necessary to execute the process to its conclusion. This view was supported by Respondent 5, who, like Respondent 2, quoted the same project as an example of how they believe more projects should be executed.

Respondent 4 spoke about an observation shared with them by a more senior Systems Engineer in the group that the amount of overhead placed on a project by Systems Engineering processes – and the documentation that is generated thereby – even has the potential to “*derail*” a project entirely.

Assigning the role to experienced engineers

Three of the respondents linked the successful application of Systems Engineering activities to experience. Respondent 1 referred to the idea of "*common sense*" and more experienced team members being able to apply this "*naturally*" where, perhaps, more junior team members struggled and needed assistance. They also stated directly, the importance of having experienced Systems Engineers. Respondent 3's view was that the team tends to rely on their experiences of what has and has not worked in the past, in lieu of more formal processes, sometimes to the detriment of the project. Respondent 4 spoke about how they perceived it to be the experience of the lead engineers in the team that separated the successful projects they had worked on from less successful projects observed in other teams. They also stressed the importance of having Systems Engineers with practical experience acquired before moving into a Systems Engineering role and of finding a balance between relying on Systems Engineering theory and practical project experience.

Factors Influencing Process Implementation

Having the support of project managers

Respondent 2 described the critical role they had to play as a project manager in supporting "Project A", in which Systems Engineering activities had received a significantly higher priority in terms of time and budget allocation than was usual. Respondent 4 stressed the importance of having a good project manager to keep things on track and to ensure that processes which should be followed are not skipped. Project management time was also identified as not being sufficiently allocated on all projects. Respondent 3 noted how project manager time was prioritised to bigger projects, resulting in smaller projects not being given enough attention and, consequently, less attention being paid to processes on such projects. Respondent 5 stressed the negative impact of not being given sufficient inputs by a project manager. Respondent 6 assumed that their lack of

interaction with project managers was due to those interactions happening "*at a higher level*", involving more senior technical people.

Clients do not necessarily appreciate the value of Systems Engineering processes

Respondents 1, 2, 3, 4 all observed that formal processes were often given less attention than needed, or even skipped altogether due to budgetary and time pressures. Respondents 1 and 3 specifically mentioned that such pressure often originated from those clients who choose not to include System Engineering outputs among project deliverables, or need to be convinced of the benefits in doing so. Respondents 1 and 6 both supported the notion that clients are frequently unaware of how poorly they sometimes understand their own requirements.

Poor alignment of the process with the individual

Respondent 1 alluded to how engineers might be tempted to "*take shortcuts*" with processes that they do not enjoy. In their experience, this would often later lead to rework. They described how it is important to "*get a person's personal approach to align best with what the organization needs*" in an effort to achieve good results. Similarly, Respondent 2 spoke at length about the importance of finding the right processes for the people expected to implement them, stating that "*it's about personality*", while Respondent 3 highlighted the need for a "*process that makes sense*" to the individual implementing it.

Respondent 1 described their team members as having "*a desire to solve problems*". Respondents 4 and 5 expanded upon this, suggesting that there was a tendency to skip certain processes, stemming from engineers wanting to solve problems rather than "*thinking about solving problems*" and "*writing documents*" respectively. Respondent 4 described team members as being "*curious and excited about new things*" and Respondent 5 described team members as being eager to "*build things and get our fingers dirty*" rather than expending time on documentation. Respondent 5 stated that they believed that many team members viewed Systems Engineering

processes as being synonymous with writing documents with Respondent 3 going so far as to refer to such processes as mere "*Check-Box*" exercises.

The benefits of Requirements Analysis are not visible

Respondent 3 referred specifically to the need for "*visible progress*" on projects, to stakeholders both internal (team and organisational management) and external (clients). They stated that even if a project might benefit in the long term from following such a process, the short-term consequences of not being able to show this visible progress often posed a bigger risk to the project. This view was supported by Respondent 2's experience working on "Project A" and how significant pressure was put on them to show visible progress. They went on to share their observation that even when "Project A" concluded very successfully, the prevailing perception among other managers in the group was that this was achieved despite the time spent on Systems Engineering rather than because of it.

Lack of a formally defined and documented process

Respondent 1 described how the approach within their team tended to be on learning "*proper engineering processes*" through experience. A strong emphasis was placed on the importance of training, mentoring and guidance from more senior engineers, acknowledging that there tended to be a lack of more formally defined and documented processes in place.

Respondent 6 observed that a lack of standardised processes impeded their ability to work efficiently. They noted that they believed that they would benefit significantly from being able to learn from organisational knowledge that had already been established by more senior members of the group. They went on to stress the potential benefits of having more formalised processes in terms of establishing a common understanding within the group of what needs to be done and how to go about achieving that consistently.

Respondent 3 stated that there tended not to be formal processes in place and that individuals were left to the own discretion to apply methods and best practices they felt most appropriate to the projects. They expressed a

need for more formalised processes for the purpose of ensuring consistency across projects, and suggested that, over time, such a process could be improved and refined based on lessons learned while implementing it.

Respondent 2 identified a need for having formal processes to achieve consistency and ensure that the proper rigour is applied to a project. They suggested that, more often than not, processes would be skimped on and used to justify a predetermined outcome rather than to try and identify the correct outcome.

Discussion

As discussed in section 4.1.4, many of the respondents described the group's Requirements Analysis process as one of thinking, discussion and collaborative problem solving. While this is not necessarily the process under investigation, many of the factors identified here could have a bearing on such a process and, as such, yield clues regarding how a Requirements Analysis process would need to be designed and implemented to be successful.

Formally Documented Definition

The theoretical framework identifies the need to have a formally documented definition of the process in place for the process to be successful. The respondents seemed to concur that there tended to be a lack of formally defined and documented processes within the group and identified problems associated with this pertaining to the three attributes that such a document should possess.

- **Captures Organisational Knowledge and Experience:** Several respondents touched on the importance of knowledge and experience in solving engineering problems. The need to pass this knowledge on was also clearly identified. In the absence of having this formally documented, it seemed that such knowledge transfer tends to rely on people passing it on directly through mentorship and junior engineers working together with more experienced engineers

on projects. The obvious risk in this in relying on this method of knowledge transfer is that knowledge will be lost if the people in whom it resides fail to pass it on, either in part or in whole.

- **Describes a Shared Vision:** While Respondents 1 and 2 clearly identified the need for their team members to share a common vision of what needs to be done for the team to work cohesively, Respondent 6 expressed the need to have that vision shared with them.
- **Leads to Continuous Improvement:** The benefits of continuous improvement in how processes are executed was generally acknowledged as given by all the Respondents. However, it was Respondent 3 who specifically identified how formalising processes and documenting them could achieve this.

Even though it was clear that most processes within the group tended to not be formally defined in any document, the attributes that such a formalised document would be expected to exhibit were all deemed to be beneficial to project outcomes. While the group tended to get by despite the lack of such formally defined processes, it was evident that the group still relied on other, arguably less effective, means of achieving the same outcomes, and it was generally acknowledged that defining and documenting processes would likely be beneficial to the group.

Requirements Analyst Attributes

Three attributes of the Requirements Analyst are identified in the theoretical framework:

- **Dedicated Role:** Respondent 2 was quite emphatic about the importance of having someone in a dedicated role performing any Requirements Analysis effort. Respondents 1 and 4 seemed to conflate the roles of Technical Lead and Systems Engineer, which confirmed the concerns raised by Respondent 2 and highlighted a possible area of improvement for the group.

- **Experience:** Being experienced in working on systems, not even necessarily as a Systems Engineer, was identified as a critical factor to project success, regardless of the actual processes being followed. It was even suggested that having relevant engineering experience before moving into a Systems Engineering role, such as Requirements Analysis, was crucial.
- **Qualification:** Even though the acquisition of System Engineering qualifications was positively affirmed to be of value by three of the respondents, they placed far greater emphasis on the expertise of the individual, gained through years of experience working on systems, and their ability to find a balance between theoretical knowledge and practical experience.

Process Attributes

Three attributes of the Requirements Analysis process are identified in the theoretical framework:

- **Tailored Process:** The need to tailor the process was clearly identified by Respondent 2. This pertained both to creating a process that would be appropriate to the person expected to implement it, as well as requiring an appropriate amount of time based on the scope, and budget, of the project.
- **Cost Effective:** While several of the respondents noted the importance of resolving requirements issues prior to the commencement of implementing a design solution, significant concerns were raised about the cost implications of doing so. A standout viewpoint, however, was that of Respondent 2, who attributed the success of “Project A”, in no small part, to spending more time than “*what our people are typically comfortable with*” on Systems Engineering activities before proceeding to implementation. Although it seems clear that the prevailing attitude within the group tended to be centred on the costs involved with performing the process, the experience of Respondent 2 suggests that the benefit

of the process are significantly greater than is generally perceived and, as such, warrants the costs involved, even if it is not immediately apparent.

- **Evolutionary:** Respondent 1 spoke of how engineers tended to develop, with time and experience, what they referred to as "*proper engineering processes*". This observation, as well as the frequent references by other respondents to the importance of experience, suggest that getting a process right tends to be the result of continuous improvement over time. The gap within the group is that such processes tended to be of an informal nature, pertaining more to the methods and techniques developed and practiced by individuals. This could, however, form the basis for developing more formalised processes that could be implemented across the group.

Aligning the Process with the Requirements Analyst

The theoretical framework identifies the importance of aligning what is expected of people within an organisation and their personal compact with the organisation. Doing so is a key factor in overcoming resistance to change, including adopting new processes.

A strong preference within the group to allow a significant amount of autonomy in how people perform their jobs was clearly identified in section 4.1.1. This assists greatly in achieving an alignment between the personal goals and objectives of engineers with the work they are doing.

Given that Systems Engineering (and Requirements Analysis) mandate, to a certain degree, what processes should be performed, what those processes should achieve and how they should be implemented, there is a somewhat limited scope to align the processes with the people. This suggests that, rather than depend on trying to assign the process to people who are not well suited to it, the organization should seek out Requirements Analysts who are already positively predisposed to such a process and then provide them with the autonomy to tailor the processes according to their personal preferences.

One specific trait, however, of Systems Engineering processes in general, that was singled out was that of needing to produce documentation. It was plainly evident from the respondents that the writing of documents was viewed as an onerous activity, not only amongst the respondents, but across the group as a whole. It seems likely that this aversion to writing documents was a significant contributor to people avoiding Systems Engineering processes in general, and could potentially deter them from electing to adopt a process like Requirements Analysis.

4.1.7 Case Study Question 7

What would be the perceived value of including an ideal Requirements Analysis process within projects undertaken by the group?

After the respondents were asked to describe their understanding of Systems Engineering and Requirements Analysis coming into the interview, they were provided with the following brief description of the type of Requirements Analysis that this study is investigating:

"The Requirements Analysis I am looking at in this study is the formal Systems Engineering Activity that analyses a set of system requirements and tests them against a number of criteria, to see how adequately they describe the system that needs to be developed. This leads to the creation of various documents such as the System Requirements Specification, the Operational Concept Description and System Verification Requirements Specification.

It is a distinct activity from requirements gathering or functional and logical design activities, the objective of which is to improve the quality of the requirements"

The objective was to allow the respondents to consider the type of process that the organisation would ideally like to have, in contrast to the potentially flawed processes with which they were familiar and had experience with.

Relevance to the Theoretical Framework

Overcoming resistance to change is key to getting people to support a new process. It is important that both the organisational management and the people expected to implement the process are convinced of the necessity of proceeding with the new process. The two primary factors that influence resistance to change are whether the change aligns with one's personal compact with the organisation (as discussed in section 4.1.6) and whether the change is seen as beneficial. This question focuses on the latter and whether the case for implementing a Requirements Analysis process would be likely to be seen as beneficial.

Interview Outcomes

All the respondents stated that they believed that having such a process would be beneficial to project outcomes. Respondent 1, the most experienced engineer in the interview, stated that having good requirements was critical to project success, citing the importance of correctly identifying the need in order to build the right system. They went so far as to state that one "*cannot design if you don't have proper set of requirements*" and that it is the quality of one's requirements that "*makes the difference between solving a problem and just spending time and money*". Respondent 2 considered such a process a necessity, lamenting that it is not being performed as needed. Respondent 3 estimated that such a process could have a significant positive impact on project outcomes, with Respondent 4 considering how such a process would specifically help in that regard with project planning and execution on brief, on budget and time. Respondent 5 believed that better quality requirements would help to focus development efforts and reduce scope creep due to changing requirements down the line. Respondent 6, like Respondent 1, believed that better requirements were important in being able to assess whether the correct system was being developed, but was concerned about spending time on Requirements Analysis in an environment in which requirements change mid-project.

Respondents 2, 3, 4, 5 and 6 all observed, to some degree at least, that requirements changing during the development process had a negative impact on project delivery.

Respondents 1, 2 and 3 all stressed the importance of having the correct or appropriate process for the project. Respondents 2 and 3 stated that the wrong process could even have a detrimental effect on project outcomes by wasting time and money that was needed by other activities.

When it came to how much time the respondents believed should be allocated to Requirements Analysis, Respondents 1 and 2, being in the positions of technical leader and project manager respectively, clearly differentiated between Systems Engineering activities and Requirements Analysis specifically. Respondent 1 was confident in stating that 5% to 10% of project costs should be allocated to Requirements Analysis while Respondent 2 was, likewise, confident to allocate 5% or more. Respondents 3 to 6 indicated less confidence in their estimates. Respondents 3 and 5 suggested spending around 10% of project time on Requirements Analysis, Respondent 6 suggested 20% and Respondent 4 suggested 20 to 30%.

Discussion

It was universally accepted that better quality requirements would be beneficial to project outcomes and all the respondents expressed support for the notion of a process that could achieve this on the proviso that it could be done at a reasonable cost and within a reasonable time frame.

The amount of project time that the respondents suggested be allocated to a hypothetical “ideal” Requirements Analysis process demonstrates that they do, indeed, perceive this to be a potentially valuable activity. The numbers quoted by Respondents 1 and 2, those in leadership positions with the most experience with regards to project planning, were made confidently and align closely with what is advocated by Halligan and Young in section 2.6.2. Respondents 3 to 6 seemed less confident in their ability to accurately gauge an appropriate time allocation and their time budgets were overly generous. This likely reflects a lack of experience in project planning,

however, it reinforced the notion that they perceived such an activity to potentially have significant importance.

4.1.8 Case Study Question 8

How would people feel about implementing or supporting a more formal implementation of a Requirements Analysis process in future projects undertaken by the group?

Relevance to the Theoretical Framework

It is clear in the Theoretical Framework that the success of any effort to use Requirements Analysis process effectively would be heavily dependent on the willingness of those expected to execute it and of management to support it. Although Case Study Question 7 established that there was, indeed, perceived value in having an ideal Requirements Analysis process in place within the group, this question seeks to ascertain whether this is sufficient to elicit the necessary support within the group to ensure that implementation thereof could become a reality.

Interview Outcomes

Respondent 1, as a team leader, expressed a desire to see a "*more thorough process*" being executed on projects and mentioned that they tended to get the best results from team members when "*one can get a person's personal approach to align best with what the organization needs*". Respondent 2, as a project manager, described how they viewed their leadership responsibility as being the "*custodian of efficiency*" to help the team to deliver on expectations. While they believed that Systems Engineering processes and Requirements Analysis were valuable tools, they maintained the importance of supporting team members in using their preferred methods and processes. They went on to suggest that, if a Requirements Analysis process is to be successful, it would need the right person to execute it, stating that "*If you've got the responsible person then the process will follow*".

As an implementor, Respondent 3 described how being given autonomy helped them to be more effective. Although they acknowledged the importance of requirements, they stated that their willingness to perform processes required a "*process that makes sense*".

Respondent 1 observed that it was challenging to convince clients of the necessity of including Systems Engineering activities in project plans. They stated that "*Some clients don't bother about it. They don't think it's important and they just want you to start designing the solution*". This was attributed to clients not being aware that "*the perceived problem and the actual problem are not the same thing*". This concern was shared by Respondent 4 who stated that "*clients don't necessarily always know what they want*".

Respondent 2, however, focussed on the challenges in overcoming resistance from other managers within the organisation. They observed how, where they had committed significant project time to performing Systems Engineering activities, they had "*spent a lot of time in management meetings and other forums defending this approach*". Respondent 3 expressed concerns about schedule pressure limiting their freedom to implement processes that failed to contribute to "*visible progress*" on projects. Similarly, Respondent 4 stated that they felt it very important to ensure that they stuck to project timelines stating that "*I'm very strict when it comes to delivering on time, in budget*".

Respondent 6 seemed to be reluctant about the idea of committing time to Requirements Analysis on the basis that requirements were likely to change later, thus rendering the efforts on Requirements Analysis ineffective.

Another view, expressed by multiple respondents in implementation roles, was an aversion among engineers in the group to spend time on documentation during the preliminary phases of a project. They expressed a preference to rather proceed directly with performing engineering/development work. Respondent 3 stated, when talking about Requirements Analysis, that "*sometimes we don't spend enough time on this because we see it as an annoyance*", a notion supported by

Respondent 5 who said that "*people want to make progress rather than documents*". Respondent 4 expressed a similar view when saying "*If you have excited people or curious people then it's almost like the Requirements Analysis step is skipped*".

Discussion

It was clearly established in Case Study Question 7 that there was, indeed, by the respondents in leadership and management positions, perceived value in implementing the type of Requirements Analysis process discussed in the interview. However, they also expressed strong reservations about forcing processes on team members without their buy-in. As such, support from leadership and management in implementing such a process seemed to be contingent on having team members willing to execute it.

Similarly, the respondents working in implementation roles recognised the value of having a better Requirements Analysis process. While they seemed to support the notion of having such a process being performed on projects, they tended to express reservations about their own willingness, as well as that of fellow team members in executing it. The consistent message was that the team was comprised primarily of people who were eager to find solutions to problems, and engage in design activities focused on delivering systems to customers to help solve their needs. At the same time there seemed to be an aversion to spending time deliberating on requirements and producing documentation.

The observation made by Respondent 2 that the right person for such a task is needed, seems to have merit. Given that there is recognition, from both management and implementors on the team that there would be value in implementing a Requirements Analysis process, it seems likely that the addition of a specialist to perform this task would find support.

A further critical issue identified was that of justifying the cost of implementing a Requirements Analysis process, both externally, to clients, and internally, to management. There was a strong sense across the respondents that clients, and the funding they provide, played a significant

role in the feasibility of executing Systems Engineering processes in general, including Requirements Analysis. It seemed apparent that clients frequently failed to understand the potential ramifications of poorly understood requirements. As a result, the group often struggled to convince clients of the need to include and finance Systems Engineering activities as part of the project plan. This suggests that a Requirements Analysis process needs to be defined in such a way that it is not reliant on specific funding by the client to be feasible.

Lastly, it was noted that pressure from managers and project leaders to show visible progress on projects led to reluctance from people to delay implementation by spending more time on Requirements Analysis. However, the evidence did suggest that the organisation was willing to allow their teams the flexibility to do so.

4.2 Research Findings

This section examines each of the three research questions and uses the Case Study Findings in conjunction with the Literature Findings to draw its conclusions.

4.2.1 Research Question 1

How effective is the group at using Requirements Analysis to improve the quality of requirements?

While the ultimate objective of all Systems Engineering activities, including Requirements Analysis, is to enhance the level of success in projects, Requirements Analysis aims to achieve this, as described in section 2.4, by means of improving the quality of requirements.

The study attempts to answer this question by examining the perceptions of the interview respondents in the context of what the literature says on the subject, by looking at:

- Process alignment: How closely do the processes that are followed align with the objective;

- Process consistency: How consistently are the processes applied across projects; and
- Process impact: What impact are the processes perceived to have on both the quality of requirements and project outcomes.

Process Alignment

Whereas the focus of this study is on using Requirements Analysis as a means of refining and improving the quality of requirements, the respondents' understanding of what Requirements Analysis is, differed somewhat. As discussed in section 4.1.3, the respondents' perceptions were of a process of either deriving requirements through an accurate understanding of the customer need, or of translating requirements into a design.

Despite the differences between what the interview respondents perceived Requirements Analysis to be, versus what is described in section 2.4, there were some similarities. Most notably, there was a general awareness among the respondents of using Requirements Analysis to better understand the need being addressed by the system that is to be developed. Five of the six respondents specifically referred to client needs or wants. Respondent 1 explicitly noted the role of Requirements Analysis in helping to understand, and thus solve, the *real* need of the client, as opposed to a *perceived* need. As identified in section 2.4, one of the ways in which a Requirements Analysis process improves the quality of requirements is by ensuring that the requirements of the system reflect the "*real needs*" of the stakeholders. Therefore, analysis of this domain can be expected to result in the creation of better requirements, even if this is not the explicitly stated objective.

However, while these activities may yield some improvements in requirements quality, they are unlikely to be as effective as a process whose specific focus is that of requirements quality improvement. Consequently, regardless of the perceived effectiveness of these Requirements Analysis

processes on project outcomes, the actual effectiveness of these processes on improving the quality of requirements would likely be somewhat limited.

Process Consistency

As discussed in section 4.1.1, all the respondents described an environment in which the individuals within the group are given much autonomy in how they choose to execute their assigned tasks. The approach followed by the leadership was described as being collaborative, rather than prescriptive. It was revealed that team members typically discuss project issues with both leadership and fellow team members, allowing for the sharing of ideas for consideration, but with the final decision on how to proceed reverting to the individuals responsible for execution of the task.

This is consistent with the observations, noted in section 4.1.4, about the level of effort that would be committed to Systems Engineering activities being left to the discretion of the team working on a project. Coupled with the statements from multiple respondents that there was no formal, documented Requirements Analysis process, and about the budgetary constraints placed on projects by clients, it is clear that both what was being done, and to what extent, varied significantly from project to project.

Multiple respondents confirmed that smaller projects simply lacked the funds to justify a formal Requirements Analysis process. At the other end of the spectrum, Respondent 2 discussed “Project A” which was notable both for the facts that the team took the necessary time to execute a rigorous Systems Engineering effort, and that it was a unique example of this being done within the group.

Process Impact

Impact on Requirements Quality

The interview process attempted to ascertain how the respondents perceived the quality of the requirements being used for projects.

Respondents 3 and 6 both commented that they felt that Requirements Analysis efforts were sometimes futile because requirements often changed

later in the project anyway. This is exactly the sort of issue that an effective Requirements Analysis process should seek to alleviate.

As noted in Appendix B.5, the perceived quality of requirements for any given project seems to be largely dependent on the experience of the technical lead. This, in turn, suggests the absence of an impact being made by the process itself which, if it was effective, should be expected to result in a more consistent outcome.

Impact on Project Outcome

The responses of the six respondents differed in terms of how effective they perceived the Requirements Analysis activities that have been executed to be, in terms of project outcome. On the one hand, Respondent 1 perceived the success of Requirements Analysis to be "*not too bad*" on the basis of having satisfied clients whose needs had been successfully met by systems that were developed. On the other hand, Respondent 2 perceived that Systems Engineering processes were not being implemented effectively, and as such, projects were not benefitting to the full extent that they could be. Rather than attributing project successes to the effectiveness of Requirements Analysis, they perceived that projects had been successful despite the ineffectiveness thereof. This contrast of opinion between Respondents 1 and 2 highlights the typical difficulty of assessing the effectiveness of Systems Engineering processes. As noted in section 0, it is impossible to know how a project might have turned out differently had different processes been followed during the execution thereof.

The experience shared by Respondent 2, regarding the successful outcome of "Project A" does, however, provide a useful benchmark against which other project outcomes can be assessed. Although there was considerable concern among the management team during the initial stages of the project around the delays in starting development work, once the development work did begin, the project was reported to have progressed remarkably well and achieved an exceptional outcome. Respondent 2 was adamant that this success was directly attributable to the time and effort committed to the

Systems Engineering processes, including Requirements Analysis. The fact that the final outcome of “Project A” was perceived by many people within the organisation as exceptional, strongly suggests that less rigorous and less formal processes that are more commonly employed, are significantly less effective and achieve significantly less impact on project outcomes.

4.2.2 Research Question 2

What are the reasons behind why Requirements Analysis isn’t being done as effectively as it could be?

Lack of Understanding of the Importance of Requirements Analysis

As discussed in section 2.5, within the Systems Engineering community, the importance of requirements is universally recognised, and Requirements Analysis is widely viewed as a critical activity. All the respondents in the case study concurred that requirements were important, and many professed to being aware that Requirements Analysis is an important Systems Engineering activity. However, the evidence suggests that the respondents lacked a proper understanding of why the type of Requirements Analysis activities that this report is investigating are important, or how they might potentially benefit project outcomes.

Critically, as noted in section 0, there was a particularly poor understanding of the importance of not just Requirements Analysis, but Systems Engineering processes in general, from clients. This in turn results in clients being unwilling to commit the financial resources, or time necessary to ensure that the teams are able to execute these processes rigorously.

Misaligned Understanding of what Requirements Analysis is

Section 2.4 sums up one view of Requirements Analysis, which describes it as a process of transforming a set of requirements from being of poor quality to being of better quality. Or put another way, a process of improving the quality of requirements. While not all Systems Engineers will agree with that description, it is not the intention of this study to attempt to obtain a complete understanding of how different Systems Engineers define

Requirements Analysis. Rather, it is to focus on the activities described by the likes of Halligan, Young and Sommerville.

Indeed, as summarised in section 4.1.3, during the interview process it became clear that all the respondents had a different understanding of what was meant by Requirements Analysis, and what, exactly, a Requirements Analysis process should entail. Most of the responses seemed to indicate that Requirements Analysis was perceived as either a process deriving requirements based on stakeholder needs, or of translating requirements into a practically realisable system. While these are certainly valid and important activities that need to happen during the development of a system, they are fundamentally different from an activity aimed at improving the quality of requirements.

It is clearly not necessary to equate an activity or process that improves the quality of a set of requirements with the term Requirements Analysis in order for the activity, which is the point of interest, to be performed. However, this does have the potential to become problematic when Systems Engineers are required to perform the activity of improving the quality of their Requirements by being directed to perform a Requirements Analysis process. If their understanding of what Requirements Analysis does not correspond with a process of improving requirements quality, then it becomes unlikely that the necessary activity will be performed.

What was revealed through the case study is that, while there seemed to be a general awareness within the group of the importance of including a Requirements Analysis process as part of system development, there was very little awareness of the need to perform an activity directed at addressing the problem of potentially poor requirements. Furthermore, even when the group believed they were performing a proper Requirements Analysis, the lack of awareness of the need to pursue the task of requirements improvement, leads to the problem of poor requirements not being addressed. This is turn means that the improvements in project outcomes that are predicted based on what is said in section 2.5 will not be

realised, which serves to undermine the perceived value of performing Requirements Analysis within the group.

Requirements Analysis is Regarded as Unnecessary

Davis and Zowghi (2004) argue the case that projects can be successful despite not utilising good requirements practices. They also argue that having good requirements practices are insufficient to guarantee project success.

It was apparent from the case study, as noted in section 4.1.7, that the respondents generally acknowledged that Systems Engineering processes and Requirements Analysis were important activities. Most of the respondents suggested that the time that should be allocated was on par with what was suggested in the literature. Yet it seems that this was not backed up by what actually happens on projects.

In spite of this, the general feeling among the respondents was that projects tended to be executed successfully. As such there is no perceived need to change the approach to projects, even though doing so could potentially result in significant improvements to project outcomes. This is important because, as discussed in section 2.7.1, change tends to be driven by a need to improve organisational effectiveness. This need becomes harder to recognise if an organisation is already achieving successful outcomes.

Suitability of the Person being Assigned in the Role

Sheard (1996a) suggests a set of twelve distinct roles in Systems Engineering, noting that it is likely that not all roles would be performed by one individual. As noted in section 2.8.1, it is deemed important by multiple authors that organizations assign people to Systems Engineering roles who not only possess broad Systems Engineering training and experience, but whose training and experience is specific to the Systems Engineering roles they are expected to perform. This speaks to the idea, discussed by Sheard (1996a), of individuals, or possibly even teams, who specialise in specific roles. Young (2002) specifically identifies the need for Requirements

Analysts to have training in Requirements Analysis. Furthermore, as discussed in section 2.8.1, Kasser (2012) notes the importance of Systems Engineers possessing domain experience in implementing engineering solutions.

These same points are evident in the case study, as presented in section 4.1.6, with many respondents reporting on the importance of experience in determining the success of Systems Engineering processes. Respondent 4 added to this, sharing the advice given by a mentor with strong Systems Engineering experience, that it is preferable for engineers to gain project experience in implementation roles before proceeding to Systems Engineering.

A point that came out strongly in the interviews, noted in section 4.1.7, was that many people within the group did not have the desire to perform an activity like Requirements Analysis, preferring instead to focus on development work. As such, it was suggested that one of the reasons that not many engineers in the group perform the process is that not many within in the group particularly want to. Respondent 2 predicted, however, that if a suitable person was found, someone with an interest in that kind of work, then "*the process would follow*".

Lack of Dedicated Role

Respondent 2 from the case study observed that there is a tendency in the Radar Group to assign the role of Systems Engineer on projects to a Technical Lead. They went on to argue the point that Systems Engineers and Technical Leads are expected to bring different perspectives to a project, and in doing so can identify potential problems in the approach of each other. By combining those roles and assigning them to the same individual, they asserted that this becomes impossible.

Additionally, being a Technical Lead on a project can be very demanding on that individual's time and effort. This impacts on their ability to devote sufficient time and effort to Systems Engineering activities – or vice versa. This is further compounded when one considers the multitude of activities

that fall under the purview of Systems Engineering. Sheard (1996a) identifies that Systems Engineering comprises of far too many roles and activities to be handled by one person alone. She defines twelve distinct Systems Engineering roles, noting that "*No one person will perform all twelve roles at once*", going on to say that it is not uncommon for many Systems Engineers to never even perform some of the roles.

It does make some degree of sense that the organisation would look to the same people who are assigned the role of Technical Leads as natural respondents for Systems Engineering roles. This is because they will likely have the requisite experience, as noted in section 4.2.2, which makes them suitable to adopt Systems Engineering roles. The point being made by Respondent 2, however, was not so much that the Technical Leads in the group were ill-suited to Systems Engineering roles, but rather that the issue resided in expecting them to perform a dual-role – of both Systems Engineer and Technical Lead.

Lack of a Formal, Documented Process

As discussed in section 2.8.1, having a formal, documented process is important to the success of being able to perform it well. Formally documenting a process provides guidance on what needs to be done, how to do it, and how much time and effort should be committed to it. This helps to ensure that a process can be applied consistently, correctly and predictably across projects and, also, that the process can be improved over time based on the experiences of past projects.

It was apparent from the interview responses that the engineering methodology followed by the group was not driven by formal processes, but rather by a combination of following best practices and a reliance on experience. Five of the six respondents described the Requirements Analysis activities that are being practiced in the group as involving people thinking about and discussing requirements collectively, in an ad hoc manner, until they are able to reach a consensus on system design.

Conflicting Priorities

The importance of making “visible progress” on projects was stated explicitly by Respondent 3. This was deemed to be important to stakeholders both external and internal to the organisation. This view was supported by other respondents who spoke about the importance of keeping to project schedules.

4.2.3 Research Question 3

What can be done to improve effective use of Requirements Analysis?

Improve Awareness of the Value of Requirements Analysis

As noted in section 2.7.2 change is driven, by management or leadership, from a need to improve *Organizational Effectiveness*, often borne from a dissatisfaction with the status quo. This requires that, for the organisation to be motivated to take steps towards implementing a more effective Requirements Analysis process, leadership would need to be aware of the potential improvement that can be achieved by doing so. Section 2.8.2 further discusses how a lack of understanding of the benefits of Requirements Analysis is widely regarded as a significant barrier in achieving its implementation.

Even if there is an awareness that poor requirements are a significant contributor to failed projects, and that the quality of requirements can be improved by means of a Requirements Analysis process, this still needs to be weighed against the costs, in both time and money, of implementing the process. To do so, it is necessary to be able to measure both the cost of the process and the benefit it achieves. While measuring the cost of implementing a Requirements Analysis process is visible and easily measurable, measuring the impact this has on project success is not. Where the improvement of the *quality of requirements* may be measured using an appropriate set of metrics as suggested by Halligan (1993), demonstrating the benefit of that improvement on the final outcome of a project is often significantly more challenging.

The dilemma is that a successful Requirements Analysis process won't necessarily receive the credit it deserves because the problems it prevents never become evident. Conversely, its value may be undermined by problems that it fails to prevent, leading stakeholders to question its value. Unfortunately, simply demonstrating that the quality of requirements has been improved by the process does not in and of itself prove the value of the process because the cost savings that will be realised as a result can only be speculated upon. This means that the time and costs incurred in executing a Requirements Analysis process in a project can be difficult to justify. An appreciation of the value of an improvement in requirements quality therefore relies on stakeholders being aware of the cost of poor requirements and the benefits of good requirements.

While many of the respondents had been made aware of the fact that Requirements Analysis is an important Systems Engineering activity, it was clear from the case study that none of the respondents were aware of the purpose of Requirements Analysis as a tool to improve the quality of requirements. This indicates a consequent lack of awareness within the team regarding the potential value of Requirements Analysis and how or why it would result in an improvement of Organisational Effectiveness. Ensuring that there is a good awareness of what Requirements Analysis is and how it benefits projects would likely help to alleviate this issue. The importance of both training and experience in Systems Engineering is highlighted in section 2.8.1 and providing more training in Systems Engineering would likely create awareness within the group, both from direct attendance and subsequent sharing of that awareness, by attendees, across the group.

Finding the Right Person for the Job

Tampering with the development process typically employed by the team, by means of introducing changes to, or even an entirely new Requirements Analysis process, would qualify as a form of change. Section 2.7.2 describes how change is often resisted when the people in group do not buy

into what is expected of them. This is frequently due to a lack of recognition of the benefit that the change would bring to the organisation, their team or themselves. A second possible factor would be the change affecting the personal compact between the individual and the organisation or team. Conversely, change can be achieved when employees do buy into it. This would require that the individual recognise the benefit of the change while also being able to reconcile that change with their personal compact with the team or organisation.

The importance of getting “buy-in” from engineers was indeed recognised in the case study by the managerial respondents, 1 and 2. Respondent 1 spoke about the need to achieve an alignment between the goals of the individuals in the team and those of the organisation, while Respondent 2 focussed on the importance of allowing people to follow the processes that they feel most comfortable with. Respondents 3,4 and 5, not in leadership positions, all agreed that leadership within the group, both technical and managerial, do indeed give team members flexibility and the freedom to solve problems using processes and methods that they feel are best suited to them. These respondents all felt that being afforded this level of autonomy was beneficial to their ability to deliver successfully on projects. It can be surmised that many within the group regard the freedom to work autonomously and choose the processes they implement as part of their personal compact with the team.

While most of the respondents seemed to acknowledge the potential benefit of implementing a Requirements Analysis process for the team and the organisation, they tended to express a lack of enthusiasm among themselves and their peers to perform a process like Requirements Analysis due to a preference for performing design and implementation activities. Even if the respondents do agree that the process should be implemented, trying to force individuals within the team to follow a process they have no desire to perform, would likely violate the terms of their personal compact with the team, which in turn would likely lead to resistance.

This implies a need to find an individual who not only recognises the benefit of implementing the process, but also who has a desire to do so personally. This was suggested by Respondent 2 who stated directly: "*If you've got the responsible person then the process will follow*".

Furthermore, it follows from what was said in section 4.2.2 that the person have both experience as an engineer in working on developing systems, and suitable training as a Systems Engineer with specialist focus on Requirements Engineering. Additionally this person should ideally be dedicated to the role of performing Requirements Analysis on a project.

Define the Process

It was mentioned explicitly by Respondents 2 and 3, while inferred by others, that size of the project affected the feasibility of performing formal processes on the basis that such processes take up too much time and budget to perform. However, the arguments presented by Halligan (1992) and Young (2002) suggest that the success of Requirements Analysis is contingent on spending a sufficient percentage of total project budget, rather than dedicating a fixed amount of time. Halligan (1992) proposes a comprehensive Requirements Analysis process. While there may indeed be merit in adopting the process in full, in light of what has been said by Young (2002:12) and Sommerville and Sawyer (1997:17), attempts to do so in a single step may be unsuccessful because they will be met with resistance by both the people expected to implement the process, and by project managers who are concerned by the impact on project planning.

The observations of the respondents confirm this and suggest that their experiences with formal processes have been that such processes have a significant, fixed overhead cost. What seems to be needed is a process that has no such overhead, a process that will scale directly with the size of a project. Focussing instead, as advocated by Young (2002:12), on first introducing elements of the process most likely to have a positive impact on projects while also having a minimal impact on timelines, would possibly elicit less resistance to implementing the process while achieving a higher

probability of a visible benefit to the project. Furthermore, achieving a successful outcome from the implementation of the first elements could help to build confidence in the process and make project engineers and managers more receptive to extending the process.

5 CONCLUSION

The objective of this research project was to gain insights into what can be done within an engineering research and development environment to make more effective use of Requirements Analysis, with an aim to improving project outcomes.

The Radar and Electronic Warfare competency area of the CSIR was identified as a viable case study due to the nature of the engineering projects it undertakes, which are well-suited to the application of a Requirements Analysis process. Six respondents participated in a series of one-on-one, semi-structured interviews. The case study sought to ascertain the perceptions of, attitudes towards, and experiences of using Systems Engineering and Requirements Analysis in particular. The current state of Requirements Analysis being used within the group was assessed and the willingness of the group to adopt a more effective Requirements Analysis process was explored.

Much of the literature on Requirements Analysis tended to focus on its importance, why it is necessary and what the process should do. The results of the case study seemed to indicate, however, that the reluctance within this group to implement the type of Requirements Analysis process advocated by the literature tended to revolve around the individuals within the group and how they felt about implementing such a process. While it was found that there was a general awareness within the group of what Systems Engineering is and its importance in the execution of engineering projects, there was a less consistent understanding of what Requirements Analysis is and how it can be used to achieve more successful project outcomes. Systems Engineering processes have not been applied consistently across projects, while Requirements Analysis processes that have been implemented tended not to be focussed on improving the quality of requirements, but rather on either deriving requirements, or how to implement them in systems. It was also found that Systems Engineering tasks tended to be undertaken as secondary responsibilities by technical leads on projects rather than being assigned to people dedicated to the role.

Furthermore, the high value that the group places on autonomy, has resulted in an aversion to processes that are perceived to impede visible progress, or that require a significant effort be expended towards the creation of documentation.

It is suggested that the group could benefit from Requirements Analysis, and improve project outcomes, by focussing on the following:

- An improved awareness of what Requirements Analysis is, what it aims to achieve, and how to implement it;
- Identifying Requirements Engineers with the correct training and experience and a desire to perform the type of processes expected of the role, who can be dedicated to that role;
- Making provision during project planning for an appropriate amount of time and budget to be allocated and implemented by the correct person/persons, based on the size and scope of the project.

Pertaining to the field of Systems Engineering in general, it is surmised that, in spite of the widely accepted potential benefits of Requirements Analysis, it is unlikely to find widespread traction unless it is able to appeal to the engineers, teams and organisations that might stand to benefit from implementing it. In particular, it would seem that addressing the problem of poor quality requirements is not likely to be solved by trying to convince people of the need to do so, so much as making the process itself more appealing.

5.1 Opportunities for Further Study

Being a single case study, the applicability of the findings cannot be assumed to extend to other organisations, so further studies would be needed to test the validity of these results in other environments. A similar case study conducted in another science council or research institute would serve to help establish whether the results of this study are unique to this case, or could be extended to similar environments. Whereas a similar study

in a private sector organisation would test the applicability of these results to engineering environments in general.

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Appendix A Interview Questionnaire

A.1 Management Role Questions

Section 1: Getting to know the respondent:

Question 1.1: Could you please describe, briefly, your history within the organisation and your current position within the team.

Question 1.2: What roles do you perform within projects undertaken by your team?

Question 1.3a: What is your role in determining how engineers on your projects go about designing systems/subsystems?

Question 1.3b: How successful do you believe project leadership and management is at getting engineers on projects to adhere to management directives on how they go about executing projects?

Question 1.4a: What kind of support do you believe engineers on your team need in order to deliver on projects?

Question 1.4b: Do you believe you have the organisational backing to provide that kind of support?

Question 1.5 Intro: In some of the literature I have read, reference is made to the idea of a “personal compact” between an employee and the organisation for which they work. That is, that there is a relationship between the employee and the organisation based on the understanding that an employee has of what is expected of them by the organisation, and what the employee expects from the organisation in return.

Question 1.5a How would you describe your “personal compact” with the organisation?

Question 1.5b: What effect do you believe this “personal compact” has on the way in which you direct those working under your leadership to approach and execute their tasks and responsibilities?

Section 2: Requirements Analysis:

Question 2.1: This study is looking at the issue of Requirements Analysis within the context of the Systems Engineering discipline. Could you please give me a bit of background on your familiarity with Systems Engineering.

Question 2.2a: What you understand by the term “Requirements Analysis”

Interviewer Note: If the interviewee understanding is poorly matched with the definition being used for the study, elaborate as follows.

“The Requirements Analysis I am looking at in this study is the formal Systems Engineering Activity that analyses a set of system requirements and tests them against a number of criteria, to see how adequately they describe the system that needs to be development. This leads to the creation of various documents such as the System Requirements Specification, the Operational Concept Description and System Verification Requirements Specification.

It is a distinct activity from requirements gathering or functional and logical design activities, the objective of which is to improve the quality of the requirements”

Question 2.3a: Are you aware of the Requirements Analysis *activities* that happen on projects you are involved with?

Question 2.3b: If so, can you describe, from your perspective, what those activities entail?

Question 2.4a: What impact would you expect a good Requirements Analysis process to have on the outcome of the sort of projects undertaken by your team?

Question 2.4b: What impact do you believe the Requirements Analysis process that is practiced by your team actually has on the outcome of its projects?

Question 2.4c1: (if the answers to Questions 3a and 3b differ) To what do you attribute this difference in outcomes?

Question 2.4c2: (if the answers to Questions 3a and 3b concur) To what do you attribute this similarity in outcomes?

Question 2.5a: How much time on a project do you believe should be spent on Requirements Analysis activities (this could either be expressed as a number of days or as a percentage of total of the total project time).

Question 2.5b: How much time do you believe is actually spent on Requirements Analysis activities?

Question 2.5c1: (if the answers to Questions 4a and 4b differ) To what do you attribute this difference in time spent?

Question 2.5c2: (if the answers to Questions 4a and 4b concur) To what do you attribute this similarity in time spent?

Question 2.6: If it were up to you, how would you suggest the approach to Requirements Analysis is changed within your team?

A.2 Implementation Role Questions

Section 1: Getting to know the respondent:

Question 1.1: Could you please describe, briefly, your history within the organisation and your current position within the team.

Question 1.2: What roles do you perform within projects undertaken by your team?

Question 1.3a: How involved are project leaders and managers in determining how you go about doing your work? (ie what type of processes and methods you follow)

Question 1.3b How do you feel the way in which you are managed by project leaders and managers affects your outputs?

Question 1.4a: What kind of support do you feel you get from project managers and project leaders on the projects you are working on?

Question 1.4b How does that support, in your opinion, affect your ability to deliver on projects?

Question 1.5 Intro: In some of the literature I have read, reference is made to the idea of a “personal compact” between an employee and the organisation for which they work. That is, that there is a relationship between the employee and the organisation based on the understanding that an employee has of what is expected of them by the organisation, and what the employee expects from the organisation in return.

Question 1.5a How would you describe your “personal compact” with the organisation?

Question 1.5b: What effect do you believe this “personal compact” has on the way in which you approach and execute your tasks and responsibilities?

Section 2: Requirements Analysis:

Question 2.1: This study is looking at the issue of Requirements Analysis within the context of the Systems Engineering discipline. Could you please give me a bit of background on your familiarity with Systems Engineering.

Question 2.2a: What you understand by the term “Requirements Analysis”

Interviewer Note: If the interviewee understanding is poorly matched with our understanding, please elaborate what I am mean when talking about it.

“The Requirements Analysis I am looking at in this study is the formal Systems Engineering Activity that analyses a set of system requirements and tests them against a number of criteria, to see how adequately they describe the system that needs to be development. This leads to the creation of various documents such as the System Requirements Specification, the Operational Concept Description and System Verification Requirements Specification.

It is a distinct activity from requirements gathering or functional and logical design activities, the objective of which is to improve the quality of the requirements”

Question 2.3a: Are you aware of the Requirements Analysis *activities* that happen on projects you are involved with?

Question 2.3b: If so, can you describe, from your perspective, what those activities entail?

Question 2.4a: What impact would you expect a good Requirements Analysis process to have on the outcome of the sort of projects undertaken by your team?

Question 2.4b: What impact do you believe the Requirements Analysis process that is practiced by your team actually has on the outcome of its projects?

Question 2.4c1: (if the answers to Questions 3a and 3b differ) To what do you attribute this difference in outcomes?

Question 2.4c2: (if the answers to Questions 3a and 3b concur) To what do you attribute this similarity in outcomes?

Question 2.5a: How much time on a project do you believe should be spent on Requirements Analysis activities (this could either be expressed as a number of days or as a percentage of total of the total project time).

Question 2.5b: How much time do you believe is actually spent on Requirements Analysis activities?

Question 2.5c1: (if the answers to Questions 4a and 4b differ) To what do you attribute this difference in time spent?

Question 2.5c2: (if the answers to Questions 4a and 4b concur) To what do you attribute this similarity in time spent?

Question 2.6: If it were up to you, how would you suggest the approach to Requirements Analysis is changed within your team?

Appendix B Presentation of Interviewee Responses

This section presents a summary of the responses given by interviewees pertaining to each of the eight case study question posed in section 3.5.1.

Each case study question drew on answers provided in various interview questions. A summary of how the case study questions map to interview questions is provided in Table 3.2.

B.1 Case Study Question 1

How do people within the group approach project work, specifically with regards to following processes and procedures?

Respondent 1 described their role as a team leader as having to "*define what happens*". Senior team members are generally entrusted to manage how they go about doing that. Their feeling is that most of the time this is successful, and interventions are not often required, with senior people executing properly on projects "*naturally*". More junior members require a more "*hands on approach*" to ensure that they follow sound processes and practices. They noted the importance of training, but that training needed to be backed up with opportunities to implement what was learned in theory and put it into practice. While pointing out the importance of "*guidance and mentoring*" they observed that "*people are mimics*", tending to model behaviour and practices on what is observed rather than what is instructed. "*If they are in the environment where people do proper processes then they will tend to follow those processes*". They expressed a desire to be more diligent about having and following proper processes, but that budgets did not always allow for it. Respondent 1 expressed a strong sense of loyalty towards the organisation and coupled this to a willingness to put in the effort required to ensure successful project outcomes.

Respondent 2 described how, in their team, the amount of effort that goes into establishing a process "*framework*" for projects tends to depend on the size and scope of the project. However, they did observe that how well people adhere to such frameworks, and follow defined processes, is a function of the personalities of the individuals working on the project. As

such perfect adherence was seldom achieved. They stated that they preferred to allow engineers the autonomy to choose how to go about doing their work. Ideally, team members would feel comfortable with choosing to work within the framework. But their belief was that the loss of efficiency due to forcing someone to stick within a framework they did not feel comfortable with exceeds any potential benefits. They felt that it was more important to try and tailor the framework to the individuals rather than to try compel individuals to fit into the framework. Respondent 2 expressed a strong belief in what the organisation stands for, summarised as "*working for the national good*". This was quoted as a strong motivator for using their position as team leader to maximise the efficiency of the team to achieve that outcome.

Respondent 3 observed that there were not many "*mature*" processes in place that they were expected to adhere to. Instead, they are allowed the freedom to negotiate with team leadership on how to approach problems. This was an approach that they preferred, and believed made them more effective. They did acknowledge, however, that this requires a degree of discipline and responsibility. They stated that while they didn't generally perceive a need in their environment for having standard processes, viewing them more as "*nice to have*", having such processes in place, to be applied where they "*made sense*" would likely be beneficial. They might also be necessary if required by specific clients. They stated that they valued experience and knowledge over "*following the standards to the letter*" and about "*best practices*" that are "*not always written down in terms of policies and procedures and processes*". Respondent 3 expressed a strong personal motivation to produce excellent work and felt best able to do this when given the freedom to operate independently.

Respondent 4 stated that while team and project leaders are very involved in monitoring activity within project teams, team members are given a lot of autonomy to choose how to approach and solve problems. They expressed a strong personal motivation to produce excellent work as well as a personal desire for the success of the team.

Respondent 5 described how, earlier in their career, the degree of involvement in how they did things was significantly greater. As their career grew, they were given a lot more autonomy, to the point where they would sometimes struggle to get feedback on their work from team and project leaders. They observed that standard processes were not always in place, but where processes for certain tasks were in place, that they tended to follow them and found that to be helpful. Respondent 5 expressed a strong desire for continuous self-improvement as a motivator to refine their own processes for solving problems more effectively.

Respondent 6 expressed a frequent need for "*a lot of self-discipline, self-management*" in the absence of defined processes and set structures for certain tasks. Team and projects leaders were perceived to be more interested in outputs rather than in how they are achieved. Respondent 6 expressed a strong desire to have integrity in what they do, motivating the effort they put into their tasks.

B.2 Case Study Question 2

Is there organisational support for ensuring that optimal processes are implemented?

Respondent 1 spoke about supporting their team members specifically with guidance and mentoring on how to do engineering work. They did note, however, that following formal processes was not always possible due to budget constraints. Although this was not specifically about the organisation prohibiting the use of processes, the organisation is limited by what clients are prepared to pay. They stressed the importance of ensuring that the organisation's goals and objectives aligned with that of the people working for the organisation and that the organisation empowered them, as a Research Group Leader, to ensure that this happens.

Respondent 2 noted that following formal processes was not always possible due to budget constraints, particularly on smaller projects. As a Research Group Leader, they expressed their desire to support team members in whatever was necessary to achieve efficiency, whether that be

to support the execution of processes, or exempt people from having to execute them. They spoke about how, in the past they could have said with confidence, "*unequivocally the organization has its people as its centremost consideration*". But in more recent years, things have changed, describing a "*complete dissonance between those objectives handed out by the senior management … and our ability to achieve good engineering outputs*".

Respondent 3 described the management team as "*enablers*" of the team to be able to perform engineering work without all the "*red tape*". They did, however, express concern about insufficient project management capacity within the group. They spoke about how project leaders tended to afford engineers in the team the freedom to approach problem solving their own way, providing support rather than directives. They also observed that not all projects were able to fund the execution of formal process.

Respondent 4 described their work environment as "*collaborative*", with team and project leaders giving inputs without dictating. They felt confident in being to ask for advice when needed. Respondent 4 expressed a different personal relationship towards their team and people with whom they worked than with the organisation. They felt that while the organisation promoted an attitude of "*chasing certain tick-boxes*", the best results are achieved when people are "*passionate about their work*", which was supported at the team level.

Respondent 5 stated that getting sufficient project management support was rare due to capacity constraints. They believed that project leaders tended to be supportive of team members, but not always available. They expressed that while their level of trust in the organisation had declined over the course of their career, they still had a strong personal relationship with their immediate team and strong trust in the leadership at that level.

Respondent 6 stated that while project and team leadership was always willing to provide support upon request, typically they were given the freedom to choose how to execute tasks. They attributed their lack of

personal interaction with project managers to them operating on a lower level, perceiving that it was their team leaders who had that interaction.

B.3 Case Study Question 3

What is understood by the term "Requirements Analysis" by members of the group?

Respondent 1 has attended several Systems Engineering short courses. Their understanding of Requirements Analysis was twofold. First it was about "untangling" requirements in order to better understand the stakeholder need. Second it was about ensuring that the requirements would be practically realisable and testable in a real system. When discussing the types of Requirements Analysis activities that happen on projects, they discussed the importance of managing requirements so that they can be verified in the final system. They identified the need for analysis to ensure that requirements are correctly "assigned to parts of the system".

Respondent 2 had trained quite extensively in Systems Engineering before switching their career path to that of project management. However, there was no practical Systems Engineering experience. Their understanding of Requirements Analysis was that it was a process of "*deriving requirements*" by analysing the need to be addressed. When presented with the definition of Requirements Analysis being used in the study, there was an immediately acknowledgement the need for "*testing the validity of those requirements against a set of metrics, or through a set of processes*". When discussing the types of Requirements Analysis activities that happen on projects they talked about the final output of the process being a requirements document.

Respondent 3 has had no formal training in Systems Engineering. Their understanding of what Requirements Analysis is revolved around trying to understand the stakeholder need and whether this could be practically realised within an expected budget and time frame. They identified Requirements Analysis activities as those concerned with figuring out whether the system implied by the requirements could be realisable, based on experiences of what has and has not worked in the past.

Respondent 4 had some exposure to Systems Engineering in the form a short course they attended at university. However most of their understanding of Systems Engineering has by shaped by working on projects with people assigned to and performing Systems Engineering roles. They expressed an interest in expanding their formal training in Systems Engineering. Their understanding of Requirements Analysis was that it was the "*process of defining what has to happen or what is required*". They identified Requirements Analysis activities as those that tried to better understand the stakeholder need and then translating those requirements into realisable systems.

Respondent 5 had started doing an online Systems Engineering courses but only completed the initial modules. Their understanding of Requirements Analysis was that it was about ensuring that the requirements, as stated by stakeholders "make sense".

Respondent 6 attended an introductory Systems Engineering course during their postgraduate studies. Their understanding of Requirements Analysis was that it was the process of breaking requirements down so that they can "translate to various systems and subsystems".

B.4 Case Study Question 4

To what extent has Requirements Analysis been used within the group?

Respondent 1 stated that it was one of their responsibilities to ensure that Requirements Analysis was done on projects. They spoke about using Model-Based Systems Engineering tools for capturing and managing requirements, but noted that the tool wasn't suitable for doing Requirements Analysis. They described the process as one of applying one's mind to the problem to "*untangle it into simplistic requirements that can be properly verified and assigned to parts of the systems, or subsystems of the system, so that they can be uniquely verified in a verification process*". They noted that they tried to dedicate sufficient time to Requirements Analysis on projects but that this was often dependent on the client's to fund the activity.

Respondent 2 was not directly involved in Requirements Analysis. Their observations were limited to witnessing of activities, the outputs generated by the processes, which included various requirements documents, and to the amount of time being spent on the activities. They felt that projects, in general, tended to "*woefully underspend*", seldom reaching the 5% mark that they felt should be aimed for. They described the process as generally being informal and without any outputs because most clients don't ask for it. A day's effort involving most of the senior members of the team was typically expended. They went on to observe that often the thinking and realisations that should be coming from Requirements Analysis were happening late into the project, at a time when the project was close to delivery. "*I don't see the explicit pre phase to think about this explicitly. Or it happens so quickly you can almost not tell it happened*".

Respondent 3 observed that Requirements Analysis tended to always happen on projects, but stated that there was no formal, universally applied process that was followed. What they described alluded more to a way of thinking, of team members constantly applying their minds to the problem at hand, discussing things regularly with the team and dealing with issues as they discovered them. Often this would result in initiating client interactions to discuss and clarify issues. It was their perception that team members tended to rely on experience rather than processes to identify potential problems and avoid pitfalls. Their perception of the time allocated to the activity was that it was very erratic, ranging from almost no time at all to excessive amounts of time – around 30% of total project time in some cases.

Respondent 4 was clear that Requirements Analysis activities happened. They spoke at length about identifying problems by working with systems and using that as a basis for generating new requirements. They also spoke about how, at the start of projects, there would be many client interactions to obtain requirements. They then described how this led to modelling and "*functional analysis of what has to happen*". They mentioned "*a massive amount of effort going into the analysis and the performance modelling as*

you're going the process of getting to the detailed designs". They also stated that they do "*detailed analysis of what you're trying to achieve and making sure that you actually can achieve that*". Their perception of the time allocated to the activity was that it was adequate on some projects but on other projects might be ignored altogether.

Respondent 5 was peripherally aware of requirements being generated for some projects, but did not believe that it happens on all projects. They identified one particular project in which a significant amount of time was devoted to Systems Engineering activities at the start, but couldn't elaborate on how much of that, if any, was specifically Requirements Analysis. They did, however, note the success on that project and that "*we should probably do more of that"*.

Respondent 6 started by saying "*What I've seen is that that doesn't really always happen in our environment*". They spoke about their experience of requirements changing during the design process. They suggested that, given the nature of the environment in which experimental systems were being developed, with many unknowns, that it was difficult to commit to user requirements given at the start of a project because "*as we research and discover what's possible, things change*". They linked this to delays and cost overruns and suggested that effort be committed initially to working on areas of the project where requirements were properly known. Their understanding of the Requirements Analysis process was that it was done by senior technical team members on a weekly basis, estimating that it consumed about 10% of project time. They also noted that while they were aware of some documentation being generated, it tended to be inconsistent and difficult to find.

B.5 Case Study Question 5

How effective have the Requirements Analysis processes that the group has implemented in the past been?

Respondent 1 rated the success of Requirements Analysis processes as "*not too bad*", basing that assessment on the observed level of client

satisfaction, stating that "*we've had fairly satisfied clients*". They shared an anecdote about a recent project in which the stated problem had turned out to be somewhat different to the problem that was realised after analysis and spending time in the field with the people who were expected to use the system being built.

Respondent 2 was expressed a deep concern about effectiveness of Systems Engineering processes, including Requirements Analysis, within the group because there was typically no-one dedicated purely to the role of Systems Engineering on projects. This was more likely to be a secondary role assigned to lead technical leads rather than Systems Engineers. As a result, Respondent 2 believed that "*the full utility of going through these types of exercises is significantly eroded. Almost to the point that we might not have needed to go through the process anyway*". They noted the importance of bringing the distinct perspectives of both roles into a project – something that becomes impossible when one doesn't have different people in those roles. Respondent 2 was able to point to one particular project, which shall be referred to from here onwards as "Project A".[2] They considered "Project A" as an exceptional case within the group due to the significant amount of time and effort was dedicated to up-front Systems Engineering. This included a formal Requirements Analysis process. Although there was significant concern, and even criticism, among the rest of the management team during this period about the apparent lack of progress on project, the final result was a system that delivered well beyond expectations in terms of schedule, cost and performance. Respondent 2 attributed this directly to the Systems Engineering efforts. However, they expressed scepticism about whether the other members of the management team shared that perception. Another concern expressed by Respondent 2 was that a lot of the thinking around requirements often only

[2] "Project A" involved the development of a new prototype system intended to demonstrate technology that could address a gap in the local market. The budget for the project was in excess of R20 million, with development spanning over a 3 year period. Multiple team members, of differing disciplines, contributed to the engineering effort.

happened late in the project cycle, resulting in changes to requirements that should, ideally, have been picked during the definition stage of a project.

Respondent 3 observed that "*we've had mixed results*". They stated that on some projects, where the Requirements Analysis has been done well, it has led to positive outcomes where client expectations have been exceeded, while in other cases it has cost projects time and money without adding sufficient value. They also noted the need to revisit requirements during development as new insights led to changing requirements.

Respondent 4 did not speak directly to the perceived impact of Requirements Analysis specifically, but rather about how client satisfaction with projects related to how well the team adhered to stated requirements and whether requirements changed over the course of the project. They did observe that in cases where a less disciplined approach was adopted in terms of managing requirements, outcomes tended to be poorer, with less satisfied clients. This was attributed to the role of the project manager in making sure that the project stayed focused on what is needed.

Respondent 5 spoke about their experiences on different projects and their perceived level of requirements that happened on those projects. Their observations were that instances where they observed proper Systems Engineering being implemented correlated with better outcomes. They opined that the notable amount of time spent on Systems Engineering spent in "Project A" should be replicated on the project they were currently working on. However, they also observed a tendency on projects they had worked on for unnecessary features to be added to systems under development, and for these to even sometimes be prioritised over core functionality.

Respondent 6 claimed to have not directly observed a clear example of Requirements Analysis being performed and elected to rather not speculate on any possible relationship between such a process and project outcomes. They did, however, speak about requirements changing during the development process and the impact this has on their ability to deliver

successfully and how it created a need for flexibility during the design process to adapt to such changes.

B.6 Case Study Question 6

To what have past successes/failures of Requirements Analysis within the group been attributed?

Respondent 1 attributed successful project outcomes to people acting with "*common sense*", acknowledging that it wasn't necessarily that common, but rather the result of experience. They also noted that a genuine desire to solve problems, working with clients to ensure that the problem is properly understood, was a significant contributor to success. They identified, however, that one of the biggest challenges lay in convincing a client of flaws in their understanding of the problem space, and/or unrealistic expectations of what can be achieved within budgets and timeframes. This results in a need to negotiate with clients to change preconceived notions of what they expected the solution to look like as well as a need to convince clients of the necessity to include Systems Engineering processes and to budget enough time to do this correctly, noting that clients who "*understand Systems Engineering and its importance*" tend to demand "*a number of deliverables which are aligned with that process*". They recognised the importance of having experienced Systems Engineers on projects and that a lack thereof would likely compromise the System Engineering efforts and effectiveness of any Requirements Analysis process.

Respondent 2 considered that the biggest problem was that "*we've conflated the notion of technical leadership with Systems Engineering*". They stated the importance of recognising technical leadership and Systems Engineering as two distinct roles each bringing its own unique perspective to a project. As such, they argued that these two roles need to be assigned to different people, each with a skillset and mindset focused on their respective role so that they can effectively challenge each other to ensure a robust design process is executed. A second problem that was identified that "*we lie to ourselves that we're taking the shortcuts in the name*

of efficiency". Processes are often skipped, or glossed over in the belief that starting the design process sooner will result in it being completed sooner. Much of this was attributed to time and budgetary pressures as well as lead engineers on projects believing that they understood the problem sufficiently without the need for going through the rigour of a more formal, albeit time-consuming process. They attributed the significant amount of time and effort spent up-front on Requirements Engineering processes in "Project A" to having engineers who were willing to put in the time and effort and a project manager willing to support that commitment. Their final observation on the success of this Requirements Engineering effort was "*it's longer - that process is longer - than what our people are typically comfortable with*".

Respondent 3 stated that because teams relied on experience when it came to planning of projects, they had a tendency to overcommit to what would be delivered before taking the time to properly analyse the problem space. As a result, many issues would only be identified after significant effort had been expended on the project, resulting in costly rework. They also stated that time and budgetary pressure, often from clients, pushed the team skip processes to try save on time and costs. Conversely, they noted that they had experienced working on projects where too much time had been spent performing upfront analyses, resulting in time-delays that compromised the ability of the project to deliver on time and on budget. They noted the importance of "*visible progress*", not just for clients, but also to management. They acknowledged that, when it comes to Requirements Analysis, "*we are not good at figuring out what is the required level of effort*". They attributed a lot of these issues to "*different perceptions of risk*" with some people feeling that it was important to spend more time understanding the problem space before committing to design efforts, while others felt that time spent on such activities could be better spent by making progress on the development work. They believed that many of these issues could be addressed by having a formal, documented process that outlined what needed to happen and defined the time-frame for the activity. They noted that support from projects managers tended to depend on the size of the

project, with smaller projects often not being assigned enough project management time due to a lack of capacity within the group.

Respondent 4 alluded to an enthusiasm among developers to engage in design and development immediately, skipping, or skimping on processes like Requirements Analysis, stating that there is a tendency among engineers on the team to "*just want to do everything because they're so excited about everything and about technology*". They highlighted the need for a good project manager, to help moderate such behaviour and keep developers on target. They mentioned how two of the senior technical leads on the team, both of whom have a significant amount of experience, tend to be better at analysing problems, resulting in better project outcomes than in other teams. They also spoke about how the limitations of working within a relatively small budget can feed into this phenomenon because it often dictates many of the design decisions at the start of a project. They also shared experiences of some Systems Engineers without enough "*practical experience*" attempting to apply theoretical techniques to projects and "*butting heads*" with technical leads, suggesting that such practical experience should be acquired before people moved into Systems Engineering. They went on to stress the importance of ensuring that project managers, technical leads and Systems Engineers work in harmony to achieve success.

Respondent 5 alluded to a preference among engineers on the team to immediately begin with design and development, skipping, or skimping on processes like Requirements Analysis, stating that "*we're engineers and we want to build things … not just thinking about building something*". They suggested the possibility that processes were viewed as little more than generating a document. They stated that writing documents was not something that people on the team particularly enjoyed doing, and often only did so because it was required as a deliverable rather than due to having any perceived value to the project. They noted that they often felt they would benefit from more interaction with project managers in terms of directing their activities.

Respondent 6 felt that the group avoided doing Requirements Analysis due to time and cost constraints placed on projects by clients. They also shared their experience of requirements changing significantly during the development cycle, suggesting that it seemed pointless to waste time on analysing a set of requirements that "*will change anyway*". They also stated that a poor understanding of requirements by clients contributed to the lack of stability of requirements during the development phases. They tended not to interact with project managers directly on projects, doing so instead through more senior technical members of the team.

B.7 Case Study Question 7

What would be the perceived value of including an ideal Requirements Analysis process within projects undertaken by the group?

Respondent 1 affirmed that Requirements Analysis has a critical impact, rating the necessity of performing Requirements Analysis as "*very important*", noting the need "*to do it properly*". They observed that "*perceived*" problems tend not to reflect "*actual*" problems and how analysing the problem correctly tends to be the difference between "*solving the problem*" versus "*just spending time and money*". This was linked this directly to client satisfaction, based on the ability of delivered to solve the real problem. They suggested that as much as 25% of total project man-hours should be dedicated to Systems Engineering activities with between 5% and 10% on Requirements Analysis.

Respondent 2 spoke at length about the importance of ensuring that the process is correctly "*tailored*" to "*fit the scope*" of the project. They acknowledged the "*necessity to go through that thinking up front*" while cautioning against being too "*heavy-handed*" and having processes that are too "*pervasive*". They suggested that there is a "*trade-off*" between time spent and value gained. They also identified the importance of having a person with the correct skills and capability tasked with this function. They concluded that, while spending the appropriate amount of time and effort by someone with the correct skills should be of significant value, without those

things there is a significant risk of the process being detrimental. After some deliberation, they suggested that at least 5%, preferably more, of total project hours should be dedicated to Requirements Analysis.

Respondent 3 expressed that it could, in the positive sense, have "*a big impact*". They spoke about importance of meeting "*client requirements*" and how, in cases they have "*done well*" on projects, it has been due to meeting those requirements. Conversely, where they have failed to meet client requirements due to misunderstandings that could have been resolved early in the project, they have not done well. They also cautioned against spending too much time coming up with "*an elaborate plan*" that might be discarded early into development, stating that "*it can have a big impact here to also not overdo things*". They acknowledged that their estimate of how much time should be dedicated to Requirements Analysis was a "thumb suck" but suggested that team members assigned to it should spend "*a bit less*" than 10% of project duration.

Respondent 4 said that they believed having a good Requirements Analysis process would result in a "*more optimized*" development process, with less waste in terms of time and budget. They also believed it would have a beneficial effect on project planning and enable the team to more accurately assess how much time and effort would be required to complete projects. They did not seem confident about quoting how much time to spend on Requirements Analysis, but suggested 20% of total project time.

Respondent 5 affirmed that they expected a good Requirements Analysis process to have a positive effect on project outcomes. They stated that having a better Requirements Analysis process could help to ensure that projects focus on building "*exactly what is needed*" rather than prioritising peripheral features. They estimated that around 10% of project time should be dedicated to considering the problem before starting with development based on their experience with developing firmware code.

Respondent 6 recognised the importance of having "*clear requirements*" in that it would help to assess project outcomes. However they expressed

concern about having a Requirements Analysis process in an environment where requirements change mid-project. They estimated that around 20% of project time should be devoted to Requirements Analysis.

B.8 Case Study Question 8

How would people feel about implementing or supporting a more formal implementation of a Requirements Analysis process in future projects undertaken by the group?

Respondent 1, when talking their expectations of team members, stressed the importance of performing "*proper engineering work*" as opposed to "*just doing haphazard designs or hacking things together*". To this end, they expressed a desire to follow a "*more thorough process*" when executing on projects, but noted that budgets tend to dictate whether this is possible, stating that this is often determined by the willingness of clients to provide sufficient funding. They perceived that members within their team were motivated by a desire to solve problems and help clients to meet their needs, stating that "*many people working in our environment have the desire to really solve the problem and not just burn the time*". But they noted that this was often hampered by a poor understanding of those needs, not only by the team, but often by the clients themselves, with the result that "*people end up designing the wrong solution*". They went on to state that it is "*important to separate the real problem from the perceived problem*", noting that it is often challenging to convince clients that "*the perceived problem and the actual problem are not the same thing*". They mentioned that they tended to get the best results from team members when "*one can get a person's personal approach to align best with what the organization needs*". They recognised the importance of requirements, stating that one "*cannot design if you don't have proper set of requirements*" and that it is the quality of one's requirements that "*makes the difference between solving a problem and just spending time and money*". They identified the biggest challenge in implementing a Requirements Analysis process as convincing clients of its

importance, stating that "*Some clients don't bother about it. They don't think it's important and they just want you to start designing the solution*".

Respondent 2 described their role in the group as being the "*custodian of efficiency*". Consequently they were eager to implement any process that they believe would improve efficiency while being resistant to any process that would hinder efficiency. While they expressed support for notion that a Requirements Analysis process would improve the efficiency of completing projects, they also expressed the view that project budget places a constraint on whether the cost, in time and budget, of formal processes can be justified. They noted how, on "Project A", they faced resistance from management, stating "*I spent a lot of time in management meetings and other forums defending this approach*". They also observed that "*it's about personality*" and how differences in personality affect the willingness of individuals in the team to follow formal processes and, consequently, the effectiveness thereof. They identified the biggest challenge in implementing a Requirements Analysis process as assigning the correct person into the role, stating that "*If you've got the responsible person then the process will follow*".

Respondent 3 spoke about the importance of having autonomy in deciding how to go about performing design work. They also spoke about how time and budget pressures affect their willingness to follow defined processes, and, to that end, the importance of having "*a process that makes sense*". While they acknowledged the importance of going through an analysis process before committing time to development, they expressed concern about people relying too much on theory without having practical experience. They also expressed concern about spending too much time analysing the problem space and eating into development time, especially when requirements might end up changing during the development cycle. They summed this up by stating that it was a question of "*perception of risk*" – on the one hand there is a risk of not spending enough time performing analysis, leading to problems during development, while on the other hand there is a risk of spending too much time on analysis leading to a "*lack of*

visible progress" and the project failing to meet schedules. Compounding the issue also, was the observation that "*Sometimes we don't spend enough time on this because we see it as an annoyance*".

Respondent 4 stated that "*I'm very strict when it comes to delivering on time, in budget*". However they also observed that this can be difficult when "*clients they don't necessarily always know what they want*". They noted the positive effect of team leaders working collaboratively with team members rather than being prescriptive, stating that, in order to produce high quality outputs, "*You have to enjoy your work. You have to be passionate*". They commented that they believed one of the roles of team leadership was to "*not necessarily stop innovation or to stop creativity, but to guide it or to contain it*". They observed that having team members feel valued is an important part of this, that people are more motivated to deliver when they have an emotional connection with their team. They also observed that team members would be more likely to buy into processes when they are personally involved in designing or selecting those processes. They noted that many projects undertaken by the group experienced tight budgetary constraints which often put pressure on teams to skip formal processes in favour of progressing on development work. At the same time, they noted a tendency for team members, in their excitement for solving the problems at hand, to want to proceed directly to creating solutions rather than spending time in Requirements Analysis, saying "*If you have excited people or curious people then it's almost like the Requirements Analysis step is skipped*".

Respondent 5 expressed a personal desire for continuous self-improvement in terms of their ability to deliver on projects stating that "*I'm always doing my best to have the best quality outputs*". However, they lamented a shortage of guidance from project managers and team leaders on what processes and practices to follow. They attributed the lack of formal processes on one the projects they were working on to not having a formal contract, and thus operating under a constrained budget. They also described how they perceived document-centric processes to be onerous

and not as attractive to engineers in the team as doing development work, stating that "*people want to make progress rather than documents*".

Respondent 6 expressed frustration at the way changing requirements over the course of a project tended to lead to rework and delays stating that "*it wouldn't really help if you have some clear requirements at the start and then that changes in the middle*". They noted that "*the client wants something delivered within a specific amount of time*" puts pressure on the team to expedite development work at the cost of dedicating time to up-front analyses. They believed that having more interactions with the client at the requirements stage could help to ensure that requirements are better understood and thus not end up changing mid-project. Furthermore, they noted a lack of visible requirements processes and perceived that, for such a process to be of value, it must be "*documented properly somewhere*" and be something "*everyone in our environment is aware of*".