A selection method for candidate systems engineers

Duarte Paulo da Silva Gonçalves

Thesis submitted for the degree Doctor of Philosophy at the Potchefstroom campus of the North-West University

Supervisor: Prof. J.E.W. Holm

29 April 2013

2013/04/29 01:46 PM

Abstract

In South Africa there is a shortage of systems engineers which is being addressed by a systems engineering (SE) development program. The purpose of this research was to design a selection method that could be used to select candidate systems engineers with potential thus increasing the probability of successful development of SE competencies. Based on literature and practical considerations, the following research question was formulated:

Can a candidate's SE competence potential can be predicted from personality preferences, cognition, and values (the SE Profile)?

Design science research was used as the research methodology. The 15 Factor Questionnaire Plus was used to assess personality, the Cognitive Process Profile for cognition, and the Value Orientations to assess values. The 21 SE competencies were assessed using the *INCOSE Systems Engineering Competencies framework*.

Specific values (high or low) on a combination of psychological measures are useful for predicting high competence and these vary between SE competencies. Thus psychological measures for SE as a whole cannot be identified as has been done in the literature. The number of engineers with high SE competence is inversely proportional to the number of SE competencies. Cognition measures seem more useful in identifying risk, but do not strongly predict SE competence for the given sample. From this research, no evidence was found that values have been considered previously in the SE selection literature, but values are useful for predicting high competence on at least 11 SE competencies.

Because the various SE competencies require different profiles, there are few "super systems engineers". SE competence required for the project can be achieved through a team rather than a single systems engineer. Assessment can be used as a tool for SE development by detecting anomalies and selecting candidates which have the potential for faster successful development.

Keywords: Systems engineers, shortage, selection method, personality, cognition, values, competencies.

Uittreksel

Daar bestaan ‘n tekort aan stelselingenieurs (SI’s) in Suid Afrika. Dit word aangespreek deur middel van ‘n stelselingenieursontwikkelingsprogram. Die doel van hierdie navorsing was om ‘n seleksiemetode te ontwerp wat gebruik kan word om kandidaat stelselingenieurs te selekteer met potensiaal, en sodoende te verseker dat sulke kandidate suksesvol ontwikkel kan word in terme van SI bevoegdhede. Die volgende navorsingsvraag is gebaseer op literatuur en pragmatiese oorwegings:

Kan ‘n kandidaat se SI bevoegdhede voorspel word uit persoonlikheidsvoorkeure, kognisie en waardes (die SI profiel)?

Ontwerpswetenskap navorsing is gebruik as die navorsingsmetodologie. Die 15-Factor Questionnaire Plus was gebruik om persoonlikheid te bepaal, die *Cognitive Process Profile* vir kognisie, en die *Value Orientations* om waardes te assesseer. Die 21 SI bevoegdhede was deur die *INCOSE Systems Engineering Competencies framework* geassesseer.

Daar is bevind dat spesifieke waardes (hoog of laag) op ‘n kombinasie van psigologiese maatstawwe bruikbaar is om bevoegdheid te voorspel, en dat hierdie tussen SI bevoegdhede sal varieer.

Daarom kan daar nie na psigologiese maatstawwe vir SI in geheel verwys word nie, soos voorheen in die literatuur gedoen is. Die aantal ingenieurs met hoë SI bevoegdheid is indirek eweredig aan die aantal SI bevoegdhede. Kognisie maatstawwe blyk meer bruikbaar te wees om risiko te voorspel, maar kon nie voorspellings maak van SI bevoegdheid vir die gegewe populasie nie. Uit die navorsing kan dit nie bewys word dat waardes voorheen oorweeg is in die SI literatuur nie, maar waardes is nuttig om voorspellings te maak van hoë bevoegdheid in ten minste 11 SI bevoegdhede.

Omdat die verskillende SI bevoegdhede verskillende profiele vereis, is daar min “super” stelselingenieurs. SI bevoegdheid wat vereis word vir ‘n projek kan bereik word deur ‘n span saam te stel, eerder as ‘n enkele ingenieur. Seleksie kan gebruik word vir SI ontwikkeling deur uitsonderings uit te wys, sowel as die seleksie van kandidate vir versnelde, suksesvolle ontwikkeling.

Acknowledgements

Janine Britz was my research intern for over a year during this research. She gathered information, organised the psychological and systems engineering assessments and coordinated with candidates to make sure that everything went smoothly. Thank you Janine!

Prof. Johann Holm's monumental patience in reviewing an endless number of drafts is not forgotten. Thank you for your support, Johann!

In addition, I would like to acknowledge the following individuals for their help and support in this research, with the review of the document at the start, be it ethical, technical, theoretical or otherwise (in alphabetical order):

Prof. Patrick Chiroro
Maj. Dr. Annette Falkson
Col. Albert Meyer
Dr. Maretha Prinsloo
Sally Satchel
Johan Strydom
Dr. Nanette Tredoux
Monique Woodborne

This research effort was partly funded by a CSIR Parliamentary grant.

This work is dedicated to my family.

Contents

FIGURES

TABLES

ABBREVIATIONS

15 FQ+	The Fifteen Factor Questionnaire Plus
ANOVA	Analysis of variance
BEI	Behavioural event interview
CEST	Capacity for engineering systems thinking
CPP	Cognitive Process Profile
CSIR	Council for Scientific and Industrial Research
DPSS	Defence, Peace, Safety and Security, a unit of the CSIR
DSR	Design Science Research
HPCSA	Health Professions Council of South Africa
INCOSE	International Council on Systems Engineering
ISO	International Organisation for Standardization
k_{com}	Number of psychological measures that are common to high competence systems engineers.
MBTI	Myers-Briggs Type Indicator
OPQ32	Occupational Personality Questionnaire
SE	Systems Engineering
SPEEX	Situation Specific Evaluation Expert
VO	Value Orientations

Chapter 1 Introduction

This chapter describes the problem relating to the shortage of systems engineers (in the next section) and the value of selecting candidate systems engineers, outlined in section 1.2. Section 1.3 scopes the research and its limitations. Finally, an overview of the thesis is given.

1.1 The shortage of systems engineers

Systems engineering (SE) is a critical capability of national importance if South Africa is to sustain growth in the face of complex technologies. However, from experience a national (and global) shortage of highly skilled systems engineers has been found. Recent attempts within DPSS at recruiting systems engineers have not been entirely successful. There are a small number of systems engineers in the market (Table 1), but these engineers are not well matched to the kind of research and development work that is performed within the CSIR. Of the candidates interviewed in 2006 and 2007, three offers were made but none were accepted. While DPSS did recruit 4 systems engineers in 2008, they were white males. Since developing and transforming human capital is one of the CSIR's organisational objectives and as a government organisation, the CSIR has an obligation to make a contribution to solving this national problem.

Table 1 Systems engineering recruitment statistics
(Source: DPSS Human Resources)

Calendar Year	2006	2007	2008
Number of applications	28	17	37
Number of interviews	10	6	10
Number of offers made	3	0	4
Number of appointments	0	0	4

In the interim, recruiting systems engineers cannot be dismissed as an option because DPSS still has a short-term need that cannot be met by development. However, one of the strategies adopted in 2007 was to develop systems engineers internally, within DPSS application areas. The objective of this development was firstly to produce enough systems engineers for DPSS' need, and secondly to produce systems engineers for South Africa in general. In terms of the scope of SE, DPSS is involved largely in the feasibility and concept phases of the systems life-cycle. In support of the development work in these early life-cycle phases, specialised test equipment is built, which is also produced in low-volume for international export. Since there is considerable variety in SE skills and applications, finding a good match is challenging and expensive in terms of interview time. Additionally, the majority of candidates are white males, which is an issue in the South African context.

Some of the approaches used to accelerate development of systems engineers are resource intensive (Gonçalves 2008). It follows, then, that a *selection* process that increases probability of successful development would be useful for *screening* internal staff for further development, and external staff for employment, with a view to development as systems engineers. This might appear to be a considerable effort just to find candidates, but selection information could be used to better place non-systems engineering candidates with potential. Internal development of systems engineers, as opposed to recruitment, also allows for development of black and female candidates with SE potential.

1.2 Value proposition and justification for the research

The results of this research have practical benefits for employers of systems engineers in South Africa, candidate systems engineers and the SE profession. The value of screening candidate systems engineers lies in the cost currently incurred because of the *shortage* of systems engineers, and the *lead time* in developing systems engineers. There may also be some collateral benefits (described below). The current costs resulting from this shortage includes:

- Opportunity cost resulting from not being able to access new projects;
- Project risk, a consequence of not having the right skills or adequate skills on current projects;
- SE recruitment costs which includes advertising costs, interviewing costs, recruitment agency fees and start-up time of new employees; and
- Training and coaching costs.

Activities on projects are the vehicle for competency development (Leonard-Barton, 1998). Larger projects with a development cycle of more than a year are limited and hence there may be limited learning opportunities. These learning opportunities are thus a development resource. Apart from this, development also requires time from more senior systems engineers for coaching. Thus, developing engineers most likely to succeed can avoid significant costs, wasted time, and effort.

In addition to these costs there is a development lead time. If a basic engineering degree and three years practical experience are assumed, then systems engineering development could start at around the age of 25. If a development time of about five years is further assumed, this makes the 30 the earliest age for a junior systems engineer.

The potential collateral benefits to participants and DPSS include:

1. Increased self-awareness of participating engineers resulting in higher performance;
2. Increased understanding of team members for participants willing to exchange their profiles with team members, leading to higher team performance;
3. Increased understanding of personality, cognition and values amongst engineers;
4. New staff can be screened in terms of organisational fit;
5. Overview of organisational health based on the mix of profiles; and
6. Tools to balance the psychological attributes of a team in order to achieve the required SE competencies for a project.

Given the severe shortage of systems engineers, cost and lead time, selecting the right engineers can offer significant advantages. The next section discusses the scope and limitations of this research.

1.3 The solution concept, challenges and research scope

Given the preceding discussion, the problem that DPSS attempts to solve is accelerating the development of systems engineers with the highest probability of success within funding constraints. The solution concept is illustrated in Figure 1. There are two sets of independent tasks that can be conducted in parallel: (i) The development of a selection method (F1, F2, and F3) and (ii) the development and implementation of a programme for training systems engineers (F.4). The development of a selection method (as outlined in (i)) is the *topic of this thesis* while the other tasks (F.4, F.5, F.6 and F.7) are out of scope but give context. The problem and proposed research methodology (F1) was presented for review and management approval in 2009 (Gonçalves & Britz, 2009). While profiles for engineers in general exist (Davis, et al., 2005), the development of a selection method (F2) and its evaluation (F3) specifically for systems engineers does not exist and is the core of this research.

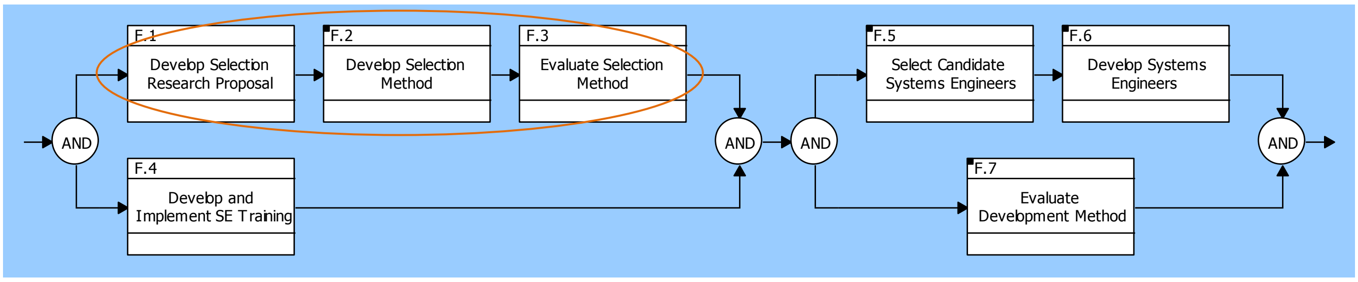


Figure 1 Research scope (highlighted in red) and context

The development and implementation of an SE training programme (Gonçalves, 2010) has been in progress for the last three years, recently in conjunction with the University of Witwatersrand. Once work on these two fronts reaches completion, candidate systems engineers are selected (F.5) and development of systems engineers (F.6) begins. One of the outputs of this research (F.1, 2, 3) is a selection method which will be used in selecting candidate systems engineers (F.5). On-going evaluation of the selection and development method (F.7) is proposed.

There are a number of challenges in developing a selection method in the context of developing systems engineers:

- Human resource practitioners sometimes fail to link work to psychological measures, picking measures without proper rationale. According to Robertson & Smith (2001, p446) there does not appear to be any basis for this:

  "… many practitioners go directly to [knowledge, skills and abilities] by asking subject-matter experts to identify the competencies required for the job. Very little is known about the validity, reliability or other psychometric properties of this process";

- There are a range of activities (each requiring competence) under the SE umbrella, but it has been treated as a homogeneous discipline. This limits options that project managers have in allocating resources to projects;

- SE is context dependant (industry and sector) which leads to either small samples or more complex analysis to account for these confounding variables;
- It is a specialised niche area and extensive literature does not exist. Where there is literature, it is generally not supported by data;
- The literature of selection for development is less developed than the literature on selection for placement (recruitment). Some job selection methods used for placement are not applicable for development (Robertson & Smith, 2001).

The scope of this research regarding the development and evaluation of a selection method is limited to:

- *Developing systems engineers*, but not recruiting or other potential uses;
- This is an exploratory study. In order to reduce risk, the scope defined at the beginning of the study was limited to using existing assessments (which will be discussed in more detail later) to get an initial indication of what is important. Each of the assessments represent a large, mature body of work. *What was absent in the literature was the relationships between these assessments*. Once important aspects have been determined, and limitations identified, further studies can be defined;
- As an exploratory study, it was *limited to a single organisation*, although as will be discussed in the research methodology section, *a broader study was considered*. This removes the industries in which SE is applied as a confounding variable, but places a limitation on the applicability of the study's results. Nonetheless, since the study used a general approach with general methods and techniques, this study can be extended to other institutions.

1.4 Thesis overview

The literature study (Chapter 2) evaluates what existing knowledge can be used to select systems engineers and to define a focused research question if there is no ready solution. Starting broadly, the literature is reviewed on what is systems engineering (SE) really and why there is a shortage of systems engineers. Much of the SE literature is focused on process but it is people that do SE and so it is necessary to move beyond process. The general literature on competence is reviewed and a model of competence synthesised that *could* be used for selecting systems engineers. This is juxtaposed against *current* psychological and competence assessment methods and measures for assessing systems engineers. Gaps identified between the model of competence and current methods and measures lead to the basic research question (defined in Chapter 3):

Can the successful development of SE competencies be predicted from personality preferences, cognition and values?

Practical concerns regarding the development time of candidate systems engineers require the research question be rephrased. Thus the hypothesis, supported by the literature, and against which the selection method is evaluated is:

$\mathbf{H_1}$: *A candidate's SE competence potential can be predicted from personality preferences, cognition, and values (the SE profile).*

The research methodology is presented in Chapter 4. A single cycle of design science research (DSR) is used as the methodology with the objective of developing a selection method. Literature relating to the formulation of the research question has been separated from literature relating to the design. This maintains separation of the research problem and the solution (and its design). Design related literature is included as the selection method development proceeds. The population and sample are selected based on how the selection method will be used, theoretical issues, and ethical considerations. The research instruments were chosen based on the research question for the development of a selection method.

Section 4.4 elaborates on the methodology for the development of a selection method for candidate systems engineers. Data was collected for the selected instruments: 15FQ+, Cognitive Process Profile (CPP), Value Orientations (VO), and the Systems Engineering Competencies Framework. *The approach to identifying SE potential is to consider what psychological measures high competence engineers have in common*. An engineer has potential on a certain SE competence based on similarity to what high competence engineers in that specific competence have in common - this is a fundamental principle for this research. These concepts are used to develop the potential identification algorithm. Section 4.5 discusses evaluation of the selection method based on concurrent cross-validation *for each SE competency*, i.e. 21 hypotheses are tested. Constraints on the research, arising from ethical and regulatory requirements that shaped the detailed design of the research methodology are covered in section 4.6.

The purpose of the results chapter, Chapter 5, is to provide evidence that the hypothesis for the various SE competencies can be accepted. General results describe the context in which SE is being performed at DPSS. To explore the data and reveal basic relationships, a pairwise correlation analysis of each of the three psychological assessments against the SE competencies was performed (results presented in section 5.3). Of interest is identifying engineers with similar characteristics to those who are currently at practitioner or expert levels in terms of the SE Competence Assessment Framework using the potential identification algorithm. Results relating to the potential identification algorithm are presented in section 5.4. Collectively, practitioner or expert levels will be referred to as “high competence”. Unlike correlation, the potential identification algorithm allows for non-linear relationships between measures in a multidimensional space.

Chapter 6 provides a summary of the important results and limitations, the main conclusions, the contributions of this thesis and future work.

The discussion of this chapter is summarised in Figure 2. The real world problem is a shortage of systems engineers nationally. The research problem is the selection of candidate systems engineers for development. The research problem together with literature and existing psychological assessments form inputs to the research process which is based on DSR. Ethics, laws and regulations govern what can be done in the research. Without resources such as a population of engineers and tools for data analysis, this research could not be performed. The research outputs are a validated selection method, correlation models, and identified gaps for future work. The selection method is part of the solution for developing systems engineers.

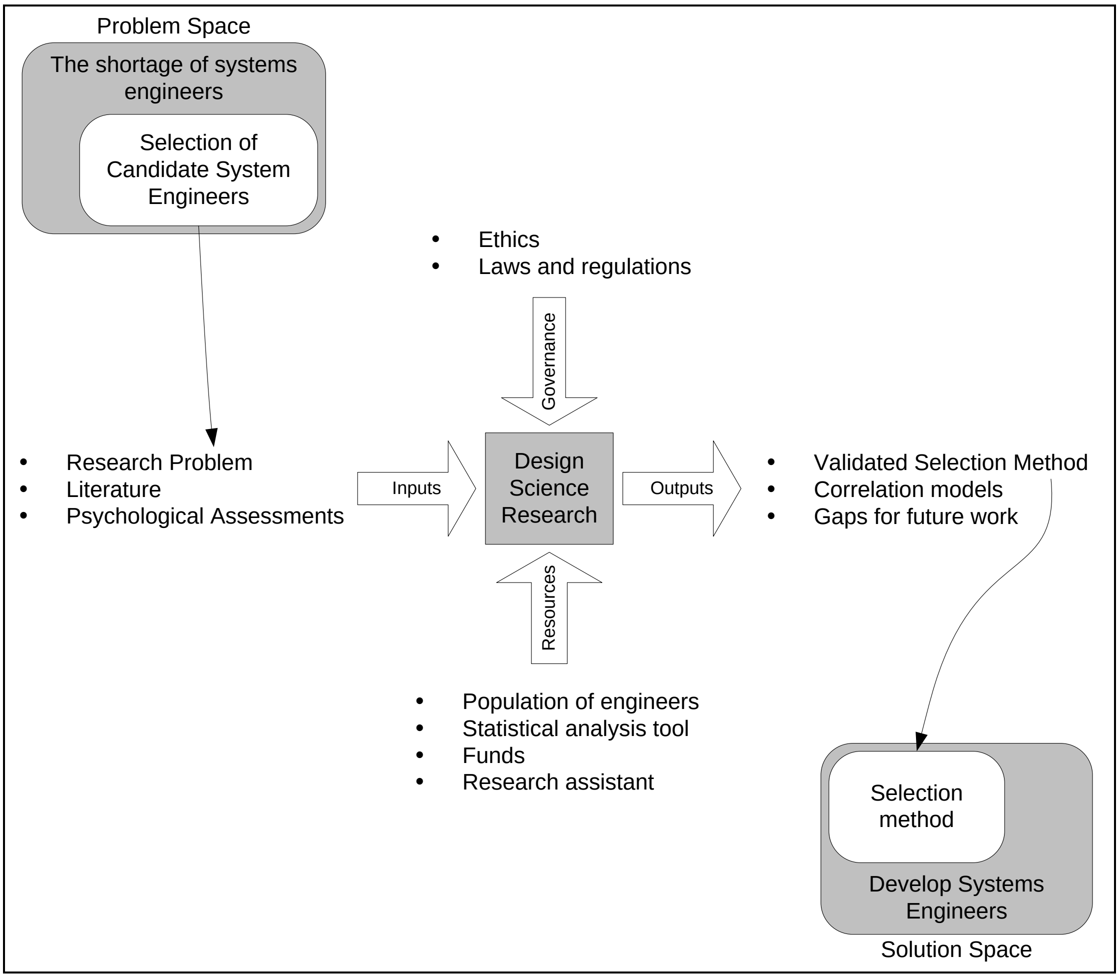


Figure 2 Thesis process overview

Chapter 2 Literature Study

The purpose of the literature study chapter is to evaluate what existing knowledge can be used to select candidate systems engineers and to define a focused research question in the absence of a ready solution. Literature outside the purpose of this chapter will be reviewed as required and within the context of later chapters.

Starting broadly, the literature is reviewed on what is systems engineering (SE) really and why there is a shortage of systems engineers. Much of the SE literature is focused on process but it is people that do SE and so it is necessary to move beyond process. SE depends on competence. The notion of competence is fragmented, however. From the literature on competence in general, a model of competence is synthesised that *could* be used for selecting systems engineers (section 2.4). This is juxtaposed against *current* methods and measures for assessing systems engineers (section 2.5).

2.1 Systems engineering background

This section discusses briefly the definition of SE, what a systems engineer does and why a shortage of systems engineers is being experienced globally.

2.1.1 What is Systems Engineering?

In order to focus the discussion and because there has not always been consensus on what SE *is*, the definition of the International Council on Systems Engineering (INCOSE) is used. INCOSE states[1]:

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem: Operations, Cost & Schedule, Performance, Training & Support, Test, Disposal, Manufacturing.

---

[1] *What is systems engineering?* http://www.incose.org/practice/whatissystemseng.aspx, last accessed on 5 February 2008.

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

From this definition, several issues are evident. Firstly, the scope of SE work is tremendous, stretching over the life-cycle of a system, multiple technical disciplines, and management. Secondly, a group of people typically performs SE, because on complex projects, no one person has all the skills or time for all that is contemplated by the INCOSE definition of SE. Finally, SE is a meta-discipline. It is applied in the areas of aerospace, or communications, for example, by engineers with educational backgrounds ranging from mechanics, electronics, software and ergonomics, to name just a few. INCOSE has been sensitive to specialisation of knowledge in various application sectors. Accordingly, it has formulated the technical matrix, illustrated in Figure 3, which presents SE enablers against application sectors. Yet, even within these application sectors, there is a range of applicable knowledge.

		Application Sectors							
		Aerospace & Defence	Market Driven Products	Emerging Technologies	Enterprise	Information Systems	Infrastructure	Public Interest	Transportation
SE Enablers	Systems Science								
	SE Technical Process								
	SE Management Process								
	SE Support Process								
	Modelling & Tools								
	Speciality Engineering								

Figure 3 INCOSE's Technical Matrix

There are two main views that describe what a systems engineer does: *role* based vs. *process* based. Neither of these views is complete and even within INCOSE there is debate about what systems engineers do – it cannot be fully reduced to a set of roles or processes. For example, none of the roles or processes describes how to be creative in order to solve a difficult problem. However, there is broad acceptance of these two views within the SE community. Sheard (1996), in her seminal paper, describes 12 systems engineering roles:

1. Requirements Owner;
2. System Designer;
3. System Analyst;
4. Validation/Verification Engineer;
5. Logistics/Operations Engineer;
6. Glue Among Subsystems;
7. Customer Interface;
8. Technical Manager;
9. Information Manager;
10. Process Engineer;
11. Coordinator; and
12. Classified Ads SE.

There is a debate as to whether these are roles performed specifically by systems engineers or by engineers in general. On smaller projects, one person could be performing a variety of these roles. For large systems, however, these roles can occupy several engineers.

The other view defines various processes, each containing various sub-activities that should nominally be performed when engineering systems. Various standardisation bodies like the International Organization for Standardization (ISO) and other organisations have sought to define SE processes. For example, ISO 15288, *Systems engineering – System life cycle processes* (which has the broadest scope of standard processes) defines four groups of processes required to engineer a system, namely: (i) enterprise, (ii) agreement, (iii) project and (iv) technical processes (Figure 4)(ISO15288, 2008). Project and agreement processes are usually the domain of a project manager on large projects. For the current study, the focus will largely be on the technical processes, since these are usually performed specifically by systems engineers.

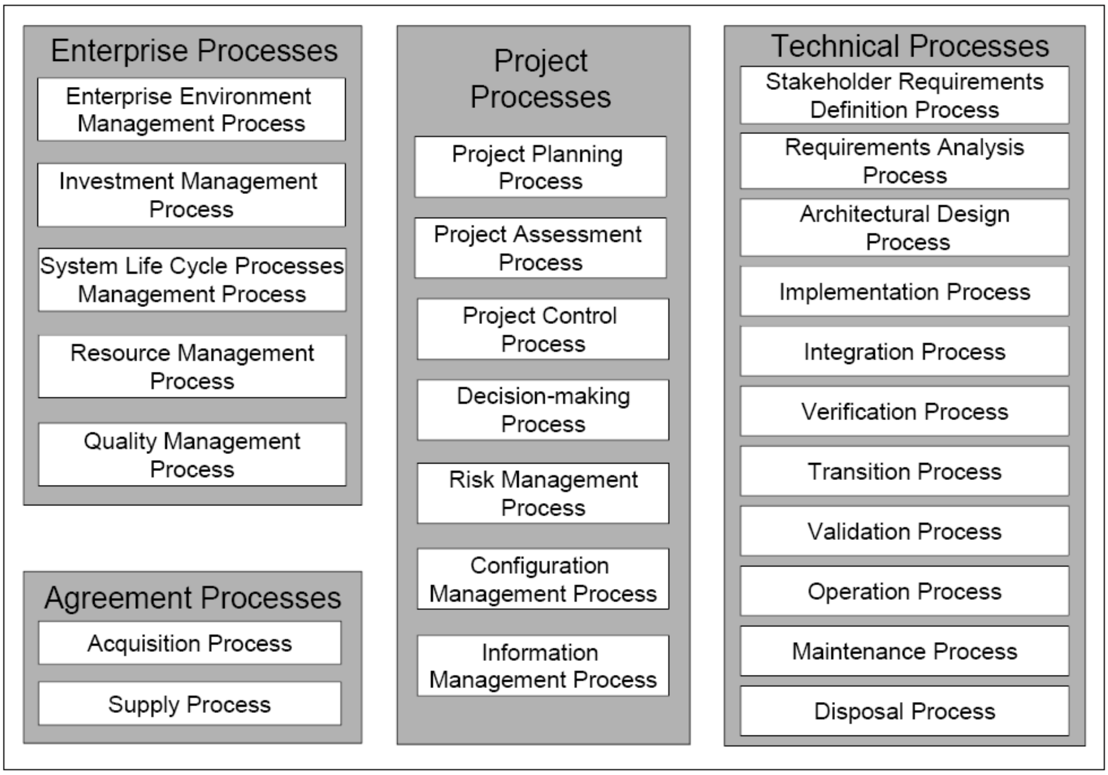


Figure 4 ISO 15288 processes (ISO15288, 2008)

The value of SE is always in question by engineers in general. But the value of SE is not the SE process as such, but rather its positive effect on delivering to cost, on time and satisfying project and system requirements (Honour, 2004 and Charette, 2005). Without adequate SE, projects have failed. The following section considers fundamentally why there is a shortage of systems engineers.

2.1.2 Why there is a shortage of systems engineers

There are two main causes of the current SE skills shortage. Firstly, the positivist epistemology that saw the rise of science in the nineteenth century permeates universities (Schon, 1995). In this positivist worldview “de-contextualised knowledge”, i.e. knowledge that is context independent, is highly valued. Professional practice became about problem *solving* with all the rigor of scientific theory and technique. But with all the emphasis on problem solving the problem context, which system should be designed, which goals are to be achieved and which means may be used have all been ignored. In short, when most engineers complete their degrees they do not know how to define a problem adequately - in the real-world problems are not closed and pre-defined, like exercises in a text book.

Secondly, design was almost driven out of Universities by the natural sciences following the Second World War (Simon, 1996). The general culture of Universities emphasised academic respectability which required highly intellectual material, specialisation, and analysis. Design, on the other hand, was seen as intellectually soft, intuitive and informal. Research became the basis of professional practice and engineering schools started to focus on physics and mathematics.

Thus the common approach to learning SE is on-the-job experience. But such skills development can be slow due to a lack of clear development focus, and if not accompanied by relevant theory, may not yield good results. The following section considers what can be done at an organisational level.

2.2 Moving systems engineering beyond just process

A standard process, such as ISO 15288 presented in Figure 4, represents a consensus or best practice of how to do SE. But SE is not just a clinical process. Calls to focus on people, and not just process, have come from within the SE community (Kasser, 2007). Some researchers have noted that “Many firms - some very successful - stubbornly refuse to adopt those [best] practices” (Cappelli & Crocker-Hefter, 1996). Cappelli and Crocker-Hefter’s explanation is that these firms that have survived have focused on “core competencies” (which will be dicussed again in the following section).

The problem with the process as presented in Figure 4 is that if people don’t know how to implement the process, then it has failed. But a methodology is much broader than a process. Defined for a *specific project*, a methodology ensures the quality of the results and assists in management. As illustrated in Figure 5, a methodology consists of related processes, methods and tools, supported within an environment by skilled and knowledgeable people (Estefan, 2008). A process defines “what” must be done as a logical sequence of tasks to achieve an objective. “How” each task is to be performed is not specified as part of the process, but as part of one or more methods. These methods are typically the challenge because they require skill. Tools increase the efficiency of processes and methods. All of this is conducted in an environment which includes physical, individual, cultural and organizational context that influence the methodology. Thus, methodology represents a more holistic perspective than standard processes.

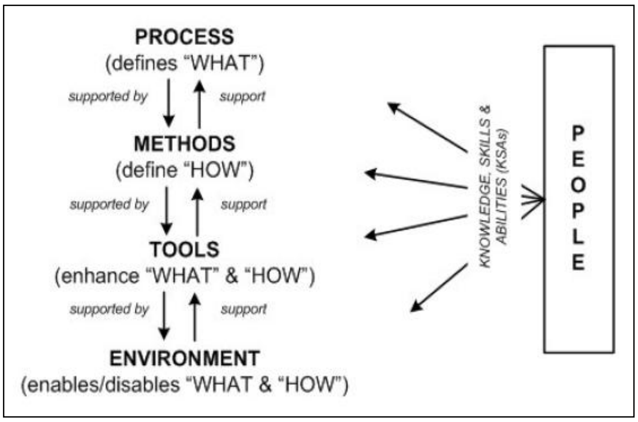


Figure 5 The Elements of a Methodology (Estefan, 2008)

The fundamental tension in an engineering enterprise, operating in the early system life-cycle phases, is the need to have processes for control while operating in a dynamic, complex and uncertain environment (Figure 6). The mechanistic organisation is built on formalisation and control and has considerable inertia (Hoogervorst, 2009). This organisation is to some extent mechanistic, characterized by top down assignments, strategic planning, etc. On the other extreme the organisation is organismic, characterized by flexibility, renewal and innovation. In the organismic state, strategy is a learning process accompanied by competence and bottom-up initiatives. This is not to say that organismic is "good" and mechanistic is "bad". For example, the mechanistic approach captures knowledge about process far better than the organismic approach. The challenge is to conduct work in complex environments while remaining stable (not going to chaos). One of the ways of doing this is though the development of competencies (Hoogervorst, 2009).

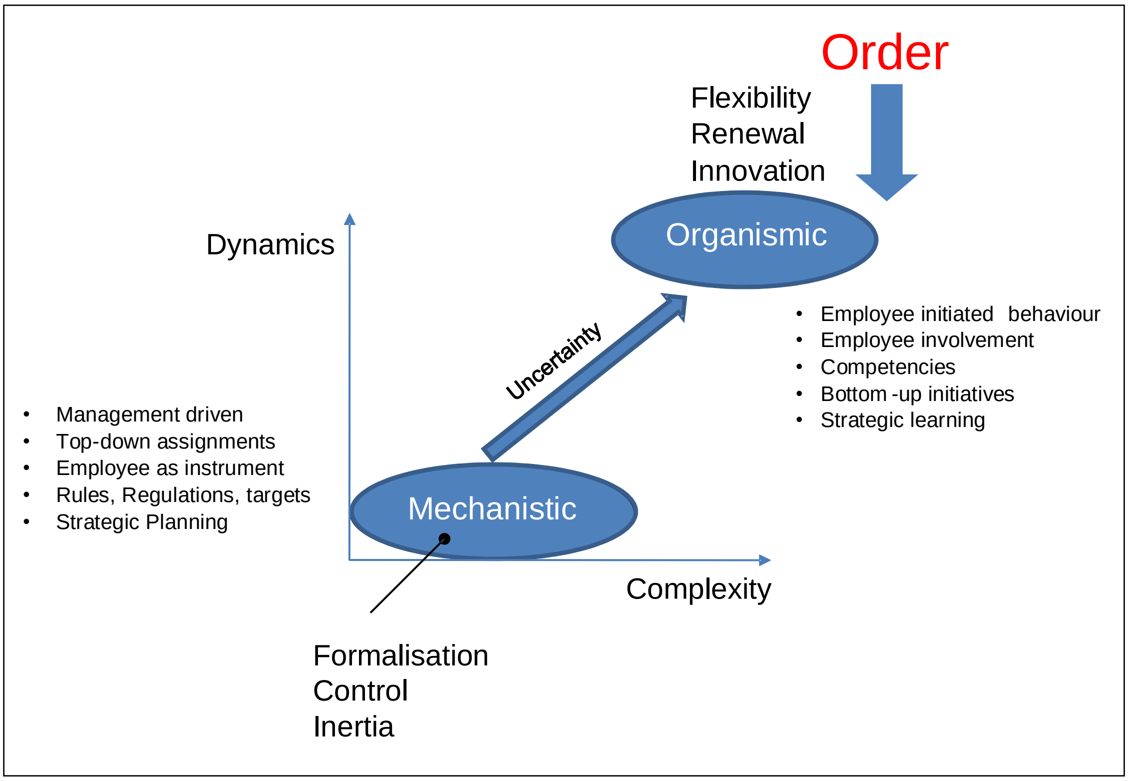


Figure 6 Mechanistic vs. Organismic ways of Organising (Hoogervorst 2009)

2.3 Competence in general

The notion of competence or competency is fraught with multiple meanings and inconsistent usage across the literature. In the strategic management literature, "core competence" was touted as the strategic lever required for competitive advantage (Hamel & Prahalad, 1994). It linked strategic intent, markets, end products, and core products to core competencies. These competencies include technologies and human resources.

Early use in the psychology literature describes competence as "a symbol for an alternative to traditional intelligence testing" (McClelland, 1973). In the human resource development literature, a number of attempts have been made to understand the different meanings and define a typology of competence (Deist & Winterton, 2005; Garavan & McGuire, 2001; Hoffmann, 1999).

Competencies have been defined in three ways (Hoffmann, 1999):

1. Observable performance of a person or *output* of a learning process. People are declared competent on the basis of this observed performance;

2. *Standard* or quality of the outcome of the person's performance. This definition is concerned with a minimum level of performance and higher levels of competence than existed before, for example during organisational change, or the need to standardise across an organisation;

3. The underlying attributes of a person such as knowledge, skills or abilities. The focus here is on the required *inputs* for competent performance. This approach is used to establish content for a training programme, for example.

Hoffman's typology of competency is shown in Figure 7. The first definition of competence above looks at observable individual outputs or performance. In the job-analysis literature this first definition of competence is related to work-oriented methods (Brannick & Levine, 2002), and task analysis (Robertson & Smith, 2001). The concern is on *what* the worker does. The third definition of competence is related to individual inputs. This third definition is about attributes and characteristics of the worker referred to as worker-oriented analysis (Brannick & Levine, 2002) and person specification (Robertson & Smith, 2001). The distinctive strengths of an enterprise are essentially the core competencies discussed earlier.

	Individual	Enterprise
Output	Performance Standards	Benchmarks
Input	Knowledge, Skills, Abilities	Distinctive strengths

Figure 7 Hoffman's typology of competency (Hoffmann, 1999)

Spencer & Spencer (1993) propose a very specific definition of competency:

"A competency is an *underlying characteristic* of an individual that is *causally related* to *criterion-referenced* effective and/or superior performance in a job or situation".

Analysing and elaborating on this definition:

- *Underlying characteristic* refers to a deep and enduring part of a person's personality;
- *Criterion-referenced* indicates that there is a specific measurable criterion against which someone can be assessed as having done well or poorly; and
- *Causally related* means that the competency causes or can predict behaviour and performance.

When comparing this definition to Hoffman's typology for the case of the individual, it would seem that the input competencies are the underlying characteristics or competencies of Spencer and Spencer. Furthermore, the criterion-referenced level of effectiveness is related to Hoffman's output competence. One could conclude that Spencer and Spencer's definition of competency links Hoffmann's input competencies to output competencies (criterion) to achieve "effective and/or superior performance".

Five types of competency characteristics are identified in the Iceberg model, illustrated in Figure 8 (Spencer & Spencer, 1993):

- **Knowledge**: Information a person has in a specific content area which becomes knowledge when used it to respond to questions and situations (Churchman, 1971);
- **Skill**: The ability to perform a physical or mental task;
- **Motives**: Recurrent concern for a goal state or condition which drives, directs and selects the behaviour of a person;
- **Traits**: Physical characteristics and consistent responses to situations or information; and
- **Self-concept**: Person's attitudes, values or self-image.

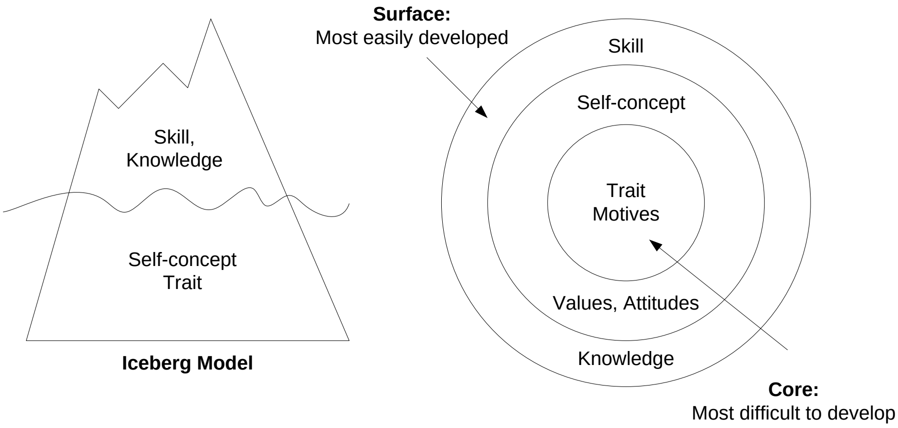


Figure 8 Iceberg model (Spencer & Spencer, 1993)

Skills and knowledge are more easily developed than traits and motives, with values and attitudes somewhere in between. Spencer and Spencer do not elaborate on much on traits, values, motives or self-concept and instead focus on behavioural event interviews. Behavioural event interviews (BEI) are derived from the critical incident technique developed by Flanagan (1954). This technique is based on asking high performers to describe what they did in the most critical situation or task encountered in their jobs. On closer reading, BEI includes probes for personality and cognitive styles (Spencer & Spencer, 1993, p.98). As the authors themselves admit this approach requires time and expense.

Competencies seem to have advantages over job analysis for the problem under consideration:

- They are strategic in nature (Shippmann, et al., 2000); and
- More relevant in the context of education and training (Hoffmann, 1999).

Shippmann *et al.* (2000) identifies a lack of rigour in the type of descriptor content collected as one of the weaknesses of the competence approach. Robertson and Smith (2001) however point out that job analysis, which serves as the rigorous anchor for all subsequent personnel selection processes, has struggled in the last 20 years with jobs that are no longer all that stable.

An additional reason for considering competence, as opposed to performance in the context of this research, is presented in Table 2. Performance is short term while competence underpins performance and has a longer term development flavour. This is important since SE candidates will be developed over a three to five year time period.

Table 2 Contrasting performance vs. competency (Spencer & Spencer, 1993)

Performance ("Pay for results")	**Competency ("Pay for skill")**
Reward oriented	Development or behaviour change oriented
Short time frame, past, e.g. last six months	Longer time frame, future oriented
"What" of performance	"How" of performance
More quantitative	More qualitative

Finally, it is important to distinguish between *threshold* competencies and *differentiating* competencies in the context of input competencies. Threshold competencies are characteristics that everyone in a job requires to be minimally effective, for instance, numerical skills in an engineering environment. Differentiating competencies are those characteristics that distinguish average performers from top performers.

This discussion has provided a broad framework and definitions of competence. Next, more specific characteristics that are relevant to systems engineers are considered.

2.4 A model of competence

The literature review has thus far given a broad overview of SE and competence. This section synthesises a model of competence that *could* be used to select systems engineers. Three criteria arising from the problem and the nature of an exploratory study are:

- **Relevance** in the context of this problem;
- **Feasibility** of assessment in the context of this exploratory study, e.g. can a characteristic be measured using relatively mature assessments?
- **Stability** of any characteristics of competence that might be measured, over the development period of individual candidate systems engineers, which could span three to five years.

For the purposes of this research, *assessment* is the measurement of psychological constructs, knowledge and skills. Figure 9 presents a model synthesised from the literature of constructs that appear to be important in the assessment of competence in the working context (Hoffmann, 1999), (Foxcroft & Roodt, 2005), (Spencer &

Spencer, 1993), (Megellan Consulting, 2008). The central hypothesis is that the input competencies predict the development of SE (output) competencies. The input competencies are determined by knowledge and skill and psychological characteristics (identified in Figure 9). For some occupations, competence also depends on physical ability as well - for instance, certain psycho-motor skills would be required of a sportsman. In SE, however, there does not seem to be any specific or special physical abilities required and therefore this construct has not been included in the model.

In the context of screening for selection one cannot expect that a candidate systems engineer would have knowledge and skill by definition. These are thus eliminated from use for candidate systems engineers. Psychological attributes are thus the most important in the context of this problem.

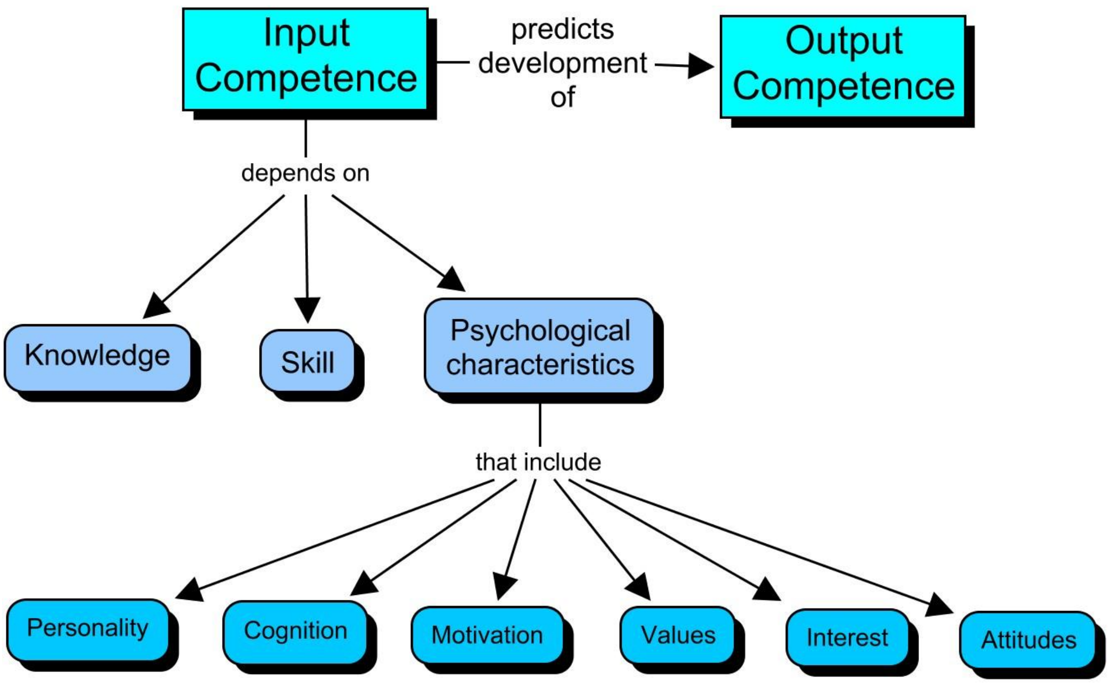


Figure 9 Model of Competence (synthesised from (Hoffmann, 1999), (Spencer & Spencer, 1993), (Foxcroft & Roodt, 2005), (Megellan Consulting, 2008))

Cognition is the leading indicator of training success in a training and development context as assessed by a meta-analysis of selection methods (Robertson & Smith, 2001). It will receive further attention on these grounds.

While Spencer and Spencer referred to traits, **personality** has been used in the model as a broader category. According to McAdams (1994) personality is understood on three levels:

- Personality **traits** as stable characteristics;
- **Personal concerns** which include motivational constructs and values; and
- A person's **identity** as a detailed and nuanced description of a specific person (relevant to adults).

The focus of this research will be on traits based on stability. The notion of personal concerns overlaps with a number of other constructs in the model, such as values. Identity is too specific however to be relevant in this study.

Personality traits can be important predictors of career choice and job satisfaction (Foxcroft & Roodt, 2005), "it is generally accepted that certain personality types fit better into certain types of jobs" (Marais, 2004, p. 1). Various psychological assessments exist that can be used to identify personality traits, and that link these traits to personnel selection, job performance, and job satisfaction.

Values provide general guidelines for behaviour. For the purposes of this research, the following definition for values (Haralambos & Holborn, 2004) is used: "a belief that something is good and desirable. It defines what is important, worthwhile and worth striving for." Values are what one *ought to do* whereas personality traits are what one *naturally tends to do* (Parks & Guay, 2009).

Fishbein and Ajzen, in a study in 1975 (cited in Pratkanis et al., 1989, p. 405) defined **attitudes** as: "... a learned predisposition to respond in a consistently favourable or unfavourable manner with respect to a given object". A more simplistic definition of attitudes was given by Petty and Cacioppo in 1981 (cited in Pratkanis et al., 1989, p.408): "a general and enduring positive or negative feeling about some person, object or issue".

In terms of values and attitudes (Figure 9), *values are of most interest because these are more stable over time* (George & Jones, 1997): "work attitudes, as knowledge structures, should exhibit a certain degree of stability, but not as much stability as values because one of the functions of attitudes is to help the individual adjust to changing conditions over time and stay attuned to the social context".

Work in **interests** has focused on vocational interests (in the context of career counselling) (Foxcroft & Roodt, 2005, p. 252-4 and Ackerman & Heggestad, 1997), but this is too broad for the purposes of this research and therefore not relevant.

Ackerman & Heggestad (1997) do however identify relationships between interests, personality, and intelligence. Other research on interests indicates that it has three components: a stable pattern of cognitive appraisals, a subjective quality, and an adaptive function (Silvia, 2008). Two specific appraisals that cause interest are novelty-complexity and, less obvious, comprehensibility. The latter involves considering whether people have the skills, knowledge and resources to deal with an event or situation. Thus if people appraise an event as new and comprehensible, then they will find it interesting according to Silvia. Interest connects to openness of experience, a trait which relates to curiosity and creativity. The function of interest is to motivate learning and exploration. However, relevant interest assessments were not found.

Barbuto and Richard (1998) have developed a taxonomy of the sources of work **motivation** which includes the following:

- **Intrinsic process motivation** – behaviour is driven by the sheer fun of it;
- **Instrumental motivation** – behaviour is driven by extrinsic tangible outcomes, e.g. pay and promotions;
- **External self-concept based motivation** – behaviour is driven by other people (inter-personal motivation) and seeking affirmation of traits, values and competencies. Includes basic needs such as affection and belonging;
- **Internal self-concept based motivation –** internally based motivation, driven by internal standards of traits, values, and competencies; and
- **Goal internalisation motivation –** Individuals adopt attitudes and behaviours because the content is congruent with their personal value systems.

Based on this taxonomy, a motivation sources inventory has been developed by Barbuto and Richard (1998). It identifies the extent to which an individual is driven by each of these sources of motivation. In the context of this research this taxonomy is useful in understanding how to motivate engineers but not directly useful in assessing motivation to develop as a SE.

Latham and Pinder, in a review of work motivation theory and research, present a framework for motivation that includes traits, values, cognition and affect/emotion (Latham & Pinder, 2005). However, traits, values and cognition are already included in the model of Figure 9. Thus motivation is related to personality, cognition and values. Affect or emotion, as an aspect of motivation, is not likely to be stable over the development period and is not considered. Latham and Pinder's framework includes three other aspects that are outside the scope of the model (Latham & Pinder, 2005): needs, context (e.g. national culture) and organisational justice.

In *summary,* based on the preceding discussion, only (i) **personality**, (ii) **cognition** and (iii) **values** will be considered in the remainder of this research. This does not mean that other characteristics should be excluded from future consideration. It is possible that personality, cognition and values are not the only predictors of, or may not fully predict the development of SE competence. Candidate interest in SE is important and in the case of marginal candidates, a strong interest in SE would allow these candidates to qualify for SE development. Apart from the psychological dimension (comprised of the psychological characteristics identified in the model), there is also a SE dimension, which relates to the performance of SE competencies. The psychological and SE dimensions are used to formulate the research question in Chapter 3.

The assessment of personality and cognition has been used to define the characteristics of a systems engineer as will be seen from the literature discussed in the following section.

2.5 Current methods and measures for assessing Systems Engineers

This section reviews literature regarding *current* methods and measures used to assess systems engineers. The competence model in the previous section showed *what could be* considered. In the context of systems engineers, the focus in the literature has been on the assessment of personality and cognition (input competencies). A summary of psychological attributes derived from the literature is presented. Related fields, such as software engineering, have been included in the review because software is a type of system and assessment of software engineers has received more attention than assessment of SE engineers. Following this, SE competencies (output competencies) are considered and how these can be assessed.

2.5.1 Personality

An array of psychological assessment measures has been used to measure **personality characteristics and traits** in SE. Previous studies have used the Myers-Briggs Type Indicator (MBTI) to investigate personality types in *Software Engineering*, a related field to SE (Capretz, 2003). It must therefore be kept in mind that the results of these studies cannot be directly applied to SE (and there is no attempt to do so) – although these studies provide useful insight on personality in the field of Engineering.

The MBTI assessment used in these studies is both extremely popular and widely used in South-Africa, and is often used to link personality characteristics to personnel selection. The MBTI is based on Carl Jung's theory on personality types (Foxcroft & Roodt, 2005). It measures four dimensions of personality, using four bipolar scales, namely Extroversion-Introversion (E-I), Thinking-Feeling (T-F), Sensing-Intuition (S-N), and Judgment-Perception (J-P) (Foxcroft & Roodt, 2005).

A high score on Extroversion means that the person tends to seek information and interaction from others or from their outside world, whereas a high score on Introversion means that the person tends to reflect on concepts and ideas inside their inner world of thoughts. A person that scores highly on Thinking tends to be more analytical and impersonal, whereas a person that scores highly on Feeling tends to be more subjective and emotional. Individuals scoring high on Sensing are more practical in nature and prefer to rely on their senses, whereas a high score on Intuition means that the person is more open-minded in nature and tends to rely on ideas. A high score on Judgment means that the individual is more organized and prefers to stay on a direct path to a goal, (Capretz, 2003), whereas a person scoring high on Perception is more adaptable and spontaneous. Combinations of these dimensions constitute 16 different personality types (for example ESFJ).

The results of most of the studies concluded that the most common type of software engineer was ISTJ (Bush, 1985; Buie, 1988; Lyons, 1985; Smith, 1989, cited in Capretz, 2003). In other words, this type of personality would score high on Introversion, Sensing, Thinking, and Judgement. This person could thus be expected to prefer working alone, and to be very practical and analytical, strategic and organized.

Unfortunately, there were certain problems with this these studies' findings. In the Bush study in 1985 (cited in Capretz, 2003), only company professionals involved with scientific programming were tested. The problem, however, is that software engineering entails more than just programming. Also, most of these studies were conducted in the late 1980's, where computer work could mostly have been seen as applying mathematical concepts practically (Capretz, 2003). Thus, it would be easy to relate an introverted, practical, analytical and organized individual to this environment. In modern day society, however, software encompasses a wider variety of every-day aspects of life, for example shopping, security, communication (like blogging websites and Facebook), advertisement, sales, finance, administration and games (Capretz, 2003), to name but a few. Thus, it could be concluded that in modern day society, software engineers can have a wide array of personality types – where one type of software engineer is involved in applying mathematical concepts (in programming, for example), another could be more involved in interacting with users (in gaming, for example), thus requiring more extroverted personality characteristics.

Capretz (2003) made use of a more representative sample which comprised software engineers who worked or studied in different environments. Interestingly, the results of this study also showed more ISTJ types. However, the sample consisted of 80% male and 20% female participants. This is a problem, because, as the author himself put it: “But it is in the thinking/feeling dimension that the gap really widens; part of this concentration may be accounted for by the disproportionate presence of men in software engineering…” (Capretz, 2003, p. 211).

Based on this bias, one could therefore ask: Is the overwhelming presence of thinking types a software engineer personality characteristic, or a male personality characteristic? Are there more Thinking type men in software engineering because these are the types of personalities attracted to the career, or is there an existing bias by recruiting only Thinking types (which happened to be predominantly males)?

A common view is that females more commonly fall into the realm of the Feeling dimension, whereas men more commonly fall into the realm of the Thinking dimension – “Stereotypes about personality and gender turn out to be fairly accurate: on both Myers–Briggs thinking–feeling […], there are large male–female gaps in the expected directions […] the thinking–feeling breakdown is about 30/70 for women versus 60/40 for men. Given these differences in preferences, one would expect some fields—such as teaching and nursing—to be predominantly female and other fields—like science and engineering—to be predominantly male, even in the absence of any discrimination whatever.” (Caplan, 2003, p. 400). An article by Williams et al. (1995) also states: “Meyers and McCaulley (1985) indicated that gender may sometimes be predictive of preferences on the MBTI (for example, male subjects show a moderate preference for T and female subjects for F on the Thinking-Feeling Scale” (Williams et al., 1995, p. 496).

All of these findings relate to the fact that SE is conducted by predominantly white males (Marais, 2004). It is hard to say whether this indicates that there is discrimination in recruiting software engineers (by recruiting mostly T-type males), or whether the types of personalities attracted to the career simply happen to be predominantly T-type males. Although more research is needed on this topic, this problem is outside of the scope of this research.

When considering the abovementioned problem, however, one should exercise care when recruiting female engineers with the idea of screening them for potential SE characteristics with the MBTI - one should keep the gender distribution on the Thinking/Feeling scale in mind. A potential female systems engineer should not be ruled out simply because she scored high on the Feeling dimension – this does not necessarily imply that her personality is not suited to SE as SE has many facets.

In a different study conducted by Kobori (1991), an attempt was made to design an aptitude test for software engineers in Japan. They made use of four inspection results: Intelligence, personality, leadership, and interest. In their study, they differentiated between programmers, systems engineers, and system analysts. Their results provided a list of suitable properties for the different categories of software engineers and concluded that the suitable properties for the system engineer are the following (Kobori, 1991, p. 205):

- “Positive, active and full of motivation”;
- “Urge others to work harder”; and
- “Regardless of his interest in any specific work, strongly aspire for leadership or management, and venture in a new work.”

The problem with this list of attributes is that it is overly generic – it can easily be applied to almost any kind of working environment. Another problem is that none of the tests used in their study have been standardized for use in South Africa.

A psychological assessment measure that has also been used to assess personality types of systems engineers is the Situation Specific Evaluation Expert (SPEEX) system. Marais (2004) made use of this system, in combination with the OPQ32 (Occupational Personality Questionnaire) in his research, to develop a proposed model of SE attributes. The results showed a list of attributes, rated from most important, to third most important. The attributes identified were as follows (Marais, 2004, p. 5):

- “MOST IMPORTANT- Conceptualization, the capability to understand the whole without understanding all the details, big picture thinking, technical leadership, structured thinking and working, problem solving.”;

- “SECOND MOST IMPORTANT - innovative, creative, verbal & written English skills, analytical thinking, and intelligence, comfortable with ambiguity and uncertainty, technical insight.”; and
- “THIRD MOST IMPORTANT: negotiation, persuasiveness, willingness to speak his/her mind, asking challenging questions, evaluative, detail orientated, hard working/dedicated, rational.”

The findings showed that “the correlation between high SPEEX marks and job success was high” (Marais, 2004, p. 4). His research thus provided an insightful look into important common attributes of systems engineers. However, his research paper did not show how “job success” was evaluated. Also, his article did not provide insight into how these attributes can be related and applied to SE competencies.

Structured methods of personality measurement are not the only ways that SE’s have been assessed in the past. In a study by Toshima (1993), an open-ended interview was used to assess a systems engineer’s intellectual ability, as well as their personality traits. Their results did show that intelligence and personality characteristics influence job performance. The personality traits identified were as follows:

“social acceptability, dynamism, achievement motivation, tolerance of ambiguity, activity: intro-extro-version, creativity, emotional stability, innovative spirit, flexibility, patience and perseverance, intellectual curiosity, rational thinking, strategic thinking, responsibility, sociability.” (Toshima, 1993, p. 185).

A limitation of the study is that the relationship between relevant SE personality characteristics and SE work-related activities and competencies was not shown (much like the research done by Marais).

2.5.2 Cognition

In a very insightful study on engineers with a “high capacity for engineering systems thinking” (referred to as CEST) (Frank, 2006, p. 91), a description of the “knowledge, abilities, cognitive characteristics and behavioural competencies” (Frank, 2006, p. 91) of systems engineers is provided. In this article, CEST is defined as “the ability to see the whole picture and all relevant aspects without getting stuck on details, to be able to identify the system’s emergent properties, capabilities, behaviours and functions, without looking inside the system and its parts/components/details” (Frank, 2006, p. 92). Three different studies (which are all interrelated) on this topic are evaluated in this article and the results are summarized and synthesised into a table of *General*

Cognitive Characteristics of Engineers with high CEST, in descending order (Table 3).

Table 3 General Cognitive Characteristics of Engineers with high CEST (Frank, 2006)

Rank	Cognitive Characteristic
1.	Understanding the whole system and seeing the big picture
2.	Understanding inter-connections; closed-loop thinking
3.	Understanding systems synergy
4.	Understanding the system from multiple perspectives
5.	Thinking creatively
6.	Understanding systems without getting stuck on details; tolerance for ambiguity and uncertainty
7.	Understanding the implications of proposed change
8.	Understanding a new system/concept immediately upon presentation
9.	Understanding analogies and parallelism between systems
10.	Understanding limits to growth

It is firstly necessary to explain the abovementioned studies in more detail to understand the results of Frank's 2006 study. In the first study done by Frank (2002), the researchers employed a qualitative-naturalistic inquiry paradigm (interviews and observations) to identify "characteristics of engineering systems thinking" (Frank, 2002). Using these characteristics, a 3-D model was produced that was used to develop a curriculum that could improve/develop engineers' CEST, early in engineering education. In the second study, done by Frank and Elata (2005), an in-depth description was provided on how the abovementioned curriculum was used to develop a project-based-learning course – "Creative Introduction into Mechanical Engineering" (Frank and Elata, 2005, p. 188). This course was applied to engineering students and from the results it was made clear that an assessment measure is needed and is being worked on to assess CEST. The CEST test had to involve the following components: "a knowledge and skills test; personality inventory; aptitude test; and attitude questionnaire" (Frank & Elata, 2005, p. 194) – in other words, a more quantitative approach. The importance of this assessment measure, as described by the author himself, is the following: “This test could then be used for selection, filtering, screening, placement and classification of candidates” (Frank, 2006, p. 92).

The most recent study (done by Frank and colleagues), follows up on the previous studies, and provides a description of this quantitative CEST tool (Frank, et al., 2007). In the author’s words, this interest inventory can be used to: “identify potentially successful systems engineers” (Frank et al., 2007, p. 39).

It appears that this assessment tool would be a valid and reliable way of quantitatively assessing CEST. A problem, however, is that this measure has not been standardized for use in South-Africa, and it is not available in English as of yet, but in Hebrew. Furthermore, as the CEST tool was developed specifically for Systems Engineers, it would appear to measure abilities as opposed to preferences.

The main problem, however, is that this tool appears to be limited in scope as it only assesses Systems Thinking. Other cognition identified in the literature will therefore not be measured by the CEST tool, for example logical and analytical thinking, etc (listed in section 2.6). For these reasons, the CEST tool does not appear to be suitable or mature enough to be included in this study.

2.5.3 SE Competencies

The INCOSE UK Advisory Board (UKAB) identified the inability of individuals and enterprises to identify the competencies that are required to conduct good SE (INCOSE UK 2006). In addition individuals did not have a clear career path to become a systems engineer, according to the UKAB. As a result of a collaboration of four large defence and aerospace companies, the UK Ministry of Defence and two universities, they developed the *Systems Engineering Competencies Framework*, (INCOSE UK 2006). However, having been developed by defence and aerospace organisations, there is a possibility of a bias when used in other industries. The framework identifies 21 competencies categorised into three categories: systems thinking, holistic lifecycle view and systems engineering management (Table 4).

Table 4 Systems Engineering Competencies Framework

(INCOSE UK, 2006)

Category	Competency	Description
Systems Thinking	System Concepts	The application of the fundamental concepts of systems thinking to systems engineering. These include understanding what a system is, its context within its environment, its boundaries and interfaces and that it has a lifecycle.
	Super System Capability Issues	An appreciation of the role the system plays in the super-system of which it is a part.
	Enterprise & Technology Environment	The definition, development and production of systems within an enterprise and technological environment.
Holistic Lifecycle View	Determining and Managing Stakeholder Requirements	To analyse the stakeholder needs and expectations to establish and manage the requirements for a system.
	Systems Design – Architectural Design	The definition of the system architecture and derived requirements to produce a solution that can be implemented to enable a balanced and optimum result that considers all stakeholder requirements.
	Systems Design – Concept Generation	The generation of potential system solutions that meet a set of needs and demonstration that one or more credible, feasible solutions exist.
	Systems Design – Design for…	Ensuring that the requirements of later lifecycle stages are addressed at the correct point in the system design. During the design process consideration should be given to manufacturability, testability, reliability, maintainability, safety, security, flexibility, interoperability, capability growth, disposal, etc.
	Systems Design – Functional Analysis	Analysis is used to determine which functions are required by the system to meet the requirements. It transforms the requirements into a coherent description of system functions and their interfaces that can be used to guide the design activity that follows. It consists of the decomposition of higher-level functions to lower-levels and the traceable allocation of requirements to those functions.

	Systems Design – Interface Management	Interfaces occur where system elements interact, for example human, mechanical, electrical, thermal, data, etc. Interface Management comprises the identification, definition and control of interactions across system or system element boundaries.
	Systems Design - Maintain Design Integrity	Ensuring that the overall coherence and cohesion of the evolving design of a system is maintained, in a verifiable manner, throughout the lifecycle, and retains the original intent.
	Systems Design – Modelling & Simulation	Modelling is a physical, mathematical, or logical representation of a system entity, phenomenon, or process. Simulation is the implementation of a model over time. A simulation brings a model to life and shows how a particular object or phenomenon will behave.
	Systems Design – Select Preferred Solution	A preferred solution will exist at every level within the system and is selected by a formal decision making process.
	System Design: System Robustness	A robust system is tolerant of misuse, out of spec scenarios, component failure, environmental stress and evolving needs.
	System Integration & Verification	Systems Integration is a logical process for assembling the system. Systems Verification is the checking of a system against its design - "did we build the system right?". Systems integration and verification includes testing of all interfaces, data flows, control mechanisms, performance and behaviour of the system against the system requirements; and qualification against the super-system environment (e.g. Electro Magnetic Compatibility, thermal, vibration, humidity, fungus growth, etc).
	Validation	Validation checks that the operational capability of the system meets the needs of the customer/end user - Did we build the right system?
	Transition To Operation	Transition to Operation is the integration of the system into its super-system. This includes provision of support activities for example, site preparation, training, logistics, etc.

Systems Engineering Management	Concurrent Engineering	Managing concurrent lifecycle activities and the parallel development of system elements.
	Enterprise Integration	Enterprises can be viewed as systems in their own right in which systems engineering is only one element. System Engineering is only one of many activities that must occur in order to bring about a successful system development that meets the needs of its stakeholders. Systems engineering management must support other functions such as Quality Assurance, Marketing, Sales, and Configuration Management, and manage the interfaces with them.
	Integration of Specialities	Coherent integration of specialities into the project at the right time. Specialities include Reliability, Maintainability, Testability, Integrated Logistics Support, Producability, Electro Magnetic Compatibility, Human Factors and Safety.
	Lifecycle Process Definition	Lifecycle Process Definition establishes lifecycle phases and their relationships depending on the scope of the project, super-system characteristics, stakeholder requirements and the level of risk. Different system elements may have different lifecycles.
	Planning, Monitoring & Controlling	Establishes and maintains a systems engineering plan (e.g. Systems Engineering Management Plan) which incorporates tailoring of generic processes. The identification, assessment, analysis and control of systems engineering risks. Monitoring and control of progress.

Systems Thinking contains the underpinning systems concepts and the system/super-system skills including the enterprise and technology environment. *Holistic Lifecycle View* contains all the skills associated with the system lifecycle - from need identification and requirements through to operation and ultimately disposal. *Systems Engineering Management* deals with the skills of choosing the appropriate lifecycle and the planning, monitoring and control of the systems engineering process (INCOSE UK 2006).

From this framework, employers can identify the required systems engineering competencies that are needed in a specific working context, for both individuals, and teams. There are 4 levels defined by the framework (INCOSE UK, 2006), namely:

1. **Awareness -** Able to understand the key issues and their implications. They are able to ask relevant and constructive questions on the subject. This level

is aimed at enterprise roles that interface with SE and therefore require an understanding of the SE role within the enterprise;

2. **Supervised Practitioner** - The person displays an understanding of the subject but requires guidance and supervision. This level defines those engineers who are "in-training" or are inexperienced in that particular competency;

3. **Practitioner** - The person displays detailed knowledge of the subject and is capable of providing guidance and advice to others; and

4. **Expert** - The person displays extensive and substantial practical experience and applied knowledge of the subject.

For brevity, practitioner and expert levels will jointly be referred to as high competence. There are 21 competency tables in the framework, each providing a description of the competency, why it matters, and a number of indicators for each of the four levels.

2.6 Conclusions

This section summarises the SE personality and cognitive characteristics, from the literature, that are important in selecting assessment measures. Finally, a synthesis of the main gaps in the SE assessment literature is presented.

SE personality preferences include:

- Creative (Marais, 2004) (Toshima, 1993);
- Sociable, good communicator (Toshima, 1993);
- Intelligent – intellectual curiosity (Marais, 2004) (Toshima, 1993);
- Forward (willing to ask challenging questions, speak mind) (Marais, 2004);
- Ambitious – hardworking, dedicated, persevering (Marais, 2004) (Toshima, 1993);
- Innovative (Marais, 2004) (Toshima, 1993);
- Flexible and adaptable – comfortable with ambiguity (Marais, 2004) (Toshima 1993);
- Self-motivated (achievement motivation), able to motivate others (Marais, 2004) (Toshima, 1993) (Kobori, 1991);

- Leadership skills – assertiveness, coordination skills (Kobori, 1991) (Marais, 2004);
- Persuasive (Marais, 2004);
- Patient (Toshima 1993);
- Rational (Marais, 2004) (Toshima 1993);
- Responsible (Toshima 1993) (Bush, 1985) (Capretz, 2003);
- Organized (Bush, 1985) (Capretz, 2003);
- Confident (Marais, 2004); and
- Assertive (Marais, 2004).

Cognitive characteristics that are important for SE include:

- Big picture thinking (understanding the whole without getting stuck on details) (Marais, 2004) (Frank, 2006);
- Systems thinking (understand relations between parts of a system) (Frank, 2006);
- Creative (Marais, 2004) (Toshima, 1993) (Frank, 2006);
- Tolerance for ambiguity (Marais, 2004) (Toshima 1993) (Frank, 2006);
- Concept generation (Marais, 2004);
- Innovative (Marais, 2004) (Toshima, 1993);
- Strategic (Marais, 2004) (Toshima, 1993);
- Analytical (Marais, 2004); and
- Logical (Bush, 1985) (Capretz, 2003).

It can thus be seen that the literature identifies personality and cognitive characteristics of systems engineers, but offers no ready solution for assessing potential systems engineers. Linking these characteristics (input competencies) required by systems engineers to output or SE competencies, as depicted by the model in section 2.4, to the INCOSE UK framework has not been attempted. Furthermore, *it appears that values of systems engineers have not been assessed.*

Attitudes have also not been assessed in the context of SE, perhaps because there are some challenges in assessing these in a SE context. It is discussed in Frank's 2005 article, but not assessed. Here, he acknowledges that a future test battery for assessing CEST should include not only a skills and knowledge test, aptitude test, and personality test, but an *attitude questionnaire* as well. However, in his 2007 article, the focus of the CEST questionnaire remains on knowledge, skills, roles, cognitive abilities, characteristics, and behavioural competencies. However, he does highlight the importance of assessing *interest*, but it is not clear from the 2007 article how interest is measured via the CEST tool. There does not appear to be any existing literature that assesses motivational constructs in-depth in systems engineers.

Considering the results of all the abovementioned studies, the knowledge gaps and limitations are as follows:

- The identification of *relevant* and *specific* SE psychological characteristics beyond personality and cognitive constructs;
- No identified quantitative interrelation between psychological characteristics, and SE competencies;
- The identification of common SE personality characteristics across race, age and gender; and
- Few assessment measures that have been adapted for use in South-Africa.

Thus, the psychological constructs, identified in Figure 9, could predict the level of competence in all 21 of the competencies measured by the *Systems Engineering Competencies Framework*, (INCOSE UK 2006). On the basis of the literature presented, the research question can be formulated.

Chapter 3 Defining the research question

In this very concise chapter, the formulation of the practical problem of selecting candidate systems engineers for training is formalised as a research question based on the literature review. The definition of the research question is sufficiently important to warrant a dedicated section.

The psychological and SE dimensions are illustrated conceptually in Figure 10. In the language of psychological assessment, the psychological dimension is the predictor and the SE dimension is the criterion. Based on the literature, important characteristics of the psychological dimension are personality, cognition and values, measured by the various psychological assessment measures which will be discussed in section 4.3. The SE dimension is defined in terms of 21 SE competencies, that are measured via the *Systems Engineering Competencies Framework*, (INCOSE UK 2006 as discussed in section 2.5.3). Where previous research, discussed in section 2.5, looked at systems engineering as an amorphous whole, considering SE in terms of the 21 competencies is a novel aspect of this research. The general research question can then be formulated as:

Can the successful development of SE competencies be predicted from personality preferences, cognition and values?

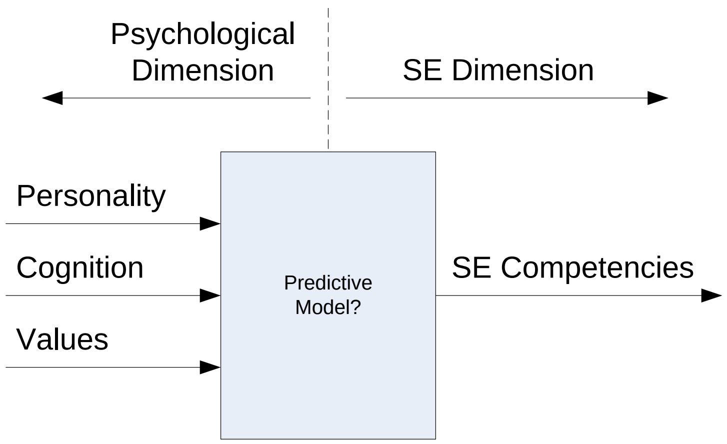


Figure 10 Predicting the development of SE competencies from psychological attributes.

The research question as it is phrased would require a SE training programme and the development of candidate systems engineers using the training programme, a process that would take several years. To overcome this issue, a practical hypothesis, $\mathbf{H_1}$, is derived from the research question:

$\mathbf{H_1}$: *A candidate's SE competence potential can be predicted from personality preferences, cognition, and values (the SE profile).*

The hypothesis $\mathbf{H_1}$ can be validated practically using concurrent cross-validation (Spencer & Spencer, 1993) *for each SE competency*, i.e. 21 hypotheses must be tested.

One of the practical consequences of answering the research question and an important objective of this research is the development of a selection method for candidate systems engineers (as discussed in section 1.3). During the development of a selection method, the level of SE competence is known from an assessment on the SE competencies framework, but when the selection method is used to select candidate systems engineers the level of SE competence is not known. The objective is not to develop a new psychological assessment, but to identify existing assessments which can predict development performance on SE competencies. Given this framework, the corollary from the basic research question is:

What are relevant and sensitive assessment measures of personality preference, cognition and values that could be used to select potential systems engineers?

With regards to the limitations identified from the literature in Chapter 2, linking personality preferences, cognition and values (the psychological dimension) with the 21 competencies on the *Systems Engineering Competencies Framework* would be an important contribution to the SE discipline. The link between the psychological attributes that have been identified in the literature, and the 21 SE competencies, has thus far not been made, to the researcher's knowledge.

Chapter 4 Research Methodology

4.1 Introduction

The research design section considers the methodological framework for the research and the design of the population and sample. A single cycle of *design science research is used as the methodology* with the objective of developing a selection method. The population and sample are selected based on how the selection method will be used and ethical considerations. The requirements on the research instruments for assessing personality preferences, cognition, values, and SE competencies and the choice of these instruments are discussed in section 4.3.

Section 4.4 elaborates on the methodology for the development of a selection method for candidate systems engineers. The approach to identifying SE potential is to consider what psychological measures high competence engineers have in common. An engineer has potential on a certain SE competence based on similarity to what high competence engineers in that specific competence have in common. Section 4.5 discusses evaluation of the selection method based on concurrent cross-validation *for each SE competency*, i.e. 21 hypotheses are tested. Constraints on the research, arising from ethical and regulatory requirements that shaped the detailed design of the research methodology are covered in section 4.6.

4.2 Research design

4.2.1 Methodological framework

Chapter 1 framed the problem of selecting candidate systems engineers. In order to solve this problem, design science research (DSR) is used as a methodological framework or lens for this research (Vaishnavi & Kuechler, 2004). The primary output of DSR in the context of this research is a practical method for selecting candidate systems engineers. This section provides general background on DSR and its specific application to this research.

In general, design is "to do or plan something with a specific purpose in mind" (Concise Oxford English Dictionary, 2006). DSR is research using design as a research method (Vaishnavi & Kuechler, 2004). The fundamental principle of design research is that "knowledge and understanding of a design problem and its solution are acquired in the building and application of an artefact" (Hevner et al. 2004, p. 82). The general DSR methodology (Vaishnavi & Kuechler, 2004) is illustrated in Figure 11.

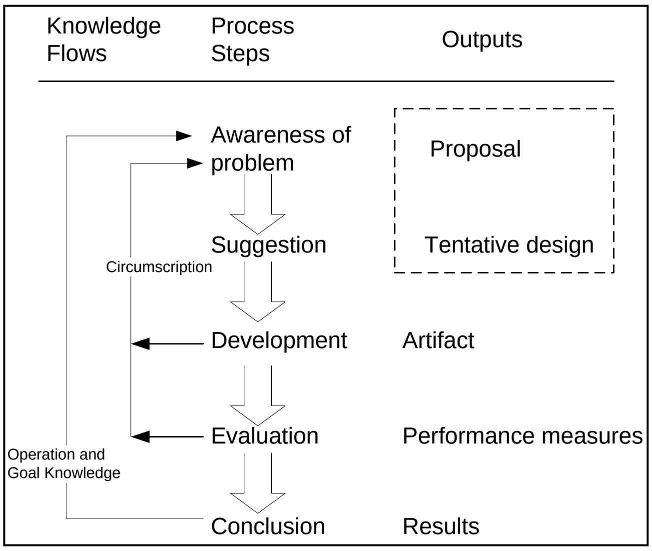


Figure 11 The general DSR methodology (Vaishnavi & Kuechler, 2004).

The process is initiated by an awareness of the problem which, in this case, arises from a human resource problem - the selection of candidate systems engineers. This is followed by an initial suggestion of a solution or design (a first iteration in other words). In this case the tentative concept for selecting candidate systems engineers for development was based on literature (sections 2.4 and 2.5). For this research the development process step indicated in Figure 11 involves:

- An empirical approach: collecting data on personality preferences, cognition, values, and SE competencies based on the tentative concept (section 4.4.1); and
- The development of an algorithm for identifying potential (section 4.4.2).

Circumspection involves re-evaluating the problem, the suggestion, or both once some design has been performed, based on new insight. In practical terms this means going down a dead end - an example of which is provided in the side note "*A discriminant function approach considered*" in section 4.4.2. The design was reformulated through several circumspection iterations to arrive at a selection method which could be evaluated given the sample size constraints. This iterative process defines an important exploratory methodology that leads to new knowledge and research questions - this is the nature of directed research.

Evaluation in design research has a different perspective to validation in positivist research (Vaishnavi & Kuechler, 2004). While in positivist research, the hypothesis is either accepted or rejected, in design science research there is “good enough” (sufficient) evidence that the hypothesis is valid (presented in section 4.5). A sufficient hypothesis may, of course, include a number of assumptions and constraints. Information, insight and shortcomings of the development are fed back as a new “suggestion” for further improvement.

The conclusions are presented in Chapter 6 along with the anomalies and deviations which are the basis for future iterations of the design science methodology. Thus, this thesis covers all the process steps for a single but complete iteration of the DSR methodology. The research is structured in an iterative manner to reduce risk relating to the following: (i) the multidisciplinary nature of the research; (ii) the unknown distribution of competence over the 21 SE competencies; and (iii) the ability to build a model between input and output competencies.

The possible outputs of development, or artefacts, that can be obtained from a DSR effort are summarised in Table 5.

Table 5 The possible outputs of DSR (based on (Vaishnavi & Kuechler, 2004)).

Item	Output	Description
1	Constructs	The conceptual vocabulary of a domain
2	Models	A set of propositions or statements expressing relationships between constructs
3	Methods	A set of steps used to perform a task – how-to knowledge
4	Instantiations	The operationalisation of constructs, models and methods.
5	Better theories	Artefact construction as analogous to experimental natural science, coupled with reflection and abstraction.

In the context of this thesis the *constructs are an input* based on existing psychological assessments and the SE competence framework (INCOSE UK, 2006). One of the objectives is to *build models* between the psychological constructs and the various SE competencies. Since SE is not a homogeneous competency, it is being investigated in terms of sub-competencies. The *method* in this context is the selection method including the potential identification algorithm developed for this use. An *instantiation* would involve using the selection method to screen candidate systems engineers in DPSS. Instantiation would require candidate systems engineers to go through development, a process which will not take less than three years to complete. This work makes a limited contribution in terms of theories – that would require additional iterations of the DSR methodology. Thus an iteration of the general DSR methodology does not necessarily produce *all* possible DSR outputs.

The following section defines the population and sample issues for data collection.

4.2.2 Population and sample design

The research design considers the following issues, listed below (Welman, et al., 2005):

1. The population and unit of analysis; and
2. The sample and the sampling method.

It is important to select the sample correctly since it is only when the sample is representative that the results can be generalised. Without this, the validity of the results is compromised. However, drawing the sample is subject to ethical constraints since no one can be coerced to participate.

The population consists of engineers from DPSS typical of a population from which candidate systems engineers would be selected for development. The population encompasses *all* the *units of analysis which in this study is the individual engineer.* This population would meet the following requirements:

1. A bachelors degree in engineering (or similar degree in computer science or physics) – this was the minimum requirement for an engineer;
2. At least three years experience for a minimum level of project and organisational process and systems experience (Gonçalves, 2010). An amount of three years experience is somewhat arbitrary. Five years was considered, but this would reduce the pool of candidate systems engineers; and
3. Various gender and race groups and various ages.

Engineers include systems engineers (defined precisely in section 2.1.1) and other engineers as two mutually exclusive subsets (Figure 12). The selection method design is based on first identifying SE competence, i.e. it is criterion referenced. This is what McCleland (1973) calls criterion sampling. A number of “other engineers” or non-systems engineers will also have an SE profile. It is this group which is intended for development.

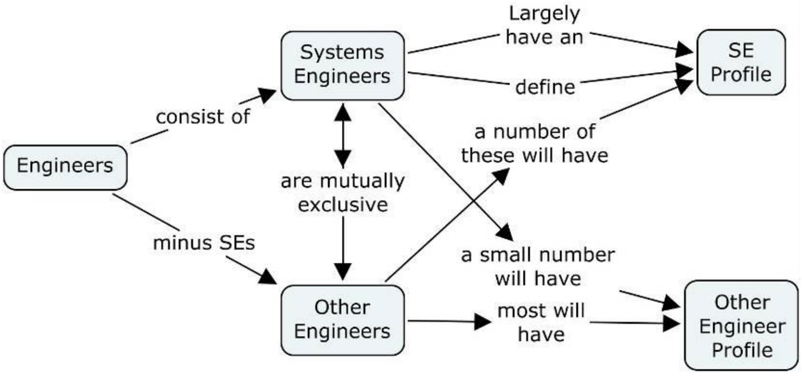


Figure 12 Definition of terminology

A DPSS staff list was obtained, which contained 337 names. Of those, N=136 candidates met the minimum population requirements (the sample frame) listed above.

Because of ethical considerations, sampling was based on self-sampling (Welman, et al., 2005). All candidates on the sample frame were sent a research brief via e-mail, and were informed that they would soon be approached for a discussion about the research and their possible participation. Candidates were invited using a personal, face-to-face approach that involved a discussion of the research project, the processes, what participation would entail, and the assessments. The candidate could then voluntarily agree to participate in the assessments, or decline.

A typical research approach calculates the sample size taking into account population size and significance level (Krejcie & Morgan, 1970). The *criterion* sample size could not be calculated *a-priori* and was one of the risks of this research. In other words, for each of the 21 SE competencies, the number of engineers at high competence levels was not known. This is in fact one of the SE aspects being investigated.

A broad sample of engineers is required to evaluate whether systems engineers can be identified from “other engineers”. Initially, drawing additional engineers from industry was considered in case there were not enough systems engineers in DPSS for this research. The industry cross-section of systems engineers and other engineers would have been based on *volunteers* who attended the INCOSE SA conference, largely from the *defence* and *nuclear* industries (but not exclusively). It was however decided not to include engineers outside of DPSS, for the following reasons:

- Volunteers could introduce a bias (Whitley, 2002);

- Since SE is industry dependant, it could introduce a confounding variable. For this thesis, this limitation is accepted given the corresponding risk reduction; and
- The required logistics and cost of the study would have made the study impractical.

The *disadvantage* is that the study loses the cross-industry perspective. However, this may be introduced in future studies.

The research instruments for assessing personality preferences, cognition, values and SE Competencies are discussed in the next section.

4.3 Research instruments

The *criteria* for assessment selection are:

- The research question;
- Characteristics of systems engineers as defined in the literature; and
- The context in which the selection is proposed (section 1.2).

Additional requirements and goals based on practical issues that must be considered are:

- The total data collection cost was to be below R2000 per person based on research budget constraints, with a target of less than R1500 per person[2];
- The total assessment time during the research phase should be less than 1.5 hours but should not exceed 2.5h for 90% of assessments on the sample. While there is no time limit on the assessments, if the total assessment time is too long, engineers would not participate in the research. This could impact on statistical significance of the results;
- Face validity of the assessments was important to avoid these being dismissed. Face validity, in this case, is the engineers' perception that important and relevant characteristics of SE are being measured. A goal would be to include assessment in the assessment battery that have high face validity;
- When used for selecting candidates who have aspirations, candidates may offer socially desirable responses. Assessments which identify these responses are preferred. Where this was not possible, the risk of socially desirable responses

[2] Costs based on 2009 Rand.

was mitigated by requesting, in the informed consent form, that participants respond truthfully;

- Since these assessments could be used for other purposes in future, like recruitment, the psychological assessments must have a scientific basis and be registered with the HPCSA. This also means that risk to participants of the study is reduced.

First the definitions of reliability and validity are reviewed as these are important in the selection of the assessments. The rationale for selecting the various assessments of the psychological dimension and the reliability and validity of each assessment are discussed in the following sub-sections. This includes a brief description, the measures (scales) and information regarding reliability and validity and where available, evidence that the assessment is fair and unbiased. Section 4.3.6 links the desired SE personality and cognition characteristics (as identified from the literature in section 2.2) to the measures as rationale for selecting the specific assessments. Practical aspects of the selected assessments are summarised in section 4.3.7.

4.3.1 Reliability and validity

The quality of a psychological measure is typically assessed on two criteria: reliability and validity. Reliability of a measure is the consistency with which it measures (Foxcroft & Roodt, 2005). Suppose that y is the observed value, x the true value and e the error. The observed value can be expressed as $y = x + e$. If the error is independent of true value, then the variance can be expressed as:

$$\sigma_y^2 = \sigma_x^2 + \sigma_e^2$$

Reliability R can be defined as follows (Foxcroft & Roodt, 2005):

$$R = \frac{\sigma_x^2}{\sigma_y^2} = \frac{\sigma_y^2 - \sigma_e^2}{\sigma_y^2}$$

When there is no error, $R = 1$ and when error is all that is observed, $R = 0$. When interpreting reliability, a value of 0.80 to 0.85 is good for assessment of individuals in the context of psychological assessment (Foxcroft & Roodt, 2005). This is because some of the variability in psychological assessment comes from the person and not just the instrument.

The validity of a measure is an assessment of how well it measures for a specific purpose, i.e. how well does it measure what it is supposed to (Foxcroft & Roodt, 2005). There are three main types of validity:

- *Content validity*: Concerned with whether a measure covers a representative sample of the aspect being measured;
- *Face Validity*: Perception that an assessment measures what it should;
- *Criterion validity*: Measure of the quality of the relationship between a predictor (input variables) and the criterion (output variable). There are two ways of determining criterion validity, namely, concurrent and predictive validity. As implied by the names, concurrent is concerned with current (or simultaneous) validity of an assessment while predictive validity is concerned with the validity of a prediction made about the future.

Validity coefficients between 0.20 and 0.30 that are statistically significant at the 0.05 level (or better) are acceptable for selection. It is important to note that the validity of a measure is directly proportional to its reliability (Foxcroft & Roodt, 2005). Thus reliability is a necessary but not a sufficient condition for validity.

Looking at the organisational psychology literature, there are a range of methods used for training selection, listed in Table 6 (Robertson & Smith, 2001). The validity of these methods has been assessed based on a meta-analysis of personnel selection methods (Schmidt & Hunter, 1998). Within this field there has been increasing confidence in the validity of results, with the most successful method being a cognitive ability test with a validity of 0.56. Interestingly, the validity of years of job experience is close to zero. *This literature gives an idea of what is achievable and the range of values that can be expected.*

Table 6 Validity of selection methods for training (Robertson & Smith, 2001)

Training selection method	Validity
Cognitive ability test	0.56
Integrity tests	0.38
Interviews – all types	0.35
Conscientiousness	0.31
Biodata	0.30
References	0.23
Years education	0.20
Interests	0.18
Years Job Experience	0.01

4.3.2 Personality - 15 Factor Questionnaire Plus (15FQ+)

A variety of personality assessments were considered, such as the Myers-Briggs Type Indicator (MBTI), Big Five factors, Occupational Personality Questionnaire (OPQ32) and The Fifteen Factor Questionnaire Plus (15FQ+). MBTI has only four measures or scales and the Big Five has five which is rather broad but not as powerful in predicting and explaining actual behaviour as are the more numerous lower-level traits. Studies have confirmed that in predicting actual behaviour more lower-level traits are more effective (Mershon & Gorsuch, 1988; Paunonon & Ashton, 2001).

The OPQ32 developed for the work context, on the other hand, has 32 measures and seems a good option. However, in the context of a specialised assessment of cognition, the thinking scales of the OPQ32 are superfluous.

The personality preference assessment which was selected was the 15 FQ+ (Psytech, Ltd, 2002). The 15FQ+ has been selected given the criteria, and provides a broad range of scales suitable for an exploratory study.

The 15FQ+ is derived from the 16 Personality Factor Questionnaire (16PF). This questionnaire is based on Raymond Cattell's list of primary personality traits, which he developed through a process of factor-analysis (Foxcroft & Roodt, 2005). The personality factors identified by this questionnaire are bi-polar and interrelated. The 15FQ+ measures 21 factors on *primary scales* and *global scales*, described below (Psytech, Ltd, 2002). Since the 5 global scales are derived from the 16 primary scales, only the **16 primary scales** are used in the analysis. Within the context of an exploratory study, this yields a wealth of information as compared to for example the MBTI which has just four scales.

The 15FQ+ primary scales are listed below (Psytech, Ltd, 2002):

- fA: **Distant-aloof – Empathic**: Cool and distant interpersonal relationships vs. friendly and warm, interested in people;
- fB: **Low Intellectance - High Intellectance**: This scale determines confidence in ones intellectual ability rather than intelligence (revised from the original 16PF scale of Intelligence);
- fC: **Affected by Feelings - Emotionally Stable**: Prone to mood swings, judgement clouded by emotion, anxious vs. emotionally steady and resilient, phlegmatic;
- fE: **Accommodating – Dominant**: co-operative and obliging vs. assertive, competitive and aggressive;

- fF: **Sober Serious – Enthusiastic**: restrained and cautious, avoid actively participating in social events vs. lively, cheerful and attention seeking;
- fC: **Expedient – Conscientious**: spontaneous, disregarding of rules, difficulty with boring and repetitive tasks, taking a broader perspective vs. attention to detail, organised;
- fH: **Retiring - Socially-bold**: timid, socially anxious or shy vs. talkative and socially confident;
- fI: **Hard headed - Tended-minded**: Utilitarian, tough-minded, lacking aesthetic sensitivity vs. sensitive, aesthetically aware and sentimental;
- fL: **Trusting – Suspicious**: Accepting and unsuspecting vs. sceptical, cynical and critical;
- fM: **Concrete – Abstract**: practical, realistic and solution focused vs. imaginative, and focused on concepts and principles;
- fN: **Direct – Restrained**: open, direct and straightforward vs. diplomatic, socially astute and restrained;
- fO: **Confident - Self-doubting**: secure, self-assured, unworried and guilt-free vs. worrying, insecure, apprehensive;
- fQ_1: **Conventional – Radical**: traditional, conservative vs. conforming vs. open to change, unconventional and experimenting;
- fQ_2: **Group Oriented - Self-sufficient**: sociable, group-dependant vs. solitary, self-reliant and individualistic;
- fQ_3: **Informal - Self-disciplined**: lax, follows urges, respect is earned vs. fastidious, maintaining social standing; and
- fQ_4: **Composed - Tense-driven**: relaxed, patient vs. impatient, low frustration tolerance.

The 15FQ+ global scales are:

- **Extraversion:** oriented to people, events, and external activities -**Introversion** oriented to an inner world of thoughts and experiences;
- **Low anxiety:** well adjusted, calm and resilient –
  High anxiety: vulnerable, touchy, sensitive and prone to mood swings;
- **Pragmatism:** influenced by hard facts rather than subjective experiences –
  Openness: influenced by ideas and feelings rather than tangible evidence;
- **Independence:** self-determined in terms of thoughts and actions, confrontational –
  Agreeableness: Obliging and tolerant, Able to compromise; and
- **Low self-Control:** (not influenced by social norms) –

High self-Control: (influenced by social norms).

The reliability for the standard 15FQ+ primary scales is 0.72 or greater for a sample of professionals and managers (Psytech, Ltd, 2002). Construct validity has also been evaluated against a number of existing instruments with the following correlations (only some examples):

- OPQ - correlations between 0.3 and 0.59;
- MBTI – correlations between 0.33 and 0.66; and
- Occupational Interest Profile Plus – correlations between 0.32 and 0.77.

The 15FQ+ does not have any significant gender bias. It would appear that the 15FQ+ is not biased *per se*, but rather the results are affected by verbal reasoning ability (Psytech, Ltd, 2002).

4.3.3 Cognition - Cognitive Process Profile (CPP)

For assessing cognition, the Cognitive Process Profile (CPP) was selected, given the criteria. Intelligence tests were not considered since they are influenced by socio-economic background and have questionable validity in the work context (McClelland, 1973). Other assessments such as Apil-B and LP-CAT were considered. These however draw on the intelligence paradigm and are based on analytical thinking in structured problems (Prinsloo, 2007).

The CPP is described as: "an advanced computerized assessment technique designed to measure thinking processes and styles and to link these to everyday cognitive functioning. Using *simulation exercises*, individuals are monitored on their ability to explore, link, structure, transform, remember, learn, and clarify information." (Megellan Consulting, 2008). The CPP measures and identifies problem solving styles, information processing competencies and levels of work.

4.3.3.1 Problem solving styles

Cognitive styles refer to one's general approach to problem-solving, particularly in unfamiliar situations. During problem-solving, certain styles (or combinations of styles) are used (Megellan Consulting, 2008):

Analytical: Characterised by a detailed, rule-orientated and systematic approach with an emphasis on precision and comparative behaviour.

Explorative: Characterised by an emphasis on the investigation of a problem. The repeated exploration of a problem and repetitive checking behaviour may, however, create unnecessary complexity and have a confusing effect.

Holistic: Associated with the tendency to view a problem situation in its totality and to place an emphasis on the global perspective (wholeness and unity), without losing track of relevant detail.

Impulsive: An impulsive style (being fast and inaccurate) is associated with inadequate pacing and with emphasis on the speed of problem-solving.

Integrative: The tendency to combine, synthesise and structure information as it is encountered in order to makes sense of it.

Intuitive: This approach usually, but not necessarily, involves the careful exploration of a problem and repetitive checking behaviour to meaningfully interpret complex information at a 'gut' level. It may result in the conceptualisation of creative ideas and/or unverified assumptions.

Learning: Usually characterised by an emphasis on memory functions, integration of feedback, understanding, and self-monitoring. This results in improved problem-solving and a flexible approach.

Logical: Characterised by the tendency to look for logical evidence to: verify arguments; follow reasoning processes through in a self-aware and logical way; and manage a high level of complexity by applying a 'process' approach to problem-solving.

Memory: Characterised by the tendency to internalise and automatise information as a problem-solving approach. It can enhance problem-solving performance; however, a memory approach in conjunction with weak strategies for managing complexity may create large memory burdens and have a confusing effect.

Metaphoric: The tendency to view a situation abstractly and symbolically, as well as to combine elements of information in novel ways to formulate analogies and metaphors.

Quick Insight: Characterised by quick insight, effective task and goal orientation, quick processing and integration of information, using effective reasoning and memory strategies.

Random: Usually characterised by a vague and unsystematic, trial-and-error approach to problem-solving. Inadequate task orientation and insufficient goal direction are often present.

Reflective: A reflective style involves the tendency to explore, the careful consideration of information, spontaneous comparative behaviour, the continual integration of new elements into existing information structures and the following through of reasoning processes. Although it is usually associated with a relatively slow approach, pace control does occur.

Structured: Usually characterised by an emphasis on the rules of the task and the careful grouping and ordering of the information. It may reflect a need for precision and structure. This can be a useful technique for managing complexity and supporting memory functions.

4.3.3.2 Information processing competencies – constructs

Exploration construct: The depth and effectiveness shown when investigating data and information to identify, focus on and select the relevant information for further processing. Purposeful search; accurate perception; thorough exploration; focus on relevance.

Linking/analysis: The application of rules – comparing, differentiating, checking and linking – to different elements of information to establish relationships between them. Detailed and precise' systematic; step-by-step approach; focus on rules.

Structuring: The ordering, categorisation and integration of different elements of information into coherent, meaningful units. Interpret and integrate; identify core elements and meanings; focus on coherence and unity.

Transformation: Following arguments through in a disciplined manner to transform the information or arrive at conclusions based on defensible evidence and according to appropriate rules for reasoning. Apply logical rules; disciplined reasoning; following processes through; focus on rational, verifiable conclusions.

Memory: The mental storing and retrieval of information. Memory of background and accumulated knowledge; frame of reference.

Meta-cognition: Being aware of and clear about the way you monitor, evaluate, plan and correct your own thinking processes. Self-awareness; focus on own thinking processes.

4.3.3.3 Information processing competencies

Pragmatic (exploration construct): Practical orientation – "will it work in practice?" Determining relevance in structured contexts.

Exploration (exploration construct): Effectiveness, depth and width of exploration.

Analytical (analysis construct): Systematic, detailed and precise in differentiating and linking, rigor.

Rule Oriented (analysis construct): A rule focus, mechanistic.

Categorisation (structuring construct): Creating external order, categories and reminders – structuring tangibles, creating meaning.

Integration (structuring construct): Synthesis of ambiguous/discrepant/conflicting information – creating meaning.

Complexity (structuring construct): The preferred level of complexity, the unit of information used – Higher score prefers dynamic complexity, lower score prefers detailed complexity. The higher one of the **complexity** and **memory use** scores can be used to indicate the level of complexity that a person prefers to function at. A discrepancy or difference between these two scores is usually quite meaningful. In such cases, the memory score normally comes out somewhat lower. This may be because of the application of checking or other weak memory strategies as well as the need for precision, a compulsion to "make sure", or a lack of confidence in own opinions. Where memory comes out lower than complexity, the complexity score should be used as an indication of the preferred unit of information focused on. These two scores are, however, two sides of a coin as "complexity management" depends on memory capacity.

Logical Reasoning (transformation – logical & lateral construct): The disciplined, logical following through of reasoning processes.

Verbal Abstraction (transformation – logical & lateral construct): Unusual, creative, abstract verbalisation and conceptualisation – expresses conceptual thinking by using abstract language. Verbally creative.

Use of Memory (memory construct): Tendency to rely on memory / concentration / degree of effort.

Memory strategies (memory construct): Effectiveness of memory strategies.

Judgement (Meta-cognition construct): Using judgement to clarify unstructured and vague information. Judgement – intuitively and consciously evaluate complex issues by prioritising and weighing them according to criteria.

Learning 1 (Meta-cognition construct): Quick insight learning. Learning – improve one's understanding by adjusting, expanding and integrating information structures in a self-aware manner.

Learning 2 (Meta-cognition construct): Gradual improvement / experiential learning.

4.3.3.4 Levels of Work

Level of work refers to the working environment that a person is currently operating at, and is able to function and be comfortable in. This does not refer to the actual job of the individual, but the preferred level of complexity with which the individual works. The CPP also indicates which level of work a person could potentially be operating at. People work at one of five work levels:

Level 1 – Pure Operations: Prefer direct involvement with practical, clearly-structured operating tasks that have obvious and clear rules for success. Deal with routine tasks that have clear linear procedures, using knowledge to complete the task. They like the information they work with to be tangible and definite (with no ambiguity), and deal with problems one by one as they emerge, usually by coming up with practical solutions. Work in a familiar environment that has well-defined rules and structures. Use a trial-and-error-approach when learning new tasks and are likely to want to explore issues practically and seek short-term feedback to confirm that they are on the right track.

Level 2 – Diagnostic Accumulative: Apply an analytical/sequential approach, following clear, linear procedures to diagnose and solve problems that are not always obvious. Use existing knowledge and experience together with theoretical knowledge to interpret information (such as symptoms), and asking either/or questions to help them decide how to solve the problem. These people often have specialist or good technical knowledge in their field. Tend to learn by drawing on memory of their theoretical / specialist knowledge base and practical experience.

Level 3 – Tactical Strategy: Usually work with whole operating systems – particularly with the interaction between tangible intra-system components. Tend to plan, structure, measure, control and pull information together in order to achieve a pre-specified goal. Evaluate systems and practices, make practical decisions about the best way to get things working efficiently, and plan how resources can best be deployed. Contingency plans are devised should things go wrong. Operational efficiencies, benchmarking and cost are important factors. Often come up with short-term solutions that pave the way for longer-term achievement. Learning takes place via systematic experimentation with different operational systems and structures, as well as through transfer and application of theoretical angles.

Level 4 – Parallel Processing: Perform work both within, and across, relatively complex systems – for example, co-ordinating the activities of several business units in a large organisation. Focus on abstract, intangible issues – theories, models, viability of projects / programmes – and come up with creative, integrated, and abstract conceptual solutions. Plan and implement business solutions, balancing and juggling resources between different projects and programmes so that these are used most effectively, ensuring that equally important demands of each project are met. Programmes have timescales of three to five years. Deal with broad strategy, the long term viability of the business, value chain integration, organisational change / transformation. As specialists, they tend to focus on and create new functionalities. They often learn via an innovative, integrative, systems approach by synthesising various abstract theoretical options into a model. Such models are then used to guide operational issues, monitoring consequences and make the necessary adaptations.

Level 5 – Pure strategy: Primarily concerned about the long term industry viability and the impact of the industry on the social and physical environment, although only involved in one organisation. Consciously evaluate and decide on a most appropriate level of analysis ranging from concrete to abstract; identify vaguely emerging opportunities within a somewhat chaotic environment; clarify this fuzzy information; and show awareness of both business and moral / ethical implications for the industry. Capitalise on intuitive awareness – more so than on analytical detail. Initiate change that may impact the whole industry and create a future through philosophical leverage. Timeframes are usually 5 to 8 years. Work with abstract, broad, sweeping issues – chaos, macro-economic factors, potential industry partners and environmental impact. Operations of a truly strategic nature will involve the creation of unified whole systems (such as national or international businesses), focusing on renewal through exploring new philosophical trends and intuitively sensing connections between apparently unconnected variables.

In summary, a total of 16 CPP measures are used in this study.

Reliability is a challenge for the CPP. Correlations between 0.4 and 0.63 were achieved for the information processing competencies (Prinsloo, 2007). This is below the 0.7 that is generally regarded as acceptable for psychometry. However, CPP is intended to be administered only once because of learning effects. In the case of CPP, construct validity is more important. Construct validity was originally established using a “goodness of fit” criterion of 0.9 (Prinsloo, 2007). Comparison against a number of intelligence tests has yielded correlations in the range of 0.4 to 0.6. There is also concurrent validity data between CPP and personality tests and CPP and emotional intelligence.

The CPP is cross-culturally unbiased and fair (Prinsloo, 2007) with variation based on educational level. However, for this research the population has a homogeneous educational level. There is also evidence that the results are valid across gender.

4.3.4 Values - Value Orientations

For the assessment of values, the Value Orientations (VO), from Cognadev International was selected. The other value assessment that could be considered is the Value Management (VM). However, the VO represents a theoretically and technically better tool than the VM (Prinsloo & Prinsloo, 2009). The VO is based on Graves' Spiral Dynamics Theory (amongst other theories) (Beck & Cowan, 2002). The essence of Spiral Dynamics is that it measures different value systems within people. For the purposes of this study, value systems are defined as the following (George & Jones, 1997, p.395): "A value system is a generalized knowledge structure or framework about what is good or desirable which develops over time through an individual's involvement in the world. A value system guides behaviour by providing criteria that an individual can use to evaluate and define actions and events in the world surrounding him or her. An individual's personal set of values determine which types of actions and events are desirable or undesirable".

Each person is said to prefer different proportions of each of these value systems, and reject others (to a certain extent). The VO measures seven broad value systems, which can be combined in a variety of ways to reveal the individual's value orientation (the value systems preferred and rejected). The VO depicts the seven different types of thinking and individual needs in terms of different colours (in order to avoid ranking), and are briefly described below (Beck and Cowan, 2002, p.5). Each value system can be either accepted, or rejected.

The values systems illustrated in Figure 13 are grouped into expressive or individual and sacrificial or interdependent. The following value systems focus on **individual needs**:

- **RED**: The need to control, to enforce dominance and power. The type of thinking here can be characterised as egocentric;
- **ORANGE**: The need to perform, to achieve and be self-reliant. This value system depicts a strategic type of thinking; and
- **YELLOW**: The need to learn, to increase knowledge and experience.

The following value systems are more sacrificial and depict **interdependent values**:

- **PURPLE**: The need to protect and be protected, to belong;
- **BLUE**: The need for order and structure, to conform and be righteous;
- **GREEN**: The need for spiritual growth and harmony, relationships. Feelings are more important than achievement; and

- **TURQUOISE**: The need to experience. Everything is interconnected. This value system depicts a holistic type of thinking.

These value systems can be linked to (Prinsloo & Prinsloo, 2009):

- The worldview adhered to;
- Expected behaviours;
- Prime motivators;
- Emotional manifestations;
- Preferred organisational settings; and
- Leadership orientation.

The VO has an acceptable reliability in the range of 0.71 to 0.83 for accepted value systems and 0.71 to 0.84 for rejected value systems. No information is available regarding the fairness of the VO.

Finally, the assessment of SE competencies is discussed.

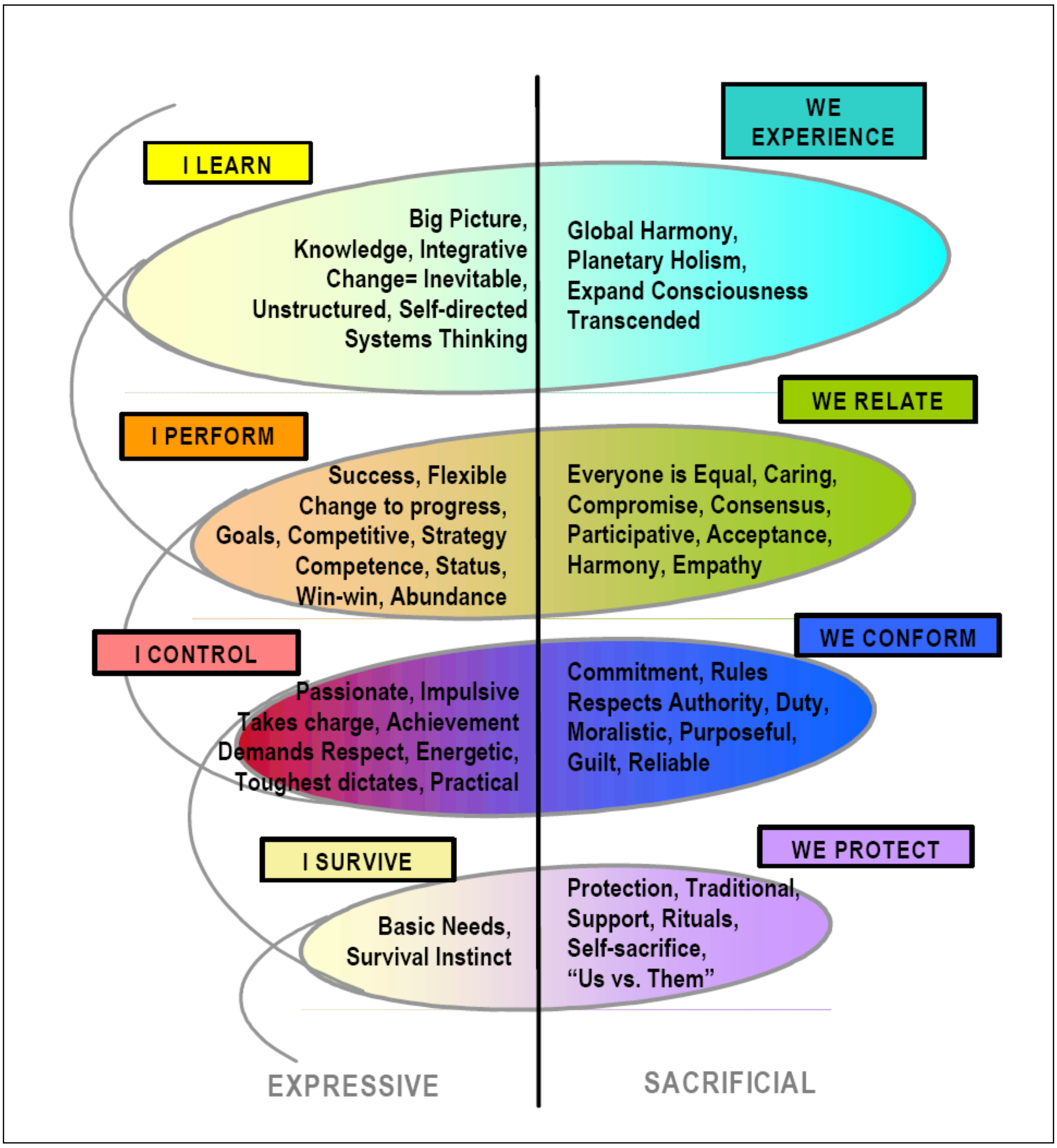


Figure 13 Value systems illustrated (Prinsloo & Prinsloo, 2009)

4.3.5 Assessment of SE competencies

SE competencies (criteria) were assessed using the *Systems Engineering Competencies Framework*, (INCOSE UK 2006), discussed in section 2.5.3. As mentioned previously, this framework identifies 21 competencies which are categorised into *Systems Thinking*, *Holistic Lifecycle View* and *Systems Engineering Management*. *It is important to note, however, that no single systems engineer will have high levels of competency in all 21 of the competencies identified in the framework.*

Participants were asked to self-rate on all three competencies in the Systems Thinking category, because these are considered fundamental. In addition, participants were asked to self-rate on the five competencies on which they spend most time from the two categories: Holistic Lifecycle view and Systems Engineering Management. The participants' choice would probably be based on work demands. In the on-going evaluation of the selection method (Appendix C), participants will rate themselves on all 21 competencies to define a baseline. This is because participants may develop competencies other than the five competencies they chose to rate themselves on in the design phase of the study.

The SE competencies were evaluated using a questionnaire based on self-assessment, implemented as an Excel spreadsheet. A spreadsheet is used for data collection purposes to avoid re-entering data and the associated risk of incorrect entry. The original INCOSE UK framework was reformatted for readability and some language was modified for South African use (Appendix B).

One of the concerns with self-assessment is that those who are not competent may over-estimate their level of competence (Kruger & Dunning, 1999). Kruger and Dunning argue that one of the reasons for over-estimation is, paradoxically, the lack of competence. Similarly, having supervisors perform assessments if they are themselves not competent does not necessarily reduce the problem. There are several aspects that would mitigate the impact of such a bias in the context of this study. Firstly, DPSS has been running an SE training program for the last 3 years in order to raise general awareness of SE. Over 91 engineers received SE training. Secondly, questions for higher levels of competence were in terms of successfully completing activities, for example at awareness level "I am aware…" while at expert level "I have…". Thirdly, inspection of the SE questionnaire results by the author (who knows the main systems engineers at DPSS) did not reveal "new" systems engineers that were the result of over-estimating self-competence.

Each competency is rated by answering either yes/no to several questions at each level, i.e. awareness; supervised practitioner; practitioner and expert and for each competency. Each SE competency level is multi-item, i.e. multiple questions are asked for each level. For instance, in the Systems Thinking Category, participants would have to answer either yes/no to the following question: *I am aware of the importance of system lifecycle.* This is one of the several questions at Awareness level, the lowest of four levels defined by the framework (INCOSE UK, 2006). The participant's assessed level for a specific competency is the highest level where "yes" responses were given to *all the questions for that level and all levels below*.

Given this framework, *a systems engineer can be defined as an engineer who has competency levels of at least **practitioner** on all eight competencies* (three from systems thinking and the five of choice). With the bar set at this level, it is unlikely that many systems engineers will be found.

Reliability and validity of the SE framework have not been assessed. Given that engineers are expected to develop competence, reliability cannot be high over the long term. Also, since there are no other SE competency assessment frameworks, construct validity of this framework cannot be established using concurrent cross-validation. The notion of construct validity is going to be a challenge given that SE is not mature:

- The definition of SE cannot be agreed on by its practitioners (the INCOSE definition is not accepted by everyone) and the SE processes are not universally accepted;
- There are competing paradigms in systems engineering – for instance, in problem definition and requirements analysis (Kasser, 2012).

4.3.6 Mapping selected assessment measures to psychological characteristics in the literature

Table 7 traces out the desired SE personality and cognition characteristics, as identified from the literature in section 2.2 to the measures (with references). Since there is no literature related to values, these are not listed. It is clear from this table that the selected assessment measures do not cover all the characteristics listed in the literature. However, compared to the other assessment measures that were considered, they cover a significant number of characteristics. It should also be noted that some of these may be measured by the VO.

Table 7 Mapping of SE personality and cognition characteristics to assessment measures

Personality	**Measured via 15FQ+**
1. Sociable, good communicator	fA: *Empathetic*; fF: *Enthusiastic*; fH: *Socially bold*; fQ2: *Group orientated*
2. Intelligent – intellectual curiosity	fB: *Intellectance*
3. Forward (willing to ask challenging questions, speak mind)	fE: *Dominant*; fN: *Direct*
4. Ambitious – hardworking, dedicated, persevering	fG: Conscientious; Attitude to work scale as Persevering, dutiful, solution focused, conscientious and conforming
5. Innovative	fM: *Abstract*; fQ1:*Radical*; Attitude to work scale as Absent-minded, lax, disregards rules and obligations, unconventional
6. Flexible and adaptable – comfortable with ambiguity	fQ1: *Radical*; fG: *Expedient*
7. Self-motivated (achievement motivation), able to motivate others	Not clear that this is measured.
8. Assertiveness	fE: *Dominant*
9. Coordination skills	Not clear that this is measured.
10. Persuasive	fE: *Dominant*
11. Patient	fQ4: *Composed*
12. Rational	fI: *Hard-headed*; fQ4: *Composed*
13. Responsible	fG: *Conscientious*
14. Confident	*f*H: *Socially bold*; fO: *Confident*
15. Organized	fG: *Conscientious*

Cognition	Measured via CPP
1. Big picture thinking (understanding the whole without getting stuck on details)	Cognitive styles: Holistic
2. Systems thinking (understand relations between parts of a system)	Cognitive styles: Integrative / Cognitive Competencies: integration
3. Tolerance for ambiguity	Cognitive Competencies: Structured
4. Concept generation	Cognitive styles: Intuitive; Cognitive competencies: verbal abstraction may be relevant; Current level of work
5. Innovative	Not clear that this is measured by CPP.
6. Strategic	Current level of work
7. Analytical	Cognitive styles: Analytical; Cognitive competence: Analytical
8. Logical	Cognitive styles: Logical; Competencies: Logical reasoning.

4.3.7 Practical aspects of the selected assessments

Important practical aspects and performance of the selected assessments against the requirements are summarised in Table 8. The cost target per person was achieved. The total planned time was not met, however, but this does not affect the results that were obtained.

Table 8 Assessment measures summary and assessment order

Order	Dimension	Assessment	Assessment time	Assessment Cost	Report	Feedback time	Feedback cost	Administration method	Materials
Intro	Ethical	Introduction and consent	10 min	N/A	N/A	N/A	N/A	Paper and pen	Consent form and pens
1	Cognitive	CPP	2 to 2.5 hours per person	R0.00	R650.00	~20 minutes	390.00* 20/60	Computer based	Computer + CPP SW
2	SE Competencies	INCOSE UK SE Competencies	10-15 min	R0.00	N/A	N/A	N/A	Computer based	Computer + Excel
3	Values	VO	30-45 min	R0.00	R450.00	~20 min	R390.00* 20/60	Internet based	Computer + Internet
4	Personality	15FQ+	30 to 45 minutes per person	R390.00 45/60	R116.00	~20 minutes	R390.00* 20/60	Internet based	Computer + Internet + Flash player
Total			3h20 to 4h25?	R292.5	R1216.0	~60min	R390		

Notes:

1. The proposed assessment order is based on the candidates being ‘fresh’ at the start.
2. Total cost is R1899 per person assuming assessments are administered individually. This cost will decrease if assessments can be administered in small groups. Research assistant (Janine Britz) administered the CPP and VO (The amount of R5800 for training is not included here). The labour cost of engineers being assessed is not included here.
3. Turn-around time to deliver the reports is 3 working days after the assessment has been completed by each individual.

4.4 Development of the selection method

The process for the development of the selection method for candidate systems engineers is shown diagrammatically in Figure 14. The most significant task, in terms of magnitude, is the collection of data (F.2.1, discussed in the following section). Exploratory analysis of the data was by means of histogram and correlation analysis (F.2.2 and F.2.3). The potential identification algorithm (F.2.4) is presented in section 4.4.2.

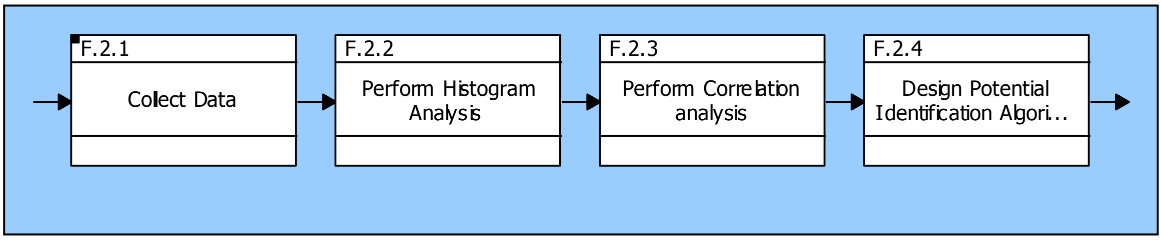


Figure 14 Process for developing the selection method (F.2 in Figure 1)

4.4.1 Data Collection

The process for collecting data is shown in Figure 15. After the assessments had been scheduled, the following data were collected from each participant using the computerized assessments discussed in section 4.3:

- Personality preferences using the 15FQ+;
- Cognition using CPP;
- Values using Value Orientation; and
- SE competencies questionnaire.

In addition, the following questions were posed as part of the SE competencies questionnaire for context:

- Gender;
- Race;
- Age;
- SE years of experience;
- SE opportunity;
- Organisational barriers/enablers; and
- Personal interest in SE.

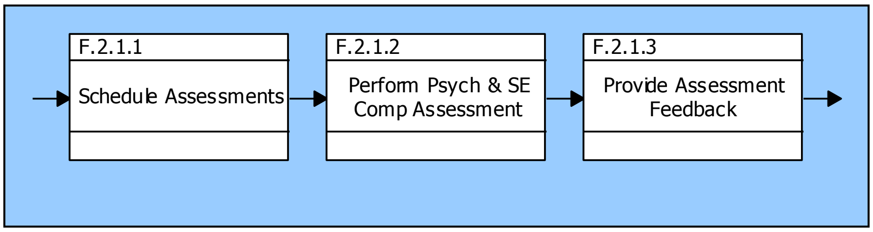


Figure 15 Process for collecting data (F.2.1)

Two psychometric companies were contracted to score the 15FQ+, CPP and VO. A research assistant was responsible for administering the CPP, VO and SE Questionnaire. The research assistant had a background in psychology and appropriate training to administer these assessment measures. For ethical and legal reasons, a registered psychometrist/psychologist administered the 15FQ+ and gave feedback on the psychological assessment measures.

Feedback on the psychological assessments was provided to participants who were interested in receiving it (the benefit of participating) (F2.1.3). The total cost of assessment, training, psychometrist fees (for administration, scoring, feedback and travel etc.) was around R232 000.

Before proceeding with the data collection in earnest, a pilot study was conducted. The purpose of the pilot study was to verify the process, questionnaires, and usefulness of the data. The pilot study followed the same process illustrated in Figure 15. Five participants were assessed and a group discussion was held after assessment to identify any possible issues, problems, discomfort, etc. Certain issues were identified with regards to the testing room (space, computers, etc.) and were corrected where possible. The SE Questionnaire was also adapted due to certain issues that became apparent in the analysis of the pilot study data.

The full data collection commenced on the 9th of March, 2009 and ended on the 4th of May, 2009. The assessment sessions were spread out over the day as outlined in Table 9. The order of this programme ensured that candidates were “fresh” to complete the CPP, as it is recommended that the CPP should not be administered after 10:00 in the morning. Breaks were allocated in between for more or less the same reason. It is important to note here that none of the assessments were time-limited. Most participants used less time than allocated to complete their assessments. They could then go back to their offices, and would return at 14:00, when a psychometrist would administer the 15FQ+.

Table 9 Daily data collection plan

Assessment Day Plan	Feedback Day Plan
09:00: Introduction by the author. Participants sign consent forms.	In parallel with the assessments, a psychometrist would provide one hour feedback sessions to participants from previous assessment sessions.
09:10: Instructions on the assessments by psychometrist.	
09:20: Assessment on the CPP by psychometrist.	
11:20: Tea-break.	
11:30: Assessment on the SE Questionnaire by psychometrist.	
12:15: Assessment on the VO by psychometrist.	
13:00: Lunch-break.	
14:00: Assessment on the 15FQ+ by a psychometrist/psychologist from Psytech.	
15:00: End.	

The number of candidates that participated (sample size) was n=99, with demographics as indicated in Table 10. Thus, the response rate was 72.8%. It should be noted that the sample does not need to be representative of the current population. Rather, it should be representative of a population when the selection method comes into operation, taking into account transformation, although this cannot be predicted. The bias is unavoidable since the overwhelming majority of systems engineers in South Africa (and other countries) are white males. Since transformation is important, this bias means that generalisation to the female and non-white population cannot be made directly. This issue is difficult to address currently.

Table 10 DPSS sample demographics (n=99)

Race (%)	
White	81
Black	4
Indian	12
Coloured	2
Chinese	1

Gender (%)	
Male	90.8
Female	9.2

4.4.2 Design of a potential identification algorithm

Given the number of measures under consideration (section 4.3), an algorithm is required. It is also expected that a number of psychological characteristics will simultaneously predict potential. Hence, this section is concerned with the design of an algorithm for identifying engineers with potential on the various SE competencies.

While there is not an extensive literature on algorithms for potential identification for training, some authors have investigated the performance of artificial neural networks against that of linear predictors (Schmidt-Atzert, et al., 2011). This study does not conclude that artificial neural networks are superior in general. In the context of personnel selection, fuzzy set multi-criteria decision analysis has been investigated (Liang & Wang, 1994). However, personnel selection, based on performance, is not relevant.

The assumptions and goals for data analysis for potential identification are listed first (section 4.4.2.1). Next, an algorithm for potential identification based on similarity measures (section 4.4.2.2) is proposed.

4.4.2.1 Assumptions and goals in the data analysis for potential identification

Implicit assumptions about the population and goals will be stated first followed by a discussion on considerations for data analysis. Based on this, approaches to the data analysis for predicting engineers with SE potential are put forward.

The first assumption relates to the relationship between population subsets shown in Figure 16. The implicit assumption is that there will be engineers in the population with potential for developing high levels of competence. It is also assumed *that a* *subset* of engineers with potential will in fact have high levels of competence in a limited number of SE competencies. Engineers with high levels of competence may even be called systems engineers. *The most significant assumption is that engineers with assessed high competence are randomly distributed over the set of engineers with potential (i.e. the red area completely covers the* **variety** *of the yellow area in* Figure 16*).* If this is not the case, ethical issues or a bias might arise in using results from this study. Ideally the sample would include:

- Different organisations and industries;
- Life-cycle phases, systems hierarchy and project types;
- All 21 competencies of the SE Competencies Framework; and
- Male and female engineers of all races and ethnic backgrounds.

However, the requirements listed above are not practically feasible. There are only a small number of black people and females in the sample. It is also possible that personality and values may vary with race and gender. The aim is to demonstrate results within the CSIR and to test the framework. Future work can extend the sample and it is acknowledged that competencies outside the sample cannot be predicted.

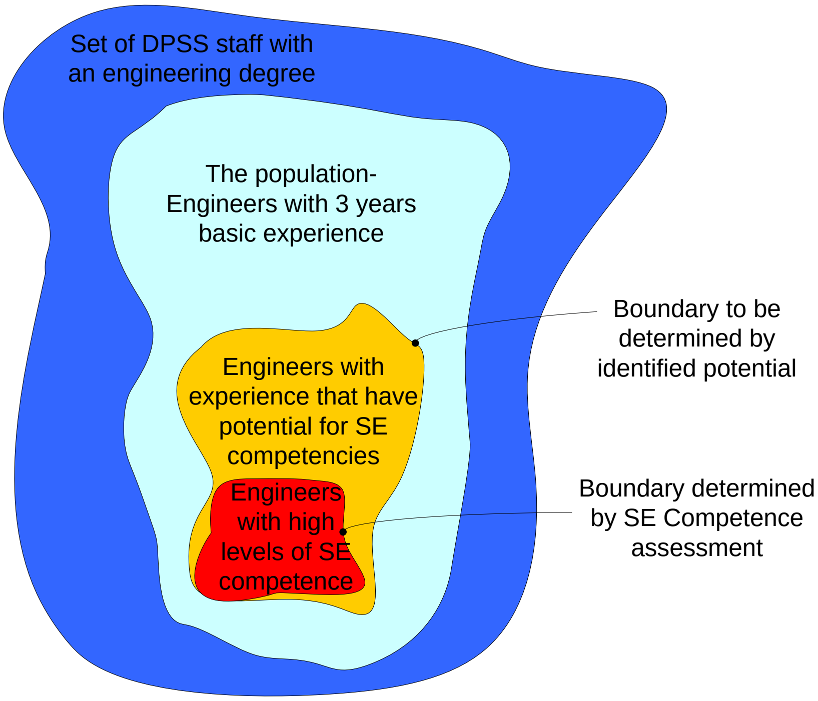


Figure 16 Set description of the population

There are few high competency engineers for most of the SE competencies at DPSS. This leads to several considerations in analysing the data for identifying potential:

- Black and female engineers with high competence could create several clusters in psychological measure space. For this study, high competency engineers are assumed to be distributed as a single cluster;
- From the diagram it can also be seen that the sets are not separable, i.e. a boundary cannot be drawn that will separate engineers with SE potential from engineers which currently have high competence, because each set is a subset of a larger set;
- "Tight" boundaries, driven by prediction effectiveness, cannot be drawn around the psychological attributes of engineers with high competence. This drives a comparative approach based on ranking rather than absolute decisions such as the candidate has potential or the candidate does not have potential, avoiding ethical pitfalls. This means that clustering and ranking approaches are favoured over discriminant analysis. This approach also does not mean that a SE profile is defined as a point. Other statistical tools like factor analysis were considered but there is insufficient data for their use;
- As little data as possible should be used for potential identification. The least that can be committed is the subset of engineers assessed as high competence because for these engineers there is no need to predict potential. This leaves the data of other engineers assessed at lower competence levels available to be tested for potential. This is the most efficient use of the available data.

A ranking approach has some limitations. Ranking cannot be performed when there is only one engineer. However in practice this not a problem since there are many applications for training opportunities at DPSS. Secondly, how are engineers with the SE profile separated from other engineers when using ranking? Engineers with the SE profile have the highest rank while those with the "other engineer" profile are at the end of the list (lowest rank). Where to "draw the line" will depend on demand, available resources and the number of candidate systems engineers.

Side note: A discriminant function approach considered.

A discriminant function (Duda & Hart, 1973) would use the psychological dimension as an input to separate engineers with the SE profile from those with the other engineer (OE) profile. The first step is to determine whether an engineer is a SE or OE based on the SE competencies assessment (defined in section 4.3.5). Not all dimensions of personality, cognition and values are important in building this model, i.e. relevance must be tested in order to establish the selection criteria for screening. The statistical problem (illustrated in Figure 17) is to define the SE profile and the "other engineer" profile by drawing a decision boundary through the psychological dimension. The psychological dimension (represented as the x-axis in Figure 17) consists of a number of measures (discussed in section 4.3). Thus the SE profile is a range of values on the psychological dimension and not just a single point. The graph shows three probability density functions: one for engineers, systems engineers and other engineers.

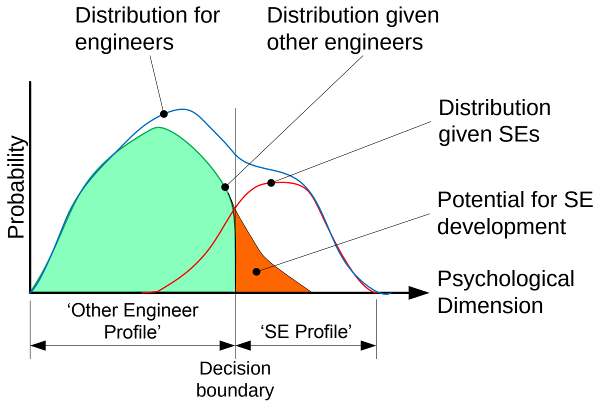


Figure 17 Notional distributions of SE's and other engineers illustrating a decision boundary (concepts from (Duda & Hart, 1973) adapted for selection)

The decision boundary is drawn based on performance to correctly classify as many SE and "other engineers" as possible. Since we are expecting these distributions to overlap there will be "other engineers" who will have an SE profile (see Figure 16) – it is these "incorrectly classified" engineers that have the potential for SE development. In order to draw this decision boundary correctly *the relative proportions of subgroups of engineers must be preserved*, for example, SE's and "other engineers", men and woman, and Black, Indian and White population groups (Duda & Hart, 1973). This requires quota sampling (Welman, et al., 2005). However, the concern is not the correct classification of engineers with high potential, but identifying those with potential for development. When coupled with stringent sample requirements and inefficient data use, discriminant functions become unattractive.

4.4.2.2 Similarity-based algorithms for potential identification

Selecting candidate systems engineers is about giving development opportunities to the candidates most likely to succeed. An approach to identifying SE potential is to consider what psychological characteristics or measures high competence engineers have in common. A candidate systems engineer has potential on a certain SE competence based on similarity to what high competence engineers in that specific competence have in common. In other words, a competency indicator is defined from characteristics that high competence engineers share. The assumption is that candidate systems engineers similar to high competence engineers are more likely to succeed in terms of SE development. The sub-problem is then to define **common measures** and **similarity**.

The definition of **common measures** will be considered first. For each competence, the first k_{com} measures with the *least variance* are defined as being common for high competence engineers. *The number of common measures,* k_{com}*, should be selected to reduce variance in the ranking of candidate systems engineers over all (or just the desired set of) SE competencies.* It is acknowledged that other definitions are possible, but an investigation of the best definition of common measures is outside the scope of this research.

In practice this definition will present some challenges. Psychological measures with the least variance *do not necessarily discriminate between systems engineers and other engineers*. These measures are simply threshold measures – if these are not present they represent a risk. Thus, with too few measures there is a risk of identifying characteristics that are generic to most engineers. Adding more and more measures, on the other hand, may result in identifying characteristics that are not important. As more and more common measures are considered in the selection of candidates, variance of measures increases, meaning that measures are becoming less important as all measures are used to make a decision. Variation in ranking across SE competencies is also expected to increase. As more measures are added, the dimensionality of the measures space increases and, because of the curse of dimensionality, leads to decreased selection performance without a larger sample (Duda & Hart, 1973). The larger the value of k_{com}, the more similar candidates will be to high competence engineers. The choice of k_{com} will be determined from the data in section 5.4.1. There is also the risk of selecting more people "like us". If DPSS engineers are less than ideal, DPSS would not want to select more engineers like them.

The aspect of **similarity** is considered next. The objective, based on section 4.4.2.1, is to *make recommendations* and not draw hard boundaries and so psychological "similarity" for engineers is defined in relation to high competence engineers. "Similarity" does not mean being equal to the mean value of measures of high competency engineers. If that were the case, a standard statistical test could be performed. However, dealing with people, variability in the measures is expected. There are a number of similarity measures that can be used (refer to (Duda & Hart, 1973) and (Spertus, et al., 2005)):

- Inner product normalised by an L_1 norm, $\frac{\mathbf{x}.\mathbf{y}}{\sum|x|\sum|y|}$;
- Inner product normalised by an L_2 norm, $\frac{\mathbf{x}.\mathbf{y}}{\|\mathbf{x}\|\|\mathbf{y}\|}$, (similar in form to a correlation to coefficient);
- L_2 distance norm (similar in form to variance), $\|\mathbf{x}-\mathbf{y}\|$; and
- Mutual information.

The L_2 distance norm has been used to assess similarity between profiles by Cronbach and Gleser as far back as 1953. However, the application of these norms is not without some issues (Edwards, 1993). The first of these issues is that the norms listed above will be applied to a range of measures which are conceptually different, e.g. personality and cognition measures. The issue is specifically that they will have equal weights. The other issue is that some information is lost, depending on the norm. For example, a L_2 distance norm, will lose sign information. Edwards (1994) has proposed a regression approach which addresses these issues. However, there is a challenge in this context because the regression must *estimate twice the number of measures* being used for a linear regression. If squared terms are included it could be as much as five times the number of measures. For regression a *criterion sample size of more than twice (and up to five times) the number of measures* (Scharf, 1991) is required. Suppose 30 measures are selected (out of a total of 60 measures) which is not an unreasonable number of measures. Then a sample size of between 60 to 150 is required, but the largest criterion sample, *Systems Design: Modelling & Simulation*, has only 29 engineers (from Table 12).

To be scientifically rigorous would require evaluating these various measures. Only two norms are evaluated, namely, an inner product normalised by an L_2 norm and a L_2 distance norm.

The algorithm for identifying engineers with SE potential is as follows:

- Normalise all measures to the range [0 1] to allow comparison of data on disparate measures. The full set of samples was used for this;

- Calculate mean μ_{HCj} and standard deviation s_{HCj} of the normalised measures for engineers with *high competence only*, for each competence $j = 1, \ldots, 21$;
- Sort measures in increasing variance. The first k_{com} measures with the least variance are defined as common to high competence engineers for a specific competency with mean denoted as μ_{HCCj};
- Rank the candidate's vector containing the common measures, x_{Ci}, against the mean μ_{HCCj} for each competency using the metrics $\frac{x_{Ci} \cdot \mu_{HCCj}}{\|x_{Ci}\| \|\mu_{HCCj}\|}$, the inner product normalised by an L_2 norm, and $\|x_{Ci} - \mu_{HCCj}\|$, the L_2 distance norm.

The proposed algorithm is not complex and can be implemented for each SE competence, since the profiles of high competence engineers are reduced to a vector (μ_{HCCj}). An assumption of the metrics is that all measures are equally important.

The algorithm described above is evaluated according to the method in the following section, with the results presented in section 5.4.2.

4.5 Evaluation of the selection method

The evaluation of the selection method was conducted by testing the hypothesis **H$_1$**, derived from the research question in Chapter 3:

H$_1$: *A candidate's SE competence potential can be predicted from personality preferences, cognition, and values (the SE profile).*

The hypothesis **H$_1$** can be validated practically using concurrent cross-validation (Spencer & Spencer, 1993) *for each SE competency*, i.e. 21 hypotheses are tested. Where there were more than four high competence engineers, this data, organised in random order, was split into two equal sets. The first data set is used to estimate required prediction parameters, while the predicted parameters are evaluated on the second data set. The process was repeated with the two data sets reversed. This yields two performance estimates. If the assessments have any predictive power the similarity measures will have the same distributions. The results of the evaluation are reported in section 5.4.2.

*Cross-validation is important as it forms the basis of the validation of the hypothesis **H$_1$** - thus completing the research. Concurrent cross-validation ensures internal* *validity of the results, i.e. variation in the SE dimension (criterion) is not caused by some confounding variable* (Welman, et al., 2005).

Concurrent validation is favoured over predictive validation since it can be done in a shorter time period (Brannick & Levine, 2002). Concern has been raised where this approach is used on current employees, when the assessment is intended for applicants. In this case, selection is from the current set of employees so this is not a concern. However, in this case systems engineers are used as opposed to candidate systems engineers.

Ethical and regulatory requirements relevant to this research and how compliance was achieved are presented in the next section.

4.6 Ethical and regulatory requirements

This section is concerned with the regulatory requirements and compliance relevant to this research. This is important from a methodological point because it constrains what can be done.

Participants in the study were informed of their ethical rights and the researcher's responsibilities verbally, and via the informed consent form (Appendix A). Ethics approval was sought and obtained (Appendix A). The consent form is in line with the "Rules of Conduct Pertaining Specifically to the Profession of Psychology" as promulgated by the Health Professions Act (Act No. 56 of 1974) and published in the Government Gazette as annexure 12 (notice no. 29079) in 2006, paragraph 11 & 89. For brevity this annexure will simply be referred to as the "Rules of conduct". The relevant rights and responsibilities include the following:

- Participation in the research was completely voluntary, but everyone in the population had an opportunity to participate. Participants were not paid to participate;
- The benefits to participants included the knowledge gained about themselves as well as making a contribution to systems engineering;
- The participants' right to confidentiality is ensured as stipulated by the Health Professions Act (Rules of conduct paragraphs 11 and 34) because, although the results of study were published, no individual names were used;
- In terms of the release of test data, the Rules of conduct paragraph 54(2b) stipulates that: "A psychologist shall not release test data to a person who is not qualified to use such information, except by virtue of informed written consent by the client concerned". Participants were asked to give their written

consent that the researchers, research assistants and registered professionals involved in the study could have access to their results, for research purposes only; and

- The individuals involved in handling and analysing the data were aware of their ethical responsibilities in terms of the Rules of conduct. The data was thus treated as confidential with adequate controls in place.

The research posed no significant psychological harm to participants:

- The psychological assessments of personality and cognition and values and do not reveal sensitive information relating to psychological disorders; and
- The assessment measures were administered, scored and interpreted by appropriately trained professionals and feedback on participants' assessment results was given by registered psychologist/independent psychometrist to ensure that results are conveyed in a caring, sensitive, professional and ethical way (Rules of conduct paragraphs 49, 51-53).

With regards to the appropriate use of assessment methods, the rules of conduct paragraph 45(a) states the assessment measures should be used: "For purposes that are appropriate in light of the research or evidence of the usefulness and proper application of such assessment methods". However, since no assessment measure has been developed to assess SE's, the proposed assessment measures are being validated (as recommended by independent Psychometrists and an Industrial Psychologist) for these purposes.

The Employment Equity Act, No. 55 of 1998 section 8 is also of concern:

"Psychological testing and other similar assessments of an employee are prohibited unless the test or assessment being used –

a) Has been scientifically shown to be valid and reliable;
b) Can be applied fairly to all employees; and
c) Is not biased against any employee or group."

Mature assessments are being used that have been shown to be reliable, valid and fair (with the exception of the VO assessment where there is no data available yet).

Thus this research was conducted in an ethical manner, to the extent practically possible.

4.7 Summary

The development of a selection methodology has been framed as a design problem and hence design science research (DSR) was selected as the methodological framework for this research. The two main outputs of this research are *models* and *methods*.

The required population consists of engineers from DPSS typical of a population from which candidate systems engineers would be selected for development. This population would meet the following requirements: a Bachelors degree in engineering (or similar degree in computer science or physics); at least three years experience; and various gender and race groups and various ages. The unit of analysis in this study is the individual engineer. The selection method design is criterion referenced thus requiring that SE competence first be identified. Engineers include systems engineers and other engineers as two mutually exclusive subsets (Figure 12). “Other engineers” or non-systems engineers who have the SE profile are the group intended for development.

A number of research instruments were selected based on a number of criteria:

- For personality – 15FQ+;
- For cognition – CPP;
- For values – the VO; and
- For SE competencies – the INCOSE UK *Systems Engineering Competencies Framework* (2006) was converted to a questionnaire.

Data was gathered on these instruments according to the data collection plan. This data was used in the development and evaluation of a selection method for candidate systems engineers. The selection method for identifying SE potential is based on psychological characteristics or measures high competence engineers have in common. An engineer has potential on a certain SE competence based on similarity to what high competence engineers in that specific competence have in common. The assumption is that candidate systems engineers similar to high competence engineers are more likely to succeed in development. Evaluation of the selection method is based on using concurrent cross-validation.

Finally, all the work was conducted in an ethical manner.

Chapter 5 Results

5.1 Introduction

This purpose of this chapter is to provide evidence that the hypothesis for the various SE competencies can be accepted.

In order to interpret the results as presented in this chapter, the context in which systems engineering (SE) is being performed at DPSS is outlined in the section on general results - section 5.2. In order to explore the data, a pairwise correlation analysis of each of the three psychological assessments against the SE competencies was performed with the results presented in section 5.3. These pairwise correlations are intended to reveal basic relationships relating to the hypothesis $\mathbf{H_1}$. However, correlations are limited to linear relationships (for the Pearson correlation coefficient). Of interest is identifying engineers with similar characteristics to those who are currently at practitioner or expert levels in terms of the SE Competence Assessment Framework using the potential identification algorithm. Collectively, practitioner or expert levels will be referred to as “high competence”. Results of the selection method evaluation are presented in section 5.4. The selection method includes the potential identification algorithm. Unlike correlation, the potential identification algorithm allows for non-linear relationships between measures in a multidimensional space.

The data collection and analysis produced considerable amounts of information. Even the summary statistics represent a vast amount of information so results not directly contributing to the main thesis, such as correlations between the 15FQ+, CPP, and VO are reported on in Appendix F. All the data analysis was performed using Matlab™ (V7.1.0.246 SP3), a commercial data analysis tool. The sections that follow refer to a large number of psychological measures which may be unfamiliar to the reader or which may require more precise definitions. For the reader’s convenience these definitions are presented in section 4.3 with additional information in Appendix C.

5.2 General results

The general results reported in this section contextualise the remainder of the results. These include questions about SE experience, awareness of SE, resources and opportunities to learn more about and apply SE. Finally, the number of DPSS engineers as a function of SE competence level is tabulated.

Figure 18 shows a histogram with *years of SE experience* on the x-axis bins and the number of DPSS engineers from the sample on the y-axis. The number of years of SE experience of the large majority of the DPSS sample is *less than five years* (Figure 18). All those engineers who do not do SE would be in this category. There is a long tail of SE experience out to thirty years. DPSS has been on a strong recruitment drive for young engineers, which underlines the need for the development of systems engineers.

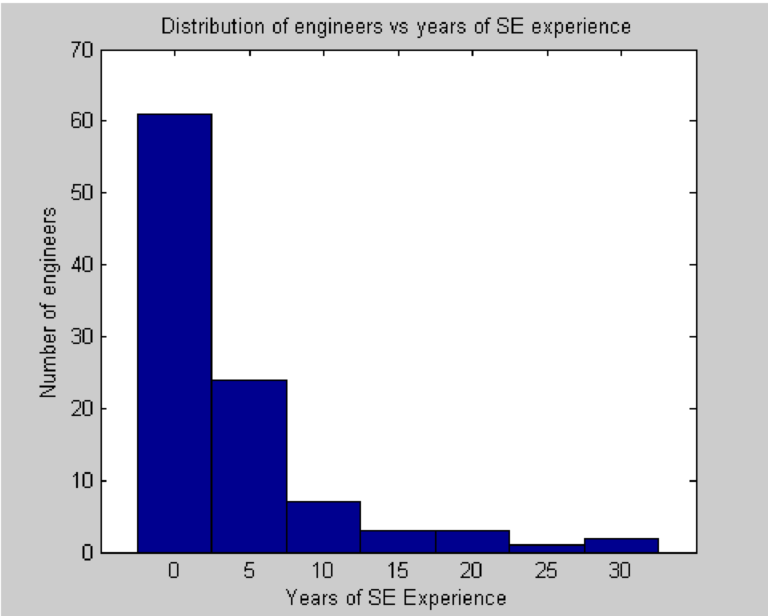


Figure 18 SE Experience distribution

The x-axis *scale* for the histograms of Figure 19 to Figure 27 is:

1= strongly disagree;	3= agree; and
2= disagree;	4= strongly agree.

The y-axis depicts the number of respondents (engineers).

There seems to be a good awareness of SE in this sample as evidenced by Figure 19. The large majority of people have resources to learn more about SE (Figure 20) – coaching and SE training (once a year) are available.

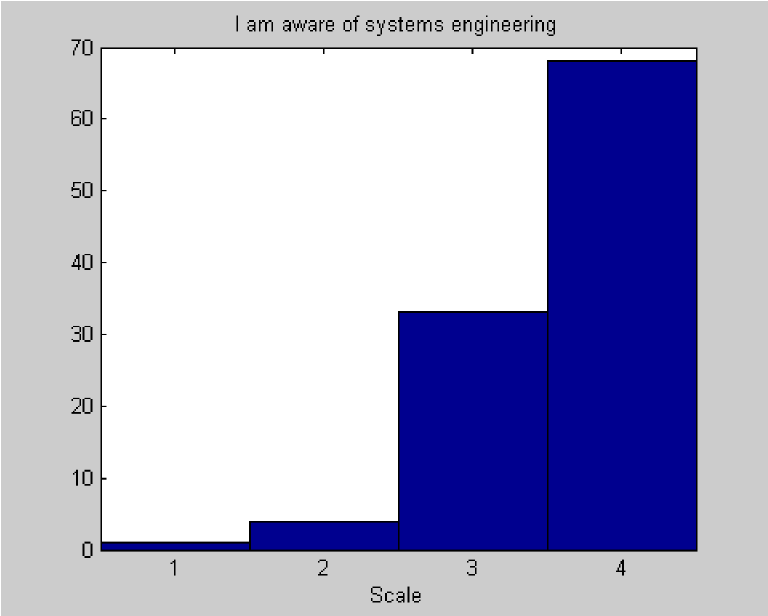


Figure 19 Question: I am aware of systems engineering distribution

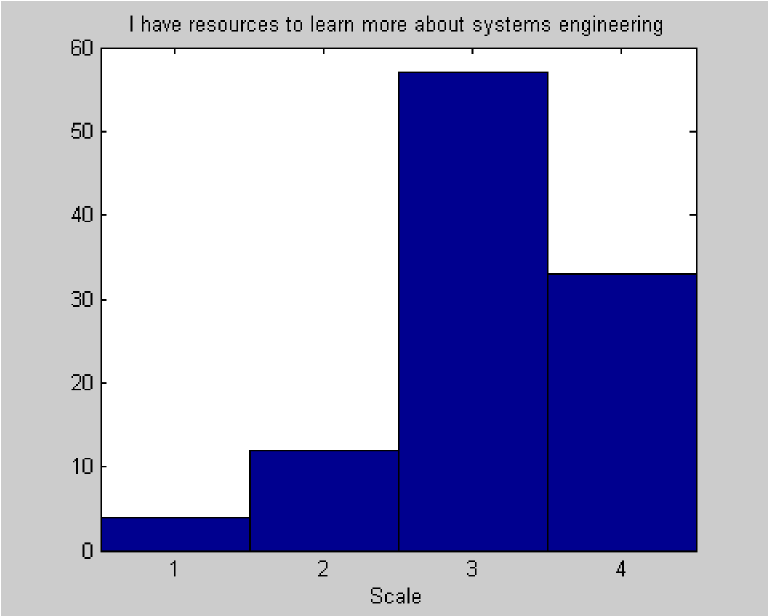


Figure 20 Question: I have resources to learn more about systems engineering distribution

It is more concerning that there is a significant minority of people who do not have resources to apply SE on projects (Figure 21) this is a bigger problem than a lack of opportunities to apply SE as illustrated in Figure 22.

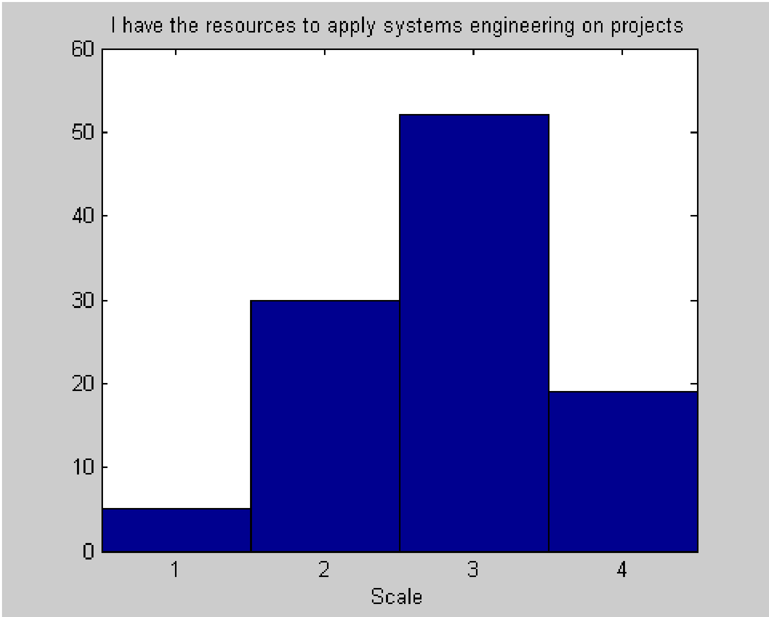


Figure 21 Question: I have the resources to apply systems engineering on projects distribution

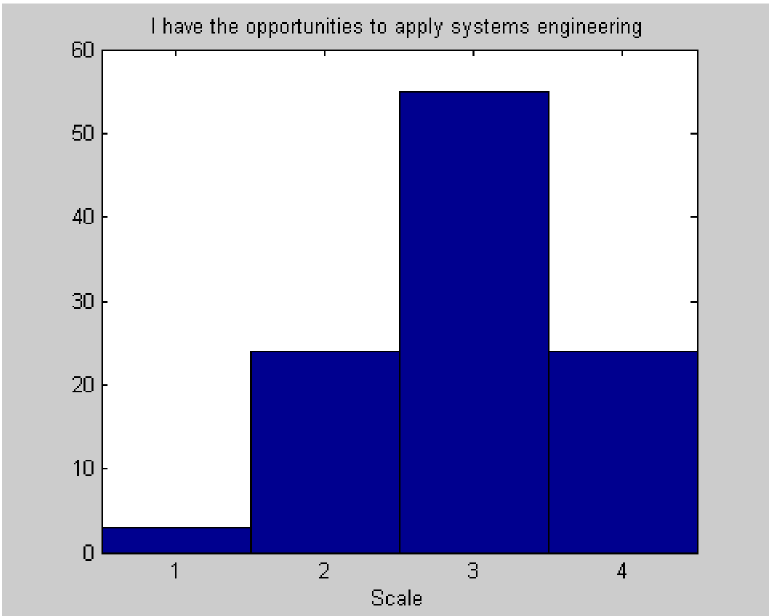


Figure 22 Question: I have the opportunities to apply systems engineering distribution

The perception is that there is generally a good appreciation of SE by clients (Figure 23). Figure 24 indicates that is a very strong perception that DPSS values SE.

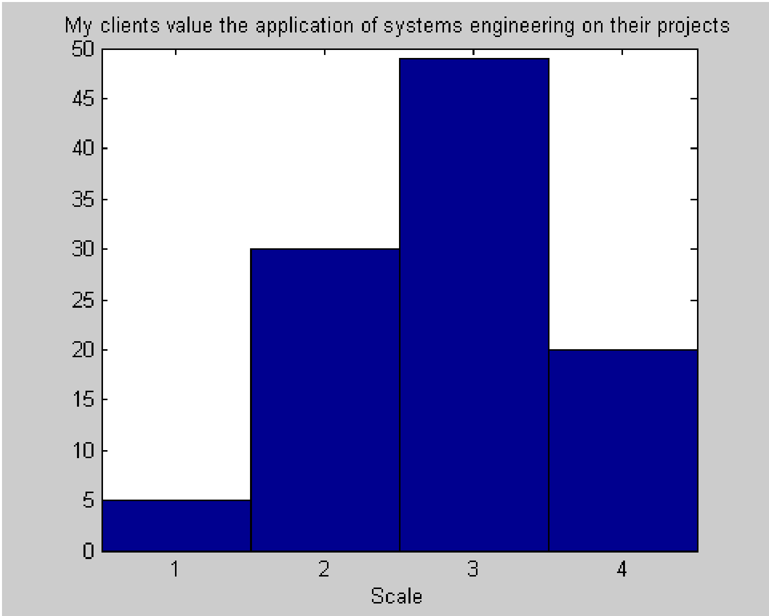


Figure 23 Question: My clients value the application of systems engineering on their projects distribution

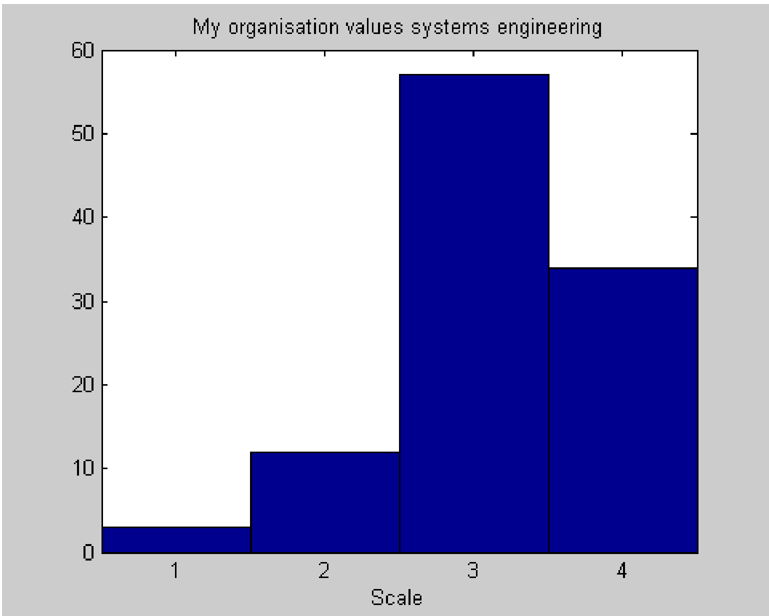


Figure 24 Question: My organisation values systems engineering distributions

Regarding a clear strategy in the individual's group that includes SE, it is concerning that there is a significant minority who do not agree (Figure 25), although this is not a concern of this study.

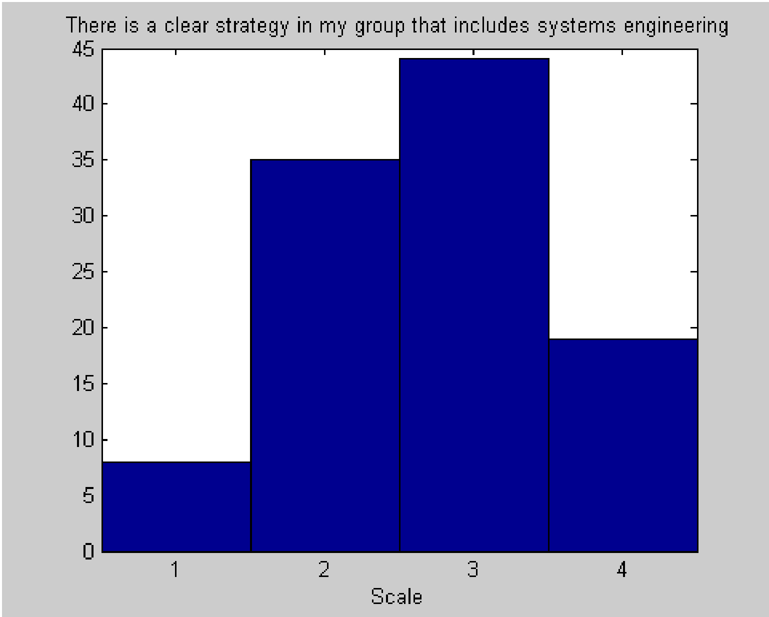


Figure 25 Question: There is a clear strategy in my group that includes systems engineering distribution

In the case of discrimination preventing people from applying SE, Figure 26, while it is limited to only a handful of individuals it is also still a concern. There is a lack of project opportunities for about one third of the sample (Figure 27). The main conclusion of this set of questions is that while there is a need for a broader set of actions than just SE development, the DPSS environment would be receptive to SE development.

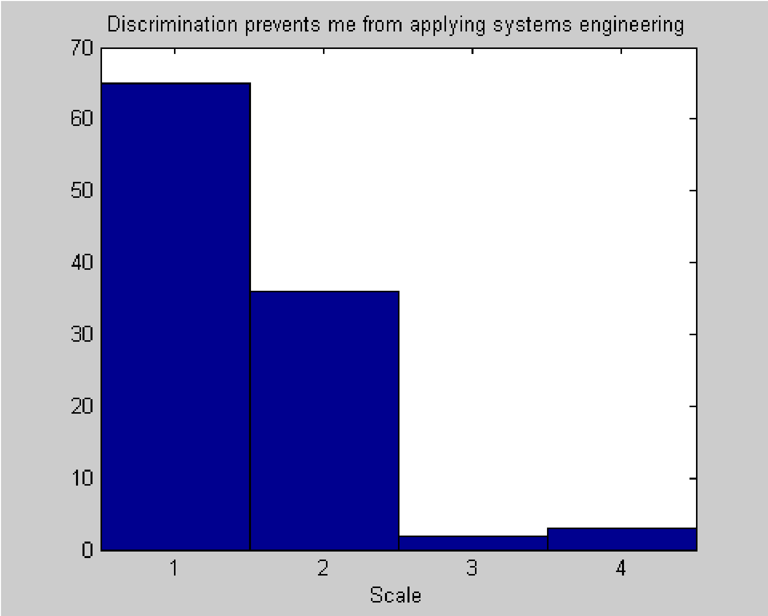


Figure 26 Question: Discrimination prevents me from applying systems engineering distribution

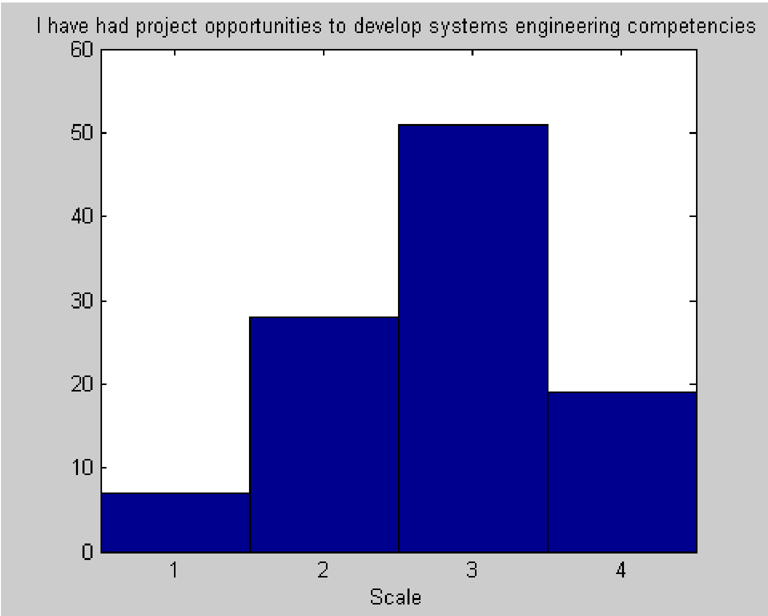


Figure 27 Question: I have had project opportunities to develop systems engineering competencies distribution

The final histogram, Figure 28, depicts the number of competencies at practitioner or expert level per engineer. There are many engineers that are highly competent in one or two SE competencies. If a systems engineer is defined as an engineer who is at practitioner level or higher in eight competencies then, there are only about one or two systems engineers in the sample of participants. *The number of engineers with*

SE competence at practitioner or expert level is inversely proportional to the number of competencies, ignoring variability. These numbers are consistent with a general scarcity of systems engineers.

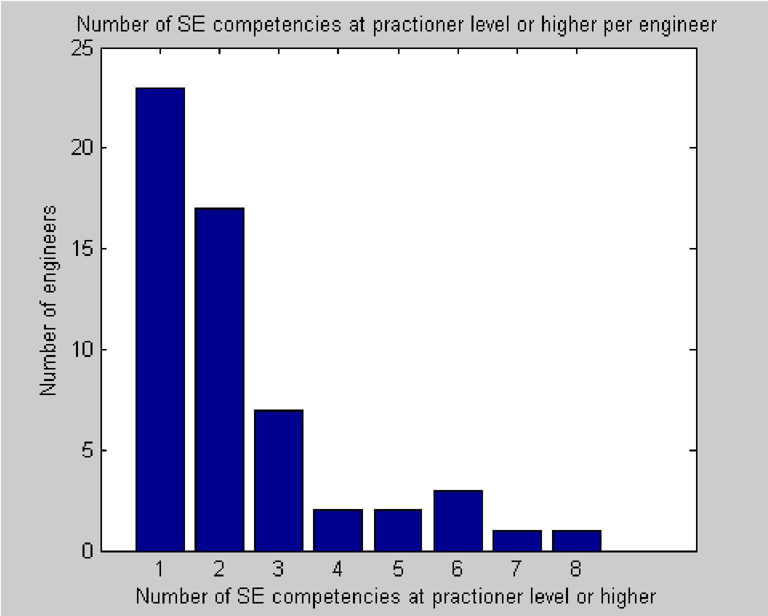


Figure 28 Number of SE competencies at practitioner level or higher

The number of engineers as a function of SE competence level is presented in Table 11, with each participant rating eight SE competencies (refer to section 4.3.5). DPSS' expertise in SE competencies, where 10 or more engineers recorded a high level of competence, i.e. practitioner or expert level lies in the following competencies: Modelling and Simulation, Systems Thinking: System Concepts and Super System Capability Issues, Concept Generation, System Integration & Verification.

There is growing competence, currently at supervised practitioner level, in the pipeline for the following areas: Systems Thinking: System Concepts Super System Capability Issues and Enterprise & Technology Environment, Determining and Managing Stakeholder Requirements, Architectural Design, Concept Generation, Design for…, Functional analysis, Interface management, Selecting Preferred Solution, systems Integration and Verification; Validation; Integration of Specialities, and Planning, Monitoring and Controlling. Some of the engineers who are currently supervised practitioner level are close to achieving the next level of competence.

Table 11 Number of engineers as a function of SE competence level

SE Competence	Awareness	Supervised Practitioner	Practitioner	Expert	Total
1 Systems Thinking: System Concepts	51	21	12	0	84
2 Systems Thinking: Super System Capability Issues	12	47	16	0	75
3 Systems Thinking: Enterprise & Technology Environment	7	58	7	0	72
4 Determining and Managing Stakeholder Requirements	33	23	5	0	61
5 Systems Design: Architectural Design	8	20	3	1	32
6 Systems Design: Concept Generation	1	66	12	2	81
7 Systems Design: Design for	6	23	3	0	32
8 Systems Design: Functional Analysis	21	39	6	0	66
9 Systems Design: Interface Management	11	29	7	1	48
10 Systems Design: Maintain Design Integrity	1	18	0	0	19
11 Systems Design: Modelling & Simulation	7	26	25	4	62
12 Systems Design: Select Preferred Solution	0	23	3	0	26
13 System Design: System Robustness	9	8	0	0	17
14 System Integration & Verification	2	38	9	1	50
15 Validation	4	27	4	0	35
16 Transition To Operation	2	9	3	0	14
17 Concurrent Engineering	5	7	2	0	14

SE Competence	Awareness	Supervised Practitioner	Practitioner	Expert	Total
18 Enterprise Integration	5	11	0	0	16
19 Integration of Specialities	0	16	1	0	17
20 Lifecycle Process Definition	5	13	0	0	18
21 Planning, Monitoring & Controlling	4	14	2	0	20

High awareness levels were found in Systems Concepts, Determining and Managing Stakeholder Requirements, and Functional Analysis. This is attributable to the SE course being presented every year at DPSS.

Higher numbers of engineers at awareness level are required to ensure the following SE areas are addressed on projects:

- Super Systems Capability Issues;
- Enterprise & Technology Environment;
- Architectural Design;
- Concept Generation (there are high numbers at supervised practitioner, though);
- Design for…;
- Interface Management;
- Maintain Design Integrity;
- Select Preferred Solution (no engineers at awareness level);
- System Robustness;
- System Integration and Verification (virtually non-existent);
- Validation;
- Transition to Operation (very low);
- Concurrent Engineering;
- Enterprise Integration (low);
- Integration of Specialities (no engineers at awareness level);

- Lifecycle Process Definition and Planning; and
- Monitoring and Controlling.

Awareness of these competencies should be achieved as soon as possible for more junior engineers so that they can seek advice and consider basic issues relating to specific competencies, although they are not experts.

In Table 12 on the next page, the number of participants at practitioner or expert level is shown per competency. There were no DPSS engineers at practitioner or expert level for the following competencies (indicated by a “0” in the table):

- Maintain Design Integrity;
- System Robustness;
- Enterprise Integration; and
- Lifecycle Process Definition.

Therefore, for some of the analyses relating to these competencies, no results can be reported. It is not unexpected, for example, that DPSS does not have high levels of competence in areas like life-cycle process definition as this has not been important in building technology demonstrators. However, the nature of the business is changing to include a broader part of the system life-cycle. It is important to note that at the time the data was gathered, the size of the high competence sample (criterion sample) for each competence was not known and could not be used in experimental design. The SE competence with the largest criterion sample **Systems Design: Modelling & Simulation** has only 29 high competence engineers. *The small criterion sample size was an important factor in the proposed selection algorithm design.*

Table 12 Number of systems engineers at practitioner or expert level per SE competency (criterion sample size)

SE Competency	Number of SEs at practitioner or expert level
1 Systems Thinking: System Concepts	12
2 Systems Thinking: Super System Capability Issues	16
3 Systems Thinking: Enterprise & Technology Environment	7
4 Determining and Managing Stakeholder Requirements	5
5 Systems Design: Architectural Design	4
6 Systems Design: Concept Generation	14
7 Systems Design: Design for	3
8 Systems Design: Functional Analysis	6
9 Systems Design: Interface Management	8
10 Systems Design: Maintain Design Integrity	0
11 Systems Design: Modelling & Simulation	29
12 Systems Design: Select Preferred Solution	3
13 System Design: System Robustness	0
14 System Integration & Verification	10
15 Validation	4
16 Transition To Operation	3
17 Concurrent Engineering	2
18 Enterprise Integration	0
19 Integration of Specialities	1
20 Lifecycle Process Definition	0
21 Planning, Monitoring & Controlling	2

5.3 SE competence correlations

This section explores correlations between SE competencies (the criterion) and the three psychological assessments 15FQ+, CPP, VO. The purpose of this section is to provide a first level of evidence of the validity of $\mathbf{H_1}$:

A candidate's SE competence potential can be predicted from personality preferences, cognition, and values (the SE profile).

The correlation between the number of years of SE experience and SE competence is also reported. First a brief description of correlation and how it has been used in this research.

5.3.1 Correlation and hypothesis testing

Correlation indicates the proportion of the variation in y that is attributed to a linear relationship with x. The sample correlation coefficient (Pearson's linear correlation coefficient) is given by (Miller & Freund, 1977):

$$r = \frac{S_{xy}}{\sqrt{S_{xx}S_{yy}}}$$

where

$$S_{xx} = n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2$$

and similarly for S_{yy} and finally

$$S_{xy} = n\sum_{i=1}^{n} x_i y_i - \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)$$

A correlation of zero indicates that there is no linear relationship. For a correlation of 1, there is a perfect linear relationship, $y = x$, while for a correlation of -1, there is a perfectly negative linear relationship, $y = -x$.

Of importance in this section is testing the null hypothesis i.e. H_0: the data is uncorrelated or $r = 0$ against the alternative H_1: $r \neq 0$[3]. A decision must be made to accept or reject H_0 but the truth about the null hypothesis, either true or false, is

[3] H_0 and H_1 are commonly used in the statistics literature for the null hypothesis and the alternative hypothesis respectively. Our use of $\mathbf{H_1}$ indicates our *first* hypothesis, but is the null hypothesis in statistical terms.

unknown. This yields a two by two table that indicates the various combinations of decisions that can be made compared to the truth (Table 13).

There are two correct decisions: Accept the null hypothesis when the null hypothesis is true and reject the null hypothesis when the null hypothesis is false. There are also two incorrect decisions: reject the null hypothesis when the null hypothesis is true which is a type I or alpha error and accept the null hypothesis when the null hypothesis is false which is a type II or beta error.

Only correlations tests where the type I error is small, will be reported. In other words there is strong evidence that the correlation is not zero, i.e. the results are significant at the 5% level. The type I error or significance level will be indicated by *p*.

Table 13 Errors in testing hypotheses

		The truth	
		H_0 is true	H_0 is false $\rightarrow H_1$ is true
The decision	Accept H_0	Correct decision	Incorrect Decision (Type II or Beta Error)
	Reject H_0 $\rightarrow$ Accept H_1	Incorrect Decision (Type I or Alpha Error)	Correct decision

5.3.2 Psychological-SE assessment correlation analysis

The correlations between SE competencies and the three psychological assessments: 15FQ+, CPP, and VO (3 pairs of correlations) were analysed and are presented in this section. Since participants in the study were only required to complete questions relating to eight out of 21 competencies, only the psychological data of those who responded to a specific competence were included in the correlation. The higher the correlation the more the level of SE competence is explained by the specific psychological measure. In the tables that follow *p* is the significance level of the correlation test and *n* is the sample size. For the 15FQ+, which has bipolar measures, the end of the scale correlating with the SE competency is indicated in italics.

For the **System Concepts** competency no statistically significant correlations were found. On closer inspection, this competency is largely dependent on knowledge. Since the SE competencies framework is focused on setting standards for SE output competencies, it defines competencies that are broader than or relevant to just SE development.

One of the most important competencies, **Super Systems Thinking**, is correlated with a lower preference for holistic, integrative and metaphoric styles (Table 14). *Positive correlation* with holistic and integrative was expected, so these results are unexpected. These results were checked and investigated. Engineers at an intermediate competence level (awareness and supervised practitioner levels, a group of about 60 engineers) were found to have a higher preference for holistic and integrative styles than those of high competence engineers.

Systems thinking: Enterprise and Technology Environment competency is correlated with dominant and not accepting Turquoise (We experience) (Table 15).

Table 14 Correlation between Psychological Assessments and Systems Thinking: Super System Capability Issues

CPP Style Preferences	Correlation	p (n=65)
Holistic	-0.259	0.038
Integrative	-0.343	0.005
Metaphoric	-0.271	0.029

Table 15 Correlation between Psychological Assessments and Systems Thinking: Enterprise & Technology Environment

15FQ+	Correlation	p (n=64)
fE: Accommodating - *Dominant*	0.314	0.011
Values	**Correlation**	**p (n=64)**
Turquoise (We experience) Accept	-0.275	0.028

In the area of **Determining and Managing Requirements**, engineers were found to be more distant and aloof (as opposed to empathetic), dominant and reject Green value system (We relate) (Table 16). This means that high competence engineers in requirements management are likely to avoid relationships and harmony. This may in fact be a risk in establishing eliciting requirements from stakeholders.

Table 16 Correlation between Psychological Assessments and Determining and Managing Stakeholder Requirements

15FQ+	**Correlation**	**p (n=56)**
fA: *Distant/Aloof* – Empathetic	-0.315	0.018
fE: Accommodating – *Dominant*	0.291	0.030
Values	**Correlation**	**p (n=56)**
Green (We relate) Reject	0.307	0.021

Engineers involved in **Architecture Design** are more serious, retiring (as opposed to socially bold), suspicious and strongly self-sufficient (Table 17). Thus, high competence architecture engineers are likely to be more introverted and have a sceptical and questioning approach to life.

Table 17 Correlation between Psychological Assessments and Systems Design: Architectural Design

15FQ+	**Correlation**	**p (n=28)**
fF: *Sober Serious* - Enthusiastic	-0.440	0.019
fH: *Retiring* - Socially-bold	-0.448	0.017
fL: Trusting - *Suspicious*	0.423	0.025
fQ2: Group-oriented - *Self-sufficient*	0.533	0.003

Concept Generation is negatively correlated with categorisation and memory strategies competencies. Engineers with high competency in concept generation accept Orange (I perform) but not Turquoise (We experience) (Table 18).

Table 18 Correlation between Psychological Assessments and Systems Design: Concept Generation

CPP Competencies	**Correlation**	**p (n=74)**
Categorisation	-0.289	0.012
Memory strategies	-0.276	0.017
Values	**Correlation**	**p (n=74)**
Orange (I perform) Accept	0.282	0.015
Turquoise (We experience) Accept	-0.280	0.016

The systems design competency, "**Design for …**", is correlated with not accepting Red (I control) while accepting Turquoise (Table 19).

Table 19 Correlation between Psychological Assessments and Systems Design: Design for…

Values	**Correlation**	**p (n=27)**
Red (I control) Accept	-0.432	0.024
Turquoise (We experience) Accept	0.414	0.032

Engineers performing **Functional Analysis** are likely to be aloof and show a negative correlation with CPP complexity competency (Table 20). Higher scores on the complexity competency indicate a preference for dynamic complexity while lower scores indicate a preference for detailed complexity. Hence the negative correlation between competence in Functional Analysis and complexity indicates a preference for detailed complexity.

Table 20 Correlation between Psychological Assessments and Systems Design: Functional Analysis

15FQ+	**Correlation**	**p (n=56)**
fA: *Distant/Aloof* - Empathetic	-0.298	0.026
CPP Competencies	**Correlation**	**p (n=56)**
Complexity	-0.284	0.034

The data also indicates that engineers who have high competence in **Interface Management** are dominant, direct and confident (Table 21). A high correlation between trusting and **Maintain Design Integrity** was found (Table 22).

Table 21 Correlation between Psychological Assessments and Systems Design: Interface Management

15FQ+	**Correlation**	**p (n=42)**
fE: Accommodating - *Dominant*	0.407	0.008
fN: *Direct* - Restrained	-0.337	0.029
fO: *Confident* - Self-doubting	-0.415	0.006

Table 22 Correlation between Psychological Assessments and Systems Design: Maintain Design Integrity

15FQ+	**Correlation**	**p (n=18)**
fL: *Trusting* - Suspicious	-0.499	0.035

One of the main DPSS competencies is **Modelling and Simulation**. This competency is correlated with abstract thinking, not rejecting Yellow (I learn), Green (We relate) or Turquoise (We experience) and not accepting Red (I control) (Table 23).

Table 23 Correlation between Psychological Assessments and Systems Design: Modelling & Simulation

15FQ+	**Correlation**	**p (n=52)**
fM: Concrete - *Abstract*	0.274	0.049
Values	**Correlation**	**p (n=52)**
Yellow (I learn) Reject	-0.341	0.013
Red (I control) Accept	-0.390	0.004
Green (We relate) Reject	-0.358	0.009
Turquoise (We experience) Reject	-0.317	0.022

Selecting the Preferred Solution is correlated with Yellow (I learn) accept and not rejecting Yellow (Table 24). At first glance this seems to be contradictory but can be explained by the correlation between yellow accept and reject which is -0.456. Since a reject is the opposite of accept a negative correlation is expected, but being less than 1, acceptance does not fully explain rejection.

Table 24 Correlation between Psychological Assessments and Systems Design: Select Preferred Solution

Values	**Correlation**	**p (n=25)**
Yellow (I learn) Accept	0.525	0.007
Yellow Reject	-0.498	0.011

Systems Robustness is strongly correlated with concrete, practical engineers (Table 25). The **System Integration and Verification** competence is correlated with engineers that are more conventional and tend to accept Red values (Table 26). **Validation** correlates with hard-headed, utilitarian engineers. **Validation** competency is also correlated with impulsive thinking, although this is a low preference (Table 27).

Table 25 Correlation between Psychological Assessments and System Design: System Robustness

15FQ+	Correlation	p (n=15)
fM: *Concrete* - Abstract	-0.566	0.028

Table 26 Correlation between Psychological Assessments and System Integration & Verification

15FQ+	Correlation	p (n=45)
fQ1: *Conventional* - Radical	-0.317	0.034
Values	**Correlation**	**p (n=45)**
Red (I control) Accept	0.308	0.039

Table 27 Correlation between Psychological Assessments and Validation

15FQ+	Correlation	p (n=31)
fI: *Hard-headed* - Tender-minded	-0.420	0.019
CPP Style Preferences	**Correlation**	**p (n=31)**
Impulsive	0.360	0.047

Table 28 shows strong correlations between high competence in **Transition to Operation** and confident and conventional personality characteristics. On **Enterprise Integration**, although DPSS did not have any engineers with high competency, the high levels of correlation (all above 0.5) are noteworthy on distant/aloof, not pragmatic, not integrative, not Red reject, not Green Accept, not Turquoise accept (Table 29). The **Integration of Specialities** competency is correlated with Turquoise (We experience) reject (Table 30).

Table 28 Correlation between Psychological Assessments and Transition to Operation

15FQ+	**Correlation**	**p (n=14)**
fO*: Confident* - Self-doubting	-0.598	0.024
fQ1: *Conventional* - Radical	-0.645	0.013

Table 29 Correlation between Psychological Assessments and Enterprise Integration

15FQ+	**Correlation**	**p (n=15)**
fA: *Distant/Aloof* - Empathetic	-0.543	0.036
CPP Competencies	**Correlation**	**p (n=15)**
Pragmatic	-0.601	0.018
Integration	-0.534	0.040
Values	**Correlation**	**p (n=15)**
Red (I control) Reject	-0.868	0.000
Green (We relate) Accept	-0.570	0.027
Turquoise (We experience) Accept	-0.572	0.026

Table 30 Correlation between Psychological Assessments and Integration of Specialities

Values	**Correlation**	**p (n=16)**
Turquoise (We experience) Reject	0.510	0.044

As with Enterprise Integration, **Lifecycle Process Definition** competency does not have high competency engineers but has high levels of correlation with confident, Red accept and Turquoise reject (Table 31). The **Planning, Monitoring and Controlling** competency is correlated with explorative, reflective, and negatively correlated with memory strategies competency (Table 32). It is also strongly correlated with not rejecting Red (I control) and not accepting Turquoise.

Table 31 Correlation between Psychological Assessments and Lifecycle Process Definition

15FQ+	**Correlation**	**p (n=15)**
fO: *Confident* - Self-doubting	-0.647	0.009
Values	**Correlation**	**p (n=15)**
Red (I control) Accept	0.559	0.030
Turquoise (We experience) Reject	0.553	0.033

Table 32 Correlation between Psychological Assessments and Planning, Monitoring & Controlling

CPP Style Preferences	**Correlation**	**p (n=19)**
Explorative	0.471	0.042
Reflective	0.469	0.043
CPP Competencies	**Correlation**	**p (n=19)**
Memory strategies	-0.471	0.042
Values	**Correlation**	**p (n=19)**
Red (I control) Reject	-0.534	0.019
Turquoise (We experience) Accept	-0.621	0.005

Personality characteristics are different for different SE competencies. Engineers competent in **Modelling and Simulation** are more abstract, shifting to conventional for **Integration and Verification**. Those competent in **Transition to Operation** are also more conventional. There are value differences between more technical competencies and management competencies. These examples illustrate differences in personality across the competencies.

No statistically significant correlations were found for the Systems Thinking: System Concepts and Concurrent Engineering SE competencies.

The limited number of statistically significant correlations is due to two reasons:

- Engineers at lower competence levels (awareness/supervised practitioner) may have SE potential but not yet fully developed this potential (as was illustrated in Figure 16); and
- The coarse SE competence categories, namely: awareness; supervised practitioner; practitioner and expert. To be at a specific level requires all questions for that level and all lower levels be answered "yes". The SE competencies raw score, summing all "yes" answers before mapping to the four competence levels, could have been used but this would present an upward bias because this is a less stringent measure.

5.3.3 Correlation analysis: SE competencies and SE experience level

One of the enduring "truths" amongst systems engineers is that the more job experience, the higher the SE competence level. In this section this statement is tested for each of the SE competencies. While the literature only reports general correlation between job performance and years of job experience as 0.18 there is no reported value for the correlation between competence and years of job experience (Robertson & Smith, 2001).

Statistically significant correlations between SE competencies and years of SE experience were found at the 5% significance level for only six out of the 21 SE competencies (Table 33). For some competencies, engineers with decades of SE experience did not necessarily have high competence, while some engineers felt they had relatively little SE experience (they did not see themselves as systems engineers) yet were at high levels of competence. There is some concern that the system concept competence, which is largely about knowledge, should have a correlation as high as 0.35. While in general more experience does not correlate with higher levels of competence, this seems to be true for some SE competencies since SE development is currently based on on-the-job training.

Table 33: Correlation between years of SE experience and SE competence

SE Competency	Correlation	p	n
1 Systems Thinking: System Concepts	0.345	0.003	73
2 Systems Thinking: Super System Capability Issues	0.492	0.000	61
3 Systems Thinking: Enterprise and Technology Environment	0.471	0.000	58
4 Determining and Managing Stakeholder Requirements	0.551	0.000	49
6 Systems Design: Concept Generation	0.285	0.022	65
8 Systems Design: Functional Analysis	0.340	0.015	51

5.4 Evaluation of the selection method

The purpose of this section is to evaluate the selection method and the validity of $\mathbf{H_1}$:

A candidate's SE competence potential can be predicted from personality preferences, cognition, and values (the SE profile).

The reader will recall that in section 4.4.2.2, the first k_{com} measures with the least variance were defined as being common for high competence engineers. The question of how to select k_{com} was left to be answered from the psychological and SE assessment data. This will be addressed in the next section. Evaluation results of the potential identification algorithm and formal testing of $\mathbf{H_1}$ is addressed in section 5.4.2.

5.4.1 Most common measures and selection of the number of common measures

One of the challenges in presenting the profiles for the 17 competencies (21 SE competencies less the 4 competencies where DPSS does not have high competence engineers), was in presenting the results. The full set of results in Appendix G are summarised here. The 20 most common measures (out of a total of 60 measures for the 15FQ+, CPP and VO together) of high competency engineers over the 17 SE competencies are (with 1 having the highest frequency of occurrence, and 20 being lower):

1. **Metaphoric**: The tendency to view a situation abstractly and symbolically, as well as to combine elements of information in novel ways to formulate analogies and metaphors;
2. **Green** (The need for spiritual growth and harmony, relationships. Feelings are more important than achievement) **reject;**
3. **Low/High Intellectance**: confidence in one's intellectual abilities;
4. **Analytical**: Characterised by a detailed, rule-orientated and systematic approach with an emphasis on precision and comparative behaviour;
5. **Integration** (cognitive competency): Synthesis of ambiguous/discrepant/ conflicting information – creating meaning;
6. **Purple** (The need to protect and be protected, to belong) **accept;**
7. **Green** (The need for spiritual growth and harmony, relationships. Feelings are more important than achievement) **accept;**
8. **Turquoise** (The need to experience, everything is interconnected - this value system depicts a holistic type of thinking) **accept;**
9. **Hard-headed – Tender minded**: Utilitarian, tough-minded, lacking aesthetic sensitivity vs. sensitive, aesthetically aware and sentimental;
10. **Informal – self-disciplined**: lax, follows urges, respect is earned vs. fastidious, maintaining social standing;
11. **Impulsive**: An impulsive style (being fast and inaccurate) is associated with inadequate pacing and with emphasis on the speed of problem-solving;
12. **Integrative** (cognitive style): The tendency to combine, synthesise and structure information as it is encountered in order to makes sense of it;
13. **Intuitive**: This approach usually, but not necessarily, involves the careful exploration of a problem and repetitive checking behaviour to meaningfully interpret complex information at a 'gut' level. It may result in the conceptualisation of creative ideas and/or unverified assumptions;
14. **Random**: Usually characterised by a vague and unsystematic, trial-and-error approach to problem-solving. Inadequate task orientation and insufficient goal direction are often present;
15. **Purple** (The need to protect and be protected, to belong) **Reject**;
16. **Blue** (The need for order and structure, to conform and be righteous) **Accept**;

17. **Blue Reject**;
18. **Accommodating – Dominant**: co-operative and obliging vs. assertive, competitive and aggressive
19. **Pragmatic** (cognitive competency): Practical orientation – "will it work in practice?" Determining relevance in structured contexts; and
20. **Exploration** (cognitive competency): Effectiveness, depth and width of exploration.

The measures listed above are common to 80% of the 17 competencies. *Integration* (cognitive competence), *integrative* (cognitive style), and analytical were expected. The logical style features at 25th position although it was expected to be higher since it is the most preferred cognitive style of engineers (Appendix F, section F.1.2). Importantly, seven of the measures in the above list relate to values, namely Green accept and reject, Purple accept and reject, Turquoise accept, and Blue accept and reject.

However, summarising the data in this way means that some of the quantitative data about the level at which each measure is required is lost. For example, the impulsive style is least preferred out of all the cognitive styles for Determining and Managing Stakeholder Requirements. Thus because the impulsive style is one of the 20 common measures does not mean it should be a preferred cognitive style. Levels of each measure vary with each SE competency (Appendix G).

The question that needs to be answered is: How many common measures should be selected as predictors of SE competence? In order to answer this question, the following process was followed:

- For each competence, all the high competence engineers were identified, the first k_{com} common measures determined and the mean vector of these common measures calculated according to section 4.4.2.2;
- For each competence all the remaining engineers, i.e. awareness and supervised practitioner, were ranked in terms of SE potential using an inner product norm and a L_2 distance norm for comparison (the norms and ranking described in section 4.4.2.2) over all SE competencies where DPSS had high competence;
- For each of the norms two graphs were plotted:

- The number of engineers vs. the number of potential SE competencies per engineer. These results are plotted in Figure 29 (p. 102) for an inner product norm and Figure 31 (p. 104) for a L_2 distance norm. The three traces indicate the number of common measures, $k_{com} = 10$, 20, 30. These graphs show SE competence prediction statistics which can be compared against high competence engineers; and
- Standard deviation of the number of potential SE competencies per engineer vs. the number of common measures, k_{com}. These results are plotted in Figure 30 (p. 103) for an inner product norm and Figure 32 (p. 105) for a L_2 distance norm. These graphs give an indication of how to select the number of common measures.

Importantly the *trend* for the number of engineers is inversely proportional to the number of potential SE competencies per engineer, for both norms. *This follows the trend for engineers with high levels of SE competence* seen in Figure 28 (p. 82). The number of engineers with higher numbers of potential SE competencies increases as the number of common measures increases from 10 to 30. With this small sample it is difficult to show that this is statistically significant.

Graphs for both norms exhibit variation, with the L_2 distance norm having more variation than the inner product norm. This is confirmed by the standard deviation graphs for both norms, where the trend is increasing standard deviation as a function of the number of common measures, k_{com}. This increasing standard deviation is expected since more and more measures are being adding, each with equal weighting and increasing variance. However it is the local minima that are of interest because they allow more common measures for the same standard deviation. The standard deviation of the number of potential SE competencies per engineer for inner product norm has a number of local minima at 5, 8, 15, 21 etc. As discussed earlier, small numbers of common measures may only indicate threshold measures. Thus 15 to 21 common measures could be a good choice. The small sample means there is more variation and such decisions are therefore more difficult.

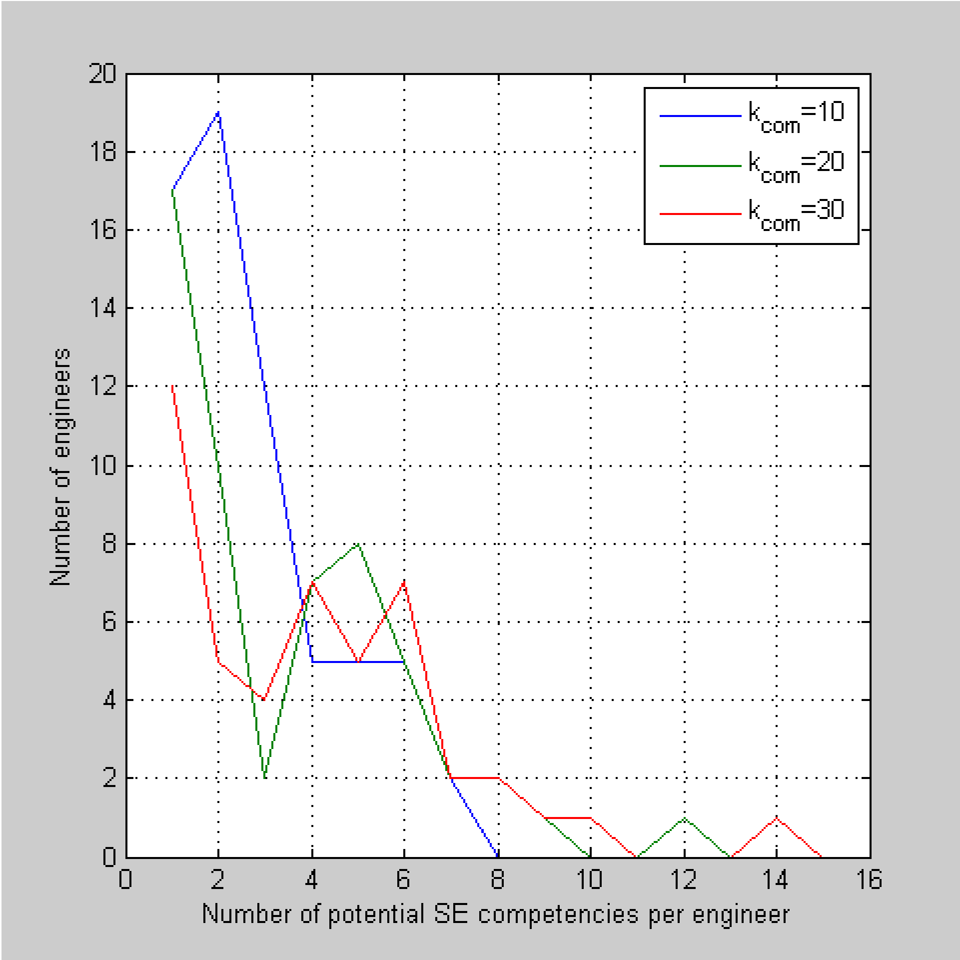


Figure 29 Number of engineers vs. the number of potential SE competencies per engineer. The three traces indicate the number common measures, 10, 20, and 30 for an inner product norm.

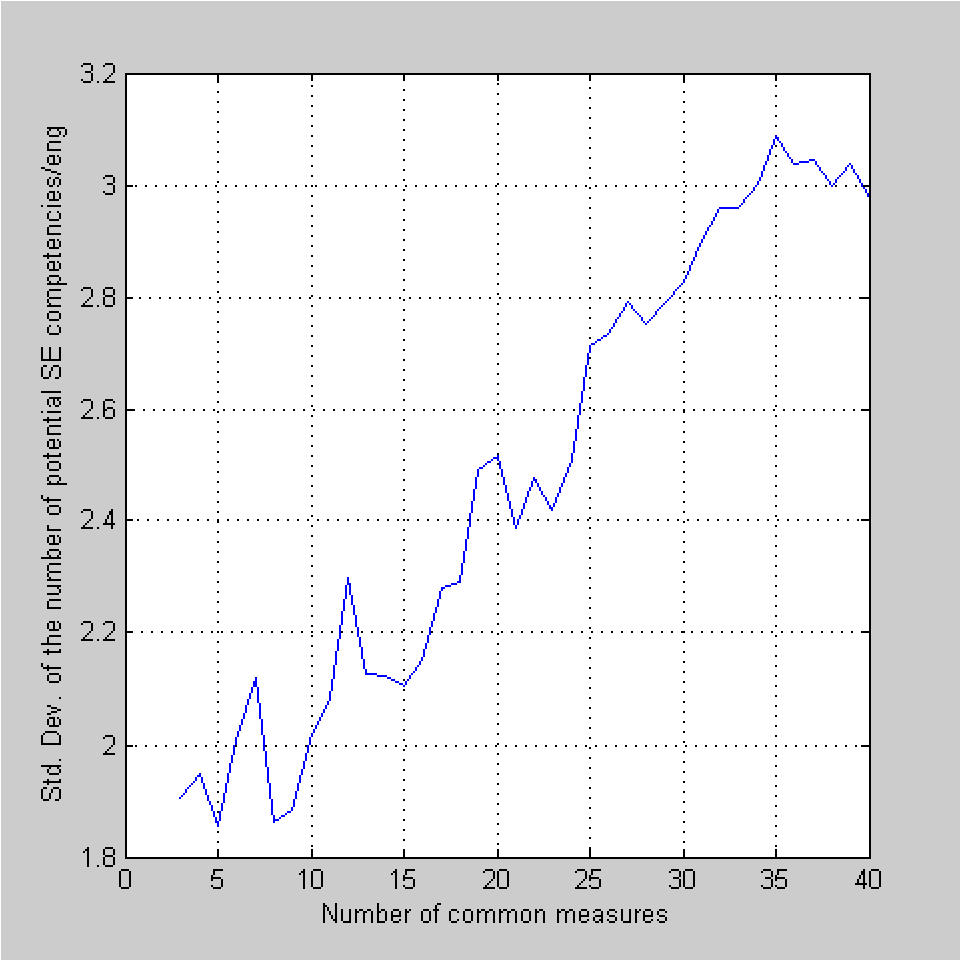


Figure 30 Standard deviation of the number of potential SE competencies per engineer vs. the number of common measures for an inner product norm.

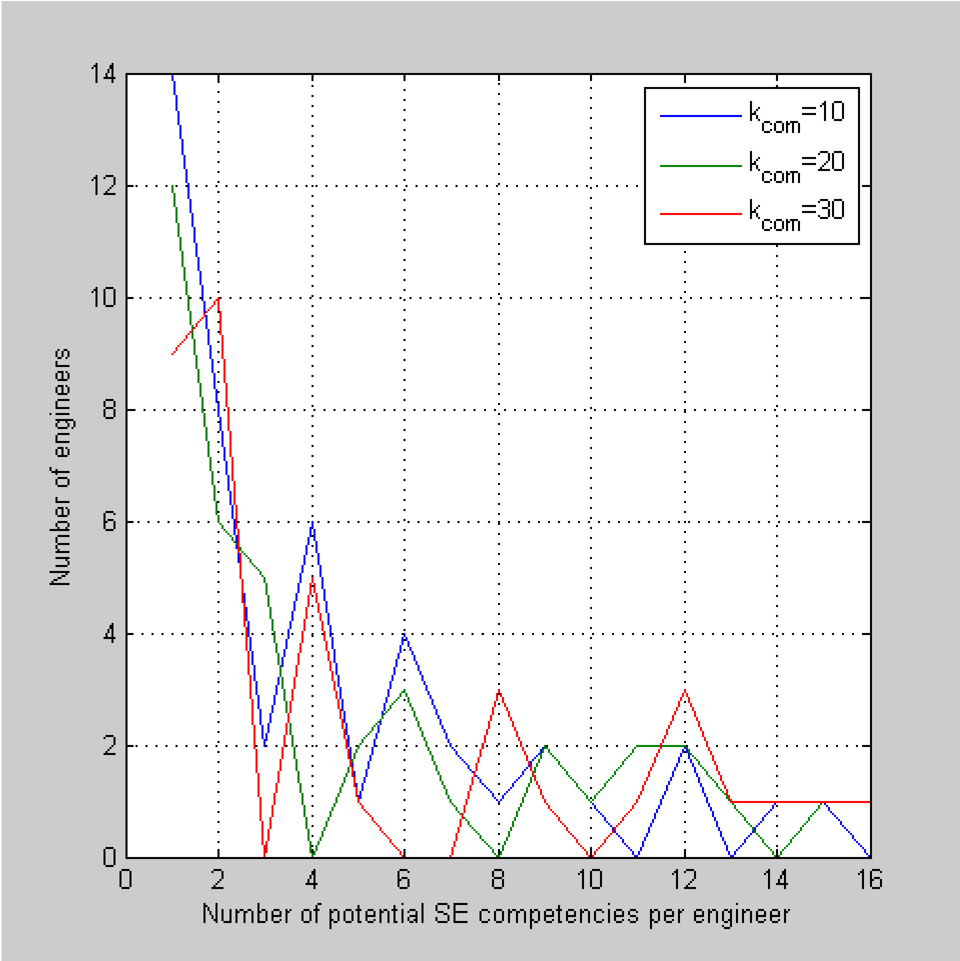


Figure 31 Number of engineers vs. the number of potential SE competencies per engineer. The three traces indicate the number common measures, 10, 20, and 30 for an L_2 distance metric.

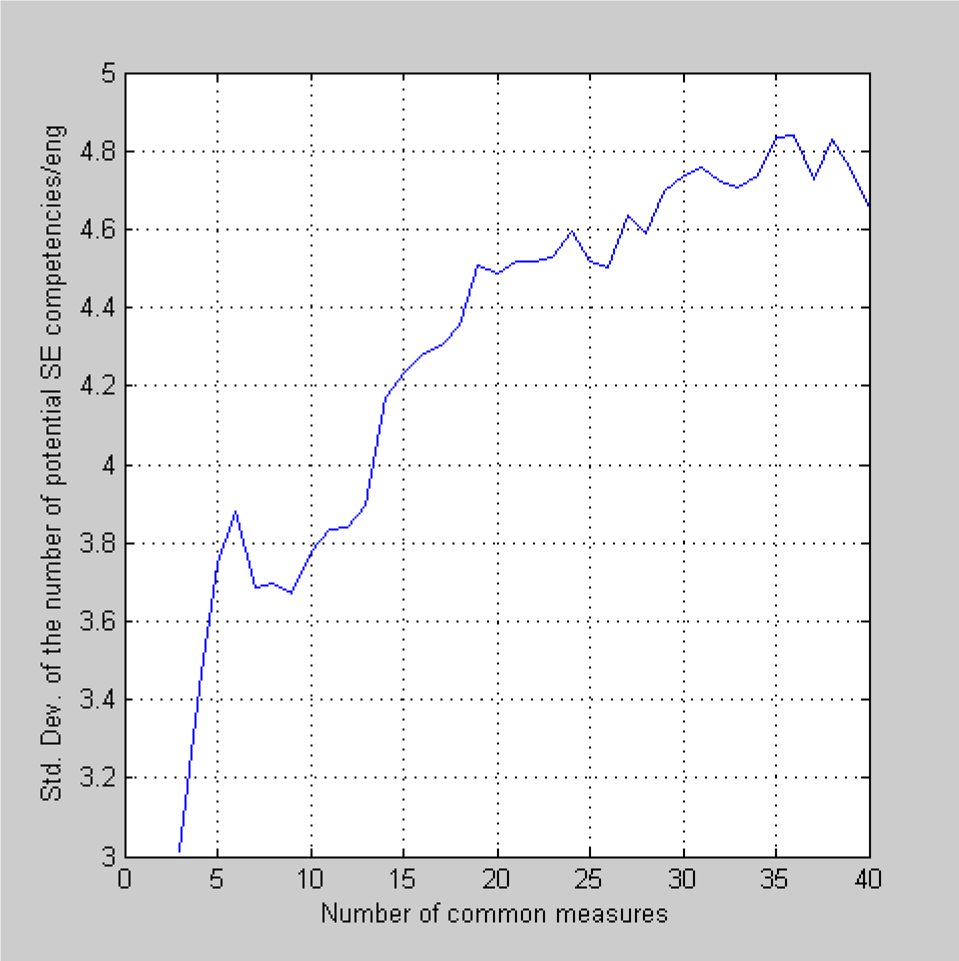


Figure 32 Standard deviation of the number of potential SE competencies per engineer vs. the number of common measures for an L_2 distance metric.

Practically, the strategy should be to start development of engineers with that have the largest number of potential SE competencies. The development is not within the scope of this work but has been considered (Gonçalves, 2010). In the next section formal validation of the potential identification algorithm is examined.

5.4.2 Potential identification algorithm results

Evaluation of the selection method for candidate systems engineers is conducted using concurrent cross-validation for SE competencies. Where an assessed SE competence has more than four high competence engineers, the data are organised in random order and split into two equal sets. The first set is used to estimate the mean, sorted in ascending variance for each measure while the similarity metric is calculated on the second data set. The process is applied again just reversing the two data sets. Such a validation process yields two similarity estimates. If the assessments have any predictive power, the similarity metric will have the same distributions. The two samples will invariably have variation in them. Is the variation due to chance or do the two samples have different distributions? Complicating factors are that the similarity metric is not linear and the data probably not normally distributed. This question above can be answered using a non-parametric analysis (distribution free) of variance (ANOVA), devised by Kruskal and Wallis (Kruskal & Wallis, 1952). The Kruskal-Wallis test was applied to values of k_{com} = 3,…,40 at the 5% significance level. The results are summarised in Table 34 for an inner product norm and a L_2 distance norm. The full set of inner product norm results are presented in Table 35, since these are the worst case. In this table *p* is the significance level of the Kruskal and Wallis test.

Where there was enough data, the results are valid with the exception of Super system capability and to a lesser extent modelling and simulation. For super system capability and k_{com} < 16 none of the results are valid. It is not clear what the cause is.

Table 34 Summary of concurrent cross-validation results, summed over k_{com} and SE competencies

Similarity measure	H_1 Accept Count	Percent valid
Inner product normalised by an L_2 norm	310	90.6%
L_2 distance norm	330	96.5%

Table 35 Validity of H1 for each of the SE competencies as a function of k_{com} for an inner product norm. H_1 accepted = A, H_1 rejected = R at $p<0.05$.

k_{com}	System Concepts	Super System Capability	Enterprise & Technology Environment	Determining and Managing	Concept Generation	Functional Analysis	Interface Management	Modelling & Simulation	System Integration & Verification
3	A	R	R	A	R	A	R	R	A
4	A	R	R	A	A	A	R	A	A
5	A	R	R	A	A	A	R	A	A
6	A	R	A	A	A	A	R	A	A
7	A	R	A	A	A	A	A	A	A
8	A	R	A	A	A	A	A	A	A
9	A	R	A	A	A	A	A	A	A
10	A	R	A	A	A	A	A	A	A
11	A	R	A	A	A	A	A	A	A
12	A	R	A	A	A	A	A	A	A
13	A	R	A	A	A	A	A	R	A
14	A	R	A	A	A	A	A	R	A
15	A	R	A	A	A	A	A	R	A
16	A	A	A	A	A	A	A	R	A
17	A	R	A	A	A	A	A	R	A
18	A	R	A	A	A	A	A	A	A
19	A	A	A	A	A	R	A	A	A
20	A	A	A	A	A	A	A	A	A
21	A	A	A	A	A	A	A	A	A
22	A	R	A	A	A	A	A	A	A
23	A	A	A	A	A	A	A	A	A
24	A	A	A	A	A	A	A	A	A
25	A	A	A	A	A	A	A	A	A
26	A	A	A	A	A	A	A	A	A
27	A	A	R	A	A	A	A	A	A
28	A	A	A	A	A	A	A	A	A

k_{com}	System Concepts	Super System Capability	Enterprise & Technology Environment	Determining and Managing	Concept Generation	Functional Analysis	Interface Management	Modelling & Simulation	System Integration & Verification
29	A	A	A	A	A	A	A	A	A
30	A	A	A	A	A	A	A	A	A
31	A	A	A	A	A	A	A	A	A
32	A	A	A	A	A	A	A	A	A
33	A	A	A	A	A	A	A	A	A
34	A	A	A	A	A	A	A	A	A
35	A	A	A	A	A	A	A	A	A
36	A	A	A	A	A	A	A	A	A
37	A	A	A	A	A	A	A	A	A
38	A	A	A	A	A	A	A	A	A
39	A	A	A	A	A	A	A	A	A
40	A	A	A	A	A	A	A	A	A

5.5 Discussion

The conclusions of the literature review (section Chapter 2) indicated that systems engineers should be **logical and analytical**. The results of the CPP in appendix F.1.2 indicate that:

- 75% of engineers have an analytical style as most, second or third most preferred cognitive style. Over 70% of engineers are at the highest end of the analytical competence scale;
- 74% of engineers have a logical style as most, second or third most preferred cognitive style. Over 65% of engineers are at the highest end of the logical competence scale;
- 96% of engineers have an impulsive style as the second least or least preferred cognitive style, however; and
- 90% of engineers have a random style as the second least or least preferred cognitive style.

Engineers are thus largely logical and analytical when solving a new problem. Logical and analytical thinking are threshold competencies for engineers. It is clear from the results above that impulsive and random thinking are indicators of risk for engineering in general.

Based on the work of Frank and others, the need for systems thinking in the context of SE is not in question (Frank, 2006). But the **Super System Capability Issues** competence produced unexpected results in the correlation analysis and the results from the concurrent cross-validation are not valid for all common measures tested. Systems thinking can be measured with more mature tools like CPP using integrative, integration and holistic measures. The yellow value system also indicates systems thinking.

The results also show that there are few systems engineers who have high competence in eight or more SE competencies. It is difficult to find engineers that have all 21 SE competencies. Instead, the various SE competencies need engineers with profiles that match each of the required SE competencies (refer to Appendix G). Hence there should be a move away from the notion of a "super systems engineer". By creating SE teams, individual engineers bring various SE competencies which together satisfy the project's overall SE needs.

Correlation can be used to identify relationships between psychological and SE competency dimensions. When validating the correlation results on the 21 SE competencies against results in the literature (section 2.5), one of the issues is that a one to one mapping does not exist. Building on Table 7, which shows the personality and cognitive characteristics of systems engineers found in the literature mapped to the assessment measures, the results are added as shown in Table 36. Some results were confirmed but in other areas, contradictory results were found. For example, the literature indicates systems engineers are innovative. However, engineers with high competence in System Integration and Verification were found to be conventional not radical.

Based on the literature, systems engineers were expected to be sociable, measured as empathic and group oriented on the 15FQ+, but DPSS engineers with high competence in managing stakeholder requirements, functional analysis and enterprise integration were found to be aloof or distant. Engineers with high competence in architectural design were self-sufficient rather than group-oriented.

Thus observations in the literature are not generally true for all 21 SE competencies. Since the existing literature treats SE competence as a whole, it cannot be compared directly against this work which considers SE competence as consisting of 21 sub-competencies. It is thus not unreasonable to expect variations.

Table 36 Mapping of SE preferences to assessment measures and results

Personality Preference	**Measured via 15FQ+**	**Results**
1. Sociable, good communicator	fA: *Empathetic*; fF: *Enthusiastic*; fH: *Socially bold*; fQ2: *Group orientated*	Managing Stakeholder Requirements – Distant not empathic Architectural Design – Self-sufficient not group oriented. Systems Design: Functional Analysis – Distant/aloof not empathic. Enterprise Integration – Distant/aloof not Empathic
2. Intelligent – intellectual curiosity	fB: *Intellectance*	No correlation found
3. Forward (willing to ask challenging questions, speak mind)	fE: *Dominant*; fN: *Direct*	Systems Design: Interface Management – dominant and direct
4. Ambitious – hardworking, dedicated, persevering	fG: Conscientious; Attitude to work scale as Persevering, dutiful, solution focused, conscientious and conforming	No correlation found
5. Innovative	fM: *Abstract*; fQ1:*Radical*; Attitude to work scale as Absent-minded, lax, disregards rules and obligations, unconventional	Modelling and Simulation fM: Abstract System Integration and Verification – conventional not radical System design: System Robustness - Concrete
6. Flexible and adaptable – comfortable with ambiguity	fQ1: *Radical*; fG: *Expedient*	No correlation found
7. Self-motivated (achievement motivation), able to motivate others	Not clear that this is measured.	Not applicable
8. Assertiveness	fE: *Dominant*	Managing Stakeholder

Personality Preference	Measured via 15FQ+	Results
		Requirements
9. Coordination skills	Not clear that this is measured.	Not applicable
10. Persuasive	fE: *Dominant*	Managing Stakeholder Requirements
11. Patient	fQ4: *Composed*	No correlation found
12. Rational	fI: *Hard-headed*; fQ4: *Composed*	Validation – Hard-headed
13. Responsible	fG: *Conscientious*	No correlation found
14. Confident	*f*H: *Socially bold*; fO: *Confident*	Architecture Design - Retiring as opposed to Socially bold Systems Design: Interface Management – Confident Lifecycle Process Definition – Confident
15. Organized	fG: *Conscientious*	No correlation found

Cognition	Measured via CPP	Results
1. Big picture thinking (understanding the whole without getting stuck on details)	Cognitive styles: Holistic	Super Systems Thinking
2. Systems thinking (understand relations between parts of a system)	Cognitive styles: Integrative / Cognitive Competencies: integration	12th and 5th most common measures
3. Tolerance for ambiguity	Cognitive Competencies: Structured	No results
4. Concept generation	Cognitive styles: Intuitive; Cognitive competencies: verbal abstraction may be relevant; Current level of work	Intuitive – 13th most common. Metaphoric – most common.

5. Innovative	Not clear that this is measured by CPP.	Not applicable
6. Strategic	Current level of work	No results
7. Analytical	Cognitive styles: Analytical; Cognitive competence: Analytical	4^{th} most common measure. Generally high levels of competence amongst engineers.
8. Logical	Cognitive styles: Logical; Competencies: Logical reasoning.	Most preferred cognitive style by engineers and generally high levels of competence.

The funnel model

The purpose of the selection method is to identify candidate systems engineers most likely to develop SE competencies. The funnel model (Figure 33) categorises the psychological measures used in the selection method according to their variability and addresses the question of sensitivity of measures posed in Chapter 3. The variability of the psychological measures illustrated in Figure 33 is notional and is intended to support the discussion only – the actual variance is shown in Appendix G. Three categories of measures based on variance and corresponding use of these categories have been identified.

The first is the risk category, largely based on the CPP, which indicates a high probability that the candidate is unlikely to develop SE competencies. This identifies outlier engineers as compared to DPSS engineers and information based on CPP studies. Measures in the risk category are essentially the same as Spencer and Spencer's threshold competencies (Spencer & Spencer, 1993). Threshold competencies are basic characteristics that everyone needs to be minimally effective. Threshold competencies are only of concern in as far as candidates do *not* have the competency, i.e. risk of not being effective in general and not developing as a systems engineer specifically. For example, the impulsive style is least preferred out of all the cognitive styles for Determining and Managing Stakeholder Requirements and is thus a threshold competence in the risk category.

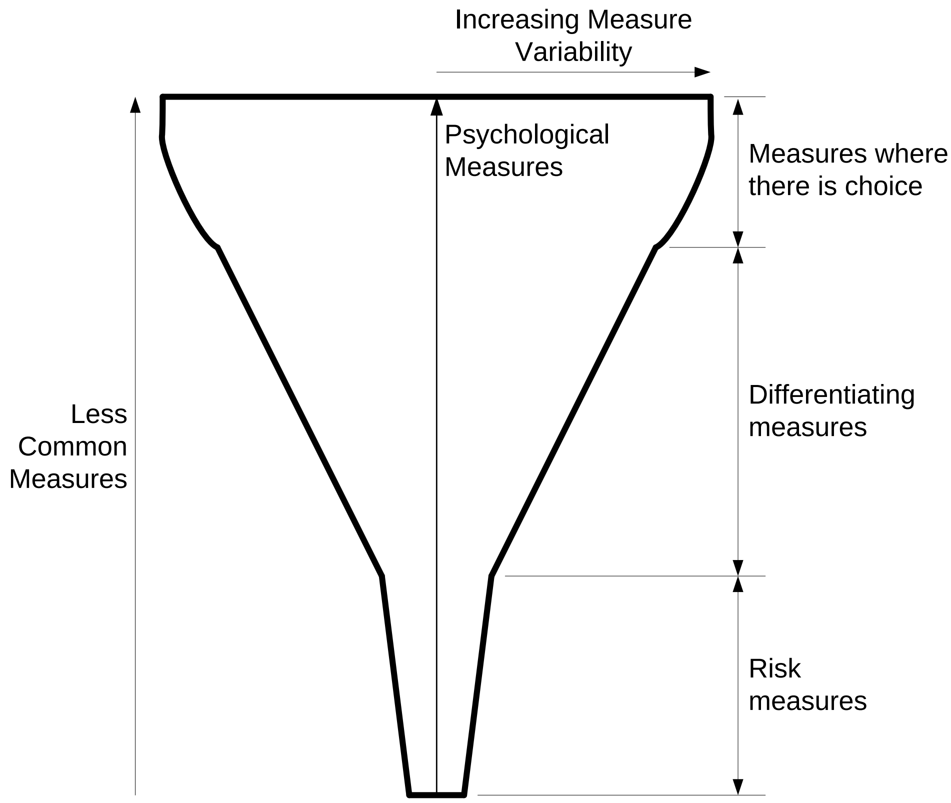


Figure 33 Funnel model of screening

Next are the differentiating measures used to identify SE potential. Spencer and Spencer refer to these as differentiating competencies. Finally, there are measures where there is a choice – a category not explicitly defined by Spencer and Spencer. The measures where there is choice can be used to build teams that are stronger in terms of other characteristics, for example, interpersonal characteristics or leadership.

Similarity of psychological profile

Using a similarity measure requires little data even with a large number of measures. But the approach is not without risk: it can drive all systems engineers to have a similar and narrow range of characteristics. Schneider's Attraction-Selection-Attrition framework (Schneider, et al., 1995) suggests that people are attracted to an environment, selected and stay in an organisation based on that organisation having a similar "personality" profile (Schneider, 1987). People in the organisation who do not have a similar profile leave the organisation over time, creating a profile that has less variation within the organisation. Thus based on this theory, organisations are likely to have similar profiles anyway. One of the important mitigation factors in this research was formulating SE as a set of 21 output competencies. Since these output competencies are likely to have different input competencies, it will drive some variety. In any case, organisations do not only employ systems engineers, but also other engineers and support staff.

SE: a singular competence or 21 competencies?

The final question that must be answered is: Are there differences in the psychological profile that justify looking at SE as different competencies? The selection algorithm uses a vector of measures that are most common to high competence systems engineers based on lowest measure variance. Of these common measures, only k_{com} are selected out of 60 measures in total, which reduces the dimensionality of the psychological space. For each of the SE competencies the measures that were common were different for each of the SE competencies (listed in Appendix G where there was enough data). Thus for each SE competence the algorithm is “looking” in different parts of the psychological measure space. Even if there is some correlation between individual measures (the highest found in Appendix F.2 being 0.33), *there are grounds to say that the profiles for the SE competencies are different*.

Chapter 6 Conclusions and future work

6.1 Introduction

The purpose of this chapter is to close the circle by showing how the problem of selecting candidate systems engineers was solved.

This chapter will summarise the important results and the selection method that has been developed while identifying the limitations that apply to these results. The main conclusions and a summary of the contributions of this work are presented. However as an exploratory study, many opportunities for future work remain – these are listed in section 6.5.

6.2 Summary and limitations

The evaluation of the selection method was conducted by testing the hypothesis $\mathbf{H_1}$, formulated from the research question in Chapter 3 as:

A candidate's SE competence potential can be predicted from personality preferences, cognition, and values (the SE profile).

$\mathbf{H_1}$ is *accepted* for the following SE competencies:

- System Concepts;
- Enterprise & Technology Environment;
- Determining and Managing Stakeholder Requirements;
- Concept Generation;
- Functional Analysis;
- Interface Management;
- Modelling & Simulation; and
- System Integration & Verification.

The same hypothesis is accepted when the number of common measures is greater than 19 for the SE competency Super System Capability Issues. There is insufficient data to make a finding regarding the remainder of the 21 SE competencies. *These results are however based on a single organisation, DPSS, and the demographics are skewed towards white males (Table 10, p. 65).*

The selection method, as developed in this research, is shown in Figure 34. It is used as part of the process to address the shortage of systems engineers originally illustrated in Figure 1, F.5. Assess candidate systems engineers on 15FQ+, CPP and VO (F.5.1, F.5. 2, and F.5.3). The potential identification algorithm is applied to the results of these assessments (F.5.4, described in 4.4.2.2). At the same time, oversight must be maintained in terms of ethics, supplying business needs through the development of engineers subject to transformation requirements and resource constraints (F.5.5).

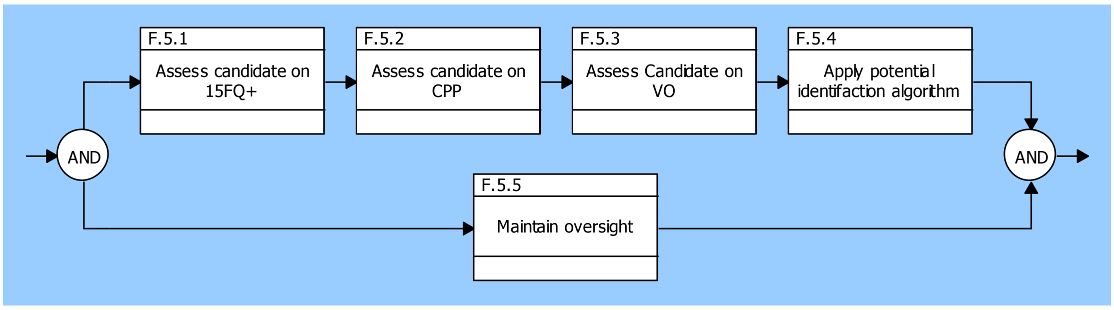


Figure 34 Selection method for candidate systems engineers

6.3 Conclusions

The purpose of the selection method is to help identify SE potential in younger, less experienced engineers. Assessing competence on the 21 SE competencies provides new insights which may tap into a broader pool of engineers. However, progress in understanding all 21 SE competencies is limited by the availability of data. Ironically, separating SE into 21 competencies actually yields more data to work with because the number of systems engineers (i.e. an engineer with 8 or more competencies) is less than the number of engineers with single SE competence. This is supported by the important finding that the number of engineers with SE competence at practitioner or expert level is inversely proportional to the number of SE competencies.

Specific values (high or low number) on a *combination of psychological measures* is useful for *predicting high competence and these will vary from SE competency to SE competency.* These measures are also different for management vs. technical competencies. Thus, psychological measures cannot be identified for SE *as whole* as has been done in some previous literature (Marais, 2004, Toshima, 1993). Treating SE as a whole or singular competency can confound the experiment because different psychological measures are required for different SE competencies.

The literature reports that systems engineers should be logical, analytical (Marais, 2004). The data indicates that this is true of most engineers: individual characteristics alone are not useful for discriminating between systems engineers and other engineers – these are just *threshold competencies*. The literature relating to screening systems engineers indicates desirable characteristics but does not normally report on characteristics that a systems engineer *should not* have, e.g. an impulsive cognitive style. Since measurable quantities are being used, a profile on both desirable and "undesirable" characteristics can be determined. Consideration must be given beyond individual measures to combinations of measures and levels on these. Cognitive constructs are very useful for reducing risk for development and appointment, based on a sample of engineers as a baseline (e.g. high preference for logical thinking, but low preference for impulsive thinking). Beyond risk, measures that differentiate SE competence and those where there is choice, based on variance, were identified.

To the researcher's knowledge, *values have not been considered in the literature* for SE screening. Values, as assessed by the Value Orientations assessment, are useful for predicting high competence on at least 11 SE competencies. For many of the SE competencies, it is about what is not rejected rather than what is accepted. Therefore, certain measures are negative indicators, which is an important finding.

However, there is also a risk of replicating or perpetuating organisational characteristics (such as culture or personality) which may be less than effective. For example, the results indicated that DPSS engineers with high competence in Determining and Managing Stakeholder Requirements were distant, dominant and reject the Green value system (not concerned with harmony and relationships). Recruiting more engineers that have exactly the same profile may pose risk to developing a good set of requirements. Assessment can be used as a tool for SE development and more broadly organisational development by detecting these anomalies and managing change to a new state.

Correlation between years of SE experience and level of SE competence could only be shown for six of the SE competencies. The highest correlation (55%) was for Determining and Managing Stakeholder Requirements. However, the notion that the number of years of SE experience leads to high competency should be examined. This is the situation because of a lack of proper development for systems engineers in South Africa and not because of some fundamental limitation. There were systems engineers with many years of "SE experience" who had not reached practitioner level on various SE competencies.

An important insight has emerged for *forming teams*. Because the various SE competencies require different profiles, there are few “super systems engineers”. There are however many more engineers with two or three SE competencies. Thus the required variety of SE competence for the project is obtained through a team rather than as a single systems engineer.

6.4 Summary of contributions

The first contribution of this thesis is the correlation model of interrelations between single psychological characteristics, namely, personality, cognition, and values on the one hand, and the *21 SE competencies* on the other. Previous work looked at SE as a whole. *No evidence was found in this research that individual values have been investigated previously in the context of SE competence - this is therefore an original contribution.* This research used commercially available assessments adapted for use in South-Africa, where much of the available literature is based largely on assessments from the United States of America. While cognition has been considered before, the sophisticated tools available today for assessing cognition have not been evaluated in this context.

Secondly, extending the basic correlation model, *a selection method for candidate systems engineers has been developed and validated as part of this study*. This model allows for ranking of candidate systems engineers based on similarity to high competence engineers using a *non-linear combination of psychological measures* in the context of a small sample.

Beyond these main contributions, there are a number of smaller, but yet important contributions:

- An *assessment of the level of SE competence on the 21 INCOSE SE Competencies* framework at DPSS, which was previously unknown, was important to DPSS management. This led to the finding that the number of engineers with SE competence at practitioner or expert level is inversely proportional to the number of SE competencies;
- The gathering and analysis of the literature across a range of disciplines from psychology, engineering, management and research methodology and the synthesis of a competence model from the literature;
- The Funnel model summarises the results in a way that extends the work of Spencer & Spencer (1993);

- A demonstration of the use of design science research as a research methodology in solving the selection problem, which has seen very limited use in psychology. Knowledge was acquired by *doing design*. On the one hand this research was conducted with a specific purpose in mind, i.e. the design of a selection method. On the other hand, there was risk regarding the outcome;

The contribution of this thesis lies in-between the disciplines of engineering, psychology and management rather than *in* any of these contributing disciplines *per se*.

6.5 Future research

There are a considerable number of suggestions for future work that flow from this exploratory research. The focus will be on future research as opposed to DPSS specific recommendations. A number of these suggestions arise from working across disciplines. The recommendations for future research are:

- Follow up on Frank's CEST tool to see if there is a English language questionnaire and establish its reliability and validity;
- A model of psychological attributes was presented in Figure 9 (p. 20), but some were not feasible in the context of this research, such as interests and attitudes. More focused investigations into these could be the subject of future research;
- The Super System Capability Issues competence produced unexpected results. The source of these unexpected results needs to be investigated;
- Reliability and validity of SE competency framework needs to be assessed. Given that SE is not a mature discipline, this will be a challenge and most probably an ongoing effort;
- Develop a research design to *increase the criterion sample size and in a way that better matches the population demographics*. As indicated care must be taken to mitigate any confounding variables;
- Selecting the number of common measures could be improved by considering the use of the Akaike information criterion (Sakamoto, et al., 1986);
- The focus of this research has been on the individual. While this is an obvious starting point, future work should also focus on the team and team level SE competencies;

- Cross-correlation between the various psychological assessments (demonstrated in Appendix F) indicates an opportunity for further investigation of sub-space methods (Scharf, 1991) and structural equation modelling (Kelloway, 1995). This however, also depends on a larger criterion sample;
- Structural equation modelling (Kelloway, 1995), an analysis technique used in psychology, is not commonly known in engineering and could potentially be used in such fields as pattern recognition. The usefulness of this technique in an engineering context should be evaluated;
- Further development and refinement of the selection method by means of a subsequent iteration of the DSR methodology describes in section 4.2.1 should be considered. This includes ongoing collection of data and evaluation of the selection method (as presented in Appendix C) would support further use;
- Since the CSIR Assessment Centre will be involved in performing assessments for selection, a tool for day-to-day use would enhance usability and allow transfer of the tool to the assessment centre; and
- The focus of this research has been on the development of SE competencies. There is utility in developing a selection method for recruitment where the concern is about performance rather than competence.

Chapter 7 References

Ackerman, P. & Heggestad, E., 1997. Intelligence, personality, and interests: evidence for overlapping traits.. *Psychological bulletin,* 121(2), p. 219.

Anon., 1998. Employment Equity Act, No. 55 Of 1998. *Government Gazette,* 400(19370).

Anon., 2006. Ethical Rules Of Conduct For Practitioners Registered Under The Health Professions Act, 1974. *Government Gazette,* Volume 29079.

Bandura, A., 1993. Perceived self-efficacy in cognitive development and functioning. *Educational psychologist,* 28(2), pp. 117-148.

Barbuto, J. & Richard, W., 1998. Motivation sources inventory: Development and validation of new scales to measure an integrative taxonomy of motivation. *Psychological Reports,* 82(3), pp. 1011-1022.

Beck, D. & Cowan, C., 2002. *Spiral Dynamics: Mastering Values, Leadership, and Change: Exploring the New Science of Memetics.* 5 ed. s.l.:Blackwell Publishing.

Brannick, M. & Levine, E., 2002. *Job analysis: Methods, research, and applications for human resource management in the new millennium.* s.l.:Sage Publications, Inc.

Caplan, B., 2003. Stigler-Becker versus Myers-Briggs: why preference-based explanations are scientifically meaningful and empirically important. *Journal of Economic Behavior and Organization,* 50(4), pp. 391-405.

Cappelli, P. & Crocker-Hefter, A., 1996. Distinctive human resources are firms' core competencies. *Organisational Dynamics,* 24(3), p. 6 – 22.

Capretz, L., 2003. Personality types in software engineering. *International Journal of Human-Computer Studies,* Volume 58, pp. 207-214.

Charette, R., 2005. Why software fails. *IEEE spectrum,* 42(9), p. 36.

Churchman, C., 1971. *The Design of Inquiring Systems: Basic Concepts of Systems and Organization,.* s.l.:Basic Books, New York, NY..

Cronbach, L. & Gleser, G., 1953. Assessing similarity between profiles.. *Psychological bulletin,* 50(6), p. 456.

Davis, D. C., Beyerlein, S. W. & Davis, I. T., 2005. Development and Use of an Engineer Profile. *Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition.*

Deist, F. L. & Winterton, J., 2005. What is competence?. *Human Resource Development International,* 8(1), pp. 27-46.

Duda, R. & Hart, P., 1973. *Pattern classification and scene analysis..* s.l.:New York.

Eccles, J. & Wigfield, A., 2002. Motivational beliefs, values, and goals. *Annual review of psychology,* 53(1), pp. 109-132.

Edwards, J., 1993. Problems with the use of profile similarity indices in the study of congruence in organizational research. *Personnel Psychology,* 46(3), pp. 641-665.

Edwards, J., 1994. The study of congruence in organizational behavior research: Critique and a proposed alternative. *Organisational Behaviour and Human Decision Processes,* Volume 58, pp. 551-100.

Estefan, J. A., 2008. Survey of Model-Based Systems Engineering (MBSE) Methodologies. *Incose MBSE Focus Group,* Volume 25.

Flanagan, J., 1954. The critical incident technique.. *Psychological bulletin,* 51(4), p. 327.

Foxcroft, C. & Roodt, G., 2005. *An introduction to Psychological Assessment in the South African context.* s.l.:Oxford University Press Southern Africa (Pty) Ltd.

Frank, M., 2002. Characteristics of engineering systems thinking - a 3D approach for curriculum content. *Systems, Man and Cybernetics, Part C, IEEE Transactions on,* Volume 32, pp. 203-214.

Frank, M., 2006. Knowledge, abilities, cognitive characteristics and behavioral competences of engineers with high Capacity for Engineering Systems Thinking (CEST). *Systems Engineering,* 9(2), pp. p. 91-103.

Frank, M. & Elata, D., 2005. Developing the capacity for engineering systems thinking (CEST) of freshman engineering students. *Systems Engineering,* 8(2), pp. 187-195.

Frank, M., Zwikael, O. & Boasson, M., 2007. Jobs Requiring a Capacity for Engineering Systems Thinking (CEST): Selection Using an Interest Inventory. *Project Management Journal,* 38(3), p. 36.

Garavan, T. & McGuire, D., 2001. Competencies and workplace learning: some reflections on the rhetoric and the reality. *Journal of Workplace learning,* 13(4), pp. 144-164.

George, M. & Jones, R., 1997. Experiencing work: Values, Attitudes and Moods. *Human Relations,* Volume 50.

Gonçalves, D., 2010. A Practice-based Systems Engineering Programme. *Proceedings of the SA Chapter conference of the INCOSE.*

Gonçalves, D., 2010. Screening Candidate Systems Engineers: Identifying Potential. *Proceedings of the EuSEC.*

Gonçalves, D. & Britz, J., 2009. Screening Candidate Systems Engineers: A Research Design. *Proceedings of the International Symposium of the INCOSE.*

Gonçalves, D. & Britz, J., 2010. Screening Candidate Systems Engineers: Exploratory Results. *Proceedings of the CSIR Conference.*

Gonçalves, D. P., 2008. Developing Systems Engineers. *Proceedings of PICMET.*

Goodman, S. & Svyantek, D., 1999. Person-organization fit and contextual performance: Do shared values matter. *Journal of Vocational Behavior,* 55(2), pp. 254-275.

Hamel, G. & Prahalad, C. K., 1994. *Competing for the Future.* s.l.:Harvard Business School Press.

Haralambos, M. & Holborn, M., 2004. *Sociology: themes and perspectives.* Sixth ed. s.l.:Collins Educational.

Hevner, A. R., March, S. T., Park, J. & Ram, S., 2004. Design science in information systems research. *MIS Quarterly,* 28(1), pp. 75-105.

Hoffmann, T., 1999. The meanings of competency. *Journal of European Industrial Training,* 23(6), pp. 275-286.

Honour, E., 2004. Understanding the Value of Systems Engineering. *Proceedings of the Annual International Symposium of INCOSE.*

Hoogervorst, J., 2009. *Enterprise governance and enterprise engineering.* s.l.:s.n.

INCOSE UK, 2006. *Systems Engineering Competencies Framework,* s.l.: s.n.

ISO15288, 2008. *ISO/IEC 15288 Systems and software engineering - System life cycle processes.* s.l.:s.n.

Kasser, J. E., 2007. Eight deadly defects in systems engineering and how to fix them. *Proceedings of the 17th International Symposium of the INCOSE.*

Kasser, J. E., 2012. Getting the requirements right. *Proceedings of the 22nd International Symposium of the INCOSE.*

Kelloway, E., 1995. Structural equation modelling in perspective. *Journal of Organizational Behavior,* 16(3), pp. 215-224.

Kleinmann, M. et al., 2011. A different look at why selection procedures work: The role of candidates' ability to identify criteria. *Organizational Psychology Review,* Volume 1, pp. 128-146.

Kobori, Y., 1991. Development of a software engineer aptitude test. *Quarterly Report of Railway Technical Research Institute,* Volume 32, pp. p200-206.

Krejcie, R. & Morgan, D., 1970. Determining Sample Size For Research Activities. *Educational And Psychological Measurement,* Volume 30, pp. 607-610.

Kruger, J. & Dunning, D., 1999. Unskilled and unaware of it: How difficulties in recognizing one's own incompetence lead to inflated self-assessments. *Journal of Personality and Social Psychology,* Volume 77, pp. 1121-1134.

Kruskal, W. H. & Wallis, W. A., 1952. Use of Ranks in One-Criterion Variance Analysis. *Journal of the American Statistical Association,* 47(260), pp. 583-621.

Latham, G. & Pinder, C., 2005. Work motivation theory and research at the dawn of the twenty-first century. *Annu. Rev. Psychol.,* Volume 56, pp. 485-516.

Leonard-Barton, D., 1998. *Wellsprings of Knowledge: Building and Sustaining the Sources of Innovation.* s.l.:Harvard Business Press.

Liang, G. & Wang, M., 1994. Personnel selection using fuzzy MCDM algorithm. *European Journal of Operational Research,* 78(1), pp. 22-33.

Marais, J. F., 2004. The Characteristics of a Great Systems Engineer. *Proceedings of the SA Chapter conference of the INCOSE.*

McClelland, D., 1973. Testing for competence rather than for "intelligence".. *American psychologist,* 28(1), p. 1.

Megellan Consulting, 2008. *Cognitive Process Profile,* s.l.: s.n.

Mershon, B. & Gorsuch, R., 1988. Number of factors in the personality sphere: Does increase in factors increase predictability of real-life criteria?. *Journal of Personality and Social Psychology,* 55(4), p. 675.

Miller, I. & Freund, J., 1977. *Probability and statistics for engineers.* Second ed. s.l.:Prentice-Hall Englewood Cliffs, New Jersey.

Parks, L. & Guay, R., 2009. Personality, values, and motivation. *Personality and Individual Differences,* 47(7), pp. 675-684.

Paunonen, S. & Ashton, M., 2001. Big Five factors and facets and the prediction of behavior.. *Journal of personality and social psychology,* 81(3), p. 524.

Pratkanis, A. & Breckler, S., 1989. *Attitude structure and function.* s.l.:Lawrence Erlbaum.

Prinsloo, M., 2007. *Metric Properties of the CPP,* s.l.: s.n.

Prinsloo, R. & Prinsloo, M., 2009. *Value Orientations: Feedback Manual,* s.l.: s.n.

Psytech, Ltd, 2002. *The 15FQ+ Technical Manual,* s.l.: s.n.

Robertson, I. & Smith, M., 2001. Personnel selection. *Journal of occupational and Organizational psychology,* 74(4), pp. 441-472.

Sakamoto, Y., Ishiguro, M. & Kitagawa, G., 1986. *Akaike information criterion statistics.* s.l.:D Reidel Pub Co.

Scharf, L., 1991. *Statistical Signal processing: Detection, Estimation, and Time Series Analysis.* s.l.:Addison-Wesley Publishing Company.

Schmidt-Atzert, L., Krumm, S. & Lubbe, D., 2011. Toward stable predictions of apprentices' training success: Can artificial neural networks outperform linear predictions?. *Journal of Personnel Psychology,* 10(1), p. 34.

Schmidt, F. & Hunter, J., 1998. The validity and utility of selection methods in personnel psychology: Practical and theoretical implications of 85 years of research findings.. *Psychological Bulletin,* 124(2), p. 262.

Schneider, B., 1987. People make the place. *Personnel Psychology,* Volume 40, pp. 437-454.

Schneider, B., Goldstein, H. W. & Smith, D. B., 1995. The ASA framework: An update.. *Personnel Psychology.Special Issue: Theory and Literature, 48(4), 747-773.,* 48(4), pp. 747-773.

Schon, D., 1995. *The Reflective Practitioner: how professionals think in action.* s.l.:Ashgate Pub Co.

Sheard, S., 1996. Twelve Systems Engineering Roles. *Proceedings of the International Symposium of the INCOSE.*

Shippmann, J. et al., 2000. The practice of competency modeling. *personnel psychology,* 53(3), pp. 703-740.

Silvia, P., 2008. Interest—The curious emotion. *Current Directions in Psychological Science,* 17(1), p. 57.

Simon, H., 1996. *The Sciences of the Artificial.* Third Edition ed. s.l.:MIT Press.

Soanes, C. & Stevenson, A. eds., 2006. *Concise Oxford English Dictionary.* Eleventh ed. s.l.:Oxford University Press.

Spencer, L. & Spencer, S., 1993. *Competence at Work: Models for superior Performance.* s.l.:John Wiley and Sons.

Spertus, E., Sahami, M. & Buyukkokten, O., 2005. *Evaluating similarity measures: a large-scale study in the orkut social network.* s.l., s.n., pp. 678-684.

Toshima, Y., 1993. Standardization of an integrated aptitude test for system engineers: intellectual abilities and personality factors. *Japanese psychological research,* Volume 35, pp. 182-192.

Vaishnavi, V. & Kuechler, W., 2004. Design Science Research in Information Systems.

Visser, P., Bizer, G. & Krosnick, J. A., 2004. Exploring the Latent Structure of Strength-Related Attitude Attributes.

Welman, C., Kruger, F. & Mitchell, B., 2005. *Research Methodology.* Third ed. s.l.:Oxford Southern Africa.

Whitley, B., 2002. *Principles of Research in Behavioral Science.* 2nd ed. s.l.:McGraw-Hill.

Williams, R., Verble, J., Price, D. & Layne, B., 1995. Relationship of Self-Management to Personality Types and Indices. *Journal of Personality Assessment,* 64(3), pp. 494-506.

Appendix A Consent form and ethics approval

This appendix contains a brief description of the ethics context at the start of this research, the consent form and the University of Pretoria (UP) ethics approval letter.

The CSIR, in an attempt to address the shortage of systems engineers, undertook research to understand the role of personality preferences, cognition, and values in the development of systems engineering competencies, starting in 2007. The author was assisted by an intern, Janine Britz, a then recent psychology graduate. The nature of the work required ethics approval, but at that time, the CSIR did *not* have an Ethics Committee. The author approached Prof. Chiroro, then at UP in November 2008, to assist in reviewing the research proposal and ethics approval via the UP Faculty of Humanities Research Proposal and Ethics Committee. Approval was granted and the experimental work for the first phase was carried out according to the proposed methodology. Registered psychometrists/ psychologists, with Psytech SA, performed the psychometric tests. No one was registered as a student with UP where this research was the topic. The extent of the collaboration with UP was regarding ethics and review and ended January 2009.

Systems Engineering Screening Research: Consent Form	CSIR our future through science

You are invited to participate in a research study conducted by our research team from the CSIR, DPSS. Through this study we hope to learn more about the personality preferences, values, cognitive preferences and competencies of potential Systems Engineers.

Title of Study:

Systems Engineering Research: Screening Candidate Systems Engineers

Purpose of study:

The purpose of the study is to develop a better understanding of the relationship between engineers' personality preferences, cognitive preferences, values, and systems engineering potential.

Procedures:

If you agree to take part in the study, you will be asked to complete four electronic questionnaires designed to gather information on your competencies, preferences and values with respect to a wide range of topics and issues. During this data collection process, you are requested to kindly **provide responses that are as honest and truthful as possible.**

The expected duration of your participation in this study is approximately 3 hours, although there is no time limit.

Benefits of participation:

- You may receive feedback (optional) on your personality preferences, cognitive preferences, and values as opportunity will be provided to discuss the results of the different assessment measures with you.
- You can use this feedback to evaluate your career, future opportunities, etc.
- The results of the study may assist DPSS to improve its planning and human resource development strategy.
- The results of this study will contribute to the body of knowledge on Systems Engineering.

Participant's rights:

Participation in this study is completely voluntary. You may refuse to participate or discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. There are no risks associated with participation in this study.

Opportunity will be provided before questionnaire completion for you to ask any questions or raise any concerns regarding the research process, your rights as participant in the research process, or any other issue.

Confidentiality:

The information that you will share with the research team will be treated as strictly confidential. The results from the questionnaires will only be made available to and discussed among the research team. In the final report, no individual names will be used. Should you withdraw from the study for any reason, your data will be destroyed.

Should you have any questions, please do not hesitate to contact any member of the research team (see contact details below). **You will be offered a copy of this letter to keep.**

If you agree to participate, please sign below to indicate that you have read and understood the information provided above, that you willingly agree to participate and that you are not waiving any legal claims.

Your name (Print): ____

Signature: ________________ Date: ________________

Signature: ________________ Date: ________________

Duarte Gonçalves

+27 12 841 3963 dgoncalv@csir.co.za

Signature: ________________ Date: ________________

Janine Britz

+27 12 841 3873 jbritz@csir.co.za

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Humanities
Research Proposal and Ethics Committee

7 January 2009

Dear Prof. Chiroro,

Project:	**The role of cognitive preferences, personality and attitudes in predicting systems engineering competencies**
Researcher:	**Prof. P Chiroro**
Department:	**Psychology**
Reference number:	**Staff Research**

Thank you for your response to the Committee's letter of 2 December 2008.

I have pleasure in informing you that the Research Proposal and Ethics Committee formally **approved** the above study at an *ad hoc* meeting held on 6 January 2009. The approval is subject to you abiding by the principles and parameters set out in your application and research proposal in the actual execution of the research.

We wish you success with the project.

Sincerely

Prof. Brenda Louw
Chair: Research Proposal and Ethics Committee
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail: brenda.louw@up.ac.za

Appendix B SE Competencies Questionnaire

The SE competencies questionnaire is supplied on a compact disk – it was designed for use as a Microsoft Excel spreadsheet and is formatted as such.

Appendix C On-going evaluation of the selection method and development method

On-going evaluation of the selection method and development method is important for continuous improvement. It starts once the SE development programme is in place and has delivered its first batch of systems engineers, which is expected to be in 3-5 years and involves testing the hypothesis:

H_2: *Successful development of SE competencies is predicted from engineers with the SE profile.*

The "successful development" is defined as an increase in SE competency beyond natural development on projects, using training, coaching and facilitated workgroup sessions (Gonçalves, 2008). In order to be able to discriminate between normal learning on projects and the effects of the development effort (Figure 35), a control group and a development group would be created. The control group would do projects as usual. The development group, in addition to doing projects, would receive training, coaching and facilitated workgroup sessions (Gonçalves 2008) over a period of 2-5 years (Figure 36).

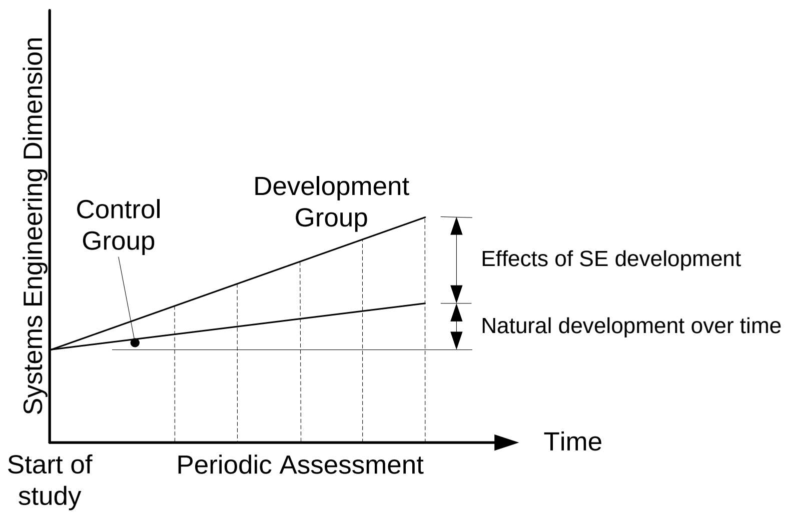


Figure 35 Separating natural vs. deliberate development using a control and development group

During validation of the selection method no "reject" decisions will be made, i.e. nobody will be turned away from development based on their assessment. The reason for this is an ethical one: at this point the selection method has not been shown to be suitable for this purpose. Validation starts by randomly selecting engineers from DPSS (Figure 36, F.5.1). Limiting the sample to DPSS means that generalising results beyond DPSS may be difficult. Although, this is not an objective of the study, the results still hold value. These engineers will be assessed on the psychological and SE dimensions (discussed in section 4.3) to determine a validation baseline (F.5.2). Selection of candidates would be conducted using the selection method (F.5.3). Participants would then be assigned randomly to the development group and the control group (F.5.4). The development group would receive training, coach, etc. (F.5.5). Given the design of the on-going evaluation, an increase in competency for both the control group and the development group for engineers having “other engineer” and SE profiles (Table 37) over the development period can be anticipated. The relative increase, however, is not expected to be the same for the four cases as illustrated in Table 37.

During development, participants in both groups would be periodically evaluated on the SE dimension (criterion) only. Only the data of candidates whose measurements have been baselined and who have been assessed at least once subsequently will be used. The proposed assessment rate is yearly, based on the rate of development of candidates and business reporting cycles (Figure 36). Once a certain sample size has been achieved, the data will be analysed to see if any validity conclusions can be made. Results of the research should indicate a difference in development between the control group and the development group, thus confirming $\mathbf{H_2}$.

$\mathbf{H_2}$ can be reformulated as a statistical hypothesis (tested as part of F.5.7, using deltas calculated in F.3.7 in Figure 36). The deltas in Table 12 are defined as:

- Δ_{SEC} *– increase in competence of an engineer with an SE profile in the control group;*
- Δ_{SED} *– increase in competence of an engineer with an SE profile in the development group;*
- Δ_{OEC} *– increase in competence of an engineer with the other engineer profile in the control group; and*
- Δ_{OED} *– increase in competence of an engineer with the other engineer profile in the development group.*

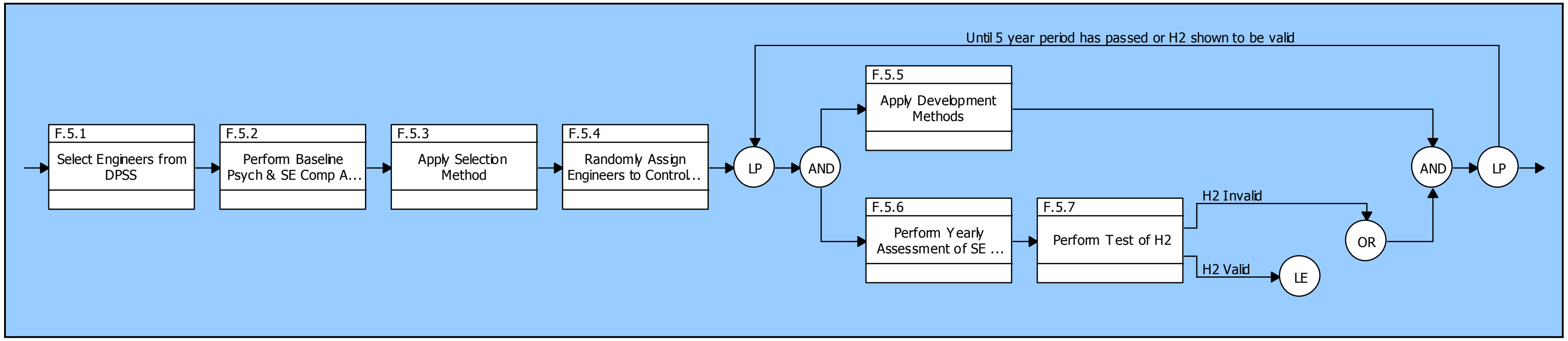


Figure 36 On-going evaluation of the selection method

H_2 is partitioned into two parts, namely, SE development leads to an increase in competence and the SE profile leads to an increase in competence:

H_{2A}: *Development of SE competencies makes a difference,*

i.e. $\Delta_{SED} > \Delta_{SEC}$ *and* $\Delta_{OED} \geq \Delta_{OEC}$

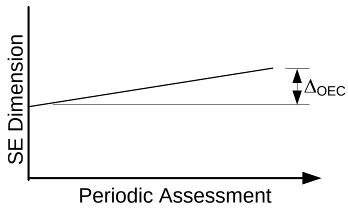
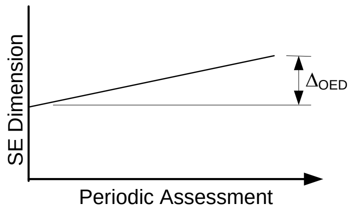
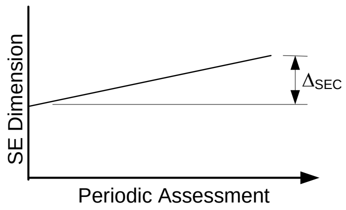
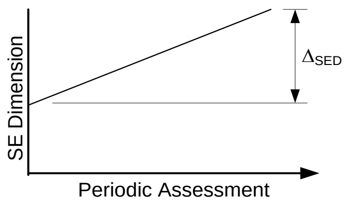
H_{2B}: *The SE profile makes a difference, i.e.* $\Delta_{SEC} \geq \Delta_{OEC}$ and $\Delta_{SED} > \Delta_{OED}$

When combined, these leads to the hypothesis:

H_2: *Successful development of SE competencies is predicted from engineers with the SE profile, i.e.* $\Delta_{SED} > \Delta_{SEC}$ *and* $\Delta_{SED} > \Delta_{OEC}$ *and* $\Delta_{SED} > \Delta_{OED}$.

In other words, a statistical test of H_2 (as illustrated by F.5.7. in Figure 36) using these deltas would need to be performed. This will be done periodically until H_2 can be shown to be valid, or until 5 years of development have passed (Figure 36). Therefore, by proving **H_2** to be valid, would show the predictive validity in this context of SE development of engineers with the SE profile, in accordance with the model illustrated in Figure 9 of section 2.4.

Table 37 Growth over the development period for the control and development groups with other engineer and SE profiles

<table>
<tr><td></td><td></td><td>Control Group</td><td>Development Group</td></tr>
<tr><td rowspan="2">Psychological Dimension</td><td>Other Engineer Profile</td><td>
</td><td>
</td></tr>
<tr><td>SE Profile</td><td>
</td><td>
</td></tr>
</table>

The conclusion is that the control *and* development group must have a mix of engineers (who are not currently systems engineers) who have the SE profile *and* the “other engineer” profile. Since the on-going evaluation will be conducted in the work place, there are specific challenges:

- People in the control group may need SE development. Considering the duration of validation and from an ethical and business point of view such development may not be denied. Such a person would be transferred to the development group;
- Another possible challenge could be the *mortality rate* for each group, i.e. the rate at which engineers might drop out of the study. In the control group, mortality rate would not necessarily present a problem. However, the problem arises in the mortality rate of the development group for candidates who have the SE profile. One would need to address this possibility by keeping count of the candidates who drop out of both groups, in order to show statistical significance in mortality rates for the different profiles, if this were to exist;
- Finally, since the development effort is personalised, it cannot be exactly controlled and will thus impact the extent of development. Thus, information regarding development and training that participants receive on the program must be recorded; and
- In the case where no development is provided, personal interest and motivation may lead to own development, although this is not expected to be significant.

Adequate SE opportunities and an enabling organisational environment are important.

Appendix D Research review

The research design was reviewed by Prof. Patrick Chiroro of the University of Pretoria, in order to assess the technical content and to ensure that the design and methodology was ethically sound before the experiment was conducted. Prof. Chiroro, a research psychologist who holds a PhD degree from the University of Durham (UK), has worked as a university lecturer/professor, researcher and consultant for a number of national, regional and international organizations during the past 15 years. Feedback was given regarding the sample size, the SE competencies framework and questionnaire, as well as data-analysis methods proposed. Where relevant and possible, the necessary changes were made. The research design was submitted for ethics review at the University of Pretoria's Faculty of Humanities Ethics Committee, and was approved.

As part of the review process, the work was published at two international conferences (Gonçalves & Britz, 2009), (Gonçalves, 2010) and one local conference (Gonçalves & Britz, 2010), all peer reviewed. Valuable feedback was received from these reviews and was incorporated.

Appendix E Description of the psychological assessments

E.1 15FQ+ Scales

The following information regarding the 15FQ+ has been sourced from the 15FQ+ Technical Manual, Psytech Ltd.

Factor fA:

Distant Aloof, Lacking empathy, Detached, Impersonal:	**Empathetic, Friendly, Personable, Participating, Warm-hearted, Caring:**
Low scorers tend to be cool, distant and somewhat aloof in their interpersonal relationships. They are disinclined to express their feelings and may feel somewhat uncomfortable with people who are overly friendly or familiar. Being extremely private individuals, they are likely to relate to others in an impersonal manner and may be seen as being somewhat detached and distant by all but their closest friends. They are likely to have difficulty understanding other's feelings, and may be viewed as lacking in empathy and warmth. They dislike talking about personal matters and will be slow to express sympathy or understanding for other's personal problems. Having a low need for affiliation, they are inclined to be slow to form close, warm relationships and emotional attachments to others.	High scorers are friendly, warm, participating individuals who are interested in the people around them and have a natural understanding of 'what makes others tick'. Quick to offer support and encouragement to friends and colleagues, they will be viewed as good listeners. Their interest in other people means they are likely to remember personal details about the people they meet, and be generous in interpersonal relationships. Their natural understanding and empathy for other's feelings means they will be seen as sympathetic, concerned, caring individuals. Warm-hearted and attentive to the needs of others, they are likely to be valued team members. Expressing their feelings in a genuine, heartfelt manner, they will have a friendly, personable interpersonal style.

Intellectance B:

Lacking confidence in one's own intellectual abilities:	**Confident in one's own intellectual abilities:**
Low scorers are likely to lack confidence in their own intellectual abilities. As a result they may be disinclined to work on intellectually demanding tasks, which they may be prone to view as being 'beyond them'. They are inclined to view themselves as not having a particularly large vocabulary, and as lacking a broad range of general knowledge. Thus, they tend to avoid discussing issues which they may consider to be 'high brow'. They may feel uncomfortable in situations where they have to explain complex ideas to others, possibly feeling somewhat 'out of their depth'.	High scorers are confident of their own intellectual ability. As a result they are likely to enjoy working on tasks that are intellectually demanding and challenging. Intellectually orientated, they will generally be keen to learn new information and acquire new intellectual skills. They may be quick to take advantage of situations in which they can display their knowledge and intellectual prowess. As a result they may be prone to use long words and talk about intricate, intellectual matters. Moreover, they are likely to enjoy explaining complex ideas and problems to others.

Factor fC:

Affected by Feelings, Emotional, Changeable, Labile, Moody:	**Emotionally Stable, Mature, Calm, Phlegmatic:**
Low scorers are inclined to experience mood swings. Lacking emotional resilience, they may at times have difficulty summoning up sufficient energy to face demanding situations. Being prone to experiencing anxiety symptoms, they may find themselves being troubled by sleep problems, psychosomatic symptoms, phobias, etc. Moreover, they may occasionally find themselves bothered by feelings of despondency or even depression. They may sometimes ‘over-react’ to situations, with their judgement being clouded by their strong emotional reactions. They are likely to be changeable, and may be viewed as being fickle, moody or capricious. However their emotional temperament may also be a source of drive, spurring them on to resolve situations they are unhappy with, or which they find unsatisfactory or unrewarding.	High scorers are likely to be emotionally stable, steady, resilient individuals. They rarely experience anxiety symptoms and are likely to have more than sufficient energy to meet life’s challenges. Phlegmatic and inclined to “take most things in their stride”, they will rarely be ruffled by life’s ups and downs. As such they are unlikely to experience feelings of depression or despondency. However, as a result, they may be viewed as somewhat lacking in emotion, drive or passion. They tend to be confident and secure in themselves and satisfied with their life and their achievements. Sometimes this may prompt them to become complacent, or overly accepting of unsatisfactory situations. Others are likely to view them as being mature, dependable individuals who can be relied upon to cope in a crisis.

Factor fE:

Accommodating, Passive, Mild, Humble, Deferential:	Dominant, Assertive, Competitive, Aggressive, Forceful:
Co-operative, accommodating and obliging, low scorers are inclined to give way to others. Passive and unassuming, they will be keen to avoid upsetting friends and colleagues. As a result they may have difficulty when called upon to take charge of situations and give orders. Self-effacing, humble and mild-mannered, they are likely to be modest and deferential in their inter-personal relationships. They may lack aggression and be inclined to be passive and overly compliant when dealing with more assertive, self-assured individuals. Quick to acquiesce to other's wishes, they may have difficulty 'standing their ground' and asserting their own views and opinions when faced with active disagreement from others. They dislike conflict, arguments and discord, which they are likely to avoid at all costs; even if this means ignoring their own personal needs and goals.	Determined to get their own way, high scorers may on occasion be aggressively assertive and pushy when dealing with others. Forceful, and vocal in expressing their opinions, they may be seen as opinionated or even somewhat dogmatic. Not being unduly concerned about upsetting people, they may be disinclined to listen to other's points of view. As a result they may have difficulty compromising, and conceding when others have a valid point. On occasion they may 'ride roughshod' over less assertive colleagues, alienating people who do not agree with them. Feeling free to criticise others, they may generate conflict and discord in those around them. They will be happy to take charge of a situation, and give clear instructions and orders, but may be overly controlling and domineering with colleagues who are less assertive and forceful.

Factor fF:

Sober Serious, Restrained, Taciturn, Cautious:	Enthusiastic, Lively, Cheerful, Happy-go-lucky, Carefree:
Low scorers are restrained individuals whom others may view as being rather dour and lacking in a sense of fun. Serious minded, and somewhat inhibited, they are disinclined to attend lively social events and parties. They are inclined to be restrained and to avoid participating actively in social events. This may cause others to view them as being somewhat taciturn or saturnine. They have little time for light-hearted trivial entertainment, preferring instead to engage in more serious-minded activities. They find it difficult to 'let their hair down' and have a good time. Lacking a sense of playful fun, and joie de vivre, they may appear somewhat constricted or stiff in social situations. They are likely to have fewer friends than many people, and it may take others a while to warm to them.	High scorers are lively, talkative individuals who enjoy 'letting themselves go' and 'having a good time'. Always 'game for a laugh', they will be keen to take part in any activity that promises fun, thrills and excitement. Drawn to stimulating social situations, they may on occasion act in a somewhat attention seeking manner. Moreover their sense of fun, and effervescent, carefree character, may cause them on occasion to step beyond the bounds of decorum. Light-hearted, cheerful, easy-going individuals, people are likely to view them as being 'young at heart' and carefree. Actively seeking excitement and stimulation, they are quick to act, and enjoy 'getting stuck into things'. Happy-go-lucky and fun-loving, others are likely to appreciate their enthusiasm for life and their joie de vivre.

Factor fG:

Expedient, Spontaneous, Disregarding of rules and obligations:	Conscientious, Persevering, Dutiful, Detail conscious:
Low scorers tend to lack a strong sense of duty, and may have difficulty persevering with boring or repetitive tasks. They are inclined to disregard well-established rules and set procedures and systems, which they may view as stifling creativity and spontaneity. Thus they may be inclined to be somewhat careless when attending to detail. They generally approach tasks in an expedient, casual manner, preferring to solve problems as they arise rather than follow a detailed action plan or schedule. They may be untidy and possibly somewhat disorganised, or even a little chaotic, in both their home and work life. Flexible and spontaneous, they are inclined to view things 'from the broader prospective'. They are likely to prefer thinking strategically, rather than being responsible for creating detailed plans and work schedules.	High scorers have a strong sense of duty and responsibility. They are persevering and are inclined to be neat, tidy and well organised. They are likely to set high standards both for themselves and for others. They believe it is important to be detail-conscious, precise and exacting in their work. On occasion they may be somewhat obsessive, perfectionistic or rigid. Thus they may be prone to obsessive compulsive symptoms (e.g. repeatedly checking or counting the same thing, etc.). Meticulous and systematic in their work, they will be keen to make sure that things are done 'just right'. As a result they may find that others do not always live up to their own high standards. They may have difficulty viewing things from 'the broader perspective', and on occasion 'may not see the wood for the trees.'

Factor fH:

Retiring, Timid, Socially anxious, Hesitant in social settings, Shy:	Socially-bold, Venturesome, Talkative, Socially confident:
Shy and retiring, low scorers may be slow to come forward in social situations. They do not find it easy to start conversations with strangers, and as a result it may take others a while to get to know them. If they suddenly and unexpectedly become the focus of attention at a social gathering they may find themselves feeling uncomfortable or self-conscious. They may be prone to feelings of ‘stage fright’, and are likely to be slow to speak up and express their views and opinions in front of people they do not know well. At parties and social events they may find themselves slipping into the background. They may feel ill at ease and self-conscious if they have to speak in front of a large group of people. In group situations they may be inclined to ‘take a back seat’ and let others do the talking.	Quick to come to the fore in social settings, high scorers will be seen as venturesome, socially bold individuals. They feel self-assured and confident in most social settings and are likely to be happy speaking in front of a large audience. In fact, they may actively seek out roles that place them ‘in the limelight’ and give them an opportunity to ‘perform on the social stage’. Quick to initiate social contacts, they are good conversationalists who enjoy meeting new people. Whatever the setting, they usually have something to say, and readily contribute to group discussions and debates. They are likely to be good at ‘making small talk’ and bringing ‘others out of their shell’. Natural, easy communicators, they are likely to make a big impression on the people they meet.

Factor fI:

Hard-headed, Utilitarian, Unsentimental, Lacks aesthetic sensitivity, tough-minded:	Tender-minded, Sensitive, Aesthetically aware, Sentimental:
Low scorers lack aesthetic sensitivity and have little interest in cultural or artistic pursuits. They are rarely moved by feelings of beauty, wonderment or awe; adopting a rather tough-minded, no-nonsense approach to life. Having little time for subjective, creative matters, they will be primarily concerned with whether things work effectively; giving little thought to aesthetic considerations such as design. They are likely to enjoy working with their hands and fixing things, participating in and watching sports and other physical activities. Others may see them as lacking refinement, culture or sophistication. They will however view themselves as being utilitarian realists who have little time for 'artistic people'. Their decisions will be based on practical, functional considerations rather than being influenced by sentiment or emotion.	High scorers have a strong interest in cultural and artistic activities and pursuits. They are likely to have refined sophisticated tastes and to appreciate fine art, literature, music, etc. Highly subjective in their outlook, they often respond to situations and events at an intuitive, emotional level. Focusing on the subtle, aesthetic aspects of a task they are unlikely to have much interest in science or engineering. They may be viewed as being impractical or 'arty' and are unlikely to approach problems in a particularly task-focused way. Their decisions are likely to be swayed by sentiment, rather than being based on cool rational logic, or on a utilitarian focus on 'what works'. Creative, aesthetically sensitive individuals, they will generally have little interest in working with their hands, in fixing or repairing things.

Factor fL:

Trusting, Accepting, Unsuspecting, Credulous:	Suspicious, Sceptical, Cynical, Doubting, Critical:
Low scorers tend to take people at face value, rather than question their motives. They are quick to place their faith in others, believing that most people are dependable and trustworthy. Not in the least cynical, they are likely to have a positive view of human nature, believing that people are basically kind, thoughtful and genuinely concerned about the welfare of others. Not at all suspicious or sceptical, they may on occasion appear to be a little naïve. Inclined to give others the benefit of the doubt, they may at times be overly trusting. If others take advantage of their trust or good-will they are likely to feel let down. However, only in the most extreme circumstances will such events prompt them to question their positive, trusting view of human nature.	High scorers tend to be doubtful and mistrusting of other's motives. Not being inclined to take people at face value, they tend to reserve their judgements about others until they have hard, irrefutable evidence of their trustworthiness and honesty. Adopting a suspicious and sceptical approach to life, others may view them as being rather jaded or cynical. Tending to believe that people are likely to try to take advantage of their goodwill if given the chance, they will be reluctant to place their faith in others. As a result they may adopt a Machiavellian, cynical approach to interpersonal relationships. This may reflect either a tendency to be manipulative or, alternatively, may be due to them having been repeatedly let down by people in the past.

Factor fM:

Concrete, Solution-focused, Realistic, Practical, Down-to-earth:	**Abstract, Imaginative, Absent-minded, Impractical, Absorbed in thought:**
Low scorers tend to be practical, down-to earth realists. They are more concerned to ensure that things work, rather than explore how or why they work. Firmly grounded in the here-and-now, they tend to be very matter of fact in their outlook. Concrete thinkers, they are inclined to reject abstract theoretical perspectives. They may be disinclined to look beyond the obvious facts in a given situation in search of deeper possibilities and meanings. As a result others may view them as being rather pedestrian or unimaginative in their outlook. Focusing on observable facts and hard data, they may on occasion be overly concrete or literal in their thinking style. Not in the least prone to flights of fantasy, and not inclined to day-dream, they will be viewed as sensible pragmatists whose decisions emphasise the practicable and achievable.	High scorers are creative, imaginative individuals who have a strong interest in abstract theoretical ideas. Lacking concern for practical day-to-day realities, they may be seen as being somewhat 'other worldly'. Concerned to understand fundamental principles and concepts, they are likely to have little interest in mundane practical matters, which they may not give due consideration and thought to. Naturally inclined to look beyond the obvious facts in a given situation, they are likely to come up with novel, innovative ideas. Without clear goals, however, they may find themselves being carried away by their own thoughts and ideas, which may sometimes be quite unrealistic or fanciful. Orientated towards the world of theory and imagination, they may become so engrossed in their own ideas and thoughts as to lose sight of practicalities.

Factor fN:

Direct, Genuine, Artless, Open, Direct, Straightforward:	**Restrained, Diplomatic, Socially astute, Shrewd, Socially aware, Restrained:**
Low scorers tend to be direct and to the point in their social interactions. On occasion this may even verge towards being somewhat blunt or tactless. Thus others may be inclined to view them as lacking discretion or social sophistication. Genuine, forthright individuals, who are open and straightforward, they are likely to be direct in their interpersonal relationships. Having little concern for the impression they create in social situations, they may on occasion express their views in an artless or ill-considered manner. Inclined to 'put their cards on the table', others are likely to know where they stand with them. Most people will appreciate their honest, open, genuineness. However, lacking awareness of the nuances of social situations they may on occasion pass ill-considered, thoughtless comments.	High scorers tend to be diplomatic and restrained in their social interactions. Acutely aware of the subtle nuances of social settings, they are likely to be concerned not to do or say anything that may seem inappropriate or out of place. As a result others are likely to consider them to be shrewd and socially astute. Conscious of the impact they make on those around them, they are inclined to monitor their behaviour closely to ensure that they do not upset or offend others. Naturally discrete and diplomatic, others may view them as being excessively guarded individuals. Shrewd and socially astute, they may on occasion be somewhat manipulative in interpersonal relationships. Tending to 'play their cards close to their chest', they may often be reluctant to reveal their true feelings and opinions.

Factor fO:

Confident, Secure, Self-assured, Unworried, Guilt-free:	Self-doubting, Worrying, Insecure, Apprehensive:
Low scorers are confident of their ability to deal successfully with life's challenges. As a result, they rarely worry about anticipated problems or difficulties. Secure and self-assured, they are rarely troubled by feelings of guilt or self-doubt. To others, they may on occasion appear to be overly confident, possibly lacking insight into their own personal weaknesses or failings. At times their lack of self-doubt, and their unquestioning belief in their own abilities, may cause them to be heedless of potential difficulties or problems. Not in the least apprehensive about facing possible challenges or threats, they rarely dwell on past problems and failures. Satisfied with their own achievements and accomplishments, they may be inclined to disregard potential opportunities for self-evaluation, self-improvement and growth, believing that this is not needed.	High scorers tend to be self-reproaching and troubled by feelings of insecurity and self-doubt. Threat sensitive, they tend to focus on anticipated dangers and pitfalls. Often fearing the worst, they may feel apprehensive when faced with new, unexpected challenges. Their natural apprehension and self-doubt may spur them on to perfect their own skills and abilities, so as to be better able to deal successfully with challenges in the future. However their lack of self-confidence, and tendency to doubt their own abilities, may on occasion prompt them to appear tentative, indecisive or lacking in resolve. Guilt prone, they may find themselves dwelling on past, often imagined, failures or mistakes. Concerned about what others may think of them, they may often need reassurance and encouragement from those around them.

Factor fQ1:

Conventional, Traditional, Conservative, Conforming:	**Radical, Experimenting, Open to change, Unconventional:**
Low scorers tend to be conventional in their outlook on life. They value traditional and tried and tested methods, and are likely to be wary of change for change's sake. Accepting of the status quo, they approach life with the motto 'if it's not broken, don't fix it'. They are inclined to question innovation, often believing that new approaches represent little more than change for the sake of change. Valuing convention and tradition, more radical colleagues may see them as being 'stick in the mud' that are not open to new ideas. Disliking change, they may on occasion reject novel, innovative ideas out of hand. They are likely to feel uncomfortable in rapidly changing environments that demand constant innovation, adaptation and adjustment.	High scorers value progress, innovation and change. They are inclined to reject tried and tested methods in favour of new, radical approaches to problems – even if these are unproven. Their attitudes and opinions are likely to be fairly unconventional, with them being naturally inclined to question the status quo. They dislike 'getting stuck in a rut' and will prefer to work in environments where they are free to initiate change, experiment and innovate. They may on occasion be overly quick to reject received opinion, which they may tend to dismiss 'out of hand' as being little more than 'old hat'. As a result they may at times ignore the value of acquired wisdom and knowledge. They should be comfortable working in rapidly changing environments, which require constant adaptation and adjustment.

Factor fQ2:

Group-orientated, Sociable, Group dependent, a 'Joiner':	**Self-sufficient, Solitary, Self-reliant, Individualistic:**
Low scorers like to be surrounded by people. They prefer to take decisions in discussion with others, rather than act in an autonomous, independent manner. They dislike being on their own for long periods of time and may have difficulty working in environments that do not provide high levels of social contact. They like to take an active part in social affairs and will generally be happy to join social organisations, participate in committees, etc. Being extremely group-orientated, they may have difficulty functioning effectively in situations where they have to work independently from others and where social contact is not readily available. They are likely to enjoy team-work, but on occasion their strong need for social contact may interfere with their ability to complete work independently of others.	High scorers are autonomous, self-sufficient individuals who prefer to take decisions on their own, rather than in discussion with others. They dislike working in team settings and may be reluctant to ask others for help or advice. As a result, they may not always give sufficient regard to public opinion, or other's expectations, when making decisions. They are comfortable spending time on their own and are likely to be happy in occupations that offer little social support or contact. They will prefer to avoid becoming actively involved with committees and group activities. They enjoy solitary pastimes, with others possibly viewing them as being somewhat reclusive, or even a little taciturn by nature. As a result, they may not always attend fully to the interpersonal aspects of a task.

Factor fQ3:

Informal, Uncontrolled, Lax, Follows own urges:	**Self-disciplined, Compulsive, Fastidious, Exacting willpower:**
Low scorers have little concern for their perceived social standing. Tending to question authority, they believe that respect has to be earned rather than simply being due to one's position or rank. Believing that it is important to be free-thinking and 'true to oneself' they tend not to conform to traditional social mores – unless they are personally convinced of their value. Inclined to question accepted moral values, they believe that it is more important to follow the spirit of the law rather than obey it to the letter. As a result they are unlikely to be rigid or moralistic. They may lack discipline and self-control, and be inclined to seek immediate gratification of their needs, wants and desires. As a result they may on occasion appear to be somewhat impetuous, and they may have difficulty conforming to strict rules and regulations.	High scorers are concerned to maintain their social standing and reputation. Valuing self-control and self-discipline, they are unlikely to seek immediate gratification of their own needs and desires. In fact, they may be inclined actively to repress any thoughts or impulses that others might consider to be socially unacceptable or inappropriate. They are respectful of authority, status and social position, and believe it is important to follow correct protocol and procedure. They have a clear, well-defined set of moral values, which they believe it is important to adhere to. As a result others may possibly view them as being somewhat moralistic or rigid, and on occasion they may be a little dogmatic or obstinate. This however simply reflects the importance they attach to adhering to their strict code of conduct and their expressed high moral standards.

Factor fQ4:

Composed, Relaxed, Placid, Patient:	**Tense-driven, Impatient, Low frustration Tolerance:**
Low scorers tend to be relaxed and composed, dealing with frustrations in a calm, steady, easygoing manner. They can work under pressure without getting unduly ‘wound-up’ or tense. They are unlikely to become short-tempered or irritable if things go wrong. In general, they will be patient with friends and colleagues and tolerant of interruptions. They do not easily lose their temper and are not prone to angry out-bursts or fits of rage. They are not easily frustrated by set-backs or failures and are rarely irritable or short-tempered. Others may view them as lacking motivation or drive, with them possibly appearing to be somewhat complacent when things go wrong. In general, they will find it easy to relax and unwind after a hard day and are unlikely to experience stress related health problems.	High scorers tend to be tense, impatient and hard-driving. Having low levels of frustration tolerance, they may at times appear to be restless, fidgety or ill-at-ease. Due to their high levels of personal drive, and resultant tense, nervous energy, they are likely to be short-tempered with people or things that get in their way. They dislike being kept waiting and may quickly become annoyed or irritable when things go wrong. As a result others may view them as being temperamental, ‘touchy’ or easily offended. Driven to succeed, they may be prone to believe that the only way to ensure that something is done properly is to do it oneself. As a result they are likely to have difficulty relaxing and may be prone to stress related health problems and feelings of excessive tension and irritability. **Note**: Extremely high scores should be interpreted with caution, as these may reflect temporary high levels of stress, rather than the presence of this trait.

15FQ+ Additional scales

eIQ:

Lacking empathy, moody, temperamental, insensitive, socially artless, low frustration tolerance:	Empathic, caring, emotionally mature, socially astute, composed, perceptive:
Low scorers tend to lack insight into other's thoughts, feelings and behaviour. As a result, in social situations, they may come across as artless and insensitive and they may be inclined to make social blunders. Failing to understand things in the broader social context, they may tend to take things personally and be defensive in the face of criticism. Having poor emotional regulation skills, they may appear moody and temperamental at times. Lacking the ability to manage frustration effectively, they may be prone to emotional outbursts. They may have difficulty dealing with the emotional challenges of setbacks and failures and this may limit their ability to meet future demands and challenges. Emotionally vulnerable, with a fragile sense of self, they may not always be in touch with their own core feelings, values and needs. As a consequence they may come across as lacking in interpersonal warmth, and as being distant, uncaring and unsympathetic.	High scorers are insightful and perceptive, having genuine empathy and understanding for others. As a result, they are likely to come across as warm, caring and considerate. Aware of the nuances of social situations, they will be motivated to avoid social gaffes or blunders. In tune with those around them, they will be viewed as being sensitive and responsive to other's needs and feelings. Emotionally mature, they have insight into their own feelings and are able to manage and regulate their emotions in a constructive manner. Feeling secure and confident in themselves, they are not prone to emotional outbursts. Generally satisfied with their past achievements, they face challenges in a constructive and mature manner and are not prone to inappropriate feelings of self-doubt, despair or despondency. Having a grasp of the broader social picture, and understanding other's motives, they are unlikely to become engaged in petty disputes and rivalries.

WA (Work Attitude)

Absent-minded, lax, disregards rules and obligations, unconventional:	**Persevering, dutiful, solution-focussed, conscientious, conforming:**
Low scorers are unconventional, radical and inclined to question accepted wisdom. Seeing little reason to blindly follow custom and practice, they may be disinclined to follow rules and may circumvent set systems and procedures. Believing that respect has to be earned, rather than being due to status and position, they are inclined to question authority. Their contribution to the organisation may be more in the areas of creation and innovation rather than ensuring that tasks are competed on time and to standard. They may be inclined to go their own way, possibly sacrificing those obligations and duties that they see as being onerous or unnecessary in order to achieve their objectives. They may be unsystematic and disorganised in their work, preferring to focus on the bigger picture than on the detailed aspects of the task at hand.	High scorers are persevering, conscientious and dutiful. Methodical and systematic, they will be motivated to diligently follow set systems and procedures. Conventional and conservative in their approach to problem solving, they will prefer established methods over experimental ways of doing things. Their contribution to the organisation will be more in the area of ensuring that tasks are completed to agreed standards, rather than being innovative and creative. Rule-bound and conforming, they will be respectful of authority and are unlikely to challenge the status-quo. This will pre-dispose them to be honest and trustworthy employees who are committed to the organisation, its culture and rules. Perfectionistic and attentive to detail, they will set themselves high standards of task completion, believing that if a job is worth doing it is worth doing well.

Social Desirability

This scale assesses a person’s desire to present an unrealistically positive image of themselves to others, with high scorers being motivated to deny the presence of the minor failings and idiosyncrasies that are typical of most people. Thus high scores on this scale (stens 8-10) may reflect either a deliberate attempt at distortion or, alternatively, a highly over-idealised (and possibly unrealistic) self-image. Therefore, before considering the likely impact of high scores on the validity of the test profile it is important to consider the candidate's motivation for responding in a socially desirable manner. Information elicited from the feedback session may be particularly useful in this regard. For example, individuals who are heavily engaged in charitable activities, or work of a self-sacrificing nature, may have higher than average scores on this scale. Similarly, people who have been brought up according to a very strict moral or religious code may be motivated to opt for more socially desirable responses to test items. Alternatively, if there are good grounds for considering that high scores are likely to reflect a deliberate attempt at distortion, then it is likely that the candidate will have under-reported their true scores on the Anxiety Global Factor, and the primary source traits that contribute to this global factor; ƒC, ƒO and ƒQ. In addition, when the 15FQ+ questionnaire is being used for occupational assessment and selection, it is possible that respondents obtaining high scores on the Social Desirability scale may have either over, or under reported their scores on any other primary source traits that may be particularly job relevant.

Central Tendency

This scale assesses the degree to which respondents have been prepared to answer the questionnaire decisively - avoiding middle, or noncommittal responses. High risk scaled scores (of 8 or 9) can suggest either that the respondent has a poorly defined self-concept, has been indecisive or reluctant to commit him or herself to particular attitudes or actions, or is genuinely moderate in respect to many personality traits and dispositions. (These competing interpretations of an elevated Central Tendency risk scaled score should be explored during the candidate feedback session, to facilitate the assessor's formulation of the most likely reason for this elevated score.) An extremely high risk scaled score (a score of 10) suggests that the personality profile is likely not to be valid, due to the respondent not having been willing to reveal very much about him or herself by seeking refuge in the middle, uncertain or in-between response. (Possible reasons why the respondent may have been reluctant to have revealed much about him or herself should be sought by considering the demand characteristics of the assessment context in greater detail.)

Infrequency

This scale assesses the extent to which a respondent has attended diligently to the questionnaire and has avoided infrequent responses. Respondents who obtain high risk scaled scores (scores of 8-10) on this scale may not have given due thought and consideration to the items when completing the questionnaire or may not have diligently followed the questionnaire's instructions. When interpreting the significance of such scores assessors need to consider a number of factors. Given that attempts at sabotaging test results are rare in most occupational assessment settings, the first question which needs to be addressed is the possibility that the respondent did not fully understand the test instructions and/or items due to a poor command of formal written English. Once this possibility has been ruled out assessors should consider the scores the respondent has obtained on the other 15FQ+ scales, along with the characteristics of the assessment context. If the respondent has high scores on the Global Anxiety Factor, consideration should be given to the possibility that the respondent was so distressed during the assessment that he/she was unable to attend adequately to the questionnaire's instructions and/or items. If the Faking Bad scale is also high, such a pattern of test scores may possibly represent a 'cry for help' from a respondent who is having difficulty coping with the pressures of work. (Such an interpretation of the test's results is most likely to occur in an outplacement or performance review context.) The assessor should then consider possible reasons the respondent may have had for sabotaging the assessment by responding in a random or semi-random way to the questionnaire. Attempts at sabotaging an assessment are most likely to have occurred if the respondent has been placed under pressure to complete the questionnaire unwillingly, in a redeployment or outplacement context.

Fake Good

This scale assesses a respondent's tendency to present him or herself in a favourable light, denying a variety of problem behaviours and difficulties that routinely apply to many people. If respondents obtain a high Faking Good score and a low Social Desirability score, then this score should be interpreted with caution as it may be elevated due to their scores on the primary factors that contribute to this scale, rather than reflecting an attempt to present a positive impression of themselves. In this situation the test user should interpret the elevated Faking Good score in the context of the person's overall personality profile, taking into account relevant information gained from the feedback session.

Fake Bad

This scale assesses a respondent's tendency to present him or herself in an unfavourable light, admitting to a variety of problem behaviours and difficulties that do not routinely apply to him or herself. If the respondent is highly anxious or distressed then a high Faking Bad score should be interpreted with caution, as it may be elevated due to his or her scores on the primary factors that contribute to this scale, rather than reflecting an attempt to present a negative impression of him or herself. In this situation the test user should interpret the elevated Faking Bad score in the context of the person's overall personality profile, taking into account relevant information gained from the feedback session. When interpreting the meaning of the impression management scales, the test user must give due consideration to the context in which the test was administered. Similarly, when interpreting the profile of a respondent who has obtained a high score on any of the impression management scales, the test user should use his or her knowledge about the demand characteristics of the assessment process to identify those personality factor scores that may have been distorted by the respondent's response set.

E.2 Cognitive Process Profile (CPP)

The following information regarding the CPP has been sourced from the CPP manual, from Cognadev International.

E.2.1 Problem solving styles

Analytical: is characterised by a detailed, rule-orientated and systematic approach with an emphasis on precision and comparative behaviour.

Explorative: is characterised by an emphasis on the investigation of a problem. The repeated exploration of a problem and repetitive checking behaviour may, however, create unnecessary complexity and have a confusing effect.

Holistic: is often associated with the tendency to view a problem situation in its totality and to place an emphasis on the global perspective (wholeness and unity), without losing track of relevant detail.

Impulsive: An impulsive style (being fast and inaccurate) is associated with inadequate pacing and with emphasis on the speed of problem-solving.

Integrative: The tendency to combine, synthesise and structure information as it is encountered in order to makes sense of it.

Intuitive: This approach usually, but not necessarily, involves the careful exploration of a problem and repetitive checking behaviour to meaningfully interpret complex information at a 'gut' level. It may result in the conceptualisation of creative ideas and/or unverified assumptions.

Learning: is usually characterised by an emphasis on memory functions, integration of feedback, understanding and self-monitoring. This results in improved problem-solving and a flexible approach.

Logical: is characterised by the tendency to look for logical evidence to: verify arguments; follow reasoning processes through in a self-aware and logical way; and manage a high level of complexity by applying a 'process' approach to problem-solving.

Memory: is characterised by the tendency to internalise and automatise information as a problem-solving approach. It can enhance problem-solving performance; however, a memory approach in conjunction with weak strategies for managing complexity may create large memory burdens and have a confusing effect.

Metaphoric: is the tendency to view a situation abstractly and symbolically, as well as to combine elements of information in novel ways to formulate analogies and metaphors.

Quick Insight/Efficient: is characterised by quick insight, effective task and goal orientation, quick processing and integration of information, using effective reasoning and memory strategies.

Random: is usually characterised by a vague and unsystematic, trial-and-error approach to problem-solving. Inadequate task orientation and insufficient goal direction are often present.

Reflective: A reflective style involves the tendency to explore, the careful consideration of information, spontaneous comparative behaviour, the continual integration of new elements into existing information structures and the following through of reasoning processes. Although it is usually associated with a relatively slow approach, pace control does occur.

Structured: is usually characterised by an emphasis on the rules of the task and the careful grouping and ordering of the information. It may reflect a need for precision and structure. This can be a useful technique for managing complexity and supporting memory functions.

E.2.2 Information processing competencies – constructs

Exploration construct: The depth and effectiveness shown when investigating data and information to identify, focus on and select the relevant information for further processing. Purposeful search; accurate perception; thorough exploration; focus on relevance.

Linking/analysis: The application of rules – comparing, differentiating, checking and linking – to different elements of information to establish relationships between them. Detailed and precise' systematic; step-by-step approach; focus on rules.

Structuring: The ordering, categorisation and integration of different elements of information into coherent, meaningful units. Interpret and integrate; identify core elements and meanings; focus on coherence and unity.

Transformation: Following arguments through in a disciplined manner to transform the information or arrive at conclusions based on defensible evidence and according to appropriate rules for reasoning. Apply logical rules; disciplined reasoning; following processes through; focus on rational, verifiable conclusions.

Memory: The mental storing and retrieval of information. Memory of background and accumulated knowledge; frame of reference.

Meta-cognition: Being aware of and clear about the way you monitor, evaluate, plan and correct your own thinking processes. Self-awareness; focus on own thinking processes.

E.2.3 Information processing competencies - descriptors

Pragmatic (exploration construct): Practical orientation – 'will it work in practice?' Determining relevance in structured contexts.

Exploration (exploration construct): Effectiveness, depth and width of exploration.

Analytical (analysis construct): Systematic, detailed and precise in differentiating and linking, rigor.

Rule Oriented (analysis construct): A rule focus, mechanistic.

Categorisation (structuring construct): Creating external order, categories and reminders – structuring tangibles, creating meaning.

Integration (structuring construct): Synthesis of ambiguous/discrepant/conflicting information – creating meaning.

Complexity (structuring construct): The preferred level of complexity, the unit of information used – Higher score prefers dynamic complexity, lower score prefers detailed complexity. The higher one of the **complexity** and **memory use** scores can be used to indicate the level of complexity that a person prefers to function at. A discrepancy or difference between these two scores is usually quite meaningful. In such cases, the memory score normally comes out somewhat lower. This may be because of the application of checking or other weak memory strategies as well as the need for precision, a compulsion to "make sure", or a lack of confidence in own opinions. Where memory comes out lower than complexity, the complexity score should be used as an indication of the preferred unit of information focused on. These two scores are, however, two sides of a coin as "complexity management" depends on memory capacity.

Logical Reasoning (transformation – logical & lateral construct): The disciplined, logical following through of reasoning processes.

Verbal Abstraction (transformation – logical & lateral construct): Unusual, creative, abstract verbalisation and conceptualisation – expresses conceptual thinking by using abstract language. Verbally creative.

Use of Memory (memory construct): Tendency to rely on memory / concentration / degree of effort.

Memory strategies (memory construct): Effectiveness of memory strategies.

Judgement (Meta-cognition construct): Using judgement to clarify unstructured and vague information. Judgement – intuitively and consciously evaluate complex issues by prioritising and weighing them according to criteria.

Learning 1 (Meta-cognition construct): Quick insight learning. Learning – improve one's understanding by adjusting, expanding and integrating information structures in a self-aware manner.

Learning 2 (Meta-cognition construct): Gradual improvement / experiential learning.

E.2.4 Levels of Work

Pure Operations – Level 1: People who are better suited to the Operational work environment prefer direct involvement with practical, clearly-structured operating tasks that have obvious and clear rules for success – for example, answering the phone and taking a customer's order correctly. They deal with routine tasks that have clear linear procedures, using their knowledge to complete the task – for example, following a step-by-step software program to re-order stock items. They like the information they work with to be tangible and definite (with no ambiguity), and they deal with problems one by one as they emerge, usually by coming up with practical solutions. They prefer to work in a familiar environment that has well-defined rules and structures. When learning new tasks, these people may use a trial-and-error-approach, and are likely to want to explore issues practically and seek short-term feedback to confirm that they are on the right track. Examples of roles reflecting the Operational work environment are customer service, retail, clerical and administrative staff (depending on their position), manual labourers and those who do routing jobs like working on a production line, maintaining equipment, etc.

Diagnostic Accumulative – Level 2: People who are best suited to the Diagnostic work environment may have an analytical \ sequential approach, following clear, linear procedures to diagnose and solve problems that are not always obvious. They do this by using their existing knowledge and experience together with theoretical knowledge to interpret information (such as symptoms), and asking either/or questions to help them decide how to solve the problem. These people often have specialist or good technical knowledge in their field. For example, a nurse has strong technical knowledge, yet will need to ask a patient questions to reach a correct diagnosis. A specialist motor mechanic will also use practical experience and theoretical knowledge to determine why a car has broken down and how to best fix it. People who reflect the Diagnostic work environment are often first-line managers, dealing with people face-to-face and supervising those who perform direct operating tasks. Those preferring this type of work environment tend to learn by capitalising on memory of their theoretical / specialist knowledge base and practical experience. Examples of roles reflecting the Diagnostic work environment are lab technicians, shop managers, emergency service staff, interior designers, food technologists, air traffic controllers, dentists, sales staff, teachers and most other technical or supervisory positions.

Tactical Strategy – Level 3: People who are best suited to Tactical work environments, usually work with whole operating systems – particularly with the interaction between tangible intra-system components. They tend to plan, structure, measure, control and pull information together in order to achieve a pre-specified goal. Such people tend to evaluate systems and practices, make practical decisions about the best way to get things working efficiently, and plan how resources can best be deployed. They also thoroughly think things through and have contingency plans in place should things go wrong. Operational efficiencies, benchmarking and cost are important factors. They often come up with short-term solutions that pave the way for longer-term achievement. Learning takes place via systematic experimentation with different operational systems and structures, as well as through transfer and application of theoretical angles. Middle and senior managers often work within the Tactical / Operational work environment, as do certain professionals and specialists. In certain industries, general management also reflects a Tactical focus. Examples of roles reflecting the Tactical work environment are doctors, lawyers, company secretaries, financial advisers, project managers, chief engineers and departmental or business unit managers. To be specific, a Tactical manager at a Publishing company may be required to create a well-organised operating system to publish a book – commissioning an author, having the book and cover designed, proofed and printed, organising PR and marketing, distributing the book to retailers, etc.

Parallel Processing – Level 4: People who are best suited to Parallel Processing environments, enjoy working both within, and across, relatively complex systems – for example, co-ordinating the activities of several business units in a large organisation. They tend to focus on both broad strategy as well as the operational implications of the strategic direction taken. They often focus on abstract, intangible issues – theories, models, viability of projects / programmes – and come up with creative, integrated, and abstract conceptual solutions. These people plan and implement business solutions, balancing and juggling resources between different projects and programmes so that these are used most effectively, ensuring that equally important demands of each project are met. People who function within a Parallel Processing environment normally work on programmes with timescales of three to five years. They often deal with broad strategy, the long term viability of the business, value chain integration, organisational change / transformation. As specialists, they tend to focus on and create new functionalities. They often learn via an innovative, integrative, systems approach by synthesising various abstract theoretical options into a model. Such models are then used to guide operational issues, monitoring consequences and make the necessary adaptations. Examples of roles reflecting the systems-focused work environment are software architects, business analysts, general managers and senior, professional and specialist positions within an organisation.

Pure strategy – Level 5: Even though individuals showing a purely strategic approach may be involved in a specific organisation, they are primarily concerned about the long term industry viability and the impact of the industry on the social and physical environment. In terms of cognitive functioning, these individuals often consciously evaluate and decide on a most appropriate level of analysis (ranging from concrete to abstract); identify vaguely emerging opportunities within a somewhat chaotic environment; clarify this fuzzy information; and show awareness of both business and moral / ethical implications for the industry. They tend to capitalise on intuitive awareness – more so than on analytical details. They often initiate change that may impact the whole industry and create a future through philosophical leverage. They deal in long timeframes – usually 5 to 8 years and sometimes even longer. They prefer to work with abstract, broad, sweeping issues – chaos, macro-economic factors, potential industry partners and environmental impact. Operations of a truly strategic nature will involve the creation of unified whole systems (such as national or international businesses), focusing on renewal through exploring new philosophical trends and intuitively sensing connections between apparently unconnected variables (e.g. Industry partners.) Examples of Pure Strategy work can be found amongst certain entrepreneurial initiatives, thought leadership, political and economic forecasting, and roles such as chairpersons and directors of national and multi-national companies.

E.3 Value Orientations (VO) – Accept or Reject

The following information regarding the VO has been sourced from the VO manual, from Cognadev International:

RED – I CONTROL: The need to control - basic motives are to enforce dominance and power; Gratifying impulses and senses. The type of thinking here can be characterised as egocentric. The person views the world as having limited resources where one has to fight for one's share – survival of the fittest. The person is likely to want attention, respect, and to "call the shots" and will avoid shame at all costs. Person is likely to be impulsive, energetic, assertive, imaginative, defensive, and proud.

ORANGE– I PERFORM: The need to perform, to achieve and be self-reliant. This value system depicts a strategic type of thinking. Basic motives include "Playing the game", autonomy and manipulation. This person is likely to be optimistic, risk-taking, self-reliant, competitive, opportunistic, resilient, flexible, and independent.

YELLOW– I LEARN: The need to learn, to increase knowledge and experience. This value system can be described as integrative. Basic motives include living fully and responsibly whilst learning. The emphasis is on flexibility, functionality and spontaneity – life is a kaleidoscope of natural hierarchies, systems and forms. Freedom of choice is emphasised. Person is likely to be individualistic, independent, seeking self-actualisation, not dependent on structure and order, somewhat emotionally distanced.

PURPLE- WE PROTECT: The need to protect and be protected, to belong. Basic motives include maintaining blood relationships and mysticism. Obedience to chief, elders, ancestors, clan. Learning is based on story-telling, repetition and modelling. Can be ethnocentric.

BLUE– I CONFORM: The need for order and structure, to conform and be righteous. Believes in obedience to authority and that laws, regulations and discipline build character and moral fibre – impulsivity should be controlled. Person is likely to be conformist, reliable, purposeful, and righteous.

GREEN– WE RELATE: The need for spiritual growth and harmony, relationships. Feelings are more important than achievement. Person is likely to be caring, sensitive, humanistic, relationship-oriented, can become radically "open-minded" and relativistic whilst "dogmatically" imposing a people orientation.

TURQUOISE– WE EXPERIENCE: The need to experience. Everything is interconnected. This value system depicts a holistic type of thinking. Person is likely to be autonomous, but seeks spiritual bonds with humanity and the universe – focused on the meaningfulness of human endeavours.

Appendix F Additional results

Additional results that may be of interest to some readers, but not central to the main thesis are presented in this appendix.

F.1 Individual analysis of the psychological assessments

Individual analysis of the 15FQ+, CPP, and VO summarises the large amounts of data produced during this study. The following analysis of these assessments was performed:

- **15FQ+**: Plot distributions for each measure using the sample as the norm group (Section F.1.1).
- **CPP**: Style preference distribution table, plot of cognitive competency distribution and plot of Level of work distributions (Section F.1.2).
- **VO**: Plot of distributions for each measure (Section F.1.3).

F.1.1 Individual assessments: 15FQ+

This section presents the histograms for each of the 15FQ+ measures in Figure 37 through to Figure 59.

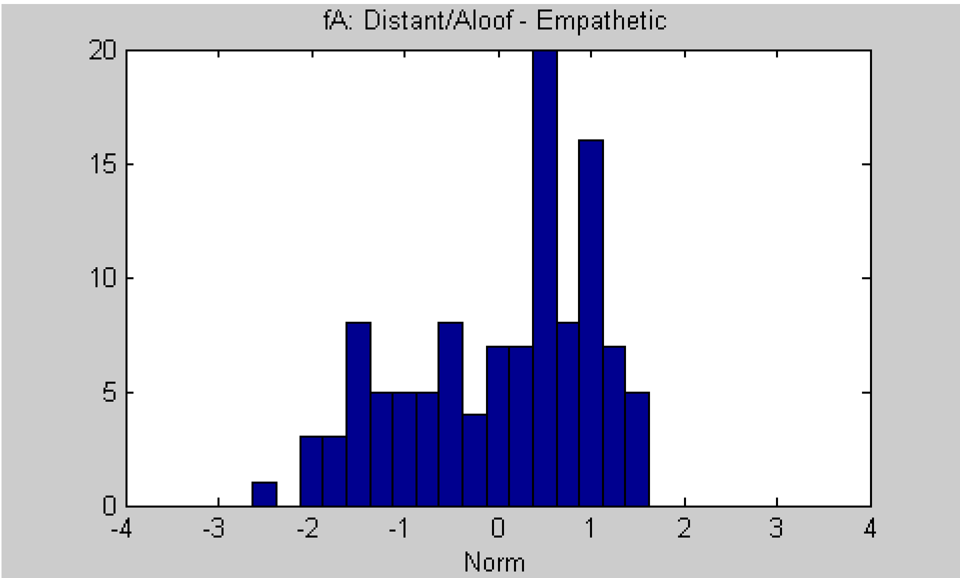


Figure 37 Factor fA: Distant/Aloof - Empathetic Distribution

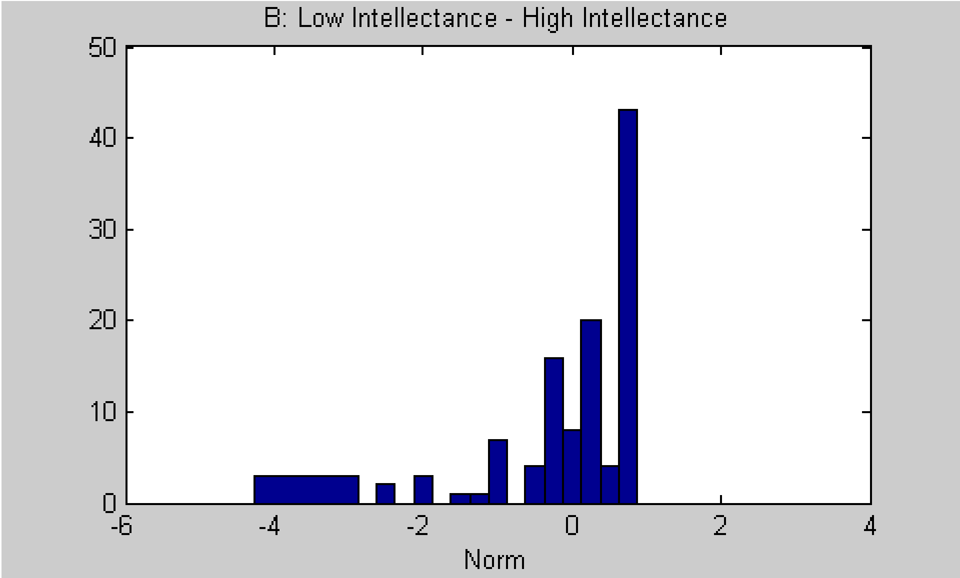


Figure 38 Intellectance B: Low Intellectance - High Intellectance Distribution

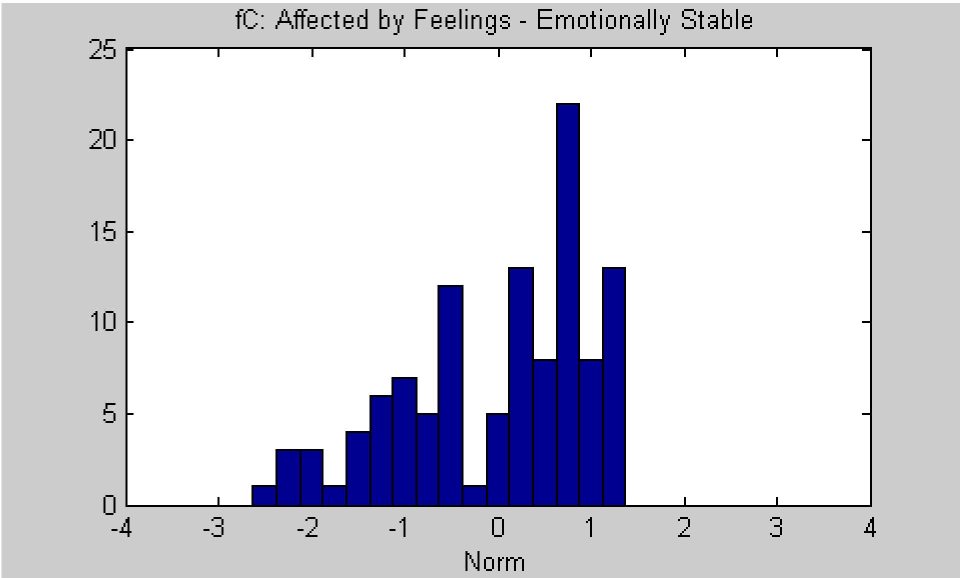


Figure 39 Factor fC: Affected by Feelings - Emotionally Stable Distribution

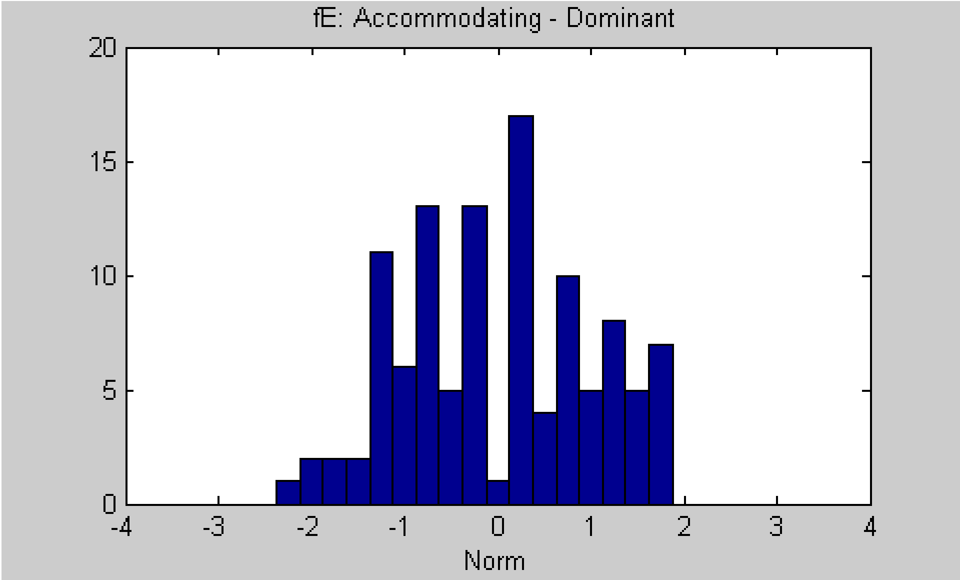


Figure 40 Factor fE: Accommodating - Dominant Distribution

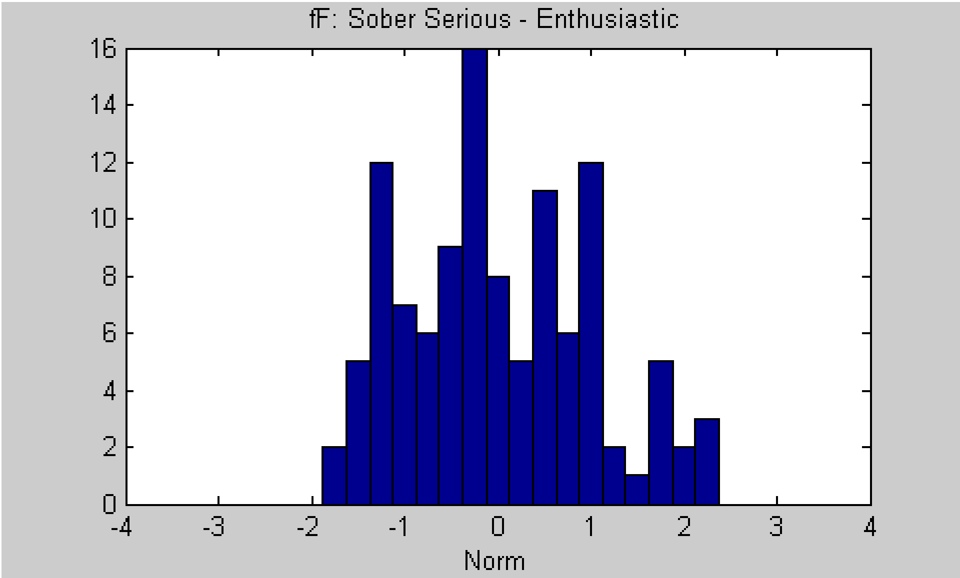


Figure 41 Factor fF: Sober Serious - Enthusiastic Distribution

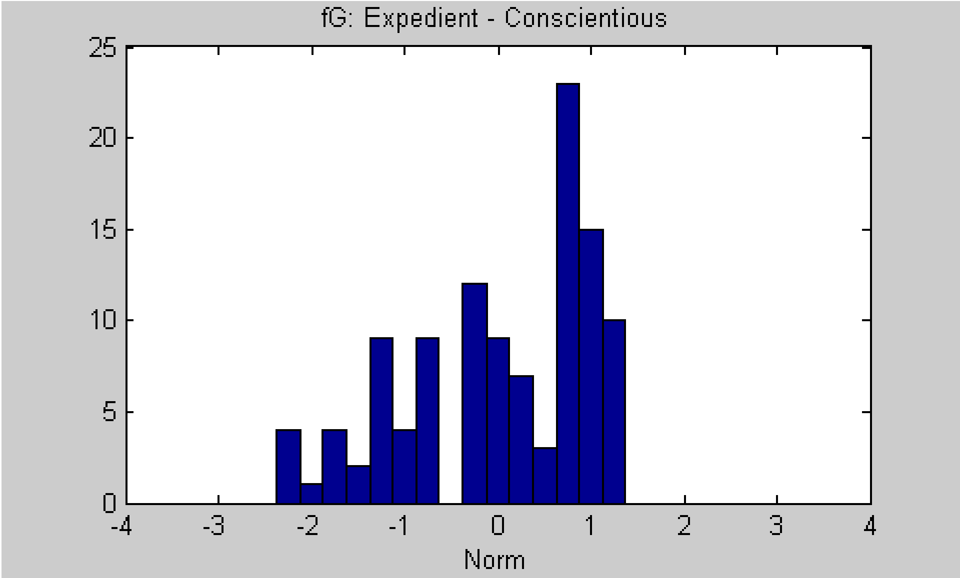


Figure 42 Factor fG: Expedient - Conscientious Distribution

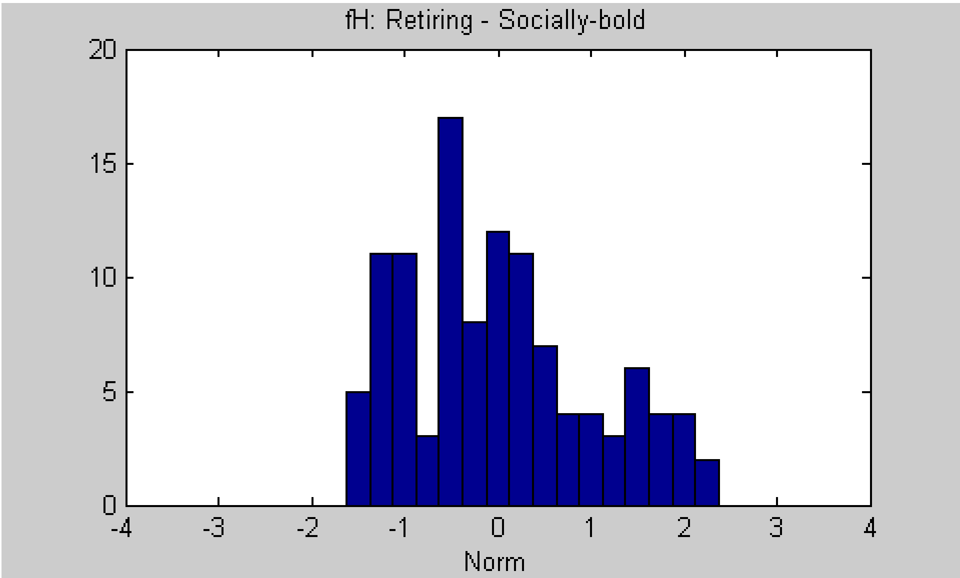


Figure 43 Factor fH: Retiring - Socially-bold Distribution

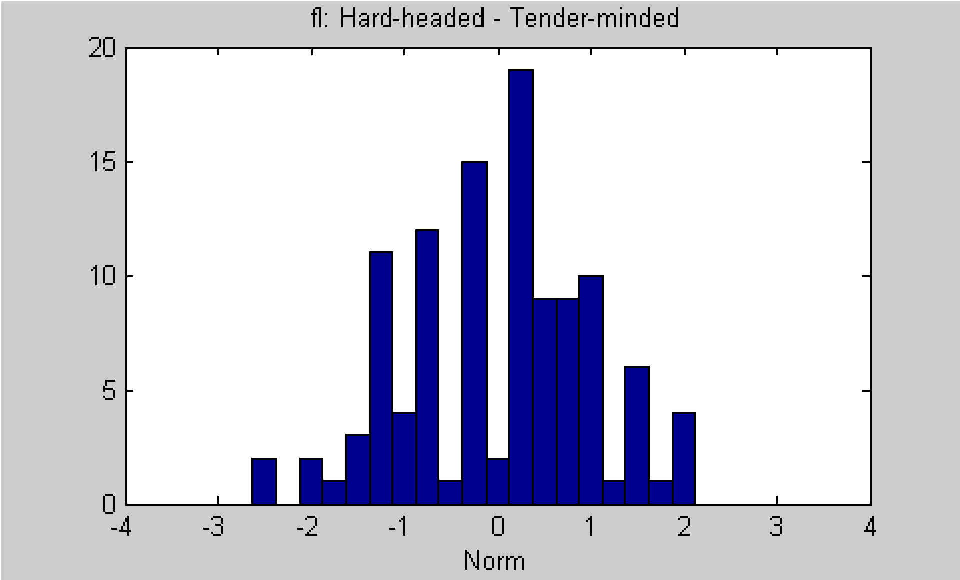


Figure 44 Factor fI: Hard-headed - Tender-minded Distribution

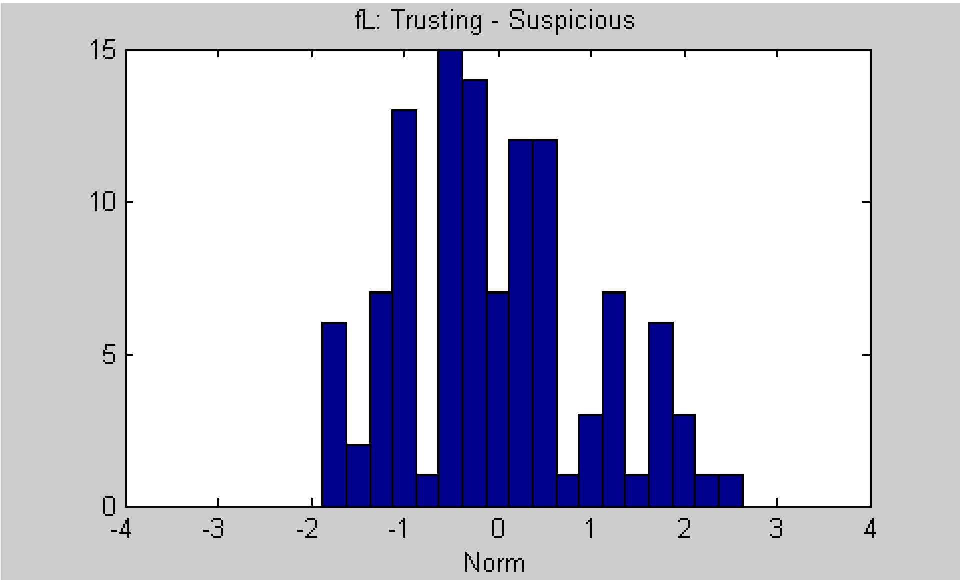


Figure 45 Factor fL: Trusting - Suspicious Distribution

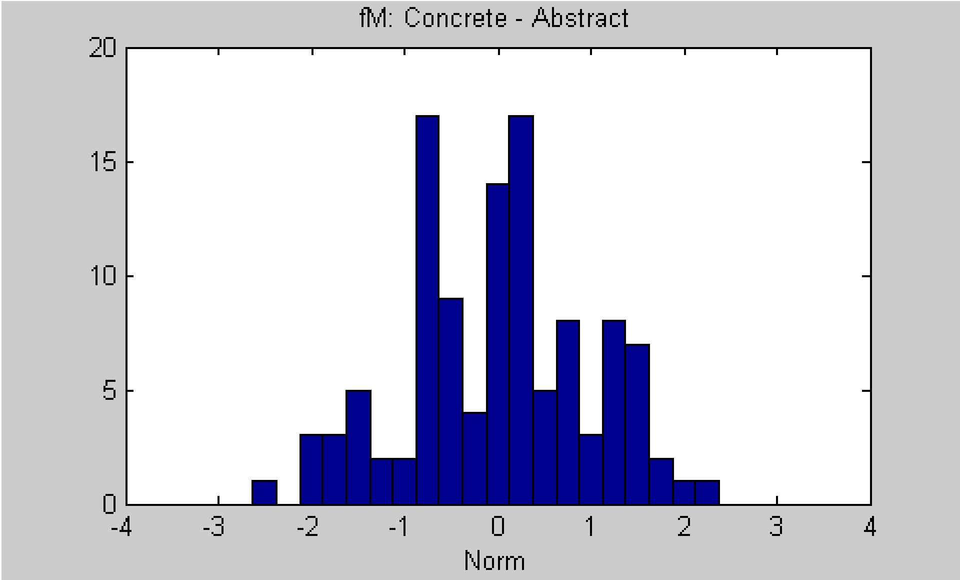


Figure 46 Factor fM: Concrete - Abstract Distribution

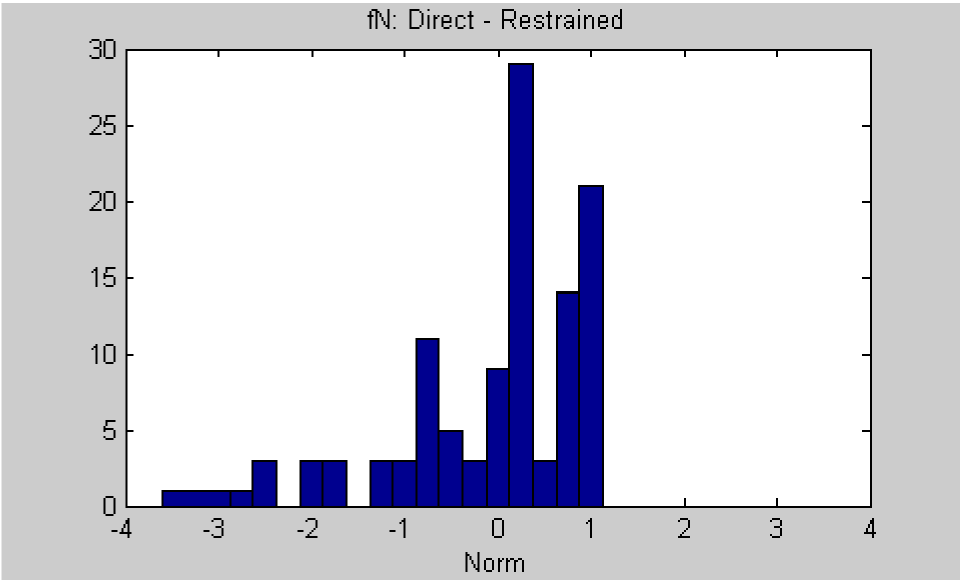


Figure 47 Factor fN: Direct - Restrained Distribution

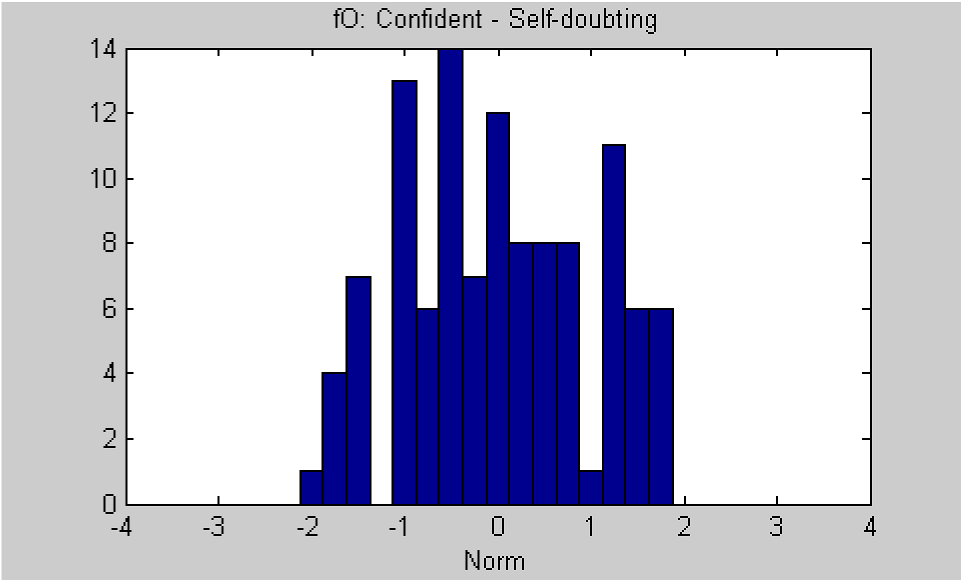


Figure 48 Factor fO: Confident - Self-doubting Distribution

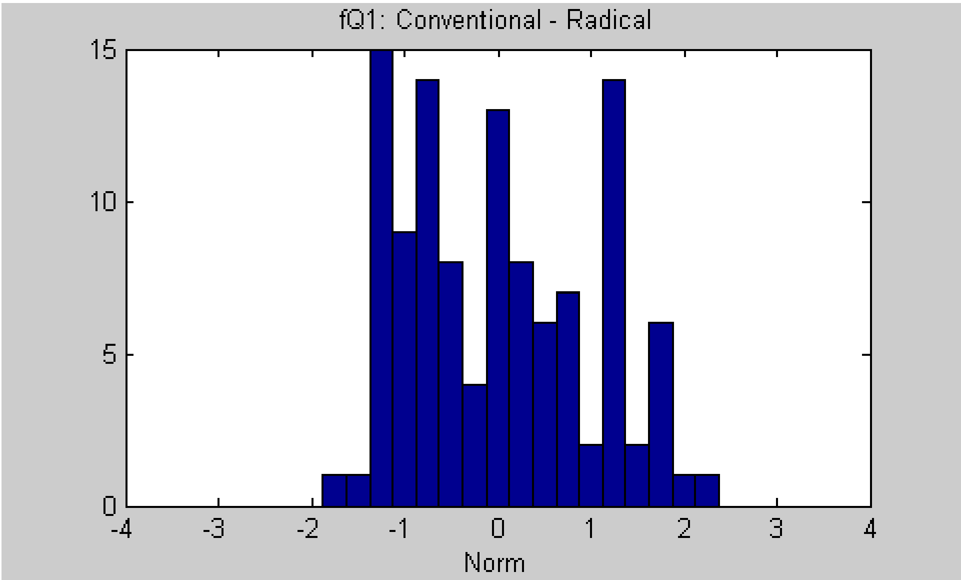


Figure 49 Factor fQ1: Conventional - Radical Distribution

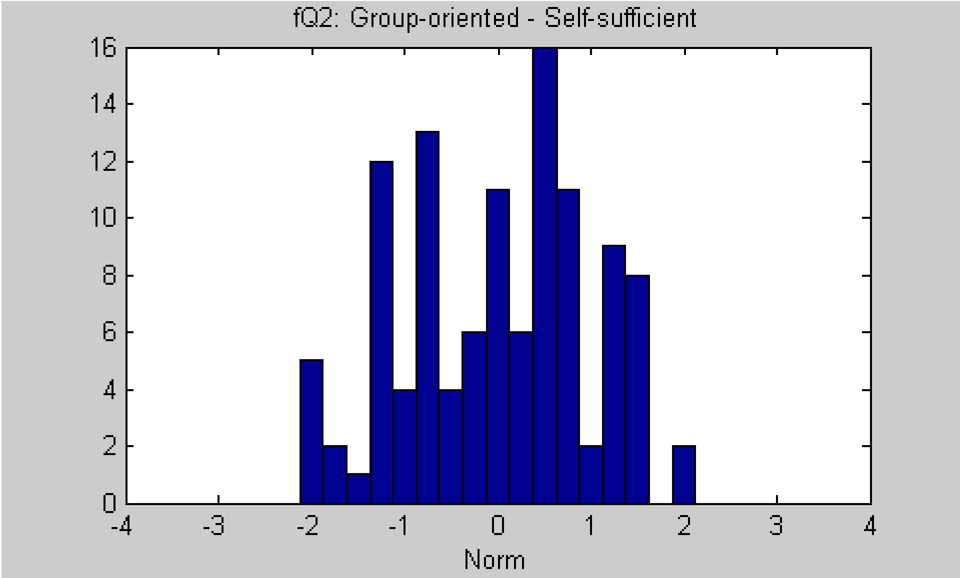


Figure 50 Factor fQ2: Group-oriented - Self-sufficient Distribution

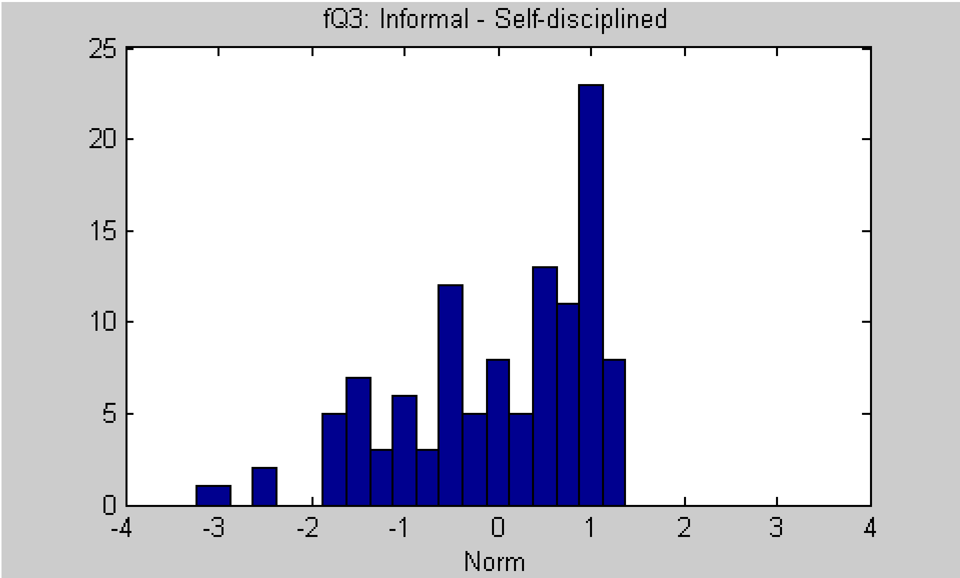


Figure 51 Factor fQ3: Informal - Self-disciplined Distribution

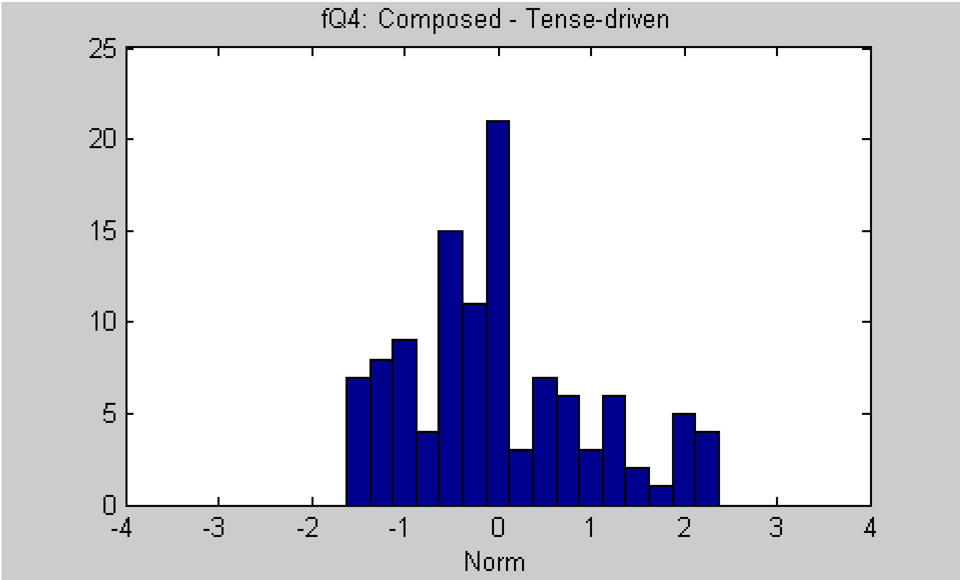


Figure 52 Factor fQ4: Composed - Tense-driven Distribution

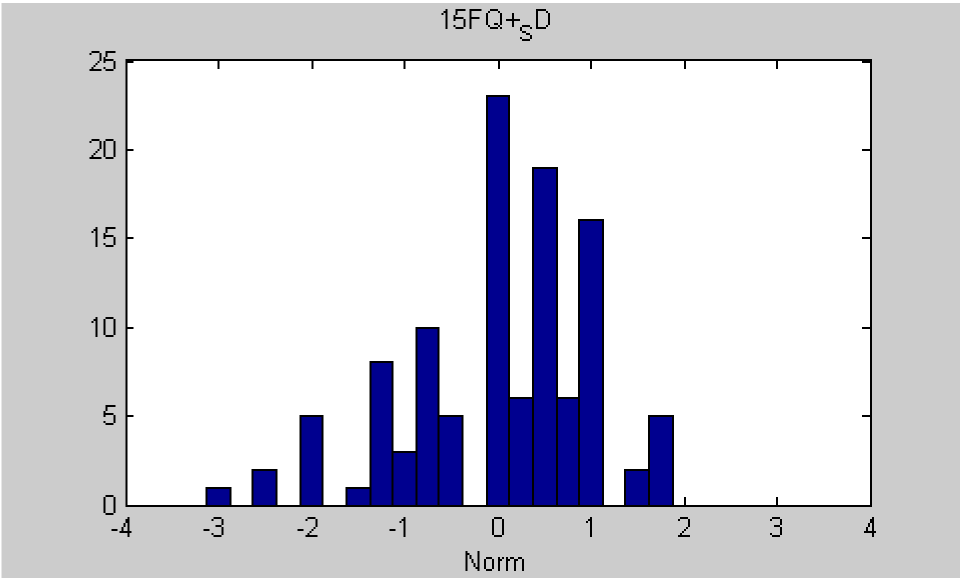


Figure 53 15FQ+ Social Desirability Distribution

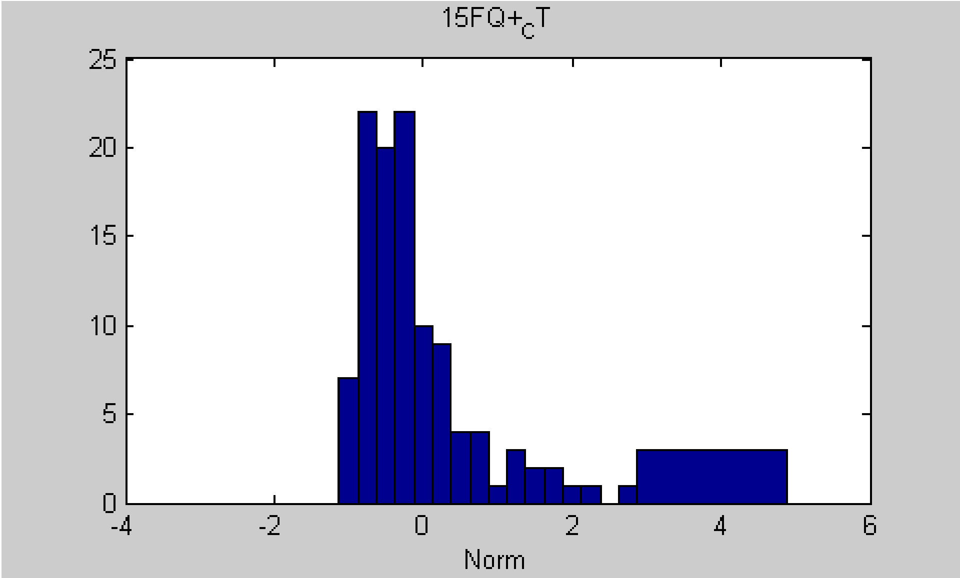


Figure 54 15FQ+ Central Tendency Distribution

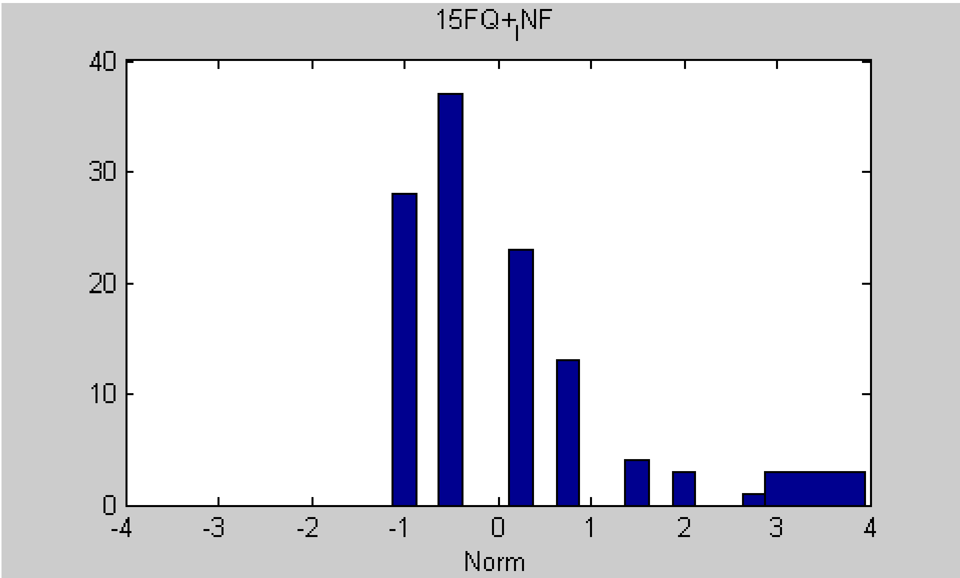


Figure 55 15FQ+ Infrequency Distribution

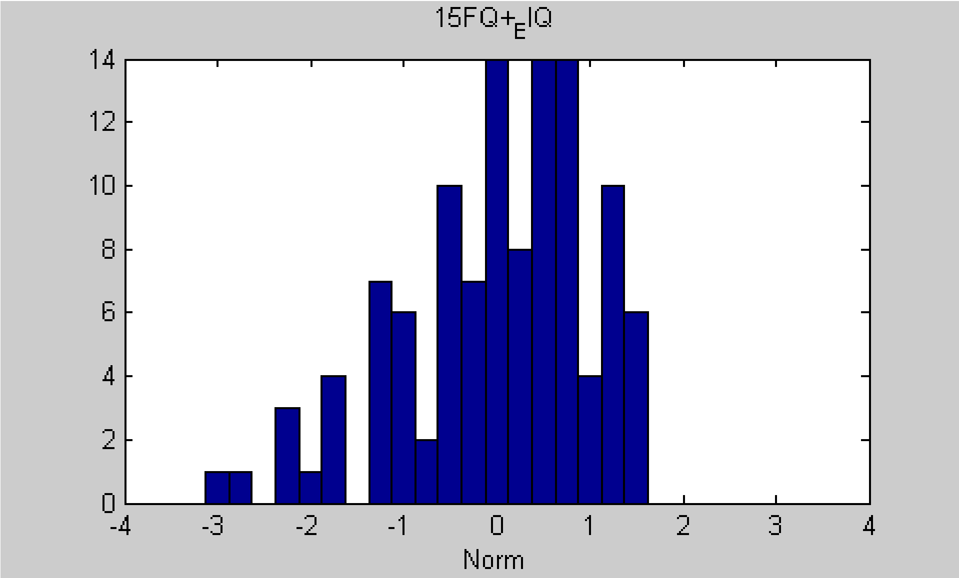


Figure 56 15FQ+_EIQ Distribution

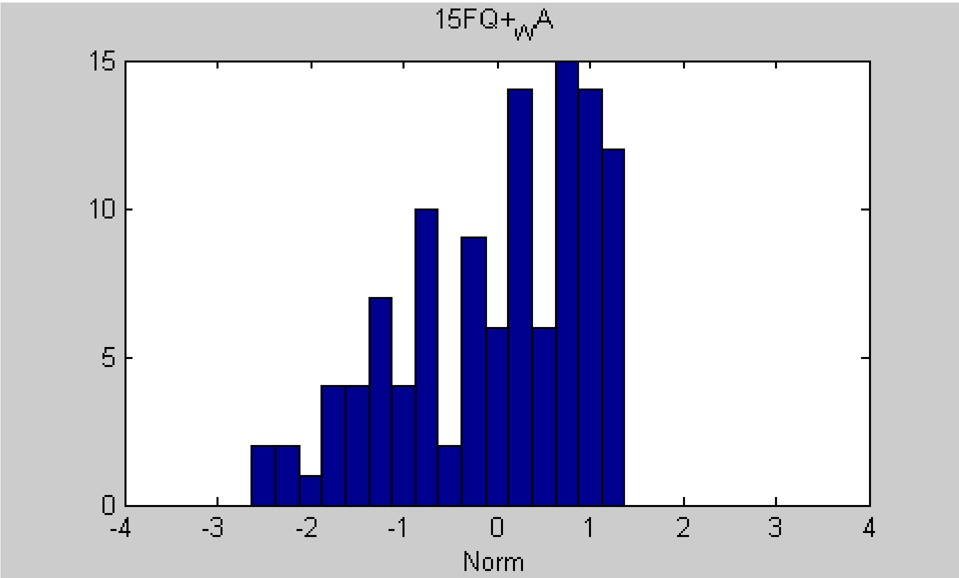


Figure 57 15FQ+ Work Attitude Distribution

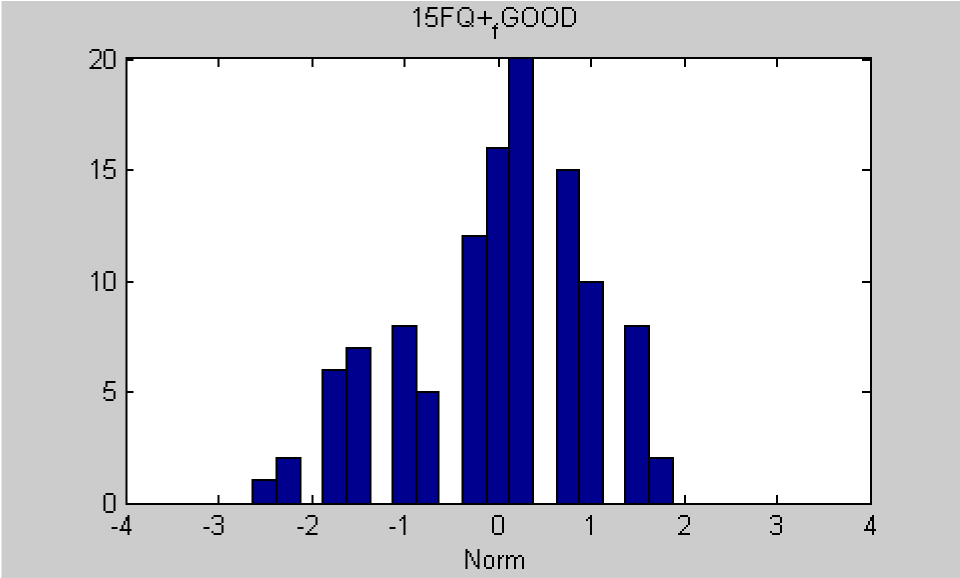


Figure 58 15FQ+ Fake Good Distribution

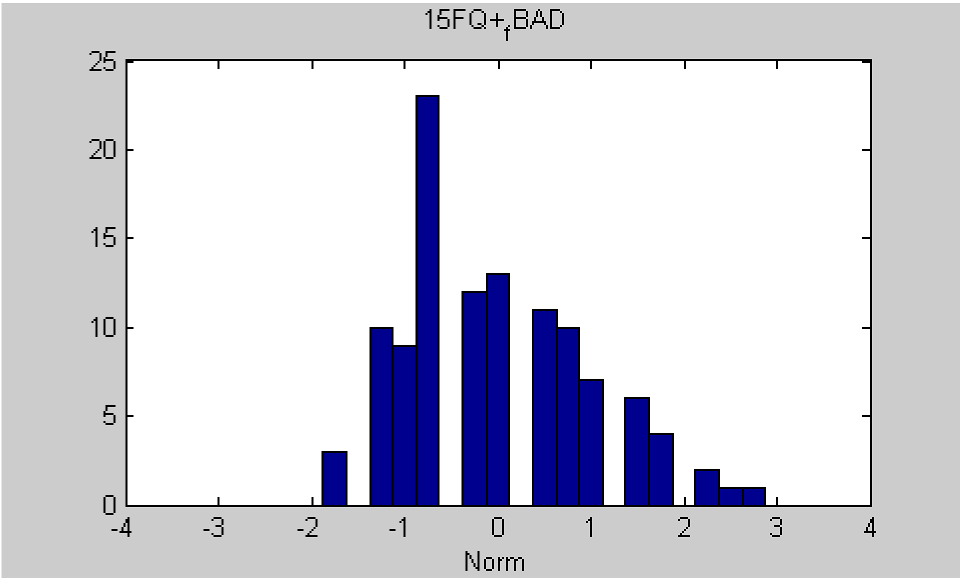


Figure 59 15FQ+ Fake Bad Distribution

F.1.2 Individual assessments: CPP

This section will discuss the CPP results in terms of cognitive styles, cognitive competencies, and level of work. Table 38 shows the CPP cognitive style preference distribution with the column marked "Preference" indicating the rank order for each of the 14 styles, followed by the 14 styles. This table shows the distribution or preference *of the* *sample* calculated from individual cognitive preferences when solving a new problem. 48% of engineers in general had the logical style as their first preference when solving a new problem. Based on the distributions, there is a low preference for impulsive and random thinking by engineers. From this and other research (Cognadev), it is unlikely that engineers who have a high preference for impulsive or random thinking would perform well in an engineering context. This identifies outliers as compared to DPSS engineers and information based on CPP studies and could be used for risk assessment when recruiting.

The ordering of cognitive styles preference can be summarised from Table 38 as follows:

1. Logical
2. Analytical
3. Reflective
4. Learning
5. Holistic
6. Integrative
7. Integrative
8. Structured
9. Quick Insight
10. Intuitive
11. Intuitive
12. Metaphoric
13. Impulsive
14. Impulsive

Integrative and impulsive were the most preferred by the sample at more than one rank. Since each cognitive style is an individual preference, the most preferred style of the sample can be the same at more that one rank.

Table 38 CPP Style Preference Distribution, (n=111)

Preference	Analytical	Explorative	Holistic	Impulsive	Integrative	Intuitive	Learning	Logical	Memory	Metaphoric	Quick insight	Random	Reflective	Structured
1	26	8	1	0	0	0	7	48	1	1	3	1	1	4
2	41	3	4	1	2	0	8	18	5	1	5	2	9	4
3	9	4	5	0	3	0	15	9	12	1	7	0	28	8
4	4	12	14	0	5	2	22	4	15	0	7	0	6	10
5	5	8	19	0	9	0	18	5	3	1	9	0	7	15
6	4	2	16	1	20	0	8	3	10	1	12	0	16	8

Preference	Analytical	Explorative	Holistic	Impulsive	Integrative	Intuitive	Learning	Logical	Memory	Metaphoric	Quick insight	Random	Reflective	Structured
7	2	6	13	0	23	2	8	4	8	2	14	0	5	14
8	4	8	9	0	17	2	6	4	5	3	10	0	14	19
9	2	3	14	1	13	5	5	1	5	4	22	1	10	16
10	0	21	3	0	6	22	0	0	19	14	11	1	3	2
11	1	16	3	0	2	46	2	2	5	21	1	1	0	1
12	3	10	0	1	1	23	0	2	12	45	0	4	1	0
13	0	0	1	48	0	0	0	0	1	5	0	46	0	0
14	1	0	0	49	0	0	0	2	0	4	0	45	0	0

For the discussion on the findings for each of the CPP competencies, a score of 1 is low while 7 is high. A large distribution in the pragmatic competency was observed ranging from 4 to 7 with a long low-competence tail. For the exploration competency a tighter spread over 5-6 was found. The participating engineers were strongly analytical, with over 70% at 7. Rule oriented competency showed a spread from 4 to 7, the majority showing high levels of competence. In terms of categorisation, a spread from 4-6 was observed, with no participants achieving a score of 7.

Of particular interest is the integration competence, where 90% of participants scored 5 or higher. This is one of the competencies where, according to the developer of the CPP, cannot be easily learnt. Scores on the complexity competency were skewed towards the high end of the scale. Over 65% of participants scored 7 for logical thinking. The participating engineers are more competent in analytical thinking than in logical thinking.

Scores on the verbal abstraction competency varied from 4 to 7. The participating engineers are competent in use of memory and memory strategies. Judgement scores also ranged over 4 to 7 with a long tail to low scores. High scores are important if engineers are to clarify vague or unstructured information. 80% of scores for Learning 1 or quick insight learning were concentrated at 6 and 7. Participating engineers showed less competence in learning 2 – gradual improvement or experiential learning.

In summary, a large number of participants scored *very highly* in the following competencies: Analytical, Integration, Complexity, Logical Reasoning, Memory Strategies, and Learning 1 (quick insight). A large group of participants had *average* scores on the following competencies: Pragmatic, Exploration, Rule-Oriented, Categorisation, Verbal Abstraction, Judgement, and Learning 2 (gradual improvement). The *lower* scores that are noteworthy can be seen on the following competencies: Pragmatic, Categorisation, Verbal Abstraction, and Judgement.

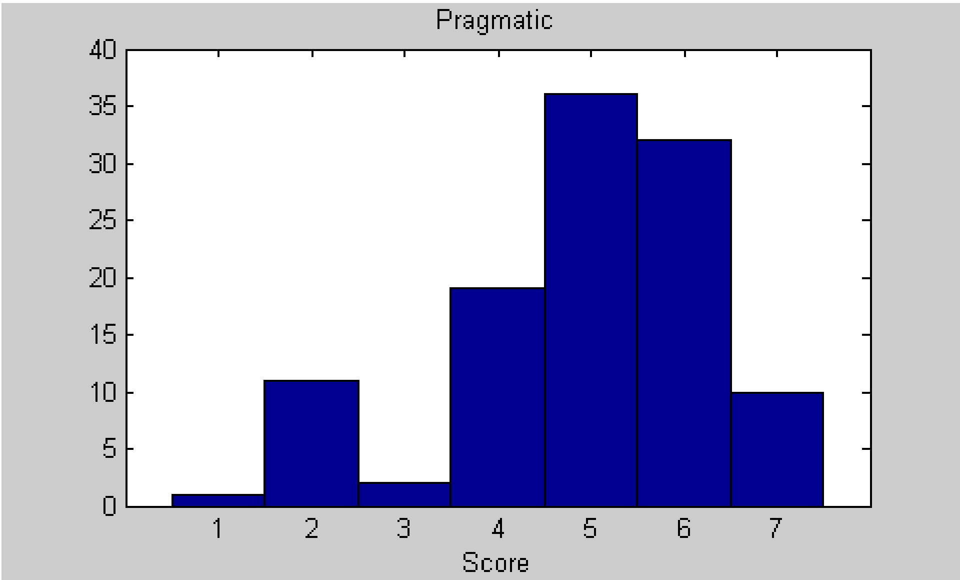


Figure 60 Pragmatic Competency Distribution

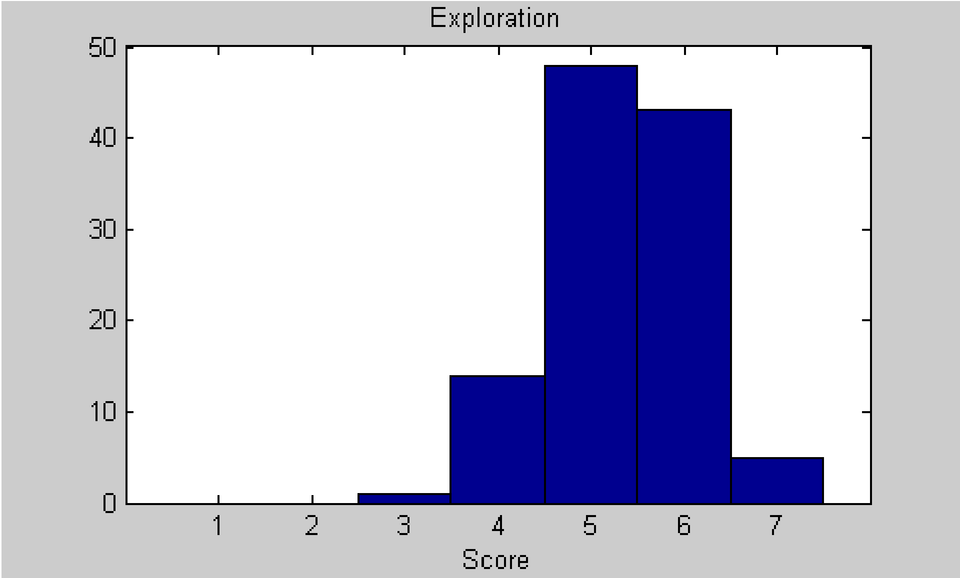


Figure 61 Exploration Competency Distribution

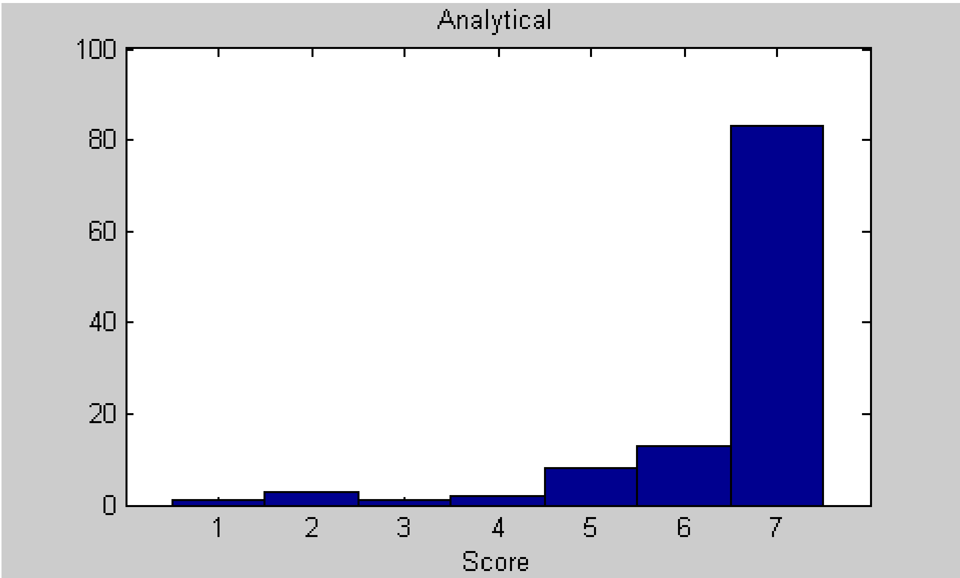


Figure 62 Analytical Competency Distribution

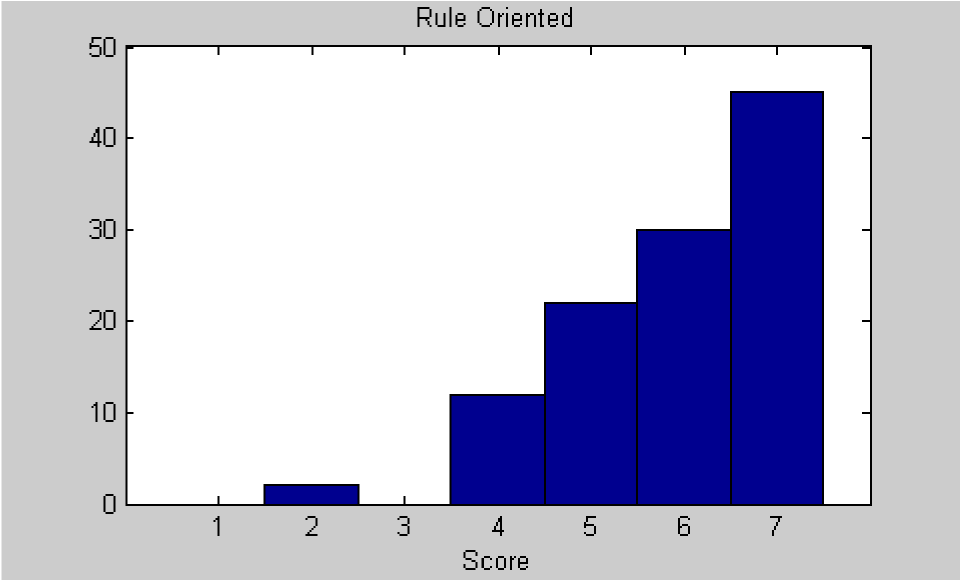


Figure 63 Rule Oriented Competency Distribution

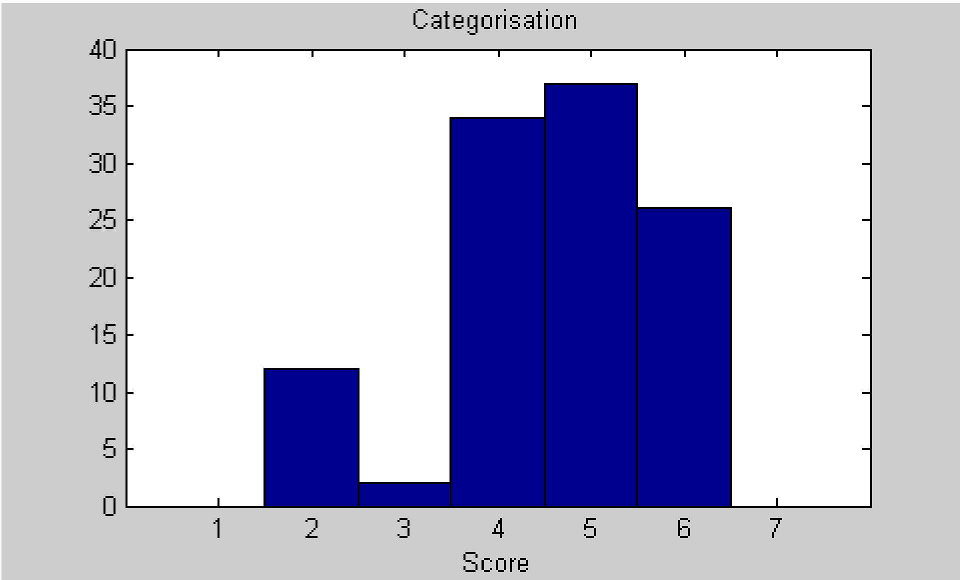


Figure 64 Categorisation Competency Distribution

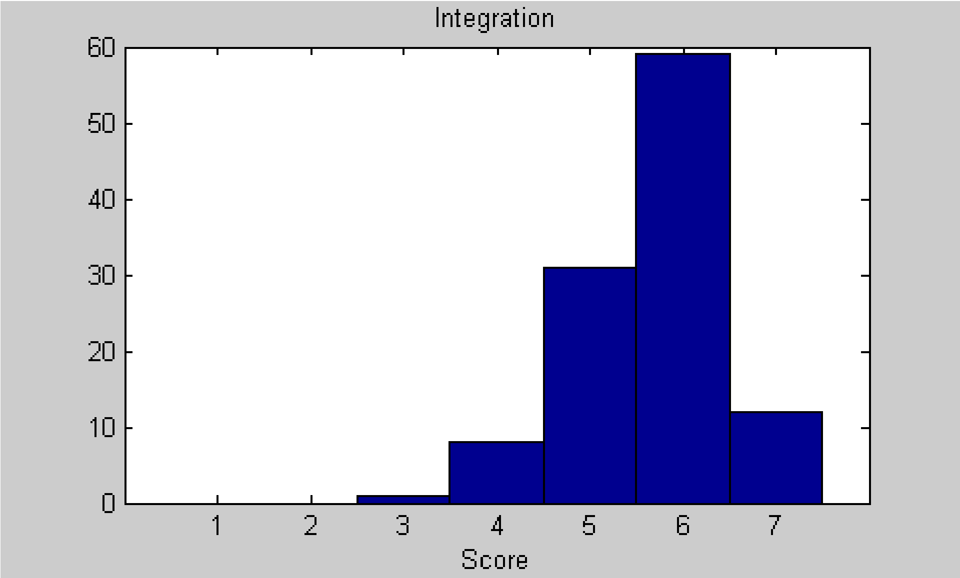


Figure 65 Integration Competency Distribution

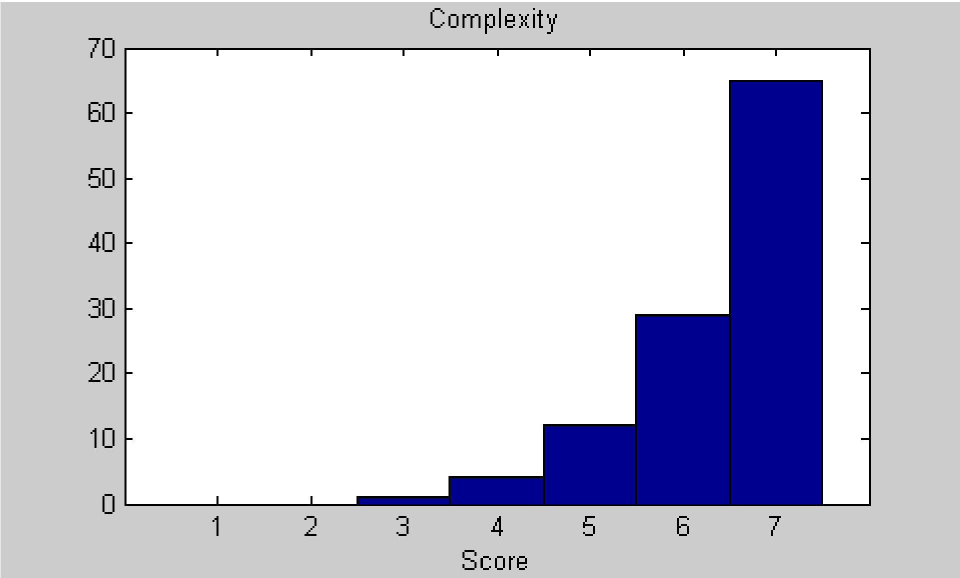


Figure 66 Complexity Competency Distribution

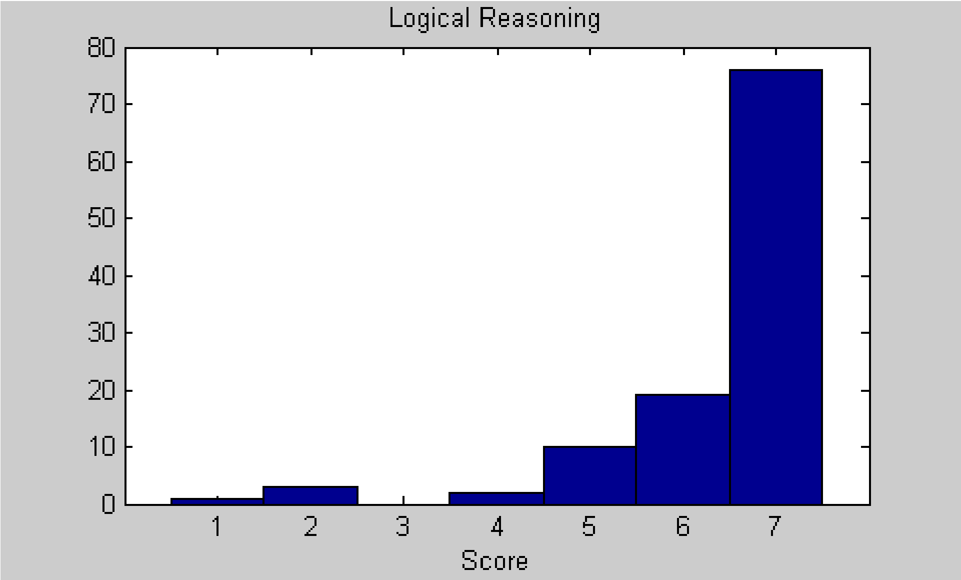


Figure 67 Logical Reasoning Competency Distribution

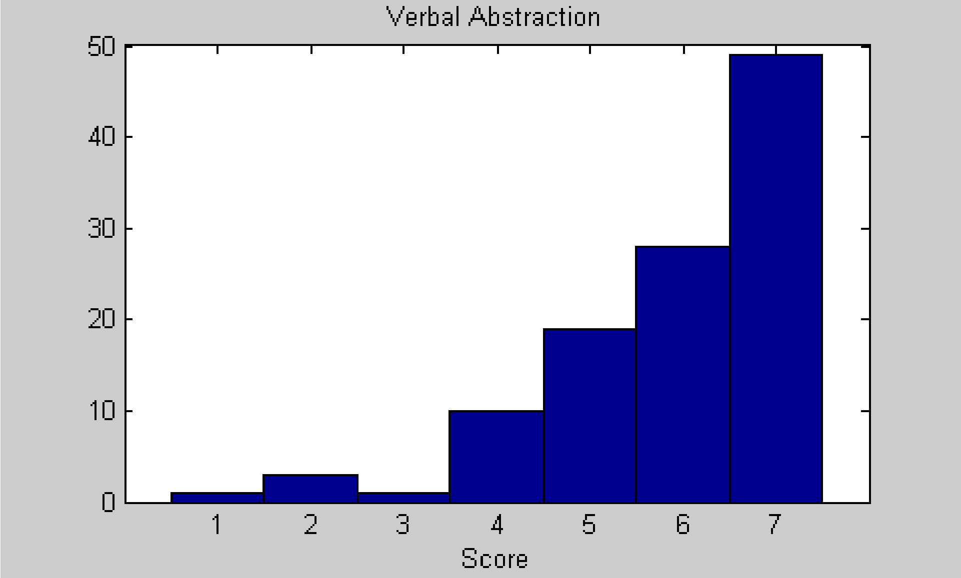


Figure 68 Verbal Abstraction Competency Distribution

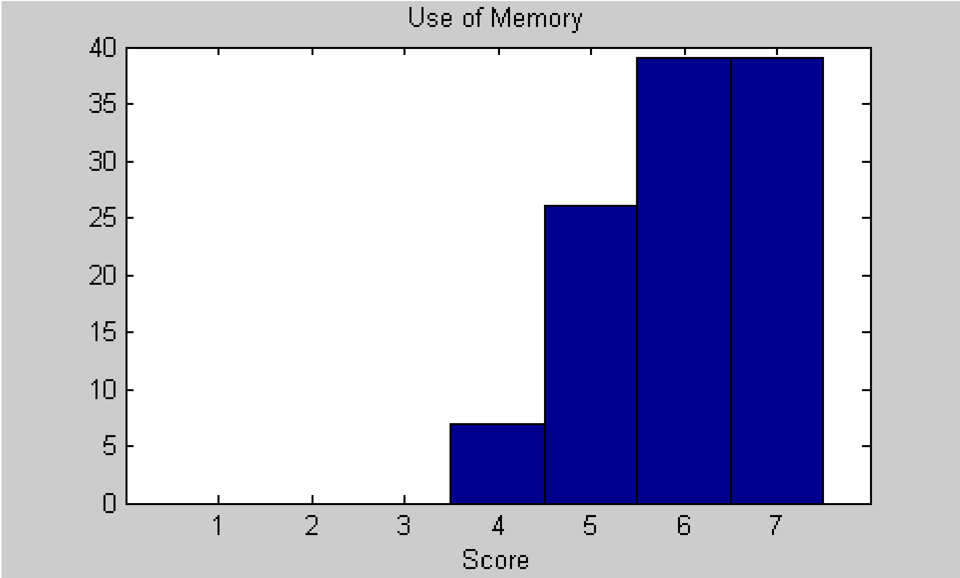


Figure 69 Use of Memory Competency Distribution

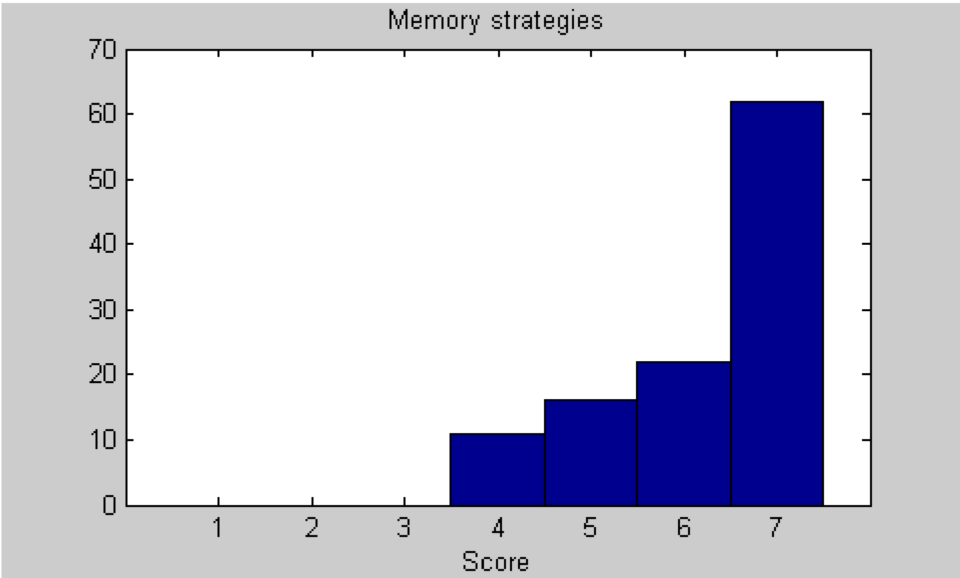


Figure 70 Memory strategies Competency Distribution

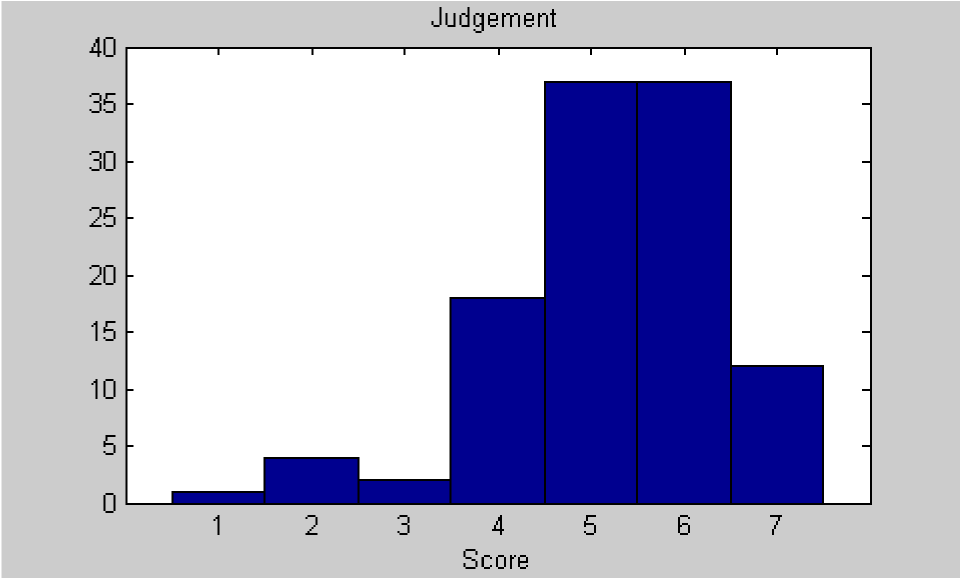


Figure 71 Judgement Competency Distribution

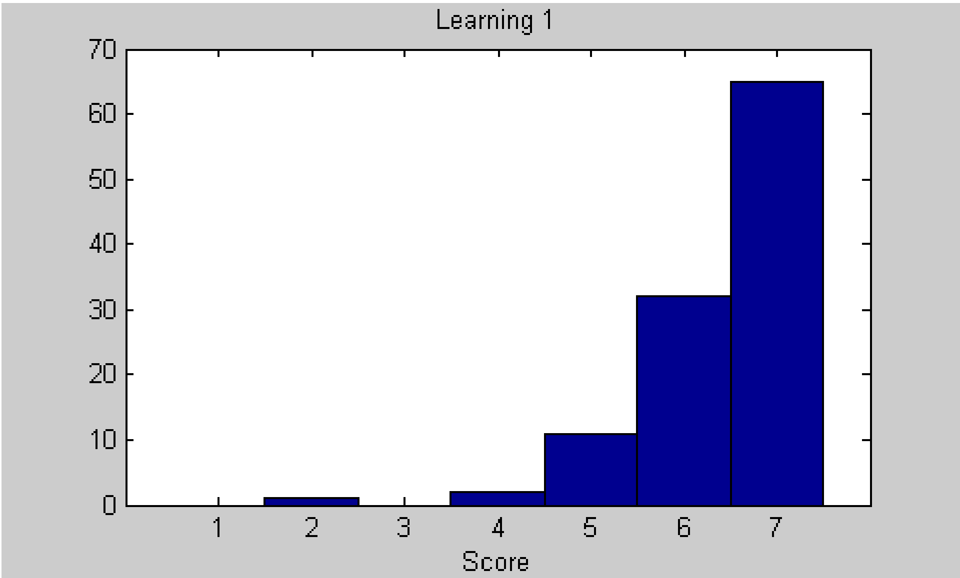


Figure 72 Learning 1 (quick insight) Competency Distribution

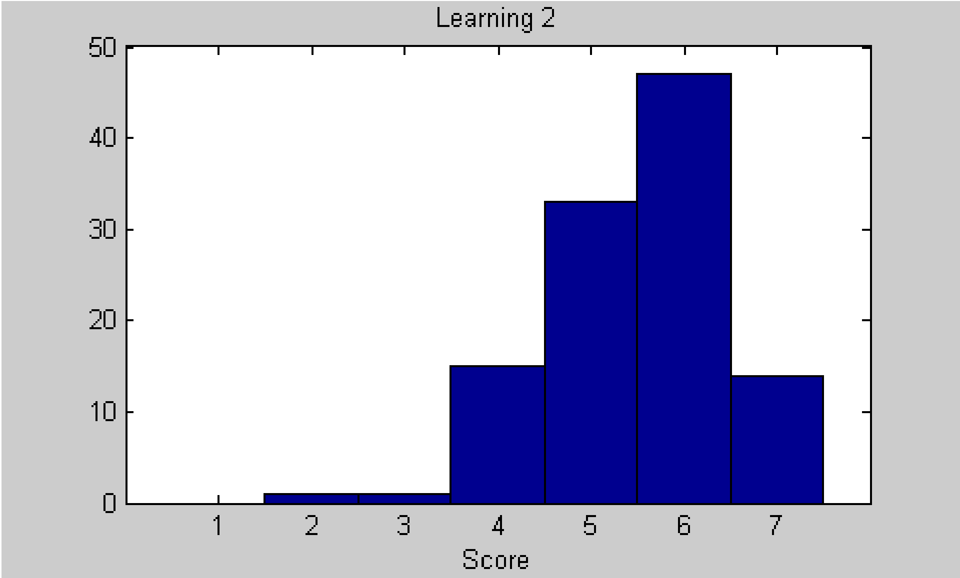


Figure 73 Learning 2 (gradual improvement) Competency Distribution

The CPP defines five levels of work related to the nature of the cognitive work and the time horizon of the required thinking:

1. Purely Operational Level of Work
2. Diagnostic Accumulative Level of Work
3. Tactical Strategy Level of Work
4. Parallel Processing Level of Work
5. Purely Strategic Level of Work

Approximately 60% of participating engineers are at level 4 with almost 30% at level 3 (Figure 74). None of the participants were at level 5 (less than 0.5% of the population are at this level), although about 25% have potential to be at this level (Figure 75).

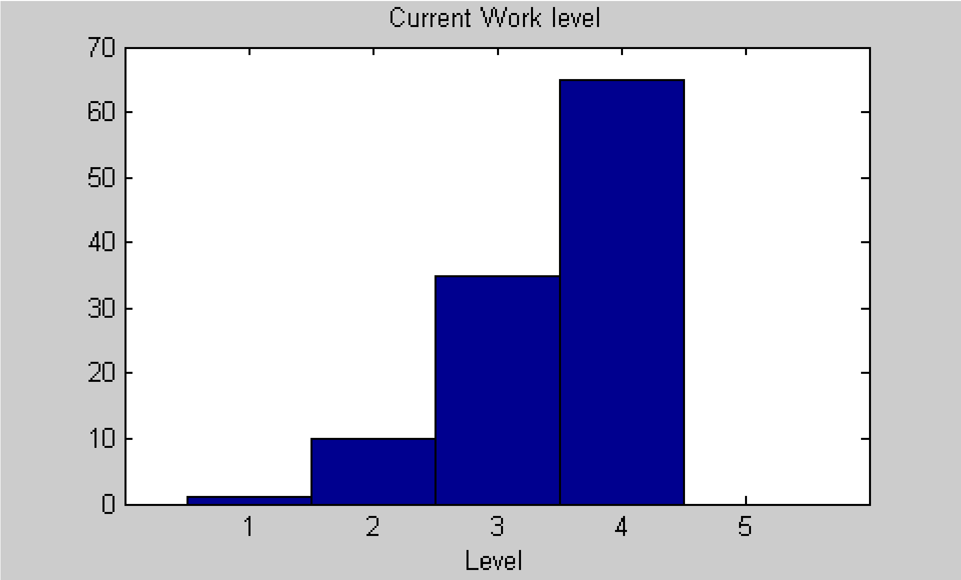


Figure 74 Current level of work

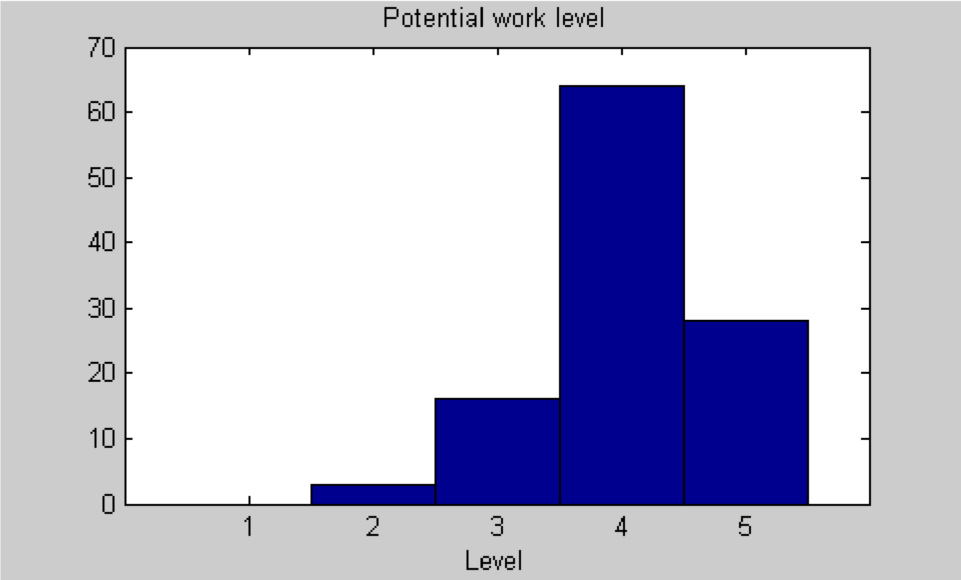


Figure 75 Potential level of work

F.1.3 Individual assessments: VO

The results of the value orientation assessment are shown in Figure 76 to Figure 89. The VO has seven value systems each being either accepted or rejected. It should be noted that the fact that someone does not accept a certain value system does not mean that the person will reject it.

Participants who accept yellow ("I learn"), accept it strongly. However, in the order of 70% do not accept yellow. On the other hand about 60% do not reject yellow, while those who reject yellow do not reject it very strongly.

Orange ("I perform") is accepted by the majority and quite strongly so. Around 30% of participants do not accept yellow. Again, as was the case with yellow, the majority do not reject orange.

With the Red accept ("I control"), the pattern changes. Over half the participants do not accept red, but only around 20% reject red.

Purple ("we protect") is accepted by only a small number of participants, while purple reject is fairly balanced between reject and not reject.

Blue ("I conform"), as with purple, is accepted by only a small number of participants. Unlike purple though, there are more people that do not reject purple. The majority of participants did not accept green ("we relate") while at the same time not rejecting it. Turquoise ("we experience") follows much the same pattern as green.

In summary, most of the participants accepted Orange. Yellow and red are not accepted by the majority, by a narrow margin. Purple, Blue, Green and Turquoise are also not accepted, but by a larger margin. None of the 7 value systems are rejected by the majority. For systems engineering in the early life-cycle, purple and blue accept are typically not desirable, except for more routine, structured tasks such as configuration management.

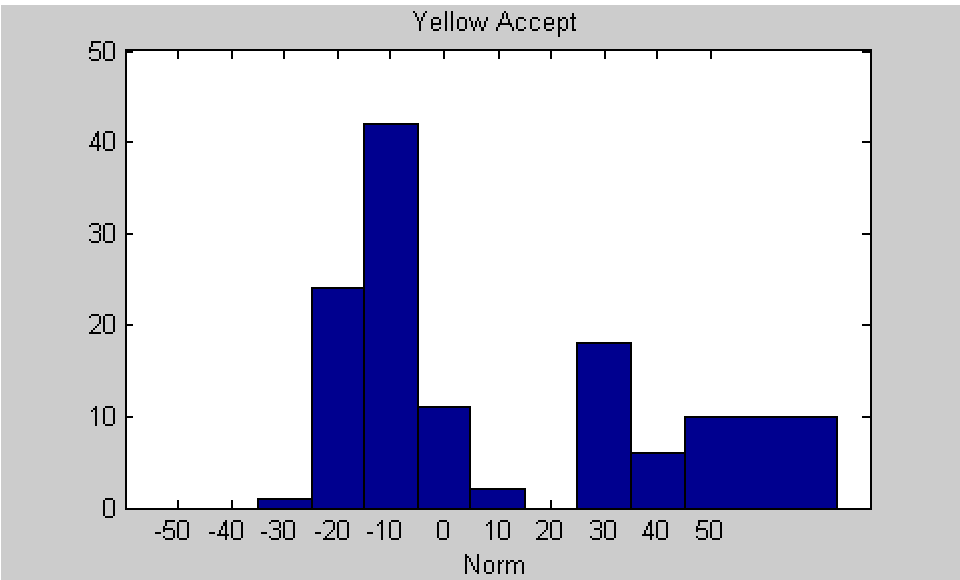


Figure 76 Yellow Accept Distribution

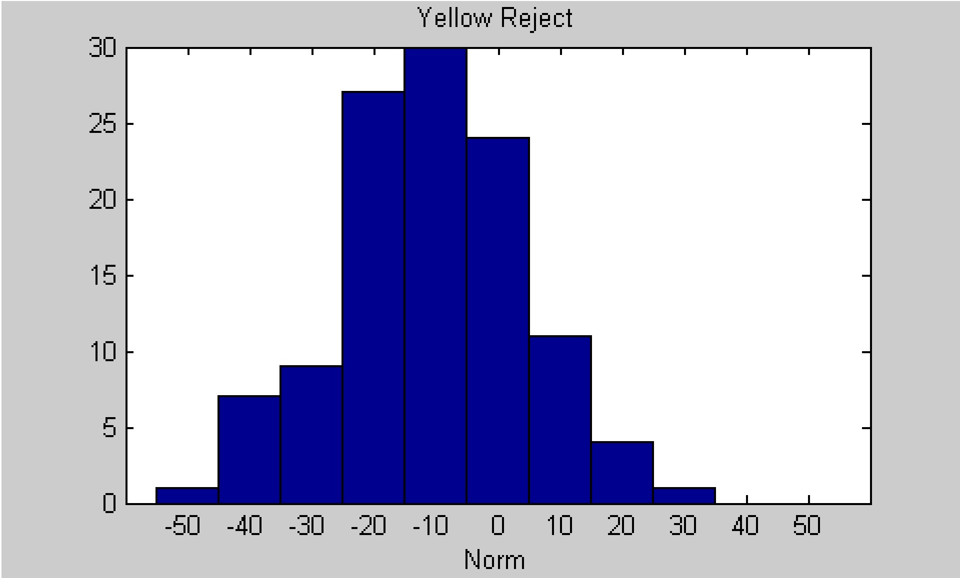


Figure 77 Yellow Reject Distribution

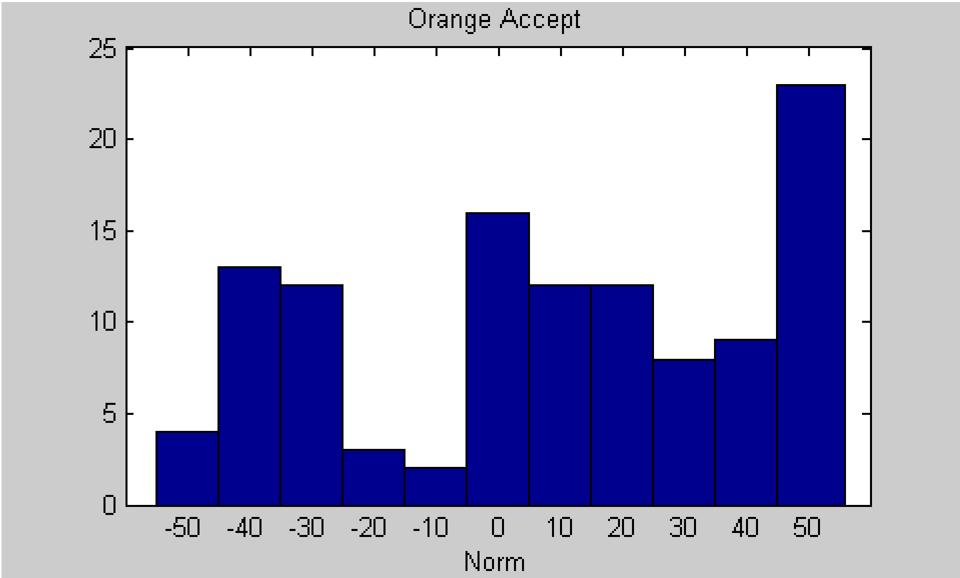


Figure 78 Orange Accept Distribution

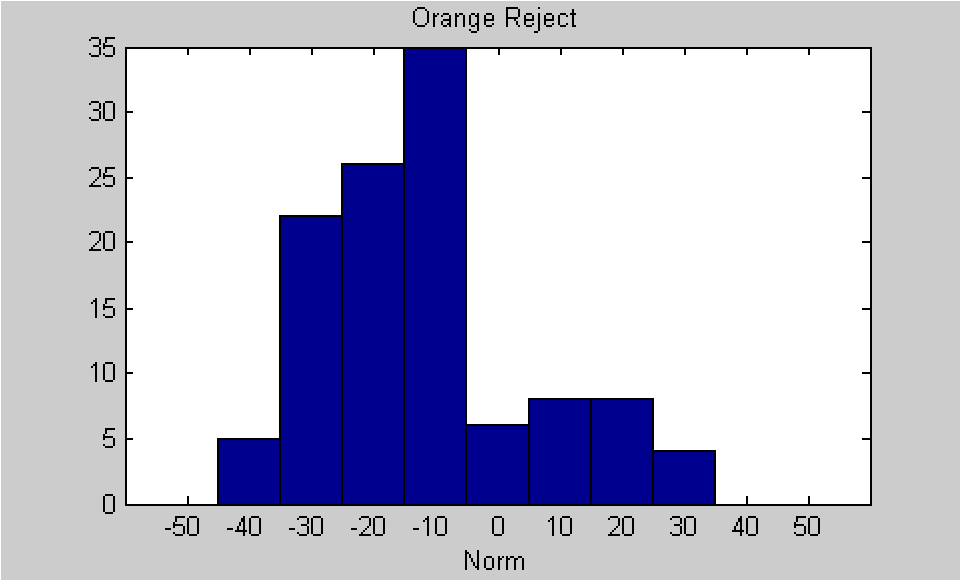


Figure 79 Orange Reject Distribution

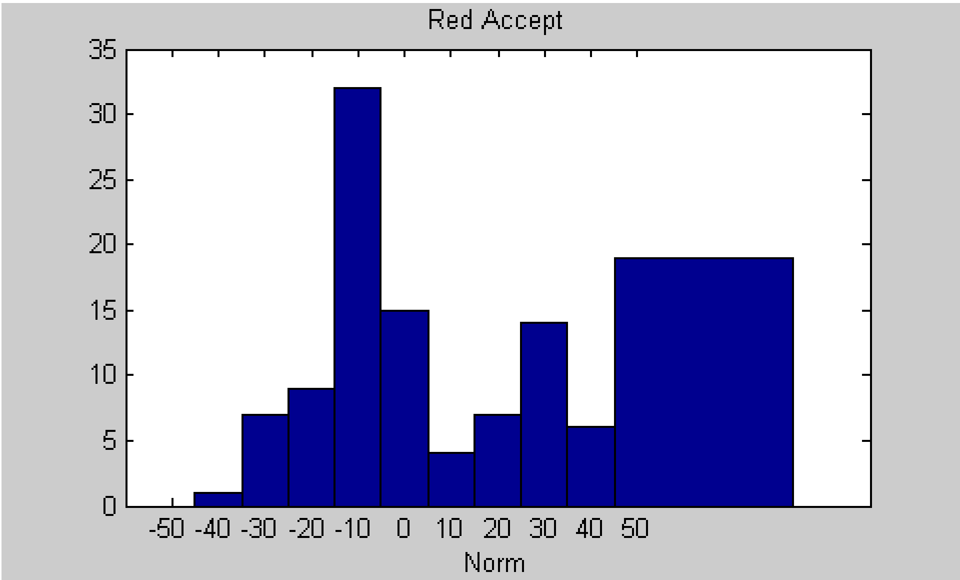


Figure 80 Red Accept Distribution

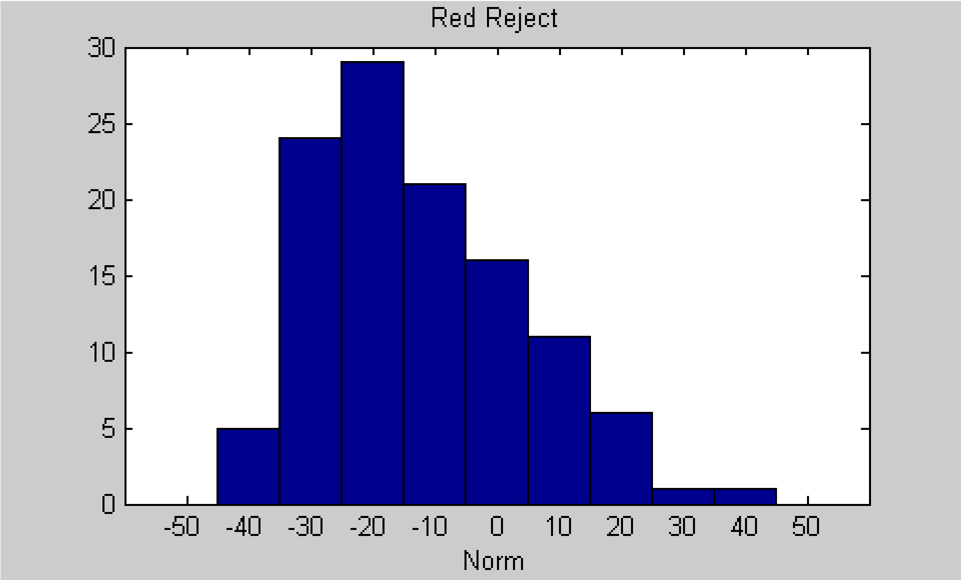


Figure 81 Red Reject Distribution

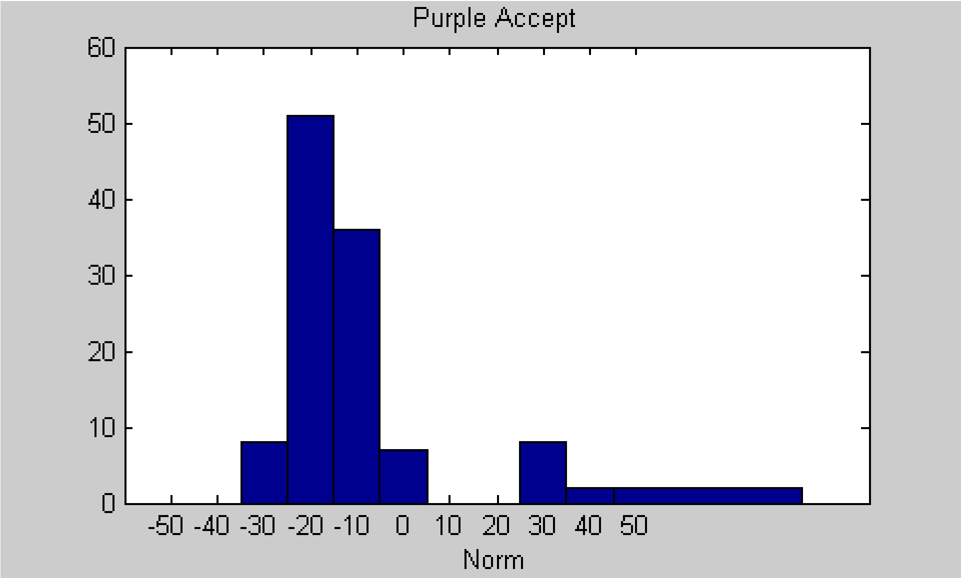


Figure 82 Purple Accept Distribution

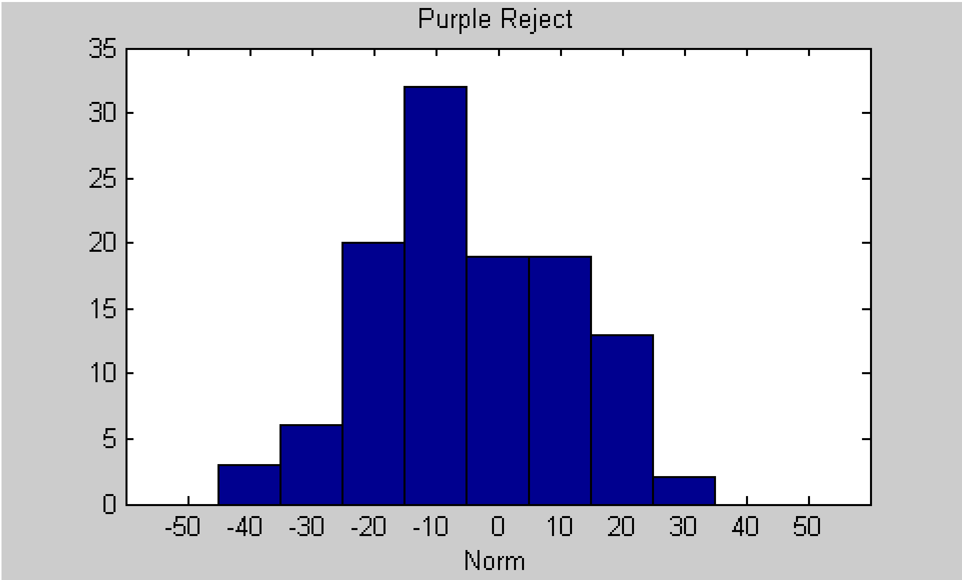


Figure 83 Purple Reject Distribution

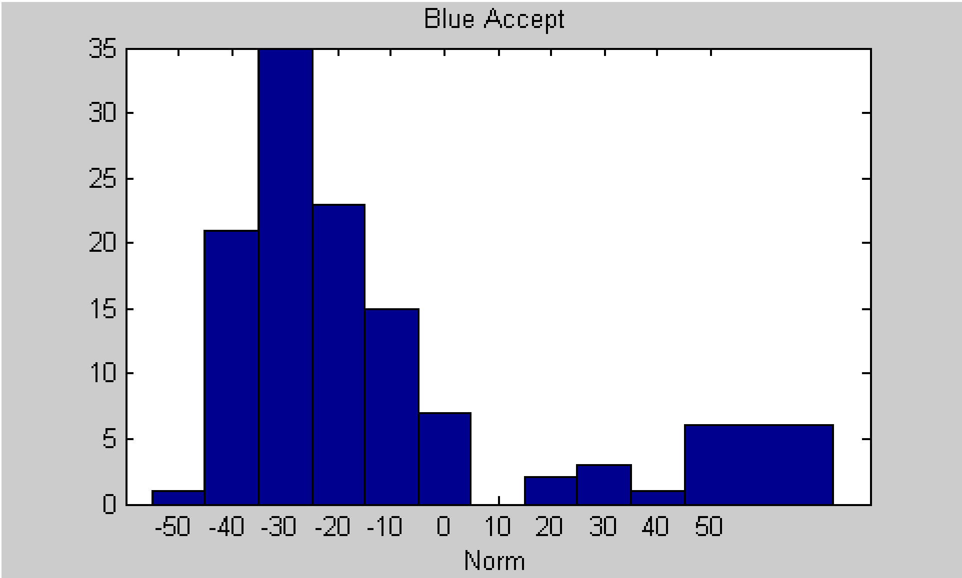


Figure 84 Blue Accept Distribution

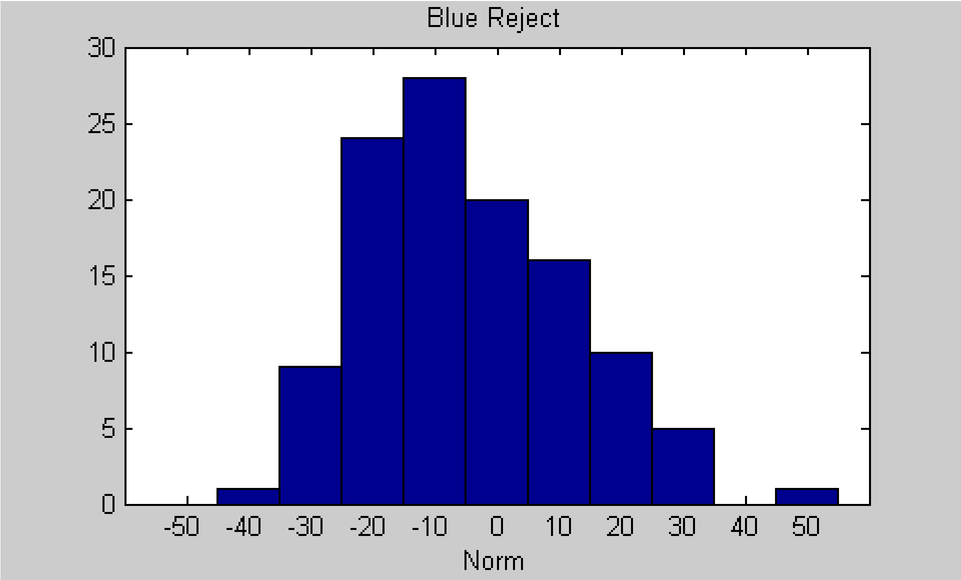


Figure 85 Blue Reject Distribution

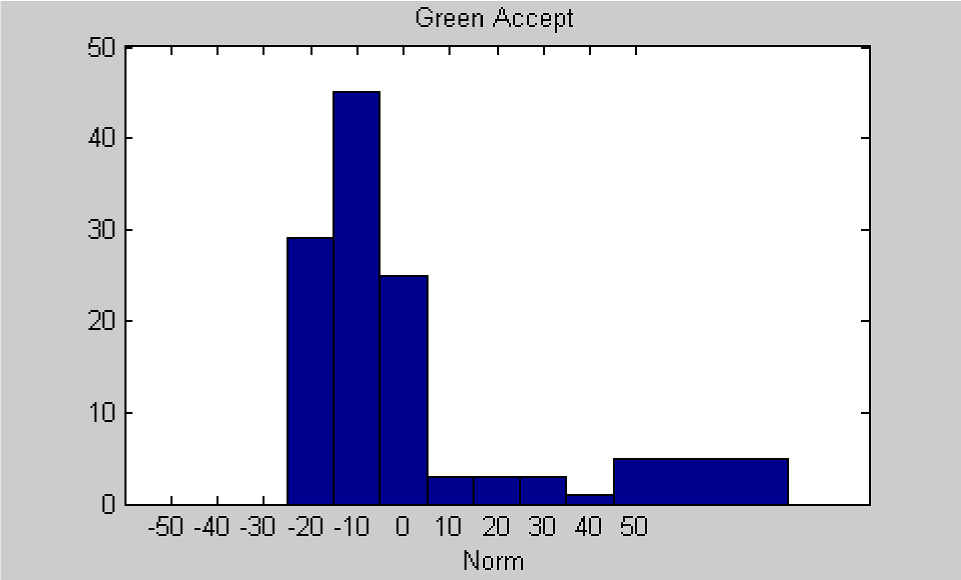


Figure 86 Green Accept Distribution

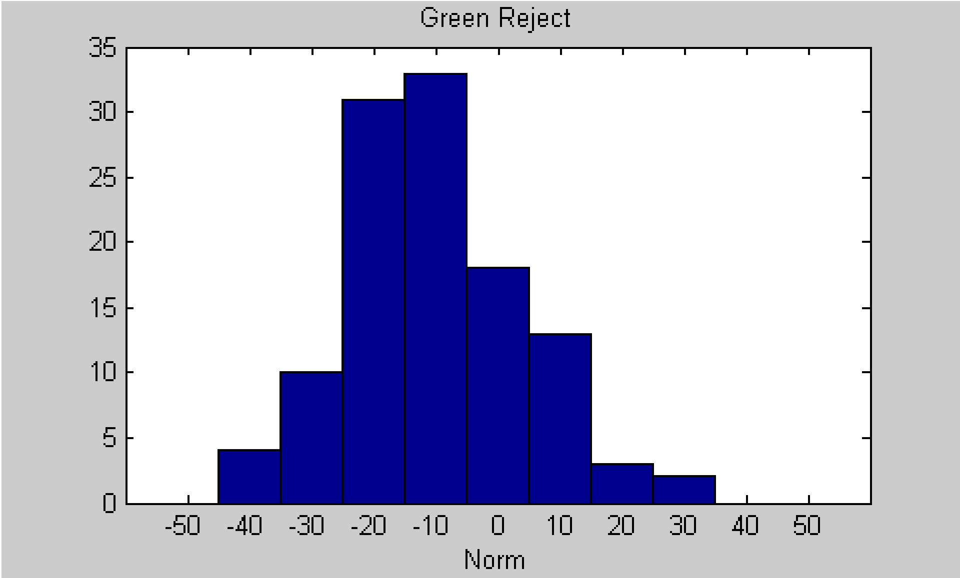


Figure 87 Green Reject Distribution

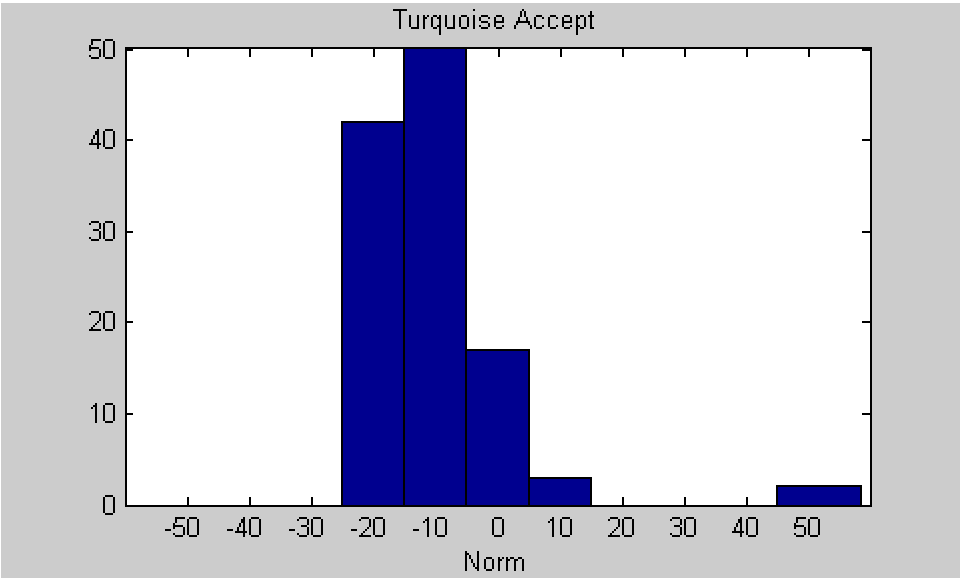


Figure 88 Turquoise Accept Distribution

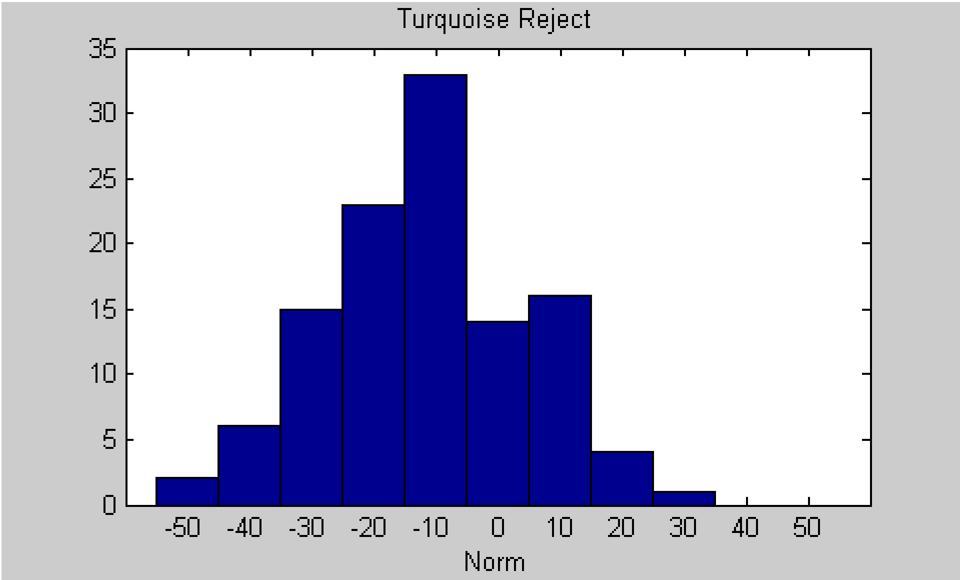


Figure 89 Turquoise Reject Distribution

F.2 Inter-psych correlation analysis

Having summarized the individual assessments, correlation is used as a first stage of analysis to identify inter-relationships between various measures. Correlation in this document refers to Pearson's linear correlation coefficient. The statistical hypothesis that the correlation is not zero at a given p value is tested.

The following correlation pairs were analysed:

- CPP-VO
- VO-15FQ+
- CPP-15FQ+

F.2.1 Correlation analysis: CPP and VO

The correlations between the **CPP style preferences and competencies, and Values** are given in Table 39 and Table 40. By looking at the statistically significant correlations, some conclusions can be drawn about the:

Yellow value system: Interestingly, from the results it would seem that engineers who reject a yellow value are not very likely to prefer Memory and Quick Insight styles. As Quick Insight is characterised by efficient strategies for managing complexity, the combination between this style and Memory allows an engineer to enhance his/her problem-solving performance, which would facilitate learning. As those who reject the yellow value are not particularly learning oriented or comfortable with unstructured situations, they would therefore not have adopted the appropriate strategies to clarify ambiguous information in a quick and effective manner. These engineers are also not likely to perform well on Judgement, which involves intuitively and consciously evaluating and clarifying unstructured and vague information.

Purple value system: Those with a purple value system place high value on protection, belonging to the group, and mysticism. From the results it seems that engineers who accept this value are very unlikely to prefer a Logical style. As the acceptance of the purple value is often characterised by obedience to the group, repetition and modelling, this person would not have the natural tendency to look for logical evidence to verify arguments, as is characterised by the Logical style. Interestingly, there was a high correlation between this value and the Metaphoric style, which is characterised by a preference for abstract thinking and the combining of information in novel ways to formulate metaphors.

Green value system: Engineers who reject the green value system, are likely to question an over-emphasis on the human factor, and would not be gullible or overly accepting. From the results it seems that engineers who reject this value are less likely to prefer a Memory style. They are, however, very likely to adopt a Reflective style. Perhaps this is because this type of person would not be emotional or overly accepting – therefore it would be easier for such a person to compare and integrate new elements into existing information, and follow through reasoning processes.

Orange value system: Those who reject the orange value system, are likely to reject an overemphasis on personal achievement, and are not likely to favour manipulation, strategic thinking or taking calculated risks. From the data, these engineers are not likely to prefer a Quick Insight style. Engineers that do not deem strategic thinking and manipulation for personal achievement all that important, would not very likely have adopted a style that is characterised by effective task and goal orientation.

Table 39 CPP Style Preference and Value Orientations Correlation (n = 94)

Cognitive style preference	Values	Correlation	p
Explorative	Yellow Reject	0.231	0.025
Integrative	Orange Accept	-0.205	0.047
Integrative	Blue Accept	0.211	0.041
Logical	Purple Accept	-0.272	0.008
Logical	Blue Accept	-0.244	0.018
Memory	Yellow Reject	-0.312	0.002
Memory	Blue Accept	-0.206	0.046
Memory	Green Reject	-0.316	0.002
Memory	Turquoise Reject	-0.270	0.009
Metaphoric	Purple Accept	0.316	0.002
Metaphoric	Blue Accept	0.237	0.022
Quick insight	Yellow Reject	-0.268	0.009
Quick insight	Orange Reject	-0.332	0.001
Quick insight	Green Accept	-0.229	0.027
Reflective	Yellow Reject	0.216	0.037
Reflective	Green Reject	0.310	0.002
Reflective	Turquoise Reject	0.210	0.042

Table 40 CPP Competencies and Value Orientations Correlation (n = 94)

Cognitive competencies	Values	Correlation	p
Exploration	Yellow Reject	-0.219	0.034
Exploration	Blue Accept	-0.238	0.021
Categorisation	Yellow Reject	-0.243	0.018
Categorisation	Green Reject	-0.234	0.023
Use of Memory	Yellow Accept	0.227	0.028
Use of Memory	Yellow Reject	-0.216	0.036
Judgement	Yellow Accept	0.238	0.021
Judgement	Yellow Reject	-0.279	0.007
Judgement	Orange Reject	-0.232	0.024
Judgement	Purple Accept	-0.251	0.015
Judgement	Blue Accept	-0.230	0.026

F.2.2 Correlation analysis: CPP and 15FQ+

A summary of statistically significant correlations between the CPP Styles and Information processing competencies and 15FQ+ scales are given in Table 41 and Table 42. The most interesting correlations can be seen with regards to the following contructs (which results in styles and competency descriptors):

Exploration: It seems that engineers leaning towards exploration as a preference are likely to be Enthusiastic and have high confidence in their Intellectual abilities.

Linking/analysis: Engineers who scored high on this competency are prone to be Tense-driven and Dominant.

Structuring: Engineers who scored high here are likely to be Expedient, Group Oriented, Enthusiastic, and have high confidence in their Intellectual abilities (with the excpetion of the Structured style – it seems that when engineers with high scores for this competency manifest a Structured style, they are more likely to have Low Intellectance).

Transformation: Engineers who have higher scores on this competency will be more likely to have High Intellectance, and to be Enthusiastic.

Memory: From the data, engineers who lean towards the Memory competency are likely to have High Intellectance, and to be Abstract, Direct, and Enthusiastic.

Meta-cognition: Engineers with high scores on this competency are more likely to be Expedient, Informal, and Direct.

Table 41 CPP Style Preference and 15FQ+ Correlation (n = 94)

Cognitive style preferences	15FQ+	Correlation	p
Analytical	fQ4: Composed - Tense-driven	0.214	0.038
Integrative	fG: Expedient - Conscientious	-0.229	0.026
Integrative	fQ2: Group-oriented - Self-sufficient	-0.205	0.048
Intuitive	fQ3: Informal - Self-disciplined	-0.228	0.027
Learning	B: Low Intellectance - High Intellectance	0.232	0.025
Logical	B: Low Intellectance - High Intellectance	0.216	0.036
Reflective	fQ3: Informal - Self-disciplined	0.208	0.045
Structured	B: Low Intellectance - High Intellectance	-0.244	0.018

Table 42 CPP Competencies and 15FQ+ Correlation (n = 94)

Cognitive competencies	15FQ+	Correlation	p
Pragmatic	B: Low Intellectance - High Intellectance	0.258	0.012
Exploration	B: Low Intellectance - High Intellectance	0.242	0.019
Exploration	fF: Sober Serious - Enthusiastic	0.266	0.009
Rule Oriented	B: Low Intellectance - High Intellectance	0.206	0.046
Rule Oriented	fE: Accommodating - Dominant	0.228	0.027

Cognitive competencies	15FQ+	Correlation	p
Integration	B: Low Intellectance - High Intellectance	0.221	0.032
Integration	fF: Sober Serious - Enthusiastic	0.207	0.045
Complexity	B: Low Intellectance - High Intellectance	0.267	0.009
Logical Reasoning	B: Low Intellectance - High Intellectance	0.241	0.019
Logical Reasoning	fF: Sober Serious - Enthusiastic	0.206	0.047
Verbal Abstraction	fF: Sober Serious - Enthusiastic	0.233	0.024
Use of Memory	B: Low Intellectance - High Intellectance	0.300	0.003
Use of Memory	fM: Concrete - Abstract	0.216	0.037
Use of Memory	fN: Direct - Restrained	-0.223	0.030
Memory strategies	fF: Sober Serious - Enthusiastic	0.249	0.015
Judgement	fN: Direct - Restrained	-0.219	0.034
Learning 1 – quick insight	B: Low Intellectance - High Intellectance	0.216	0.036
Learning 2 – gradual improvement	fF: Sober Serious - Enthusiastic	0.232	0.025
Learning 2 – gradual improvement	fM: Concrete - Abstract	0.209	0.043

F.2.3 Correlation analysis: VO and 15FQ+

In Table 43, the most significant and interesting correlations with regards to the following value systems are:

Yellow value system: Engineers who accept the yellow value system, are likely to be Radical. This makes sense as these kinds of engineers value learning and innovation and are inclined to reject tried and tested methods. Engineers who reject this value system are likely to be Concrete (focus on tangible issues, practical), Conventional (focus on tried-and-tested methods) and Self-disciplined (value protocol and procedure), which is consistent with the results.

Orange value system: Engineers who accept this value system are more likely to be Dominant and Direct. These characteristics would allow a self-reliant person with this value system to gain personal achievement through manipulation, competitiveness, and strategy. Those who reject this value system, are most likely to be Conventional and Self-disciplined – they would be inclined to dislike manipulation and competition and would prefer to stick to the way things have been done for years and what they are familiar with, and value authority and conformity.

Red value system: Those who accept this value would be Dominant, Conscientious, Hard-headed, Concrete and Direct. These characteristics allow a person with this value system to enforce dominance and power, to get things done, survive, and learn as a result of reinforcement and conditioning (focus on tried-and-tested methods, how things have been done for years). Engineers who reject this value would dislike a forceful, impulsive and dominant approach, would be more open-minded, and would question self-centered behaviour. Therefore it is very consistent with this profile that these engineers are likely to be Empathetic, Tender-minded and Abstract.

Purple value system: Those who embrace this value system are likely to be Concrete and Conventional, as they place high value on customs and traditions, and learning through repetition and modelling. Those who reject this value system are likely have high confidence in their intellectual abilities (question the tendency to be too reliant on in-groups, so will be more self-sufficient), and to be Dominant, Direct, and Radical (not too concerned with preservation of customs/traditions).

Blue value system: Those with a blue value systems will be more Concrete, Conventional, and Self-disciplined as they place high value on rules, order, discipline, authority, and tried-and-tested methods. Those who reject this value dislike the overemphasis on conformity, order, discipline and authority and it therefore makes sense that they are more Dominant, Direct, and Radical. Interestingly, it seems that those who reject a blue value system are also more likely to have higher confidence in their intellectual abilities than those who accept this value system.

Green value system: Those who accept this value are more Empathetic and Accomodating on the 15FQ+, as they are sensitive, open-minded and compassionate individuals. Those who reject this value are more Dominant, Concrete, and Conventional, as they would question an over-emphasis on the human factor and radical open-mindedness. Interestingly, engineers who reject this value are also more likely to be more Conscientious and Self-disciplined.

Turquoise value system: Those who embrace the turquoise value system are more likely to be Abstract, as these individuals are more creative, imaginative, and holistic, and not too concerned with practical, day-to-day issues. Consistent with these results, those who reject this value are more inclined to be Conscientious, Hard-headed and Concrete, as they will have little interest in artistic or creative matters and would rather be concerned with whether things work effectively.

Table 43 15FQ+ and Values Correlation (n = 94)

Values	15FQ+	Correlation	p
Yellow Accept	fM: Concrete - Abstract	0.393	0.000
Yellow Accept	fQ1: Conventional - Radical	0.354	0.000
Yellow Accept	fQ3: Informal - Self-disciplined	-0.267	0.009
Yellow Reject	fG: Expedient - Conscientious	0.288	0.005
Yellow Reject	fM: Concrete - Abstract	-0.410	0.000
Yellow Reject	fQ1: Conventional - Radical	-0.433	0.000
Yellow Reject	fQ2: Group-oriented - Self-sufficient	-0.218	0.034
Yellow Reject	fQ3: Informal - Self-disciplined	0.424	0.000
Orange Accept	B: Low Intellectance - High Intellectance	0.310	0.002
Orange Accept	fC: Affected by Feelings - Emotionally Stable	0.222	0.032
Orange Accept	fE: Accommodating - Dominant	0.441	0.000
Orange Accept	fH: Retiring - Socially-bold	0.271	0.008
Orange Accept	fN: Direct - Restrained	-0.325	0.001
Orange Accept	fO: Confident - Self-doubting	-0.268	0.009
Orange Accept	fQ1: Conventional - Radical	0.299	0.003
Orange Reject	fA: Distant/Aloof - Empathetic	0.260	0.011
Orange Reject	fG: Expedient - Conscientious	0.223	0.031

Values	15FQ+	Correlation	p
Orange Reject	fN: Direct - Restrained	0.203	0.049
Orange Reject	fQ1: Conventional - Radical	-0.373	0.000
Orange Reject	fQ3: Informal - Self-disciplined	0.344	0.001
Red Accept	fA: Distant/Aloof - Empathetic	-0.255	0.013
Red Accept	fE: Accommodating - Dominant	0.425	0.000
Red Accept	fG: Expedient - Conscientious	0.308	0.002
Red Accept	fI: Hard-headed - Tender-minded	-0.304	0.003
Red Accept	fM: Concrete - Abstract	-0.296	0.004
Red Accept	fN: Direct - Restrained	-0.276	0.007
Red Accept	fO: Confident - Self-doubting	-0.204	0.049
Red Accept	fQ1: Conventional - Radical	-0.208	0.045
Red Reject	fA: Distant/Aloof - Empathetic	0.296	0.004
Red Reject	fE: Accommodating - Dominant	-0.213	0.039
Red Reject	fI: Hard-headed - Tender-minded	0.285	0.005
Red Reject	fM: Concrete - Abstract	0.338	0.001
Red Reject	fQ1: Conventional - Radical	0.205	0.047
Purple Accept	B: Low Intellectance - High Intellectance	-0.262	0.011
Purple Accept	fM: Concrete - Abstract	-0.268	0.009
Purple Accept	fO: Confident - Self-doubting	0.214	0.038
Purple Accept	fQ1: Conventional - Radical	-0.295	0.004
Purple Accept	fQ3: Informal - Self-disciplined	0.221	0.033
Purple Reject	B: Low Intellectance - High Intellectance	0.341	0.001
Purple Reject	fE: Accommodating - Dominant	0.269	0.009
Purple Reject	fH: Retiring - Socially-bold	0.211	0.041
Purple Reject	fN: Direct - Restrained	-0.308	0.002
Purple Reject	fQ1: Conventional - Radical	0.276	0.007

Values	15FQ+	Correlation	p
Blue Accept	B: Low Intellectance - High Intellectance	-0.254	0.014
Blue Accept	fG: Expedient - Conscientious	0.247	0.017
Blue Accept	fM: Concrete - Abstract	-0.289	0.005
Blue Accept	fO: Confident - Self-doubting	0.204	0.049
Blue Accept	fQ1: Conventional - Radical	-0.368	0.000
Blue Accept	fQ3: Informal - Self-disciplined	0.317	0.002
Blue Reject	B: Low Intellectance - High Intellectance	0.288	0.005
Blue Reject	fE: Accommodating - Dominant	0.259	0.012
Blue Reject	fM: Concrete - Abstract	0.253	0.014
Blue Reject	fN: Direct - Restrained	-0.440	0.000
Blue Reject	fO: Confident - Self-doubting	-0.237	0.021
Blue Reject	fQ1: Conventional - Radical	0.363	0.000
Green Accept	fA: Distant/Aloof - Empathetic	0.301	0.003
Green Accept	fE: Accommodating - Dominant	-0.272	0.008
Green Accept	fI: Hard-headed - Tender-minded	0.224	0.030
Green Accept	fN: Direct - Restrained	0.250	0.015
Green Reject	fE: Accommodating - Dominant	0.281	0.006
Green Reject	fG: Expedient - Conscientious	0.323	0.001
Green Reject	fM: Concrete - Abstract	-0.280	0.006
Green Reject	fQ1: Conventional - Radical	-0.332	0.001
Green Reject	fQ3: Informal - Self-disciplined	0.368	0.000
Turquoise Accept	fA: Distant/Aloof - Empathetic	0.218	0.035
Turquoise Accept	fE: Accommodating - Dominant	-0.245	0.017
Turquoise Accept	fM: Concrete - Abstract	0.327	0.001
Turquoise Accept	fQ1: Conventional - Radical	0.235	0.022
Turquoise Reject	fG: Expedient - Conscientious	0.302	0.003

Values	15FQ+	Correlation	p
Turquoise Reject	fI: Hard-headed - Tender-minded	-0.279	0.006
Turquoise Reject	fM: Concrete - Abstract	-0.361	0.000
Turquoise Reject	fQ1: Conventional - Radical	-0.233	0.024
Turquoise Reject	fQ3: Informal - Self-disciplined	0.253	0.014

Appendix G Potential identification algorithm profiles

This appendix provides the potential identification algorithm profiles described in section 4.4.2.2. The mean μ_{HCCj} and standard deviation s_{HCj}, and the mean and standard deviation expressed as a percentage of the full range are shown in Table 44 to Table 57, for SE competencies where the criterion sample size, n>2. The tables are ranked in increasing standard deviation, with the first 40 measures listed.

Table 44 Systems Thinking: System Concepts: Mean and standard deviation (n=12)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Impulsive	13.3	0.5	94	4
2	Green Accept	-7.7	4.9	15	5
3	Random	13.6	0.7	97	5
4	Turquoise Accept	-13.0	4.4	9	6
5	Purple Accept	-18.7	6.6	8	6
6	Metaphoric	11.6	0.9	81	7
7	Blue Accept	-28.0	11.7	15	10
8	Logical	1.8	1.3	6	10
9	fC: Affected by Feelings - Emotionally Stable	19.5	2.5	80	11
10	B: Low Intellectance - High Intellectance	22.0	2.1	89	12
11	Red Reject	-15.6	9.8	35	13
12	Logical Reasoning	6.6	0.8	93	13
13	Analytical	6.4	0.8	90	13

Rank	Measure	Mean	Std	Mean (%)	Std (%)
14	Learning 1	6.6	0.7	92	13
15	Intuitive	10.7	1.1	83	13
16	Purple Reject	3.4	10.0	65	15
17	Exploration	5.7	0.7	67	16
18	Learning 2	5.7	0.9	73	18
19	fM: Concrete - Abstract	13.6	4.1	59	18
20	Judgement	5.4	1.1	74	18
21	Blue Reject	3.1	16.0	50	18
22	Yellow Reject	-13.3	14.9	48	19
23	Rule Oriented	6.2	0.9	83	19
24	Integration	5.8	0.8	69	19
25	Green Reject	-5.2	15.1	50	19
26	Orange Reject	-15.8	14.2	35	19
27	Reflective	4.7	2.1	33	19
28	Pragmatic	5.3	1.2	72	19
29	fL: Trusting - Suspicious	5.4	4.3	25	19
30	Analytical	4.0	2.5	23	19
31	fQ3: Informal - Self-disciplined	18.1	3.9	70	20
32	Categorisation	4.9	0.8	73	20
33	Complexity	6.6	0.8	90	20
34	Structured	7.1	2.1	61	21
35	fE: Accommodating - Dominant	15.7	5.0	65	21
36	Holistic	6.3	2.5	44	21

Rank	Measure	Mean	Std	Mean (%)	Std (%)
37	Turquoise Reject	-5.3	16.1	59	21
38	fQ4: Composed - Tense-driven	8.0	5.0	33	21
39	fO: Confident - Self-doubting	11.8	5.3	49	22
40	Verbal Abstraction	5.8	1.3	81	22

Table 45 Systems Thinking: Super System Capability Issues: Mean and standard deviation (n=16)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Metaphoric	11.5	0.9	81	7
2	Green Accept	-9.8	7.4	13	7
3	Turquoise Accept	-11.8	6.1	11	8
4	Purple Accept	-16.7	12.7	10	11
5	B: Low Intellectance - High Intellectance	22.1	2.1	89	12
6	Yellow Reject	-14.0	13.1	47	16
7	Turquoise Reject	-11.4	13.2	51	17
8	Purple Reject	-1.0	11.8	59	17
9	Structured	7.2	1.8	62	18
10	Green Reject	-10.0	14.0	44	18
11	Blue Reject	0.6	16.2	47	19
12	Holistic	6.9	2.2	49	19
13	Analytical	3.1	2.4	16	19
14	Learning	4.9	1.9	39	19
15	Rule Oriented	6.1	1.0	83	19

Rank	Measure	Mean	Std	Mean (%)	Std (%)
16	Learning 2	5.4	1.0	68	19
17	fE: Accommodating - Dominant	14.6	4.6	61	19
18	Blue Accept	-23.8	23.0	18	19
19	fQ3: Informal - Self-disciplined	18.5	4.0	73	20
20	Integrative	7.5	1.8	61	20
21	Quick insight	6.7	2.0	57	20
22	Categorisation	4.6	0.8	64	20
23	Exploration	5.5	0.8	63	20
24	Orange Reject	-15.0	16.2	36	22
25	fC: Affected by Feelings - Emotionally Stable	17.9	4.8	72	22
26	Integration	5.6	0.9	66	22
27	fO: Confident - Self-doubting	12.4	5.3	52	22
28	Judgement	5.3	1.3	71	22
29	fF: Sober Serious - Enthusiastic	7.2	5.0	33	23
30	Intuitive	10.4	1.8	80	23
31	Red Reject	-12.9	18.0	39	23
32	fM: Concrete - Abstract	13.5	5.4	59	23
33	fI: Hard-headed - Tender-minded	12.6	4.9	51	23
34	fN: Direct - Restrained	17.3	5.8	72	24
35	Reflective	4.6	2.7	33	24

Rank	Measure	Mean	Std	Mean (%)	Std (%)
36	Random	12.7	3.2	90	24
37	Potential work level	4.0	0.7	67	24
38	Impulsive	12.8	2.9	90	24
39	Logical	2.4	3.2	11	25
40	fA: Distant/Aloof - Empathetic	14.3	5.8	62	25

Table 46 Systems Thinking: Enterprise & Technology Environment: Mean and standard deviation (n=7)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Random	13.3	0.5	95	4
2	Turquoise Accept	-15.4	3.1	6	4
3	Impulsive	13.7	0.5	98	4
4	Purple Accept	-16.6	6.6	10	6
5	Metaphoric	11.1	0.9	78	7
6	Green Accept	-10.7	8.1	12	8
7	Intuitive	11.1	0.7	89	9
8	Red Reject	-23.1	7.0	26	9
9	Analytical	2.6	1.4	12	11
10	Integrative	7.9	1.1	65	12
11	B: Low Intellectance - High Intellectance	21.9	2.3	88	13
12	Analytical	6.6	0.8	93	13
13	Categorisation	4.6	0.5	64	13
14	Integration	5.6	0.5	64	13

Rank	Measure	Mean	Std	Mean (%)	Std (%)
15	Exploration	5.4	0.5	61	13
16	Blue Reject	-4.2	11.7	41	13
17	Blue Accept	-23.7	17.1	18	14
18	Purple Reject	-3.1	10.2	56	15
19	Rule Oriented	6.3	0.8	86	15
20	Learning 1	6.3	0.8	86	15
21	Learning 2	5.3	0.8	66	15
22	Logical Reasoning	6.3	1.0	88	16
23	fE: Accommodating - Dominant	16.6	4.1	69	17
24	Orange Reject	-17.2	13.1	33	18
25	Holistic	6.1	2.1	43	18
26	Judgement	5.1	1.1	69	18
27	Yellow Accept	-1.9	17.6	24	18
28	Turquoise Reject	-12.0	14.1	50	18
29	Pragmatic	5.3	1.1	71	19
30	Learning	5.0	1.9	40	19
31	fF: Sober Serious - Enthusiastic	6.9	4.3	31	19
32	Yellow Reject	-12.3	15.5	49	19
33	Orange Accept	15.7	20.7	62	19
34	Green Reject	-5.0	15.8	50	20
35	Verbal Abstraction	5.9	1.2	81	20
36	Reflective	4.4	2.3	31	21
37	fQ3: Informal - Self-disciplined	19.3	4.3	76	21

Rank	Measure	Mean	Std	Mean (%)	Std (%)
38	Logical	2.9	3.0	14	23
39	fI: Hard-headed - Tender-minded	12.0	4.9	48	23
40	Quick insight	7.4	2.4	64	24

Table 47 Determining and Managing Stakeholder Requirements: Mean and standard deviation (n=5)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Random	13.2	0.4	94	3
2	Turquoise Accept	-14.7	2.7	7	3
3	Impulsive	13.8	0.4	98	4
4	Purple Accept	-17.3	5.6	9	5
5	Intuitive	11.2	0.4	90	6
6	Logical	1.6	0.9	5	7
7	Blue Reject	-14.6	6.1	29	7
8	Metaphoric	11.0	1.0	77	8
9	Green Accept	-14.6	8.2	8	8
10	Yellow Accept	-5.6	8.7	21	9
11	Learning	5.4	0.9	44	9
12	Integrative	8.2	0.8	69	9
13	Orange Accept	3.9	9.9	51	9
14	Red Reject	-26.0	8.4	22	11
15	Categorisation	4.2	0.4	55	11
16	Analytical	2.6	1.5	12	12
17	Purple Reject	-6.4	8.7	51	13
18	fQ1: Conventional -	4.4	3.2	18	13

Rank	Measure	Mean	Std	Mean (%)	Std (%)
	Radical				
19	fN: Direct - Restrained	20.4	3.2	85	13
20	Integration	5.4	0.5	60	14
21	Blue Accept	-23.4	16.6	19	14
22	B: Low Intellectance - High Intellectance	22.6	2.6	92	14
23	Analytical	6.4	0.9	90	15
24	Logical Reasoning	6.4	0.9	90	15
25	fF: Sober Serious - Enthusiastic	4.0	3.5	18	16
26	Learning 1	6.2	0.8	84	17
27	Rule Oriented	5.8	0.8	76	17
28	fH: Retiring - Socially-bold	5.8	4.0	24	17
29	fQ3: Informal - Self-disciplined	20.2	3.4	81	17
30	fO: Confident - Self-doubting	15.0	4.3	63	18
31	Pragmatic	5.2	1.1	70	18
32	fA: Distant/Aloof - Empathetic	12.6	4.3	55	19
33	Holistic	6.4	2.3	45	19
34	Green Reject	-2.2	15.4	54	19
35	fE: Accommodating - Dominant	16.8	4.9	70	20
36	Verbal Abstraction	6.0	1.2	83	20

Rank	Measure	Mean	Std	Mean (%)	Std (%)
37	Judgement	5.0	1.2	67	20
38	Memory	9.8	2.5	73	21
39	Exploration	5.2	0.8	55	21
40	fM: Concrete - Abstract	9.8	4.9	43	21

Table 48 Systems Design: Architectural Design: Mean and standard deviation (n=4)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Random	13.3	0.5	94	4
2	Impulsive	13.8	0.5	98	4
3	Turquoise Accept	-16.2	4.4	5	6
4	Intuitive	11.3	0.5	91	6
5	Purple Accept	-13.2	7.9	13	7
6	Green Accept	-13.3	9.1	9	9
7	fG: Expedient - Conscientious	21.8	2.1	90	9
8	Yellow Accept	-6.9	10.6	19	11
9	Blue Accept	-19.1	12.9	22	11
10	Integrative	7.5	1.0	61	11
11	fN: Direct - Restrained	20.8	3.0	86	12
12	Exploration	5.3	0.5	56	13
13	Learning	6.3	1.3	53	13
14	Analytical	2.5	1.7	12	13
15	fI: Hard-headed - Tender-minded	8.0	2.8	29	13
16	Judgement	5.0	0.8	67	14

Rank	Measure	Mean	Std	Mean (%)	Std (%)
17	fO: Confident - Self-doubting	15.8	3.3	66	14
18	B: Low Intellectance - High Intellectance	21.5	2.5	86	14
19	Integration	5.5	0.6	63	14
20	Orange Reject	-16.3	10.9	34	15
21	Yellow Reject	-4.4	11.7	59	15
22	Logical	2.5	1.9	12	15
23	fF: Sober Serious - Enthusiastic	4.0	3.3	18	15
24	fQ2: Group-oriented - Self-sufficient	19.3	3.4	78	15
25	Purple Reject	-1.3	10.5	58	16
26	Reflective	3.5	1.7	23	16
27	Metaphoric	9.8	2.1	67	16
28	Green Reject	-3.7	12.7	52	16
29	fA: Distant/Aloof - Empathetic	8.5	3.8	37	16
30	Pragmatic	5.5	1.0	75	17
31	Analytical	6.5	1.0	92	17
32	fH: Retiring - Socially-bold	4.3	4.0	18	17
33	fQ4: Composed - Tense-driven	11.0	4.1	46	17
34	Structured	4.5	1.7	35	17
35	Blue Reject	-7.1	15.4	38	18
36	fQ3: Informal - Self-disciplined	21.3	3.6	86	18

Rank	Measure	Mean	Std	Mean (%)	Std (%)
37	Red Reject	-26.3	14.5	21	19
38	Learning 1	5.8	1.0	75	19
39	Logical Reasoning	6.0	1.2	83	19
40	Turquoise Reject	-1.8	14.8	63	19

Table 49 Systems Design: Concept Generation: Mean and standard deviation (n=14)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Turquoise Accept	-16.2	2.5	5	3
2	Green Accept	-11.9	5.8	11	5
3	Purple Accept	-14.1	6.5	12	6
4	B: Low Intellectance - High Intellectance	22.1	1.8	90	10
5	Blue Accept	-22.6	13.6	19	11
6	Red Reject	-21.2	9.2	28	12
7	Blue Reject	-2.7	11.6	43	13
8	Purple Reject	0.2	9.4	61	14
9	Green Reject	-8.0	11.1	47	14
10	Yellow Reject	-7.5	12.3	55	15
11	Metaphoric	10.6	2.1	74	16
12	Yellow Accept	-1.4	15.9	25	16
13	fO: Confident - Self-doubting	13.1	4.1	54	17
14	Orange Reject	-19.5	12.8	30	17
15	Turquoise Reject	-6.5	13.8	57	18

Rank	Measure	Mean	Std	Mean (%)	Std (%)
16	fQ3: Informal - Self-disciplined	18.1	3.8	70	19
17	fC: Affected by Feelings - Emotionally Stable	17.6	4.2	71	19
18	fM: Concrete - Abstract	14.1	4.4	61	19
19	fE: Accommodating - Dominant	15.1	4.7	63	20
20	Learning	5.1	2.0	41	20
21	Orange Accept	30.0	21.4	75	20
22	Holistic	7.0	2.4	50	20
23	Analytical	3.5	2.6	19	20
24	Learning 2	5.1	1.0	63	21
25	fI: Hard-headed - Tender-minded	13.0	4.4	52	21
26	Structured	6.4	2.3	54	23
27	Integration	5.4	0.9	61	23
28	Exploration	5.1	0.9	54	24
29	Red Accept	24.8	27.7	50	24
30	Integrative	7.4	2.2	60	24
31	fL: Trusting - Suspicious	8.0	5.4	36	24
32	Quick insight	7.3	2.5	63	25
33	Judgement	4.9	1.5	64	25
34	Rule Oriented	5.9	1.3	79	25
35	Intuitive	10.3	2.1	79	26
36	Random	12.4	3.3	88	26

Rank	Measure	Mean	Std	Mean (%)	Std (%)
37	Impulsive	12.8	3.1	90	26
38	fF: Sober Serious - Enthusiastic	7.2	5.8	33	26
39	fA: Distant/Aloof - Empathetic	13.9	6.1	60	27
40	Pragmatic	4.9	1.6	65	27

Table 50 Systems Design: Design for: Mean and standard deviation (n=3)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Analytical	7.0	0.0	100	0
2	Rule Oriented	7.0	0.0	100	0
3	Categorisation	5.0	0.0	75	0
4	Integration	6.0	0.0	75	0
5	Complexity	7.0	0.0	100	0
6	Logical Reasoning	7.0	0.0	100	0
7	Memory strategies	7.0	0.0	100	0
8	Judgement	6.0	0.0	83	0
9	Learning 1	7.0	0.0	100	0
10	Current Work level	4.0	0.0	100	0
11	Metaphoric	11.3	0.6	79	4
12	Random	13.7	0.6	97	4
13	Impulsive	13.3	0.6	94	5
14	Turquoise Accept	-6.2	4.6	18	6
15	Red Accept	-5.1	6.9	24	6
16	Integrative	7.3	0.6	59	6

Rank	Measure	Mean	Std	Mean (%)	Std (%)
17	Logical	2.0	1.0	8	8
18	Turquoise Reject	-19.8	6.1	40	8
19	fH: Retiring - Socially-bold	6.3	2.1	26	9
20	Verbal Abstraction	6.3	0.6	89	10
21	fN: Direct - Restrained	17.3	2.3	72	10
22	B: Low Intellectance - High Intellectance	22.0	2.0	89	11
23	fE: Accommodating - Dominant	12.0	3.0	50	13
24	Intuitive	11.0	1.0	88	13
25	Holistic	4.7	1.5	31	13
26	fQ2: Group-oriented - Self-sufficient	18.3	2.9	74	13
27	Green Reject	-2.2	10.9	54	14
28	fI: Hard-headed - Tender-minded	17.0	3.0	71	14
29	Exploration	5.3	0.6	58	14
30	Analytical	2.7	2.1	13	16
31	Pragmatic	5.0	1.0	67	17
32	fQ1: Conventional - Radical	9.0	4.4	38	18
33	Explorative	10.0	2.0	82	18
34	Green Accept	0.1	20.2	22	19
35	Use of Memory	6.7	0.6	89	19

Rank	Measure	Mean	Std	Mean (%)	Std (%)
36	Potential work level	4.3	0.6	78	19
37	fF: Sober Serious - Enthusiastic	7.0	4.6	32	21
38	fQ4: Composed - Tense-driven	12.0	5.3	50	22
39	Blue Reject	7.6	19.5	55	23
40	fA: Distant/Aloof - Empathetic	13.3	5.5	58	24

Table 51 Systems Design: Functional Analysis: Mean and standard deviation (n=6)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Random	13.3	0.5	95	4
2	Impulsive	13.7	0.5	97	4
3	Metaphoric	11.2	0.8	78	6
4	Turquoise Accept	-13.4	6.3	9	8
5	Intuitive	11.2	0.8	90	9
6	Turquoise Reject	-8.2	7.3	55	9
7	fH: Retiring - Socially-bold	7.7	2.9	32	12
8	Pragmatic	5.2	0.8	69	13
9	Analytical	2.7	1.6	13	13
10	Exploration	5.7	0.5	67	13
11	Integration	5.7	0.5	67	13
12	Purple Reject	-2.1	9.1	57	13
13	Integrative	7.7	1.2	63	13
14	Analytical	6.5	0.8	92	14

Rank	Measure	Mean	Std	Mean (%)	Std (%)
15	Logical Reasoning	6.5	0.8	92	14
16	B: Low Intellectance - High Intellectance	22.0	2.5	89	14
17	Quick insight	7.0	1.4	60	14
18	Green Accept	-10.4	16.8	12	16
19	Purple Accept	-9.6	18.3	16	16
20	Rule Oriented	6.3	0.8	87	16
21	Learning 1	6.7	0.8	93	16
22	Judgement	5.2	1.0	69	16
23	Blue Reject	-1.2	14.3	45	17
24	Learning	3.8	1.7	28	17
25	Logical	2.7	2.3	13	17
26	fF: Sober Serious - Enthusiastic	6.2	4.2	28	19
27	Green Reject	-5.7	16.1	49	20
28	Categorisation	4.7	0.8	67	20
29	Complexity	6.3	0.8	83	20
30	Learning 2	5.5	1.0	70	21
31	Potential work level	4.0	0.6	67	21
32	Reflective	4.5	2.3	32	21
33	fQ2: Group-oriented - Self-sufficient	17.5	4.7	70	21
34	Holistic	6.5	2.6	46	22
35	fI: Hard-headed - Tender-minded	11.2	4.5	44	22

Rank	Measure	Mean	Std	Mean (%)	Std (%)
36	fQ3: Informal - Self-disciplined	18.7	4.5	73	22
37	Verbal Abstraction	5.5	1.4	75	23
38	Structured	6.5	2.4	55	24
39	fE: Accommodating - Dominant	14.0	6.0	58	25
40	fQ4: Composed - Tense-driven	13.5	6.0	56	25

Table 52 Systems Design: Interface Management: Mean and standard deviation (n=8)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Random	13.5	0.5	96	4
2	Impulsive	13.5	0.5	96	4
3	Purple Accept	-15.5	6.9	11	6
4	Analytical	6.8	0.5	96	8
5	Integration	5.9	0.4	72	9
6	Judgement	5.5	0.5	75	9
7	Learning 1	6.8	0.5	95	9
8	Intuitive	11.0	0.8	88	9
9	Green Reject	-5.4	8.3	50	11
10	Blue Reject	-3.0	9.3	43	11
11	Blue Accept	-23.0	13.4	19	11
12	Potential work level	4.1	0.4	71	12
13	Turquoise Reject	-9.4	9.2	53	12
14	Logical	6.5	0.8	92	13

Rank	Measure	Mean	Std	Mean (%)	Std (%)
	Reasoning				
15	Learning 2	5.9	0.6	78	13
16	Complexity	6.5	0.5	88	13
17	Holistic	6.1	1.6	43	14
18	Metaphoric	10.8	2.0	75	15
19	Exploration	5.9	0.6	72	16
20	fQ3: Informal - Self-disciplined	16.8	3.2	64	16
21	Pragmatic	5.1	1.0	69	17
22	Yellow Reject	-9.3	13.3	53	17
23	Learning	3.6	1.7	26	17
24	Use of Memory	6.4	0.5	79	17
25	Current Work level	3.6	0.5	88	17
26	Purple Reject	-5.4	11.8	52	17
27	Analytical	2.6	2.3	13	18
28	Quick insight	7.4	1.8	64	18
29	Structured	7.6	1.8	66	18
30	B: Low Intellectance - High Intellectance	21.5	3.3	86	19
31	Logical	2.1	2.4	9	19
32	fE: Accommodating - Dominant	15.1	5.0	63	21
33	Verbal Abstraction	5.8	1.3	79	21
34	fI: Hard-headed - Tender-minded	11.8	4.5	46	22

Rank	Measure	Mean	Std	Mean (%)	Std (%)
35	Red Accept	14.8	27.2	41	23
36	Rule Oriented	6.0	1.2	80	24
37	Reflective	4.9	2.6	35	24
38	Integrative	6.3	2.2	47	24
39	Yellow Accept	4.8	24.6	31	25
40	fF: Sober Serious - Enthusiastic	10.5	5.7	48	26

Table 53 Systems Design: Modelling & Simulation: Mean and standard deviation (n=29)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Impulsive	13.3	0.6	95	5
2	Random	13.4	0.7	95	6
3	Intuitive	10.6	1.0	82	12
4	Learning 1	6.6	0.6	92	13
5	Logical Reasoning	6.5	0.8	92	14
6	Green Reject	-16.3	11.1	36	14
7	Metaphoric	11.2	1.8	79	14
8	B: Low Intellectance - High Intellectance	21.6	2.6	87	14
9	Purple Accept	-11.2	18.6	14	16
10	Yellow Reject	-15.7	13.2	45	16
11	Rule Oriented	6.0	0.9	81	17
12	Holistic	6.3	2.2	44	18
13	Analytical	6.4	1.1	90	18

Rank	Measure	Mean	Std	Mean (%)	Std (%)
14	fI: Hard-headed - Tender-minded	14.4	3.8	59	18
15	Exploration	5.4	0.7	60	18
16	Turquoise Accept	-8.9	14.5	15	18
17	Learning 2	5.7	0.9	74	18
18	Logical	2.7	2.4	13	19
19	Blue Accept	-21.3	22.8	20	19
20	Integration	5.7	0.8	66	19
21	fL: Trusting - Suspicious	6.7	4.2	30	19
22	Red Accept	-0.7	23.2	28	20
23	Red Reject	-11.9	15.7	40	20
24	Turquoise Reject	-15.9	15.5	45	20
25	Judgement	5.2	1.2	70	21
26	Complexity	6.4	0.8	86	21
27	Potential work level	4.0	0.6	68	21
28	fQ4: Composed - Tense-driven	8.2	5.0	34	21
29	Green Accept	-3.6	22.2	18	21
30	Structured	6.0	2.1	50	21
31	Blue Reject	-4.1	18.3	41	21
32	fN: Direct - Restrained	18.3	5.1	76	21
33	fC: Affected by Feelings - Emotionally Stable	17.2	4.8	69	22
34	Integrative	7.0	2.0	56	22
35	fM: Concrete -	13.9	5.0	61	22

Rank	Measure	Mean	Std	Mean (%)	Std (%)
	Abstract				
36	Orange Reject	-16.6	16.5	34	22
37	Pragmatic	5.0	1.4	67	23
38	fA: Distant/Aloof - Empathetic	15.5	5.3	67	23
39	Current Work level	3.6	0.7	85	23
40	fO: Confident - Self-doubting	12.8	5.6	53	23

Table 54 Systems Design: Select Preferred Solution: Mean and standard deviation (n=3)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Intuitive	11.0	0.0	88	0
2	Analytical	7.0	0.0	100	0
3	Categorisation	4.0	0.0	50	0
4	Integration	6.0	0.0	75	0
5	Purple Accept	-25.7	1.6	2	1
6	fI: Hard-headed - Tender-minded	9.7	0.6	37	3
7	Red Accept	-7.8	3.6	22	3
8	Blue Accept	-36.6	4.3	8	4
9	Random	13.7	0.6	97	4
10	Analytical	1.7	0.6	5	4
11	Logical	1.3	0.6	3	4
12	Impulsive	13.3	0.6	94	5
13	Turquoise Accept	-11.6	4.0	11	5
14	Purple Reject	10.8	3.6	76	5

Rank	Measure	Mean	Std	Mean (%)	Std (%)
15	Green Accept	-5.6	6.0	17	6
16	Integrative	7.7	0.6	63	6
17	Orange Reject	-27.0	5.9	20	8
18	Metaphoric	11.3	1.2	79	9
19	Logical Reasoning	6.7	0.6	94	10
20	Pragmatic	5.3	0.6	72	10
21	Judgement	5.7	0.6	78	10
22	Structured	8.0	1.0	70	10
23	fO: Confident - Self-doubting	12.0	2.6	50	11
24	B: Low Intellectance - High Intellectance	22.0	2.0	89	11
25	Learning 1	6.7	0.6	93	12
26	Learning 2	5.7	0.6	73	12
27	Yellow Reject	-25.2	9.7	33	12
28	fQ4: Composed - Tense-driven	10.3	3.2	43	13
29	Exploration	5.3	0.6	58	14
30	Complexity	6.7	0.6	92	14
31	Red Reject	-8.4	11.7	44	15
32	fE: Accommodating - Dominant	15.0	3.6	63	15
33	Learning	4.3	1.5	33	15
34	fQ3: Informal - Self-disciplined	18.7	3.1	73	15
35	fH: Retiring - Socially-bold	4.3	3.8	18	16

Rank	Measure	Mean	Std	Mean (%)	Std (%)
36	fF: Sober Serious - Enthusiastic	7.7	3.5	35	16
37	Green Reject	-9.2	13.8	45	17
38	fA: Distant/Aloof - Empathetic	10.3	4.0	45	18
39	Reflective	4.7	2.1	33	19
40	Use of Memory	6.3	0.6	78	19

Table 55 System Integration & Verification: Mean and standard deviation (n=10)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Yellow Accept	-11.0	6.2	15	6
2	B: Low Intellectance - High Intellectance	22.4	1.5	91	8
3	Purple Reject	-9.9	6.3	46	9
4	Blue Reject	-9.0	10.2	36	12
5	fI: Hard-headed - Tender-minded	11.0	2.9	43	14
6	fH: Retiring - Socially-bold	9.0	3.5	38	14
7	fC: Affected by Feelings - Emotionally Stable	18.4	3.3	75	15
8	Learning	4.8	1.5	38	15
9	fM: Concrete - Abstract	10.2	3.9	44	17
10	fE: Accommodating - Dominant	16.5	4.2	69	18
11	fQ4: Composed -	7.8	4.3	33	18

Rank	Measure	Mean	Std	Mean (%)	Std (%)
	Tense-driven				
12	fQ3: Informal - Self-disciplined	20.0	3.8	80	19
13	Learning 2	5.3	0.9	66	19
14	Analytical	3.4	2.7	18	21
15	Yellow Reject	-5.4	16.8	57	21
16	Green Reject	-4.5	16.8	51	21
17	fF: Sober Serious - Enthusiastic	6.5	4.7	30	21
18	fN: Direct - Restrained	18.7	5.1	78	21
19	Structured	6.4	2.2	54	22
20	fO: Confident - Self-doubting	11.3	5.3	47	22
21	fL: Trusting - Suspicious	8.6	4.9	39	22
22	Turquoise Reject	-3.4	17.7	61	23
23	Quick insight	7.1	2.3	61	23
24	fA: Distant/Aloof - Empathetic	15.3	5.4	67	24
25	fQ2: Group-oriented - Self-sufficient	12.5	5.2	48	24
26	Rule Oriented	5.9	1.2	78	24
27	Holistic	6.3	3.1	44	25
28	Exploration	5.2	1.0	55	26
29	Metaphoric	10.6	3.5	74	27
30	Integration	5.5	1.1	63	27
31	Green Accept	-5.5	29.3	17	28
32	Red Reject	-18.4	21.7	32	28

Rank	Measure	Mean	Std	Mean (%)	Std (%)
33	fQ1: Conventional - Radical	5.8	6.8	24	28
34	Explorative	7.6	3.1	60	28
35	Purple Accept	1.3	32.5	25	29
36	Memory	6.4	3.5	45	29
37	Integrative	6.5	2.6	50	29
38	Turquoise Accept	-6.2	23.4	18	30
39	Blue Accept	0.0	35.2	38	30
40	Orange Reject	-7.1	22.2	47	30

Table 56 Validation: Mean and standard deviation (n=4)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Turquoise Accept	-12.4	3.6	10	5
2	Blue Accept	-29.3	6.3	14	5
3	Green Accept	-9.9	9.2	13	9
4	Metaphoric	11.8	1.3	83	10
5	Purple Accept	-16.7	11.5	10	10
6	fI: Hard-headed - Tender-minded	8.5	2.4	31	11
7	Learning	4.5	1.3	35	13
8	fO: Confident - Self-doubting	10.5	3.7	44	15
9	fE: Accommodating - Dominant	14.0	3.9	58	16
10	Green Reject	-6.7	13.1	48	17
11	Turquoise Reject	-19.0	12.8	41	17
12	fQ4: Composed -	8.5	4.0	35	17

Rank	Measure	Mean	Std	Mean (%)	Std (%)
	Tense-driven				
13	Structured	7.3	1.7	63	17
14	fH: Retiring - Socially-bold	6.0	4.2	25	18
15	Integrative	8.0	1.6	67	18
16	Red Reject	-16.5	15.1	34	19
17	Yellow Reject	-11.3	15.5	50	19
18	fG: Expedient - Conscientious	14.8	4.5	58	20
19	Red Accept	12.2	24.8	39	21
20	fQ3: Informal - Self-disciplined	17.5	4.4	68	22
21	Explorative	8.0	2.4	64	22
22	fN: Direct - Restrained	18.0	5.4	75	22
23	fC: Affected by Feelings - Emotionally Stable	17.0	5.0	68	23
24	Purple Reject	1.1	16.7	62	25
25	Quick insight	6.3	2.5	53	25
26	Orange Reject	-11.6	18.7	40	25
27	Orange Accept	32.5	27.4	78	26
28	Holistic	7.0	3.2	50	26
29	B: Low Intellectance - High Intellectance	21.0	4.8	83	26
30	fA: Distant/Aloof - Empathetic	13.0	6.3	57	27
31	fF: Sober Serious - Enthusiastic	7.5	6.0	34	27

Rank	Measure	Mean	Std	Mean (%)	Std (%)
32	fL: Trusting - Suspicious	12.0	6.1	55	28
33	Learning 2	5.0	1.4	60	28
34	Analytical	3.5	3.7	19	28
35	Blue Reject	11.8	25.6	60	30
36	Rule Oriented	5.8	1.5	75	30
37	fQ1: Conventional - Radical	9.0	7.4	38	31
38	Categorisation	4.3	1.3	56	31
39	fM: Concrete - Abstract	11.3	7.3	49	32
40	Pragmatic	4.0	2.0	50	33

Table 57 Transition To Operation: Mean and standard deviation (n=3)

Rank	Measure	Mean	Std	Mean (%)	Std (%)
1	Potential work level	4.0	0.0	67	0
2	Yellow Accept	-9.2	0.4	17	0
3	Turquoise Accept	-17.3	1.0	4	1
4	Purple Accept	-9.8	3.0	16	3
5	Green Accept	-17.2	3.0	6	3
6	Random	13.3	0.6	95	4
7	Impulsive	13.7	0.6	97	5
8	fQ3: Informal - Self-disciplined	21.0	1.0	85	5
9	Purple Reject	-5.5	4.2	52	6
10	Blue Accept	-8.9	7.6	31	6

Rank	Measure	Mean	Std	Mean (%)	Std (%)
11	Intuitive	11.3	0.6	92	7
12	Metaphoric	11.0	1.0	77	8
13	Analytical	6.7	0.6	94	10
14	Logical Reasoning	6.3	0.6	89	10
15	Verbal Abstraction	6.7	0.6	94	10
16	Judgement	4.7	0.6	61	10
17	fQ1: Conventional - Radical	3.3	2.3	14	10
18	Learning 1	6.3	0.6	87	12
19	Learning 2	4.3	0.6	47	12
20	Rule Oriented	5.3	0.6	67	12
21	fN: Direct - Restrained	20.3	3.2	85	13
22	fG: Expedient - Conscientious	20.7	3.1	85	14
23	Blue Reject	-9.9	12.4	35	14
24	Categorisation	4.3	0.6	58	14
25	Integration	5.7	0.6	67	14
26	Complexity	6.3	0.6	83	14
27	B: Low Intellectance - High Intellectance	21.0	2.6	83	15
28	Turquoise Reject	5.0	13.0	72	17
29	Yellow Reject	9.8	13.8	77	17
30	Green Reject	0.9	15.0	58	19
31	Use of Memory	5.7	0.6	56	19

Rank	Measure	Mean	Std	Mean (%)	Std (%)
32	Pragmatic	4.7	1.2	61	19
33	Current Work level	3.3	0.6	78	19
34	Red Reject	-20.9	15.6	28	20
35	Analytical	3.0	2.6	15	20
36	fI: Hard-headed - Tender-minded	13.0	4.4	52	21
37	Quick insight	5.7	2.1	47	21
38	Explorative	6.3	2.3	48	21
39	fM: Concrete - Abstract	9.7	5.0	42	22
40	Red Accept	52.0	26.8	73	23

Systems Engineering Competencies Framework

Prepared By Representatives From:

BAE Systems

EADS Astrium

General Dynamics United Kingdom Limited

Loughborough University

Ministry of Defence

Thales

Ultra Electronics

University College London

Acknowledgements

The 'Systems Engineering Competencies Framework' (Phase 1 Working Group) and 'Guide to Competency Evaluation' (Phase 2 Working Group) have been produced from the output of a number of INCOSE UK Advisory Board (UKAB) workshops attended by the following people:

BAE Systems - Samantha Brown (Phase 1), Ayman El Fatatry (Phase 1 & 2), Sue Goodlass (Phase 2)

EADS Astrium - Les Oliver (Phase 1 & 2)

Elipsis Ltd. – Allen Fairbairn (Phase 2)

General Dynamics United Kingdom Limited - Sandra Hudson (Phase 1 & 2)

Loughborough University - John Hooper (Phase 1 & 2)

Ministry of Defence - Keith Barnwell (Phase 1), David Hawken (Phase 2)

Qinetiq – Stuart Arnold (Phase 2)

Sula Systems - Doug Cowper (Phase 1)

Thales - Richard Allen-Shalless (Phase 1 & 2), Jocelyn Stoves (Phase 1 & 2)

Ultra Electronics - Shane Bennison (Phase 2)

University College London - Alan Smith (Phase 1 & 2), Ady James (Phase 2)

Feedback on the content, and on experience of use, should be provided to Sandra Hudson, sandra.hudson@generaldynamics.uk.com, or to any of the individuals named above.

A feedback form will also be provided on the INCOSE UK Web site, www.incose.org.uk .

Contents

1 Introduction

The purpose of this document is to provide a set of Competencies for Systems Engineering and a competency framework to enable both employers and employees to define the required systems engineering skills needed from both individuals and teams. This document is intended as a framework and will require tailoring to meet the needs of individual enterprises. The focus of this document is on the Competencies of Systems Engineering rather than the Competencies of a Systems Engineer.

1.1 What Is Systems Engineering?

"*Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:*

- *Cost & Schedule*
- *Performance*
- *Test*
- *Manufacturing*
- *Training & Support*
- *Operations*
- *Disposal.*

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs."
Definition of the International Council on Systems Engineering (INCOSE).

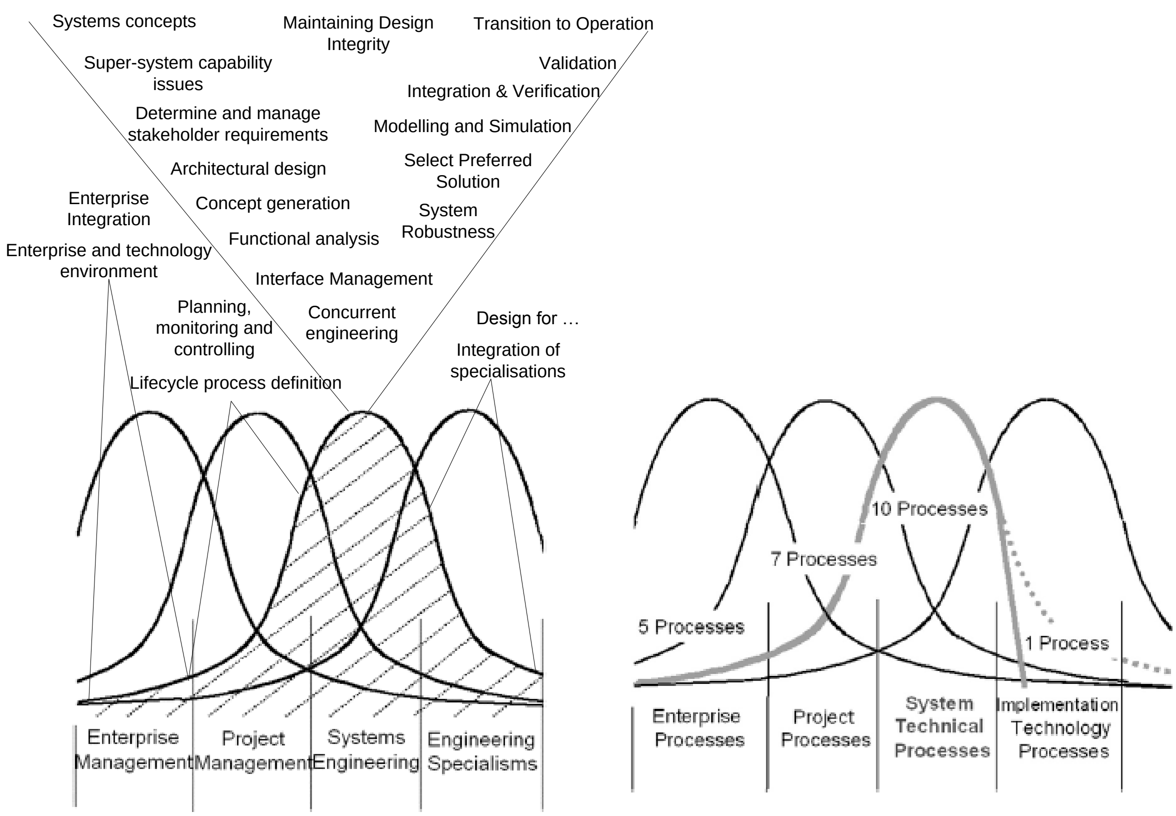
1.2 Systems Engineering Competencies Objective

An issue identified by the INCOSE UK Advisory Board (UKAB) was the inability of individuals and enterprises to identify the competencies that are required to conduct good systems engineering. Some enterprises found that they "*did not know what it is they did not know*" about systems engineering and that individuals did not have a clear career path to become a "chartered systems engineer".

The objective determined by the INCOSE UKAB was '*to have a measurable set of competencies for systems engineering which will achieve national recognition and will be useful to the enterprises represented by the UKAB'*. To achieve this objective it is recognised that collaboration with other interested Systems Engineering bodies is essential.

1.3 Systems Engineering Competency Development

The competencies described in this document are those predominantly associated with Systems Engineering, rather than those which overlap with other areas, for example Project Management. These overlapping competencies are already defined by their respective professional bodies, for example the Association of Project Managers (APM), but may require tailoring to meet the needs of Systems Engineering.



Responsibility and Influence of Primary Organisational Roles

Process Scope of ISO/IEC 15288

Figure 1 – Mapping of Systems Engineering Competencies to the Continuum of Business Processes and ISO/IEC 15288 (based on Arnold & Lawson, 2004).

The systems engineering competencies developed for this guide are based on the following systems engineering standards:

- International Standards Organisation ISO15288
- Capability Maturity Model Integration
- EIA731
- INCOSE Systems Engineering Body of Knowledge & Handbook
- NASA Handbook
- IEE/BCS Safety Competency Guidelines,

a review of systems engineering competency work conducted by:

- BAE Systems
- EADS Astrium
- General Dynamics United Kingdom Limited
- Loughborough University
- Ministry of Defence
- Thales
- University College London,

and feedback from the Systems Engineering Community.

1.4 Systems Engineering Ability

Systems Engineering ability comprises of:

- Competencies [Understanding]
- Supporting Techniques [Technical Skills]
- Basic Skills and Behaviours [Behavioural Skills]
- Domain Knowledge [Knowledge]

The terms in square brackets are the mapping of those used by the Engineering Council (UK).

The *Competencies* of Systems Engineering are discussed in more detail in the next section of this document.

Supporting Techniques are the skills and techniques required to carry out the Systems Engineering tasks. For example:

- Availability, Reliability and Maintainability Analysis
- Decision Analysis & Resolution
- Failure Analysis
- Graphical Modelling
- Human Factors
- Mathematical Modelling
- Safety Analysis
- Structured Methods
- Technical Risk and Opportunity Management

- Technology Planning
- Testability Analysis

An advisory list is given in appendix A.

Basic Skills and Behaviours include the usual common attributes required by any professional engineer, for example:

- Abstract Thinking
- Communicating
  - Verbal, non-verbal
  - Technical report writing
  - Listening skills
- Developing others
- Knowing when to ask
- Knowing when to stop
- Negotiation and influencing
- Team working

An advisory list is given in appendix B.

Due to the interdisciplinary nature of Systems Engineering, Systems Engineers need particular strengths in these skills and behaviours.

Domain Knowledge will vary from industry to industry. Domain Knowledge acknowledges that industrial context, the specific commercial environment and types of supply chain have a big impact on the systems engineering being conducted and that this will be specific to particular industrial fields. It is therefore difficult to produce a generic set of competencies for domain knowledge and will be left to the enterprise implementing these competencies to define what domain knowledge is required.

2 System Engineering Competencies

2.1 Competency Framework

The competencies that are predominantly associated with Systems Engineering are listed below and expanded in full in a series of competency tables. The competencies are grouped into three themes; Systems Thinking, Holistic Lifecycle View, and Systems Engineering Management.

Systems Thinking contains the under pinning systems concepts and the system/super-system skills including the enterprise and technology environment.

Holistic Lifecycle View contains all the skills associated the systems lifecycle from need identification, requirements through to operation and ultimately disposal.

Systems Engineering Management deals with the skills of choosing the appropriate lifecycle and the planning, monitoring and control of the systems engineering process.

The distinguishing feature of Systems Engineering is its interdisciplinary nature. All these competencies may be present in single discipline individuals, for example, Software Systems Engineers. However, to be a "Systems Engineer" requires the definition and integration of a system solution that comprises a number of discipline areas, for example mechanics, electronics, software, including specialist disciplines such as human factors and electromagnetic compatibility.

2.2 Competency Table Format

Each competency table provides:

- A description
- Why it matters
- Effective indicators of knowledge and experience
    - Awareness
    - Supervised Practitioner
    - Practitioner
    - Expert

Description explains what the competency is and provides meaning behind the title. Each title can mean different things to different individuals and enterprises.

Why it matters indicates the importance of the competency and the problems that may be encountered in the absence of that competency.

Effectiveness indicators of knowledge and experience given in the tables are detailed below and are **entry** level requirements, i.e. an individual must satisfy all the effective indicators for a particular level to be considered competent at that level. The time-lapse involved since a particular effectiveness indicator was last met should be taken into consideration.

Each competency should be assessed in terms of the levels of comprehension and experience defined by "Awareness" through to "Expert".

Awareness
The person is able to understand the key issues and their implications. They are able to ask relevant and constructive questions on the subject. This level is aimed at enterprise roles that interface with Systems Engineering and therefore require an understanding of the Systems Engineering role within the enterprise.

Supervised Practitioner
The person displays an understanding of the subject but requires guidance and supervision. This level defines those engineers who are "in-training" or are inexperienced in that particular competency.

Practitioner
The person displays detailed knowledge of the subject and is capable of providing guidance and advice to others.

Expert
The person displays extensive and substantial practical experience and applied knowledge of the subject.

2.3 Competency Titles

The competencies of systems engineering are:

Systems Thinking
- Systems concepts
- Super-system capability issues
- Enterprise and technology environment

Holistic Lifecycle view
- Determine and manage stakeholder requirements
- *System Design:*
  - Architectural design
  - Concept generation
  - Design for …
  - Functional analysis
  - Interface Management
  - Maintaining Design Integrity
  - Modelling and Simulation
  - Select Preferred Solution
  - System Robustness
- Integration & Verification
- Validation
- Transition to Operation

Systems Engineering Management
- Concurrent engineering
- Enterprise Integration
- Integration of specialisms
- Lifecycle process definition
- Planning, monitoring and controlling

Design issues related to in-service support and disposal are addressed as part of the design for.. and transition to operation competencies. A separate competency for carrying out support and disposal is not required as these activities will be conducted by specialisms and not systems engineering. Integrating these specialisms as part of the system's lifecycle is covered by the Systems Engineering Management competency of Integration of Specialisations. The design of support equipment, infrastructures and services can be considered as another systems engineering design activity and this whole set of competencies are equally applicable.

COMPETENCY AREA - Systems Thinking: *System Concepts*

Description:

The application of the fundamental concepts of systems thinking to systems engineering. These include understanding what a system is, its context within its environment, its boundaries and interfaces and that it has a lifecycle.

Why it matters:

Systems thinking is a way of dealing with increasing complexity. The fundamental concepts of systems thinking involves understanding how actions and decisions in one area affect another, and that the optimisation of a system within its environment does not necessarily come from optimising the individual system components.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Is aware of systems concepts. Aware of the importance of; • system lifecycle • hierarchy of systems • system context • interfaces	Understands systems concepts. Understands the system lifecycle in which they are working. Understands system hierarchy and the principles of system partitioning in order to deal with complexity. Understands the concept of emergent properties. Can identify system boundaries and understands the need to define and manage the interfaces. Understands how humans and systems interact and how humans can be elements of systems.	Able to identify and manage complexity with appropriate techniques in order to reduce risk. Able to predict resultant system behaviour. Able to define system boundaries and external interfaces. Able to assess the interaction between humans and systems. Able to guide supervised practitioner.	Able to review and judge the suitability of systems solutions. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA *Systems Thinking* : *Super System Capability Issues*

Description:

An appreciation of the role the system plays in the super system of which it is a part.

Why it matters:

A system is not successful unless it meets the needs of the overall super-system of which it is a part. Capturing the complete set of system requirements is not possible unless the context of the super system is fully appreciated.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands the concept of capability. Understands that super-system capability needs impact on the system development. Appreciates the difficulties of translating super-system capability needs into system requirements.	Can describe the environment and super system into which the system under development is to be delivered. Identifies, with guidance, the super system capability issues which will affect the design of a system.	Able to identify the super system capability issues which will affect the design of a system and translates these into system requirements. Able to assess extent to which the proposed system solution meets the super-system capability, and provide advice on trade offs. Able to guide supervised practitioner.	Has reviewed and advised on the suitability of systems solutions. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA - Systems Thinking : *Enterprise & Technology Environment*

Description:

The definition, development and production of systems within an enterprise and technological environment.

Why it matters:

Systems Engineering is conducted within an enterprise and technological context. These contexts impact the lifecycle of the system and place requirements and constraints on the Systems Engineering being conducted. Failing to meet such constraints can have a serious effect on the enterprise and the value of the system.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Aware of the influence the enterprise (environment, objectives, social, political, financial, cultural) has on the definition and development of the system. Aware of the influence technology has on the definition and development of the system. Aware of the influence the system has on the enterprise. Aware of the influence the system has on technology.	Can identify, with guidance, the various enterprise issues (markets, products, policies, finance etc.) which interact with the system to be developed. Can contribute, with guidance, to the technology plan.	Identifies the enterprise and technology issues which will affect the design of a system and translates these into system requirements. Able to produce and implement a technology plan that includes technology risk, maturity, readiness levels and insertion points. Able to guide supervised practitioner.	Influences and maintains the technical capability and strategy of their enterprise. Recognised as an authority in technology planning and management. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Holistic Lifecycle View: *Determining and Managing Stakeholder Requirements*

Description:

To analyse the stakeholder needs and expectations to establish and manage the requirements for a system.

Why it matters:

The requirements of a system describe the problem to be solved (its purpose, how it performs, how it is to be used, maintained and disposed of and what the expectations of the stakeholders are). Managing the requirements throughout the lifecycle is critical for implementing a successful system.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands the need for good quality requirements. Able to identify major stakeholders. Understands the importance of managing requirements throughout the lifecycle. Understands the need to manage both technical and non-technical requirements.	Able to identify all the stakeholders and their sphere of influence. Can support the elicitation of requirements from stakeholders. Understands the characteristics of good quality requirements. Understands methods used in requirements gathering. Understands the need for traceability between the design and the requirements. Understands the relationship between requirements and acceptance. Understands the relationship between requirements and modelling. Able to establish acceptance criteria for simple requirements	Has successfully elicited stakeholder requirements. Has written good quality requirements. Able to produce a system requirements specification. Able to write the requirements management plan including categorisations and structures. Able to define a process to manage the requirements and ensure its effective implementation. Can demonstrate effective assessment of the impact of change. Able to resolve and negotiate requirement conflicts in order to establish a complete and consistent requirement set. Able to establish acceptance criteria for interconnected requirements. Identifies areas of uncertainty and risk when determining requirements. Able to challenge appropriateness of requirements in a rational way. Able to validate the requirements. Able to guide supervised practitioner.	Reviews and judges the suitability of requirements management plans. Reviews and judges the suitability and completeness of the requirements set. Acknowledged as an authority in the elicitation and management of requirements. Advises on the sensitive requirements negotiations on major programmes. Advises on the likelihood of compliance. Able to advise on the validity of requirements. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Holistic Lifecycle View : Systems Design – *Architectural Design*

Description:

The definition of the system architecture and derived requirements to produce a solution that can be implemented to enable a balanced and optimum result that considers all stakeholder requirements (business, technical….).

Why it matters:

Effective architectural design enables systems to be partitioned into realisable system elements which can be brought together to meet the requirements.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands the principles of architectural design and its role within the lifecycle. Aware of the different types of architecture.	Able to use techniques to support architectural design process. Able to support the architectural design trade offs.	Able to generate alternative architectural designs that are traceable to the requirements. Able to assess a range of architectural solutions and justify the selection of the optimum solution. Able to define a process and appropriate tools and techniques for architectural design. Able to choose appropriate analysis and selection techniques Able to partition between discipline technologies and derive discipline specific requirements. Able to guide supervised practitioner.	Can demonstrate a full understanding of architectural design techniques and their appropriateness, given the levels of complexity of the system in question. Reviews and judges the suitability of architecture designs. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Holistic Lifecycle View : Systems Design – *Concept Generation*

Description:

The generation of potential system solutions that meet a set of needs and demonstration that one or more credible, feasible solutions exist.

Why it matters:

Failure to explore alternative solutions may result in a non-optimal system. There may be no viable solution (e.g. technology not available).

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands the need to explore alternative ways of satisfying the need. Understands that alternative discipline technologies can be used to satisfy the same requirement.	Able to participate in the process of concept generation.	Understands the strengths and weaknesses of relevant technologies in the context of the requirement. Able to create a range of alternative interdisciplinary concepts. Able to assess the alternative solutions for feasibility, risk, cost, schedule, technology requirements, human factors, -ilities etc. Able to down select to a number of possible solutions and demonstrate that credible, feasible solutions exists. Able to guide supervised practitioner.	Able to guide and advise practitioners in techniques for concept generation. Reviews down selected concepts for credibility, feasibility, etc. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Holistic Lifecycle View : Systems Design – *Design for…..*

Description:

Ensuring that the requirements of later lifecycle stages are addressed at the correct point in the system design. During the design process consideration should be given to manufacturability, testability, reliability, maintainability, safety, security, flexibility, interoperability, capability growth, disposal, etc.

Why it matters:

Failure to design for these attributes at the correct point in the development lifecycle may result in the attributes never being achieved or achieved at escalated cost.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands the need to design for the requirements of later lifecycle stages.	Assists in planning for the incorporation of later lifecycle design attributes.	Able to identify and plan for the incorporation of later lifecycle design attributes at the correct point within the design process. Able to work with appropriate specialists to ensure that these design attributes are addressed. Able to guide supervised practitioner.	Able to review and judge the suitability of plans for the incorporation of later lifecycle design attributes at the correct point within the design process. Able to advise on complex issues and resolve conflicting design requirements. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Holistic Lifecycle View : Systems Design – *Functional Analysis*			
Description: *Analysis is used to determine which functions are required by the system to meet the requirements. It transforms the requirements into a coherent description of system functions and their interfaces that can be used to guide the design activity that follows. It consists of the decomposition of higher-level functions to lower-levels and the traceable allocation of requirements to those functions.*			
Why it matters: *Functional Analysis is a way of understanding what the system has to do. Failure to carry out this activity may result in a solution that fails to meet its key requirements.*			
EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE			
AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands the need for Functional Models. Understands the relevance of the outputs from Functional Analysis and how these relate to the overall system design.	Able to use the tools and techniques to conduct Functional Analysis.	Able to define the strategy and approach to be adopted for the functional analysis of the system. Has performed functional analysis. Able to define a process and appropriate tools and techniques for functional analysis. Able to guide supervised practitioner.	Can demonstrate a full understanding of the techniques and their appropriateness, given the levels of complexity of the system in question. Reviews and judges the suitability of functional analyses. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Holistic Lifecycle View : Systems Design – *Interface Management*

Description:

Interfaces occur where system elements interact, for example human, mechanical, electrical, thermal, data, etc. Interface Management comprises the identification, definition and control of interactions across system or system element boundaries.

Why it matters:

Poor interface management can result in incompatible system elements (either internal to the system or between the system and its environment) which may ultimately result in system failure or project overrun.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands the need for interface management and its impact on the integrity of the system solution. Understands the possible sources of complexity in interface management, e.g. multinational programmes, multiple suppliers, different domains, novel technology, etc.	Able to follow interface management procedures. Able to identify and define simple interfaces.	Able to define a process and appropriate techniques to be adopted for the interface management of system elements. Able to identify, define and control system element interfaces. Able to describe the sources of complexity for the interface management of the system, e.g. multinational programmes, multiple suppliers, different domains, novel technology, etc. Able to liaise and arbitrate where there are conflicts in the definition of interfaces Able to guide supervised practitioner.	Has demonstrated expertise in interface management. Reviews and judges the suitability of interface management strategies. Able to negotiate on the issues of interface complexity. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Holistic Lifecycle View : Systems Design - *Maintain Design Integrity*

Description:

Ensuring that the overall coherence and cohesion of the "evolving" design of a system is maintained, in a verifiable manner, throughout the lifecycle, and retains the original intent.

Why it matters:

Failure to maintain design integrity throughout the lifecycle can result in a system that fails to meet its stakeholder requirements, contains unnecessary design features or exhibits unexpected behaviours.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands the need to maintain the integrity of the design.	Ability to track specific aspects of the design to the original intent Supports remedial actions and change control. Understands the process of change control and configuration management	Able to identify parameters to track critical aspects of the design. Relates the current design to the original intent throughout the supply chain. Takes remedial actions in the presence of inconsistencies. Able to establish a system which allows the tracking of specific aspects of the design. Able to manage and trade technical margins both horizontally and vertically through the hierarchy. Able to guide supervised practitioner.	Reviews and judges the suitability of the complete set of critical parameters that allows the tracking of the system design. Influences system trade offs. Able to advise on the allocation of technical margins. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Holistic Lifecycle View : Systems Design – *Modelling & Simulation*

Description:

Modelling is a physical, mathematical, or logical representation of a system entity, phenomenon, or process. Simulation is the implementation of a model over time. A simulation brings a model to life and shows how a particular object or phenomenon will behave.

Why it matters:

Modelling and Simulation provides an early indication of function and performance to enable risk mitigation as well as supporting the verification and validation of a solution. Modelling and Simulation also allows the exploration of scenarios outside the normal operating parameters of the system.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands the need for system representations. Understands the scope and limitations of models and simulations.	Able to use modelling and simulation tools and techniques to represent a system or system element. Understands the risks of using models and simulations which are outside the validated limits.	Able to define an appropriate representation of a system or system element. Has used appropriate representations of a system or system element in order to derive knowledge about the real system. Able to implement the strategy and approach to be adopted for the modelling and simulation of a system or system element Able to guide supervised practitioner.	Demonstrates a full understanding of complex simulations for a system or system element. Able to advise on the suitability and limitations of models and simulations. Able to define the strategy and approach to be adopted for the modelling and simulation of a system or system element. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Holistic Lifecycle View : Systems Design – *Select Preferred Solution*

Description:

A preferred solution will exist at every level within the system and is selected by a formal decision making process.

Why it matters:

At some point in the development lifecycle a single solution must be identified in order to engineer it. Determination of a "preferred" solution which best matches the diverse requirements is critical to achieving stakeholder satisfaction.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands the need to select a preferred solution. Understands the relevance of comparative techniques (e.g. trade studies, make/buy, etc.) to assist decision processes.	Able to participate in the selection of preferred solutions.	Able to define selection criteria, weight and assess potential solutions against selection criteria such as technology requirements, off-the-shelf availability, competitive considerations, performance assessment, maintainability, capacity to evolve, standardisation considerations, integration concerns, cost, schedule, etc. Able to choose the appropriate tools and techniques for selecting the preferred solution, e.g. trade analysis, make/buy analysis. Ability to perform trade analysis and justify the result chosen in terms that can be quantified and qualified. Able to negotiate trades. Able to guide supervised practitioner.	Able to guide and advise practitioners in techniques for selection of preferred solutions. Reviews selected solutions and the criteria for selecting the solution. Able to act as an arbitrator in marginal cases. Able to carry out sensitivity analysis on selection criteria. Able to negotiate complex trades Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – – Holistic Lifecycle View : System Design : *System Robustness*

Description:

A robust system is tolerant of misuse, out of spec scenarios, component failure, environmental stress and evolving needs.

Why it matters:

A robust system gives greater availability in practice.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands how the design, throughout the lifecycle, affects the robustness of the solution. Aware of analytical techniques and the importance of design integrity, legislation, whole life costs and customer satisfaction.	Ability to use tools and techniques to ensure delivery of robust designs. Able to support robustness trade offs. Understands the relationship between reliability, availability, maintainability and safety.	Able to define the strategy and approach to be adopted for ensuring system robustness. Able to select the appropriate techniques for ensuring system robustness. Understands the operational environment and underlying domain specific issues related to robustness. Able to perform robustness trade offs. Able to use scenarios to determine robustness. Able to specify procurement of system elements in terms of reliability, availability, maintainability and safety. Able to guide supervised practitioner.	Able to predict evolving needs and their impact on the system. Reviews and advises on trade offs between non-functional requirements, cost and schedule. Able to define scenarios to determine robustness. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Holistic Lifecycle View: *System Integration & Verification*

Description:

Systems Integration is a logical process for assembling the system. Systems Verification is the checking of a system against its design – "did we build the system right?". Systems integration and verification includes testing of all interfaces, data flows, control mechanisms, performance and behaviour of the system against the system requirements; and qualification against the super-system environment (e.g. Electro Magnetic Compatibility, thermal, vibration, humidity, fungus growth, etc).

Why it matters:

Systems Integration has to be planned so that system elements are brought together in a logical sequence in order to avoid wasted effort. Systematic and incremental integration and verification makes it easier to find, isolate, diagnose and correct problems. A system or system element that has not been verified cannot be relied on to meet its requirements. Systems Verification is an essential prerequisite to customer acceptance and certification.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands the importance of verification against the system requirements. Understands the need to integrate the system in a logical sequence. Aware of the need to plan for Systems Integration and verification. Aware of the relationship between verification and acceptance.	Able to conduct system integration and test according to the plan. Able to write an integration and verification plan for a small non-complex system. Able to diagnose simple faults, document, communicate and follow up corrective actions.	Able to trace verification requirements back to system requirements and vice versa. Able to write an Integration and Verification plan for a complex system, including identification of method and timing for each activity. Can demonstrate effective management of systems integration and verification activities. Able to write detailed integration & verification procedures. Able to diagnose complex faults, document, communicate and follow up corrective actions. Able to plan and prepare evidence for customer acceptance and certification. Able to identify the integration and verification environment Able to guide supervised practitioner.	Acts as an authority in the development of systems integration and verification strategies. Reviews & judges the suitability of systems integration and verification plans. Able to lead complex systems integration and verification activities. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Holistic Lifecycle View: *Validation*

Description:

Validation checks that the operational capability of the system meets the needs of the customer/end user – "did we build the right system?".

Why it matters:

Validation is used to check that the system meets the needs of the customer/end user.
Failure to satisfy the customer will impact on future business. Validation provides some important inputs to future system development.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands the purpose of validation. Aware of the need for early planning for validation.	Able to conduct system validation activities according to the plans. Able to collate validation results.	Able to focus on customer needs and communicate in the language of the customer/user. Able to trace validation requirements back to user needs and vice versa. Able to write validation plans for a complex system, including identification of method and timing for each activity. Able to write detailed validation procedures. Can demonstrate effective management of systems validation activities. Able to assess validation results. Able to plan and prepare evidence for customer acceptance. Able to guide supervised practitioner.	Acts as an authority in the development of validation strategies. Able to write validation plans for a highly complex system. Reviews & judges the suitability of validation plans. Able to lead the validation activity. Able to advise the customer on validation issues. Conducts the sensitive negotiations in the language of the customer/end user. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA - Holistic Lifecycle View: *Transition To Operation*

Description:

Transition to Operation is the integration of the system into its super-system. This includes provision of support activities for example, site preparation, training, logistics, etc.

Why it matters:

Incorrectly transitioning the system into operation can lead to misuse, failure to perform, and customer/user dissatisfaction. Failure to plan for transition to operation may result in a system that is delayed into service/market with a consequent impact to the customer. Failure to satisfy the customer will impact on future business.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Aware of the need to carry out ‘transition to operation’. Aware of the type of activities required for transition to operation.	Able to plan simple transition to operation activities. Able to conduct ‘transition to operation’ activities according to a plan. Aware of the system’s contribution to the super system.	Able to communicate in the vocabulary of the user. Understands the system’s contribution to the super system. Able to plan and oversee a transition to operation activity. Able to guide supervised practitioner.	Able to plan and oversee highly complex transition to operation activities. Has successfully transitioned a system to operation. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Systems Engineering Management : *Concurrent Engineering*

Description:

Managing concurrent lifecycle activities and the parallel development of system elements.

Why it matters:

Systems engineering lifecycles involve multiple, concurrent processes which must be coordinated to mitigate risk and prevent nugatory work, paralysis and a lack of convergence to an effective solution. Concurrency may be the only approach to meeting customer schedule or gaining a competitive advantage. Performance can be constrained unnecessarily by allowing individual system elements to progress too quickly.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Aware that lifecycle activities and the development of systems elements can occur concurrently. Aware of the advantages and disadvantages of concurrency.	Able to describe the systems engineering lifecycle processes that are in place on their programme. Able to support co-ordination of concurrent engineering activities.	Able to identify which system elements can be developed concurrently. Able to manage the interactions within a systems engineering lifecycle. Has co-ordinated concurrent activities and dealt with emerging issues. Able to contribute to the Systems Engineering Management Plan. Able to advise on concurrency issues and risks. Able to guide supervised practitioner.	Known as an authority in systems engineering management. Able to develop new strategies for concurrent engineering. Able to advise customers and senior programme managers on concurrency issues and risks. Reviews and judges the suitability of Systems Engineering Management Plans Able to influence the implementation of concurrent engineering within the enterprise. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Systems Engineering Management : *Enterprise Integration*

Description:

Enterprises can be viewed as systems in their own right in which systems engineering is only one element. System Engineering is only one of many activities that must occur in order to bring about a successful system development that meets the needs of its stakeholders. Systems engineering management must support other functions such as Quality Assurance, Marketing, Sales, and Configuration Management, and manage the interfaces with them.

Why it matters:

As enterprises become larger, more complex and the functions within the enterprise more insular, the interdependencies between the functions should be engineered using a systems approach at an enterprise level to meet the demands of increased business efficiency.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Is aware that an enterprise is a system in its own right. Is aware that other functions of the enterprise have inputs to and outputs from the systems engineering process.	Understands the other functions (e.g. Quality Assurance, Marketing, Sales, Strategic Management, Configuration Management, Research, Human Resources) and relationships that make up an enterprise. Able to manage the creation of systems engineering products required by other functions.	Able to manage the relationship between the systems engineering function and other elements of the enterprise. Able to identify systems engineering products required by other functions and vice versa. Able to use systems engineering techniques to contribute to the definition of the enterprise. Able to identify the constraints placed on the systems engineering process by the enterprise. Able to guide supervised practitioner.	Acts as a consultant on business organisations. Able to advise on the effectiveness of the enterprise as a system. Able to review the impact of systems engineering capability within a business context. Able to review the impact of inputs from other functions on the systems engineering process. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – *Systems Engineering Management : Integration of Specialisms*

Description:

Coherent integration of Specialisms into the project at the right time. Specialisms include Reliability, Maintainability, Testability, Integrated Logistics Support, Producability, Electro Magnetic Compatibility, Human Factors and Safety.

Why it matters:

Specialisms support the systems engineering process by applying specific knowledge and analytical methods from a wide variety of disciplines to ensure the resulting system is able to meet its stakeholder needs. The technical effort of Specialisms must be integrated in terms of time and content to ensure project goals are met and the outputs generated add value commensurate with their costs.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Aware of the different specialisms. Aware of the importance of integrating specialisms into the project and that this is a potential source of conflict. Understands that the specialisms can affect the cost of ownership.	Understands the role and purpose of the specialisms. Able to work with appropriate specialists to support trade-offs.	Able to manage the integration of specialisms within a project. Able to conduct trade-offs involving conflicting demands from the specialisms. Understands how the specialisms affect the cost of ownership. Able to identify the constraints placed on the system development by the needs of the specialisms. Able to guide supervised practitioner.	Understands primary tasks of each specialism. Has successfully applied integration principles across a number of specialisms Able to resolve conflicts involving specialisms. Able to estimate the combined effect of the specialisms on the cost of ownership and the system development. Able to advise on the organisation of specialist functions. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Systems Engineering Management : *Lifecycle Process Definition*

Description:

Lifecycle Process Definition establishes lifecycle phases and their relationships depending on the scope of the project, super system characteristics, stakeholder requirements and the level of risk. Different system elements may have different lifecycles.

Why it matters:

Lifecycle forms the basis for project planning and estimating. Selection of the appropriate lifecycles and their alignment has a large impact on and may be crucial to project success. Ensuring co-ordination between related lifecycles at all levels is critical to the realisation of a successful system.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Aware of systems lifecycles. Understands the need to define an appropriate lifecycle process.	Understands systems engineering lifecycle processes. Able to support lifecycle definition activities. Able to describe the systems engineering lifecycle processes that are in place on their programme.	Able to identify the programme, enterprise and technology needs that affect the definition of the lifecycle. Able to influence the lifecycle of related super system elements. Able to identify dependencies and align the lifecycles of different system elements. Able to guide supervised practitioner.	Acts as an authority on lifecycle definitions and the implication of the lifecycle on the programme. Able to resolve conflicts between lifecycles. Reviews and judges the suitability of the definition of multiple concurrent lifecycles. Able to advise programme management on the implication of lifecycle issues including project and commercial. Has successfully determined and documented lifecycles matched to the needs of the programme. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

COMPETENCY AREA – Systems Engineering Management : *Planning, Monitoring & Controlling*

Description:

Establishes and maintains a systems engineering plan (e.g. Systems Engineering Management Plan) which incorporates tailoring of generic processes .The identification, assessment, analysis and control of systems engineering risks. Monitoring and control of progress.

Why it matters:

It is important to identify systems engineering needs and coordinate activities through planning. The alternative to planning is chaos.
Failure to plan and monitor prevents adequate visibility of progress and, in consequence, appropriate corrective actions may not be identified and/or taken when the project/programme's performance deviates from that required.

EFFECTIVE INDICATORS OF KNOWLEDGE AND EXPERIENCE

AWARENESS	SUPERVISED PRACTITIONER	PRACTITIONER	EXPERT
Understands the importance of planning, monitoring and controlling systems engineering activities.	Understands the role of systems engineering planning as part of an overall project plan. Able to monitor progress against the systems engineering plan. Able to assist in the management of systems engineering risks.	Able to plan systems engineering activities as part of an overall project plan. Able to identify, assess, analyse and control systems engineering risks. Able to influence project management in order to secure the systems engineering needs of the project. Able to control systems engineering activities by applying necessary corrective actions. Able to tailor systems engineering processes to meet the needs of a specific project. Able to guide supervised practitioner.	Has successfully planned, monitored and controlled complex systems engineering activities. Reviews and judges the suitability of systems engineering plans. Able to advise on systems engineering risks and their mitigation. Able to define appropriate generic systems engineering processes for the enterprise. Able to influence the relationship between systems engineering and project management at the enterprise level. Has coached new practitioners in this field. Has championed the introduction of novel techniques and ideas in this field which produced measurable improvements Has contributed to best practice.

3 Guidance for Using The Systems Engineering Competencies

This section provides guidance for using the Systems Engineering Competencies for both individuals and enterprises. Additional guidance on the subject of engineering competencies can be found on the websites of the Engineering Institutions and the Engineering Council (UK). For example, the IEE:
www.iee.org/EduCareers/ProfDev/competencies.

3.1 Individual Professional Development

The competencies defined in this document should enable individual engineers to determine the competencies and level of ability they need. This assessment will usually be in conjunction with the types of activities and levels of performance expected by their employing enterprise and national/international standards. This assessment should not only be a review of what is already expected of the individual, but what their future roles and activities might be. Most enterprises have some form of career development activity and it is envisaged that these competencies can help towards that process.

3.2 Enterprise ability Development

One of the aims of this Systems Engineering Competency document is to provide a competency framework that can be used to:

- Tailor/complement/supplement enterprise competency frameworks,
- Enterprise profiling,
- Team profiling,
- Job/Role descriptions,
- Recruitment,
- Identifying gaps in skill base.

An enterprise will need to review their requirements for the different competencies and competency level and generate a profile for the skills required across the enterprise, within teams and at an individual level. These profiles can then be mapped to existing and potential employees. These competencies provide a framework for career development and recruitment processes.

Although this competency framework requires tailoring to individual enterprises, a general definition of a ‘Systems Engineer’ is proposed below to enable enterprises to understand a common level of competency for a ‘Systems Engineer’.

3.3 Academic/Training Provider Educational Programme Development

The competencies for Systems Engineering can also be used by academic institutions and training providers to develop educational programmes in systems engineering that will provide the raw material for enterprises.

These competencies can also be used by the engineering institutions to assess and accredit systems engineering courses.

3.4 What Level Of Competency Is Required By A 'Systems Engineer'?

Competency	**Required Level**	
Systems Thinking		
Systems concepts	Practitioner	Compulsory
Super-system capability issues	Practitioner	Compulsory
Business and technology environment	Practitioner	Compulsory
Holistic Lifecycle View		50% of these competencies should be at Practitioner level and the remaining at Supervised Practitioner level
Determine and manage stakeholder requirements	Practitioner or Supervised Practitioner	
Integration & Verification	Practitioner or Supervised Practitioner	
Validation	Practitioner or Supervised Practitioner	
Transition to Operation	Practitioner or Supervised Practitioner	
System Design:		
Architectural design	Practitioner or Supervised Practitioner	
Concept generation	Practitioner or Supervised Practitioner	
Design for …	Practitioner or Supervised Practitioner	
Functional analysis	Practitioner or Supervised Practitioner	
Interface Management	Practitioner or Supervised Practitioner	
Maintaining Design Integrity	Practitioner or Supervised Practitioner	
Modelling and Simulation	Practitioner or Supervised Practitioner	
Select Preferred Solution	Practitioner or Supervised Practitioner	
System Robustness	Practitioner or Supervised Practitioner	
Systems Engineering Management		
Concurrent engineering	Practitioner or Supervised Practitioner	
Enterprise Integration	Practitioner or Supervised Practitioner	
Integration of specialisations	Practitioner or Supervised Practitioner	
Lifecycle process definition	Practitioner or Supervised Practitioner	
Planning, monitoring and controlling	Practitioner or Supervised Practitioner	

The definition of what level of competency is required for each competency for the role of 'Systems Engineer' will depend upon the structure of the employing enterprise and the industrial domain. Enterprises will need to develop a competency profile for their definition of the 'Systems Engineer' role. This profile will define which competencies are required and at what level.

However, as a guide to facilitate a common understanding of what would be expected of a 'Practicing Systems Engineer', the following competency profile is suggested in the table above.

Appendix A – Example List Of Supporting Techniques

This list is not exhaustive.

Category	Supporting Techniques	Specific Techniques
Analysis & Design	Operational Analysis	
	Behavioural analysis	Event Simulation Transaction Analysis
	Logical Analysis	
	Physical Analysis	N2 partitioning DSM Axiomatic design
	Functional Analysis	
	Structured Methods	Yourdon Quality Function Deployment – QFD SSADM Agile methods OOAD
	Decision Analysis & Resolution	Trade Studies
	Failure analysis	FMECA FTA FMEA
	Lean Design	
	Management of Margins	
	Six Sigma Design	Statistical Analysis
Management	Estimating	COCOMO COSYSMO
	Budgeting	EVM
	Scheduling	Material Requirements Planning (MRP) Manufacturing Resource Planning (MRP II)
	Planning	Network analysis Schedule analysis Critical path analysis
	Change Management	
	Configuration Management	
	Progress Monitoring	Earned Value management Critical Parameter Management
	Technical Risk and Opportunity Management	PESTEL

Category	Supporting Techniques	Specific Techniques
	Technology Planning	TRL SRL DML
Specialist	Human Factors	
	Availability Reliability	
	Maintainability Analysis	
	Reliability Analysis	
	Testability Analysis	
	Safety Analysis	
	Security Analysis	
Modelling & Simulation	Mathematical Modelling	
	Graphical Modelling	
	Physical Modelling	
	Synthetic Environments	

Appendix B – Example List of Basic Skills and Behaviours

This list is not exhaustive.

Basic Skills & Behaviour	Specific Techniques
Abstract Thinking	Ability to see multiple perspectives Ability to see big picture
Developing others	Coaching, mentoring, training
Communicating	Listening Skills Verbal & non-verbal communication Written
Knowing when to ask	
Creativity	Lateral thinking, brainstorming, TRIZ, Six thinking hats
Negotiating	
Team working	Belbin Team Roles, Meyers-Briggs Type Indicator, TQM tools (Cause/effect, force field, pareto etc.)
Problem solving	TQM tools (Cause/effect, force field, pareto etc.) SWOT analysis PESTEL analysis Decision Trees
Decision making	Risk/benefit analysis Pareto analysis, pair-wise comparison, Decision Trees, Force field analysis, six thinking hats
Objectivity	
Knowing when to stop	

Annex 1 – Guide to Competency Evaluation

Output of the Phase 2 WG – to be added at a later date

Screening Research:
Systems Engineering Competencies
Answer Sheet

Please complete the following information. Your name is required to allow us to match these results with the assessment results for each person.

1	Name				
2	Number of years of Systems Engineering experience				
3	I would like to receive feedback on my assessments	Yes		No	

For the following questions, please indicate your answer on a scale of 1-4 where: 1= STRONGLY DISAGREE, 2= DISAGREE, 3=AGREE and 4= STRONGLY AGREE

4	I am aware of systems engineering	
5	I have resources to learn more about systems engineering	
6	I have the resources to apply systems engineering on projects	
7	I have the opportunities to apply systems engineering	
8	My clients value the application of systems engineering on their projects	
9	My organisation values systems engineering	
10	There is a clear strategy in my group that includes systems engineering	
11	Discrimination prevents me from applying systems engineering	
12	I have had project opportunities to develop systems engineering	

Now, proceed to the Instructions tab below.

Instructions:
There are a total of 21 systems engineering (SE) competencies defined on separate sheets (refer to tabs below). Underneath the instructions box on this page, there is a summary of each SE competency with a description. Please read through these descriptions carefully to make sure you understand the meaning of each competency. Please complete the questions on competency 1-3. For competencies 4-21, please indicate the relative percentage of time that you spend on the specific competencies in the column marked "Time spent on Competency". The total percentage of time spent does not have to add up to a 100% if you do not perform SE on a full-time basis. Please select the 5 competencies from competencies 4-21 that you spend the most time on and indicate your choice by marking these with an x in the column "Chosen Competency". Then, please answer the questions for your selected competencies. Each question has either a 'yes' or 'no' answer. Please indicate your answer by using either a Y for yes or a N for no (default). It is normal not to have competence in all 21 competencies. **The results of this competency assessment will NOT influence your Key Result Area outcomes or salary.**

Definition of terms:
Competency: The necessary ability, which consists of talent and skill, to do something successfully. **Supervised Practitioner:** The person displays an understanding of the subject but requires guidance and supervision. Supervised practitioners are engineers who are "in-training" or are inexperienced in that particular competency. **Practitioner:** The person displays detailed knowledge and skill of the subject and is capable of providing guidance and advice to others.

Description and choice of SE competencies:

	SE Competency	Description
Required	**1 Systems Thinking: System Concepts**	*The application of the fundamental concepts of systems thinking to systems engineering. These include understanding what a system is, its context within its environment, its boundaries and interfaces and that it has a lifecycle.*
Required	**2 Systems Thinking: Super-system Capability Issues**	*An appreciation of the role the system plays in the super-system of which it is a part.*
Required	**3 Systems Thinking: Enterprise & Technology Environment**	*The definition, development and production of systems within an enterprise and technological environment.*

Chosen Competency	SE Competency	Description	Time spent on Competency (%)
	4 Holistic Lifecycle View: Determining and Managing Stakeholder Requirements	*To analyse the stakeholder needs and expectations to establish and manage the requirements for a system.*	
	5 Holistic Lifecycle View: Systems Design - Architectural Design	*The definition of the system architecture and derived requirements to produce a solution that can be implemented to enable a balanced and optimum result that considers all stakeholder requirements (business, technical?.).*	
	6 Holistic Lifecycle View: Systems Design - Concept Generation	*The generation of potential system solutions that meet a set of needs and demonstration that one or more credible, feasible solutions exist.*	
	7 Holistic Lifecycle View: Systems Design - Design for…	*Ensuring that the requirements of later lifecycle stages are addressed at the correct point in the system design. During the design process consideration should be given to manufacturability, testability, reliability, maintainability, safety, security, flexibility, interoperability, capability growth, disposal, etc.*	
	8 Holistic Lifecycle View: Systems Design - Functional Analysis	*Analysis is used to determine which functions are required by the system to meet the requirements. It transforms the requirements into a coherent description of system functions and their interfaces that can be used to guide the design activity that follows. It consists of the decomposition of higher-level functions to lower-levels and the traceable allocation of requirements to those functions.*	
	9 Holistic Lifecycle View: Systems Design - Interface Management	*Interfaces occur where system elements interact, for example human, mechanical, electrical, thermal, data, etc. Interface Management comprises the identification, definition and control of interactions across system or system element boundaries.*	
	10 Holistic Lifecycle View: Systems Design - Maintain Design Integrity	*Ensuring that the overall coherence and cohesion of the evolving design of a system is maintained, in a verifiable manner, throughout the lifecycle, and retains the original intent.*	
	11 Holistic Lifecycle View: Systems Design - Modelling & Simulation	*Modelling is a physical, mathematical, or logical representation of a system entity, phenomenon, or process. Simulation is the implementation of a model over time. A simulation brings a model to life and shows how a particular object or phenomenon will behave.*	
	12 Holistic Lifecycle View: Systems Design - Select Preferred Solution	*A preferred solution will exist at every level within the system and is selected by a formal decision making process.*	
	13 Holistic Lifecycle View: System Design: System Robustness	*A robust system is tolerant of misuse, out of spec scenarios, component failure, environmental stress and evolving needs.*	
	14 Holistic Lifecycle View: System Integration & Verification	*Systems Integration is a logical process for assembling the system. Systems Verification is the checking of a system against its design - "did we build the system right?". Systems integration and verification includes testing of all interfaces, data flows, control mechanisms, performance and behaviour of the system against the system requirements; and qualification against the super-system environment (e.g. Electro Magnetic Compatibility, thermal, vibration, humidity, fungus growth, etc).*	
	15 Holistic Lifecycle View: Validation	*Validation checks that the operational capability of the system meets the needs of the customer/end user - Did we build the right system?*	
	16 Holistic Lifecycle View: Transition to Operation	*Transition to Operation is the integration of the system into its super-system. This includes provision of support activities for example, site preparation, training, logistics, etc.*	
	17 Systems Engineering Management: Concurrent Engineering	*Managing concurrent lifecycle activities and the parallel development of system elements.*	
	18 Systems Engineering Management: Enterprise Integration	*Enterprises can be viewed as systems in their own right in which systems engineering is only one element. System Engineering is only one of many activities that must occur in order to bring about a successful system development that meets the needs of its stakeholders. Systems engineering management must support other functions such as Quality Assurance, Marketing, Sales, and Configuration Management, and manage the interfaces with them.*	
	19 Systems Engineering Management: Integration of Specialities	*Coherent integration of specialities into the project at the right time. Specialities include Reliability, Maintainability, Testability, Integrated Logistics Support, Producability, Electro Magnetic Compatibility, Human Factors and Safety.*	
	20 Systems Engineering Management: Lifecycle Process Definition	*Lifecycle Process Definition establishes lifecycle phases and their relationships depending on the scope of the project, super-system characteristics, stakeholder requirements and the level of risk. Different system elements may have different lifecycles.*	
	21 Systems Engineering Management: Planning, Monitoring & Controlling	*Establishes and maintains a systems engineering plan (e.g. Systems Engineering Management Plan) which incorporates tailoring of generic processes .The identification, assessment, analysis and control of systems engineering risks. Monitoring and control of progress.*	
		Total Time	0.00%

Acknowledgement

This questionnaire has been adapted from the INCOSE UK *Systems Engineering Competencies Framework* . The framework has been reformatted for readability and some language has been modified for South African use.

1 Systems Thinking: System Concepts		
Description	*The application of the fundamental concepts of systems thinking to systems engineering. These include understanding what a system is, its context within its environment, its boundaries and interfaces and that it has a lifecycle.*	
Question	**Descriptor**	**Y/N**
1	I am aware of system concepts	
2	I am aware of the importance of System Lifecycle	
3	I am aware of the importance of Hierarchy of Systems	
4	I am aware of the importance of System Context	
5	I am aware of the importance of Interfaces	
6	I understand system concepts.	
7	I understand the system lifecycle in which I am working.	
8	I understand system hierarchy and the principles of system partitioning in order to deal with complexity.	
9	I understand the concept of emergent properties.	
10	I can identify system boundaries and understand the need to define and manage the interfaces.	
11	I understand how humans and systems interact and how humans can be elements of systems.	
12	I have successfully identified and managed complexity with appropriate techniques in order to reduce risk.	
13	I have successfully predicted resultant system behaviour.	
14	I have successfully defined system boundaries and external interfaces.	
15	I have successfully assessed the interaction between humans and systems.	
16	I have successfully guided the supervised practitioner regarding systems thinking.	
17	I have successfully reviewed and judged the suitability of systems solutions regarding systems thinking.	
18	I have coached new practitioners in this field.	
19	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
20	I have contributed to best practice on an international level.	

2 Systems Thinking: Super-system Capability Issues		
Description	*An appreciation of the role the system plays in the super-system of which it is a part.*	
Question	**Descriptor**	**Y/N**
1	I understand the concept of capability.	
2	I understand that super-system capability needs impact on the system development.	
3	I appreciate the difficulties of translating super-system capability needs into system requirements.	
4	I can describe the environment and super-system into which the system under development is to be delivered.	
5	I can identify, with guidance, the super-system capability issues which will affect the design of a system.	
6	I have successfully identified the super-system capability issues which will affect the design of a system and translated these into system requirements.	
7	I have successfully assessed the extent to which the proposed system solution meets the super-system capability, and have provided advice on trade offs.	
8	I have successfully guided a supervised practitioner.	
9	I have reviewed and advised on the suitability of systems solutions.	
10	I have coached new practitioners in this field.	
11	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
12	I have contributed to best practice on an international level.	

3 Systems Thinking: Enterprise & Technology Environment

Description	*The definition, development and production of systems within an enterprise and technological environment.*	
Question	**Descriptor**	**Y/N**
1	I am aware of the influence the enterprise (environment, objectives, social, political, financial, cultural) has on the definition and development of the system.	
2	I am aware of the influence technology has on the definition and development of the system.	
3	I am aware of the influence the system has on the enterprise.	
4	I am aware of the influence the system has on technology.	
5	I can identify, with guidance, the various enterprise issues (markets, products, policies, finance etc.) which interact with the system to be developed.	
6	I can contribute, with guidance, to the technology plan.	
7	I have successfully identified the enterprise and technology issues which will affect the design of a system and have translated these into system requirements.	
8	I have successfully produced and implemented a technology plan that includes technology risk, maturity, readiness levels and insertion points.	
9	I have successfully guided a supervised practitioner.	
10	I have successfully influenced and maintained the technical capability and strategy of my enterprise.	
11	I am recognised as an authority in technology planning and management.	
12	I have coached new practitioners in this field.	
13	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
14	I have contributed to best practice on an international level.	

4 Holistic Lifecycle View: Determining and Managing Stakeholder Requirements		
Description	*To analyse the stakeholder needs and expectations to establish and manage the requirements for a system.*	
Question	**Descriptor**	**Y/N**
1	I understand the need for good quality requirements.	
2	I am able to identify major stakeholders.	
3	I understand the importance of managing requirements throughout the lifecycle.	
4	I understand the need to manage both technical and non-technical requirements.	
5	I am able to identify all the stakeholders and their sphere of influence.	
6	I can support the elicitation of requirements from stakeholders.	
7	I understand the characteristics of good quality requirements.	
8	I understand methods used in requirements gathering.	
9	I understand the need for traceability between the design and the requirements.	
10	I understand the relationship between requirements and acceptance.	
11	I understand the relationship between requirements and modelling.	
12	I am able to establish acceptance criteria for simple requirements	
13	I have successfully elicited stakeholder requirements.	
14	I have written good quality requirements.	
15	I have successfully produced a system requirements specification.	
16	I have successfully written the requirements management plan including categorisations and structures.	
17	I have successfully defined a process management plan including categorisations and structures.	
18	I have successfully demonstrated effective assessment of the impact of change.	
19	I have successfully resolved and negotiated requirement conflicts in order to establish a complete and consistent requirement set.	
20	I have successfully established acceptance criteria for interconnected requirements.	
21	I have successfully identified areas of uncertainty and risk when determining requirements.	
22	I have successfully challenged appropriateness of requirements in a rational way.	
23	I have successfully validated the requirements.	
24	I have successfully guided a supervised practitioner.	
25	I have successfully reviewed and judged the suitability of requirements management plans.	
26	I have successfully reviewed and judged the suitability and completeness of the requirements set.	
27	I am acknowledged as an authority in the elicitation and management of requirements.	
28	I have successfully advised on the sensitive requirements negotiations on major programmes.	
29	I have successfully advised on the likelihood of compliance.	
30	I have successfully advised on the validity of requirements.	
31	I have coached new practitioners in this field.	
32	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements	
33	I have contributed to best practice on an international level.	

5 Holistic Lifecycle View: Systems Design - Architectural Design

Description	*The definition of the system architecture and derived requirements to produce a solution that can be implemented to enable a balanced and optimum result that considers all stakeholder requirements (business, technical?).*	
Question	**Descriptor**	**Y/N**
1	I understand the principles of architectural design and its role within the lifecycle.	
2	I am aware of the different types of architecture.	
3	I am able to use techniques to support architectural design process.	
4	I am able to support the architectural design trade offs.	
5	I am able to generate alternative architectural designs that are traceable to the requirements.	
6	I have successfully assessed a range of architectural solutions and justified the selection of the optimum solution.	
7	I have successfully defined a process and appropriate tools and techniques for architectural design.	
8	I have successfully chosen appropriate analysis and selection techniques	
9	I have successfully partitioned between discipline technologies and derived discipline specific requirements.	
10	I have successfully guided a supervised practitioner.	
11	I have successfully demonstrated a full understanding of architectural design techniques and their appropriateness, given the levels of complexity of the system in question.	
12	I have reviewed and judged the suitability of architecture designs.	
13	I have coached new practitioners in this field.	
14	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements	
15	I have contributed to best practice on an international level.	

6 Holistic Lifecycle View: Systems Design - Concept Generation		
Description	*The generation of potential system solutions that meet a set of needs and demonstration that one or more credible, feasible solutions exist.*	
Question	**Descriptor**	**Y/N**
1	I understand the need to explore alternative ways of satisfying the need.	
2	I understand that alternative discipline technologies can be used to satisfy the same requirement.	
3	I am able to participate in the process of concept generation.	
4	I understand the strengths and weaknesses of relevant technologies in the context of the requirement.	
5	I have successfully created a range of alternative interdisciplinary concepts.	
6	I have successfully assessed the alternative solutions for feasibility, risk, cost, schedule, technology requirements, human factors, -ilities etc.	
7	I have successfully down-selected to a number of possible solutions and demonstrated that credible, feasible solutions exists.	
8	I have successfully guided a supervised practitioner.	
9	I have successfully guided and advised practitioners in techniques for concept generation.	
10	I have successfully selected concepts for credibility, feasibility, etc.	
11	I have coached new practitioners in this field.	
12	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements	
13	I have contributed to best practice on an international level.	

7 Holistic Lifecycle View: Systems Design - Design for…		
Description	*Ensuring that the requirements of later lifecycle stages are addressed at the correct point in the system design. During the design process consideration should be given to manufacturability, testability, reliability, maintainability, safety, security, flexibility, interoperability, capability growth, disposal, etc.*	
Question	**Descriptor**	**Y/N**
1	I understand the need to design for the requirements of later lifecycle stages.	
2	I assist in planning for the incorporation of later lifecycle design attributes.	
3	I have successfully identified and planned for the incorporation of later lifecycle design attributes at the correct point within the design process.	
4	I have successfully worked with appropriate specialists to ensure that these design attributes are addressed.	
5	I have successfully guided a supervised practitioner.	
6	I have successfully reviewed and judged the suitability of plans for the incorporation of later lifecycle design attributes at the correct point within the design process.	
7	I have successfully advised on complex issues and resolved conflicting design requirements.	
8	I have coached new practitioners in this field.	
9	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements	
10	I have contributed to best practice on an international level.	

8 Holistic Lifecycle View: Systems Design - Functional Analysis		
Description	*Analysis is used to determine which functions are required by the system to meet the requirements. It transforms the requirements into a coherent description of system functions and their interfaces that can be used to guide the design activity that follows. It consists of the decomposition of higher-level functions to lower-levels and the traceable allocation of requirements to those functions.*	
Question	**Descriptor**	**Y/N**
1	I understand the need for Functional Models.	
2	I understand the relevance of the outputs from Functional Analysis and how these relate to the overall system design.	
3	I am able to use the tools and techniques to conduct Functional Analysis.	
4	I have successfully defined the strategy and approach to be adopted for the functional analysis of the system.	
5	I have performed functional analysis.	
6	I have successfully defined a process and appropriate tools and techniques for functional analysis.	
7	I have successfully guided a supervised practitioner.	
8	I have successfully demonstrated a full understanding of the techniques and their appropriateness, given the levels of complexity of the system in question.	
9	I have successfully reviewed and judged the suitability of functional analyses.	
10	I have coached new practitioners in this field.	
11	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements	
12	I have contributed to best practice on an international level.	

9 Holistic Lifecycle View: Systems Design - Interface Management		
Description	*Interfaces occur where system elements interact, for example human, mechanical, electrical, thermal, data, etc. Interface Management comprises the identification, definition and control of interactions across system or system element boundaries.*	
Question	**Descriptor**	**Y/N**
1	I understand the need for interface management and its impact on the integrity of the system solution.	
2	I understand the possible sources of complexity in interface management, e.g. multinational programmes, multiple suppliers, different domains, novel technology, etc.	
3	I am able to follow interface management procedures.	
4	I am able to identify and define simple interfaces.	
5	I have successfully defined a process and appropriate techniques to be adopted for the interface management of system elements.	
6	I have successfully identified, defined and controlled system element interfaces.	
7	I have successfully described the sources of complexity for the interface management of the system, e.g. multinational programmes, multiple suppliers, different domains, novel technology, etc.	
8	I have successfully liaised and arbitrated where there were conflicts in the definition of interfaces	
9	I have successfully guided a supervised practitioner.	
10	I have demonstrated expertise in interface management.	
11	I have successfully reviewed and judged the suitability of interface management strategies.	
12	I have successfully negotiated on the issues of interface complexity.	
13	I have coached new practitioners in this field.	
14	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
15	I have contributed to best practice on an international level.	

10 Holistic Lifecycle View: Systems Design - Maintain Design Integrity		
Description	*Ensuring that the overall coherence and cohesion of the "evolving" design of a system is maintained, in a verifiable manner, throughout the lifecycle, and retains the original intent.*	
Question	**Descriptor**	**Y/N**
1	I understand the need to maintain the integrity of the design.	
2	I have the ability to track specific aspects of the design to the original intent.	
3	I support remedial actions and change control.	
4	I understand the process of change control and configuration management.	
5	I have successfully identified parameters to track critical aspects of the design.	
6	I have successfully related the current design to the original intent throughout the supply chain.	
7	I have successfully taken remedial actions in the presence of inconsistencies.	
8	I have successfully established a system which allows the tracking of specific aspects of the design.	
9	I have successfully managed and traded technical margins both horizontally and vertically through the hierarchy.	
10	I have successfully guided a supervised practitioner.	
11	I have successfully reviewed and judged the suitability of the complete set of critical parameters that allowed the tracking of the system design.	
12	I influence system trade-offs.	
13	I have successfully advised on the allocation of technical margins.	
14	I have coached new practitioners in this field.	
15	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
16	I have contributed to best practice on an international level.	

11 Holistic Lifecycle View: Systems Design - Modelling & Simulation		
Description	*Modelling is a physical, mathematical, or logical representation of a system entity, phenomenon, or process. Simulation is the implementation of a model over time. A simulation brings a model to life and shows how a particular object or phenomenon will behave.*	
Question	**Descriptor**	**Y/N**
1	I understand the need for system representations.	
2	I understand the scope and limitations of models and simulations.	
3	I am able to use modelling and simulation tools and techniques to represent a system or system element.	
4	I understand the risks of using models and simulations which are outside the validated limits.	
5	I have successfully defined an appropriate representation of a system or system element.	
6	I have used appropriate representations of a system or system element in order to derive knowledge about the real system.	
7	I have successfully implemented the strategy and approach to be adopted for the modelling and simulation of a system or system element.	
8	I have successfully guided the supervised practitioner.	
9	I have successfully demonstrated a full understanding of complex simulations for a system or system element.	
10	I have successfully advised on the suitability and limitations of models and simulations.	
11	I have successfully defined the strategy and approach to be adopted for the modelling and simulation of a system or system element.	
12	I have coached new practitioners in this field.	
13	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
14	I have contributed to best practice on an international level.	

12 Holistic Lifecycle View: Systems Design - Select Preferred Solution		
Description	*A preferred solution will exist at every level within the system and is selected by a formal decision making process.*	
Question	**Descriptor**	**Y/N**
1	I understand the need to select a preferred solution.	
2	I understand the relevance of comparative techniques (e.g. trade studies, make/buy, etc.) to assist decision processes.	
3	I am able to participate in the selection of preferred solutions.	
4	I have successfully defined selection criteria, weights and assessed potential solutions against selection criteria such as technology requirements, off-the-shelf availability, competitive considerations, performance assessment, maintainability, capacity to evolve, standardisation considerations, integration concerns, cost, schedule, etc.	
5	I have successfully chosen the appropriate tools and techniques for selecting the preferred solution, e.g. trade analysis, make/buy analysis.	
6	I have successfully performed trade analysis and justified the result chosen in terms that can be quantified and qualified.	
7	I have successfully negotiated trades-offs.	
8	I have successfully guided a supervised practitioner.	
9	I have successfully guided and advised practitioners in techniques for selection of preferred solutions.	
10	I have successfully reviewed selected solutions and the criteria for selecting the solution.	
11	I have successfully acted as an arbitrator in marginal cases.	
12	I have successfully carried out sensitivity analysis on selection criteria.	
13	I have successfully negotiated complex trades-offs.	
14	I have coached new practitioners in this field.	
15	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
16	I have contributed to best practice on an international level.	

13 Holistic Lifecycle View: System Design: System Robustness		
Description	*A robust system is tolerant of misuse, out of spec scenarios, component failure, environmental stress and evolving needs.*	
Question	**Descriptor**	**Y/N**
1	I understand how the design, throughout the lifecycle, affects the robustness of the solution.	
2	I am aware of analytical techniques and the importance of design integrity, legislation, whole life costs and customer satisfaction.	
3	I have the ability to use tools and techniques to ensure delivery of robust designs.	
4	I am able to support robustness trade offs.	
5	I understand the relationship between reliability, availability, maintainability and safety.	
6	I have successfully defined the strategy and approach to be adopted for ensuring system robustness.	
7	I have successfully selected the appropriate techniques for ensuring system robustness.	
8	I understand the operational environment and underlying domain specific issues related to robustness.	
9	I have successfully performed robustness trade offs.	
10	I have successfully used scenarios to determine robustness.	
11	I have successfully specified procurement of system elements in terms of reliability, availability, maintainability and safety.	
12	I have successfully guided a supervised practitioner.	
13	I have successfully predicted evolving needs and their impact on the system.	
14	I have successfully reviewed and advised on trade-offs between non-functional requirements, cost and schedule.	
15	I have successfully defined scenarios to determine robustness.	
16	I have coached new practitioners in this field.	
17	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
18	I have contributed to best practice on an international level.	

14 Holistic Lifecycle View: System Integration & Verification		
Description	*Systems Integration is a logical process for assembling the system. Systems Verification is the checking of a system against its design - "did we build the system right?". Systems integration and verification includes testing of all interfaces, data flows, control mechanisms, performance and behaviour of the system against the system requirements; and qualification against the super-system environment (e.g. Electro Magnetic Compatibility, thermal, vibration, humidity, fungus growth, etc).*	
Question	**Descriptor**	**Y/N**
1	I understand the importance of verification against the system requirements.	
2	I understand the need to integrate the system in a logical sequence.	
3	I am aware of the need to plan for Systems Integration and verification.	
4	I am aware of the relationship between verification and acceptance.	
5	I am able to conduct system integration and test according to the plan.	
6	I am able to write an integration and verification plan for a small non-complex system.	
7	I am able to diagnose simple faults, document, communicate and follow up corrective actions.	
8	I have successfully traced verification requirements back to system requirements and vice versa.	
9	I have successfully written an Integration and Verification plan for a complex system, including identification of method and timing for each activity.	
10	I have successfully demonstrated effective management of systems integration and verification activities.	
11	I have successfully written detailed integration & verification procedures.	
12	I have successfully diagnosed complex faults, documented, communicated and followed up corrective actions.	
13	I have successfully planned and prepared evidence for customer acceptance and certification.	
14	I have successfully identified the integration and verification environment	
15	I have successfully guided a supervised practitioner.	
16	I act as an authority in the development of systems integration and verification strategies.	
17	I have successfully reviewed & judged the suitability of systems integration and verification plans.	
18	I have successfully lead complex systems integration and verification activities.	
19	I have coached new practitioners in this field.	
20	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
21	I have contributed to best practice on an international level.	

15 Holistic Lifecycle View: Validation		
Description	*Validation checks that the operational capability of the system meets the needs of the customer/end user - Did we build the right system?*	
Question	**Descriptor**	**Y/N**
1	I understand the purpose of validation.	
2	I am aware of the need for early planning for validation.	
3	I am able to conduct system validation activities according to the plans.	
4	I am able to collate validation results.	
5	I have successfully focused on customer needs and communicated in the language of the customer/user.	
6	I have successfully traced validation requirements back to user needs and vice versa.	
7	I have successfully written validation plans for a complex system, including identification of methods and timing for each activity.	
8	I have successfully written detailed validation procedures.	
9	I have successfully demonstrated effective management of systems validation activities.	
10	I have successfully assessed validation results.	
11	I have successfully planned and prepared evidence for customer acceptance	
12	I have successfully guided a supervised practitioner.	
13	I act as an authority in the development of validation strategies.	
14	I have successfully written validation plans for a highly complex system.	
15	I have successfully reviewed & judged the suitability of validation plans.	
16	I have successfully led the validation activity.	
17	I have successfully advised the customer on validation issues.	
18	I have successfully conducted the sensitive negotiations in the language of the customer/end user.	
19	I have coached new practitioners in this field.	
20	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
21	I have contributed to best practice on an international level.	

16 Holistic Lifecycle View: Transition to Operation		
Description	*Transition to Operation is the integration of the system into its super-system. This includes provision of support activities for example, site preparation, training, logistics, etc.*	
Question	**Descriptor**	**Y/N**
1	I am aware of the need to carry out 'transition to operation'	
2	I am aware of the type of activities required for transition to operation.	
3	I am able to plan simple transition to operation activities.	
4	I am able to conduct 'transition to operation' activities according to a plan	
5	I am aware of the system's contribution to the super-system.	
6	I have successfully communicated in the vocabulary of the user.	
7	I understand the system's contribution to the super-system.	
8	I have successfully planned and overseen a transition to operation activity	
9	I have successfully guided a supervised practitioner.	
10	I have successfully planned and overseen highly complex transition to operation activities.	
11	I have successfully transitioned a system to operation.	
12	I have coached new practitioners in this field.	
13	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
14	I have contributed to best practice on an international level.	

17 Systems Engineering Management: Concurrent Engineering		
Description	*Managing concurrent lifecycle activities and the parallel development of system elements.*	
Question	**Descriptor**	**Y/N**
1	I am aware that lifecycle activities and the development of systems elements can occur concurrently.	
2	I am aware of the advantages and disadvantages of concurrency.	
3	I am able to describe the systems engineering lifecycle processes that are in place on their programme.	
4	I am able to support co-ordination of concurrent engineering activities.	
5	I have successfully identified which system elements could be developed concurrently.	
6	I have successfully managed the interactions within a systems engineering lifecycle.	
7	I have co-ordinated concurrent activities and dealt with emerging issues.	
8	I have successfully contributed to the Systems Engineering Management Plan.	
9	I have advised on concurrency issues and risks.	
10	I have successfully guided a supervised practitioner.	
11	I am known as an authority in concurrent engineering.	
12	I have successfully developed new strategies for concurrent engineering.	
13	I have successfully advised customers and senior programme managers on concurrency issues and risks.	
14	I have successfully reviewed and judged the suitability of Systems Engineering Management Plans.	
15	I have successfully influenced the implementation of concurrent engineering within the enterprise.	
16	I have coached new practitioners in this field.	
17	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
18	I have contributed to best practice on an international level.	

18 Systems Engineering Management: Enterprise Integration		
Description	*Enterprises can be viewed as systems in their own right in which systems engineering is only one element. System Engineering is only one of many activities that must occur in order to bring about a successful system development that meets the needs of its stakeholders. Systems engineering management must support other functions such as Quality Assurance, Marketing, Sales, and Configuration Management, and manage the interfaces with them.*	
Question	**Descriptor**	**Y/N**
1	I am aware that an enterprise is a system in its own right.	
2	I am aware that other functions of the enterprise have inputs to and outputs from the systems engineering process.	
3	I understand the other functions (e.g. Quality Assurance, Marketing, Sales, Strategic Management, Configuration Management, Research, Human Resources) and relationships that make up an enterprise.	
4	I am able to manage the creation of systems engineering products required by other functions.	
5	I have successfully managed the relationship between the systems engineering function and other elements of the enterprise.	
6	I have successfully identified systems engineering products required by other functions and vice versa.	
7	I have successfully used systems engineering techniques to contribute to the definition of the enterprise.	
8	I have successfully identified the constraints placed on the systems engineering process by the enterprise.	
9	I have successfully guided a supervised practitioner.	
10	I act as a consultant on business organisations.	
11	I have successfully advised on the effectiveness of the enterprise as a system.	
12	I have successfully reviewed the impact of systems engineering capability within a business context.	
13	I have successfully reviewed the impact of inputs from other functions on the systems engineering process.	
14	I have coached new practitioners in this field.	
15	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
16	I have contributed to best practice on an international level.	

19 Systems Engineering Management: Integration of Specialities		
Description	*Coherent integration of specialities into the project at the right time. Specialities include Reliability, Maintainability, Testability, Integrated Logistics Support, Producability, Electro Magnetic Compatibility, Human Factors and Safety.*	
Question	**Descriptor**	**Y/N**
1	I am aware of the different specialities.	
2	I am aware of the importance of integrating specialities into the project and that this is a potential source of conflict.	
3	I understand that the specialities can affect the cost of ownership.	
4	I understand the role and purpose of the specialities.	
5	I am able to work with appropriate specialists to support trade-offs.	
6	I have successfully managed the integration of specialities within a project.	
7	I have successfully conducted trade-offs involving conflicting demands from the specialities.	
8	I understand how the specialities affect the cost of ownership.	
9	I have successfully identified the constraints placed on the system development by the needs of the specialities.	
10	I have successfully guided a supervised practitioner.	
11	I understand the primary tasks of each speciality.	
12	I have successfully applied integration principles across a number of specialities.	
13	I have successfully resolved conflicts involving specialities.	
14	I have successfully estimated the combined effect of the specialities on the cost of ownership and the system development.	
15	I have successfully advised on the organisation of specialist functions.	
16	I have coached new practitioners in this field.	
17	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
18	I have contributed to best practice on an international level.	

20 Systems Engineering Management: Lifecycle Process Definition		
Description	*Lifecycle Process Definition establishes lifecycle phases and their relationships depending on the scope of the project, super-system characteristics, stakeholder requirements and the level of risk. Different system elements may have different lifecycles.*	
Question	**Descriptor**	**Y/N**
1	I am aware of systems lifecycles.	
2	I understand the need to define an appropriate lifecycle process.	
3	I understand systems engineering lifecycle processes.	
4	I am able to support lifecycle definition activities.	
5	I am able to describe the systems engineering lifecycle processes that are in place on their programme.	
6	I have successfully identified the programme, enterprise and technology needs that affect the definition of the lifecycle.	
7	I have successfully influenced the lifecycle of related super-system elements.	
8	I have successfully identified dependencies and aligned the lifecycles of different system elements.	
9	I have successfully guided a supervised practitioner.	
10	I act as an authority on lifecycle definitions and the implication of the lifecycle on the programme.	
11	I have successfully resolved conflicts between lifecycles.	
12	I have successfully reviewed and judged the suitability of the definition of multiple concurrent lifecycles.	
13	I have successfully advised programme management on the implication of lifecycle issues including project and commercial.	
14	I have successfully determined and documented lifecycles matched to the needs of the programme.	
15	I have coached new practitioners in this field.	
16	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
17	I have contributed to best practice on an international level.	

21 Systems Engineering Management: Planning, Monitoring & Controlling		
Description	*Establishes and maintains a systems engineering plan (e.g. Systems Engineering Management Plan) which incorporates tailoring of generic processes .The identification, assessment, analysis and control of systems engineering risks. Monitoring and control of progress.*	
Question	**Descriptor**	**Y/N**
1	I understand the importance of planning, monitoring and controlling systems engineering activities.	
2	I understand the role of systems engineering planning as part of an overall project plan.	
3	I am able to monitor progress against the systems engineering plan.	
4	I am able to assist in the management of systems engineering risks.	
5	I have successfully planned systems engineering activities as part of an overall project plan.	
6	I have successfully identified, assessed, analysed and controlled systems engineering risks.	
7	I have successfully influenced project management in order to secure the systems engineering needs of the project.	
8	I have successfully controlled systems engineering activities by applying necessary corrective actions.	
9	I have successfully tailored systems engineering processes to meet the needs of a specific project.	
10	I have successfully guided a supervised practitioner.	
11	I have successfully planned, monitored and controlled complex systems engineering activities.	
12	I have successfully reviewed and judged the suitability of systems engineering plans.	
13	I have successfully advised on systems engineering risks and their mitigation.	
14	I have successfully defined appropriate generic systems engineering processes for the enterprise.	
15	I have influenced the relationship between systems engineering and project management at the enterprise level.	
16	I have coached new practitioners in this field.	
17	I have championed the introduction of novel techniques and ideas in this field which produced measurable improvements.	
18	I have contributed to best practice on an international level.	