"Systems engineering influences on projects and the systems engineering workforce"

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Abstract

This research was an investigation into the influences systems engineering has on projects and the systems engineering workforce conditions. It focussed on all industries that have projects and utilised the systems engineering process in South Africa. The research examined the knowledge and understanding of the workforce in the systems engineering domain and some of the specific functions of systems engineering that add value to projects. The constraints the organisation and the workforce experience with regard to culture, resources, management support and systems thinking were also investigated.

The research methodology followed a deductive reasoning approach. The most suitable strategy, given the cross-sectional time horizon, was a mono-method survey. This was represented with a quantitative questionnaire and non-probability sampling techniques. Respondents i.e. project managers, engineers and clients from related organisations, were invited to participate.

The results revealed that the systems engineering was fairly new field in the South African environment. Although respondents understood the basic concept of systems engineering, they were uncertain of the actual functions of systems engineering. There was clear indication that skills shortages existed. Respondents were willing to learn and the organisation could do more to develop the systems engineering field.

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Declaration

I declare that this research project is my own work. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration at the Gordon Institute of Business Science, University of Pretoria. It has not been submitted before for any degree or examination at any other University. I further declare that I have obtained the necessary authorisation and consent to carry out this research.

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Abbreviations

CE	–	Chief Engineer
FMCG	–	Fast Moving Consumable Goods
IT	–	Information technology
ITS	–	Information technology systems
NASA	–	National Aeronautics and Space Administration
PM	–	Project Manager
ROI	–	Return on investment
SA	–	South Africa
SD	–	Systems developer
SE	–	Systems engineering
SEnr	–	Systems Engineer
URS	–	User Requirement Statement
USA	–	United States of America
USD	–	United States Dollar
ZAR	–	South African Rand

1 INTRODUCTION TO RESEARCH PROBLEM

1. 1 Research title

The research is entitled “Systems engineering influences on projects and the systems engineering workforce”.

1. 2 Research problem

Sometime during World War II, large-scale systems began to emerge. This phenomenon continued throughout the Cold War with military systems, and reached maturity with NASA's Apollo programme. Today, the phenomenon of large-scale, highly-complex systems is not limited to the defence environment, but has extended to commercial infrastructure as well. Development and management roles became more complex as systems became more complex. Projects had large costs associated with them. Failure at later stages of these projects caused the costs to escalate exponentially. Industry, government and academia were scurrying to establish programmes to develop systems skills (Davidz and Nightingale, 2008),

As technology spiralled upwards, the complexity and potential for unforeseen problems increased at the same rate. At one time, it was relatively easy to split the technical and management disciplines because they were unique and distinct from each other (Carr, 2000). The literature review contained evidence of the following:

- Involvement of SE at the start of a project reduced risks and assisted in the successful completion of the projects in terms of time, cost and quality.
- There were exorbitant costs associated with projects not meeting the requirement, also known as failure, due to unclear user requirement statement (URS). The URS generated by the client was in concept state and systems engineering (SE) was used to translate the URS into technical terms.
- One of the reasons for failure or lack of SE was skills shortage, and
- The organisation and the SE workforce experienced constraints in applying SE for projects (e.g. organisational culture, management support, systems thinking)

Projects all over the world were similar in structure; however; the research was customised for South Africa (SA). An important observation was that environmental conditions (such as: political; economic; social; technological; legal and ecological) differed. For example, countries such as the United States of America (USA) had much larger budgets; higher involvement in cross broader wars and the USA had access to more skilled workers, although skills shortage was a worldwide problem. The skills shortage aspect of the research focussed on the SE experience of current project managers (PM) and engineers and the attitude of the workforce towards the use of SE in projects.

The military/aerospace industries had several decades of experience in the application of SE. In the world of complex systems developed under contract, SE had a well-articulated, generally accepted, client-mandated methodology. This was not the case in most commercially oriented research and development organizations. Unlike the military/aerospace environment, it was not widely accepted that SE could or would deliver value within commercial enterprises. This said, it was possible that a SE-like methodology may be routinely employed but not so stated, or was recognized under a different label (Vanek, Jackson and Grzybowski, 2008).

There were also broader economic challenges. Thomas Friedman's best seller, The World Is Flat (2005 quoted in Rouse, 2008), provided a clarion call to the business and technology communities. Several countries, particularly in Asia, caught up with the USA in terms of various indices of innovation, and were producing huge numbers of talented college graduates, particularly in engineering. This challenged both industry in terms of how to best compete and academia in terms of educating people with competitive knowledge and skills.

1. 3 Research aim and motivation

This research was conducted to determine the influence SE had on projects in SA; the challenges the workforce experiences in practising SE, and the organisational environment for SE. Selected industries were used and the intent was to gain information in general from projects in as many companies as possible in SA. Projects were analysed by inviting PMs, engineers and clients to share their SE knowledge and experience.

One of the gaps that Vanek *et al*, (2008) found after conducting a literature review on several papers for groundwork on SE in product development, was the ability to quantify the return on investment (ROI) for the use of SE. Although the research did not focus on numeric quantification, it started the process of determining value of SE in projects. For the workforce, Frank (2002) believed that a thorough understanding of engineering systems thinking at both the theoretical and operational levels would prove useful in the design of curricula intended to improve and develop thinking of SE.

Defence institutes had several projects that extended beyond timelines with no SE resulting in unclear URS and poor risk evaluation in the early stages of projects. This has cost the government millions of dollars (USD). It was commonly found in defence projects that PMs are expected to proceed with complex projects with insufficient SE capabilities. Although the SE discipline was not new, it was not clearly defined in industry. There was a misconception that if one was an engineer, he or she automatically has SE capabilities. Senior management and clients were reluctant to contract for SE or build the SE in-house capability. This research was also an attempt to recommend to high-level management that it may or may not be feasible to compromise on SE costs.

Davidz and Nightingale (2008) stated that improved SE capabilities in contractors were being demanded by the USA government agencies. Davidz and Nightingale (2008) also expressed that as systems became more complex; there was increasing interest in SE and the SE workforce. There was a need for broad enterprise perspective that would require integration of behavioural, social and life sciences, as well as management, to address systems of increasing scale and complexity (Rouse, 2008).

Millions of Rands (ZAR) of public funds could be saved in defence projects if SE was utilised. Projects would finish on time, within budget and with the desired quality. Most importantly, the customer's requirements would be addressed adequately. SE can be used in all engineering industries and information technology (IT) industries. The models and principles could be adapted to other fields, such as financial institutions or organisations that require more than one function to complete a product or service.

Davidz and Nightingale's (2008) research also suggested that academia affected systems thinking development in engineers in a multiple of ways: by offering systems programmes to teach systems skills and to research the mechanisms for effective systems thinking development. Perhaps SE would enjoy greater success if it, too, were taught in business schools as a management skill rather than in engineering departments (Emes, Smith and Cowper, 2005)?

1. 4 Research scope

The geographic location of the research was in SA. The main idea was to gather respondents involved in projects from as many organisations in varying industry sectors as possible. The results were a mixture of respondents from the industries such as defence; engineering; financial; information technology, motor and petro-chemical. A detailed description of the respondents selected and research method was discussed in chapter 4.

1. 5 Conclusion

This chapter provided an introduction to the research problem on SE. it explained the constraints that the organisation and the workforce were experiencing in the project environment. The research aim was supported with motivation from various authors. The scope of the research resided in South African companies that had PMs, engineers and clients. The next chapter reviewed the literature that was relevant to this research to help gain insight to this topic.

2 LITERATURE REVIEW

2.1 Introduction

After reviewing many literature papers on SE, several themes emerged. These were: project management versus SE; complex projects & industry; SE effectiveness & the URS; skills shortage; systems thinking; project failure; organisational culture; learning organisation and project risks. The arguments were debated in this chapter to gain insight on the research topic.

These themes were divided into three main sections: 1) SE domain which defined SE, described the industry and characterised the roles of the project teams; 2) SE which described SE effectiveness, the URS, uncovered the impact of the global skills shortage problem and the need for systems thinkers; and 3) Projects and the organisation which explored the reasons for project failure, the organisational culture and the risks associated with not attending to the problems that were emerging.

This chapter will examine each of the sections mentioned above to find common aspects that relate to the research problem. It also provides direction for the research methodology that follows in chapter 4. This chapter is concluded by demonstrating the relationship of all these themes to the research topic.

2.2 Systems engineering domain

The review was tackled in three steps. This section is the first step that sets the scene for SE by defining it and describing the domain.

2.2.1 Definitions

Many authors have defined SE. Although the definitions are similar, there are some variations. Some definitions are outlined in Table 2-1.

"Systems engineering is a discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspects."   Haskins (2007: 2.1)
"Systems engineering operates in the space between research and business, and assumes the attitudes of both. For those projects which it finds most worthwhile for development, it formulates the operational, performance and economic objectives, and the broad technical plan to be followed."   Emes *et al* (2005:p. 165)
"Systems Engineering is a professional endeavour that leads to the engineering of a system of humans, organizations and technologies through knowledge management efforts associated with bringing the perspectives of all stakeholders to the associated issues to bear, such as to enable the appropriate definition of the system to be engineered such as to achieve needed capabilities and fulfil requirements; development of the system through appropriate architecture, design, and integration efforts; and ultimate deployment of the system in an operational environment and associated maintenance and reengineering of it throughout a useful lifetime of trustworthy service to these stakeholders."   Cook & Ferris (2007: p. 171)

Table 2-1: Systems engineering definitions

To summarise these definitions, SE could be interpreted as that part of the technical management process that coordinates and oversees the translation of an operational need into a system designed to meet that need.

2.2.2 The industry

This section describes the industry that SE is used in. Sauser & Boardman (2008; Eriksson, Borg and Börstler, 2008; Meade & Farrington, 2008) explained that the principles of SE management and SE historically were utilized and developed in government with projects such as manned space flight, nuclear-powered submarines, communications satellites, launch vehicles, aircraft, and deep space probes. Eriksson *et al*, (2008) summarised that the difficulties faced by defence organisations was in both the market place and the system domain:

- Long life cycles: Systems life cycle could last 30 years and even longer.
- Limited units: Only a limited number of units were produced.
- High degree of customisation: Systems were often part of a product line of related systems while some units were manufactured to be customer specific.
- Complexity: systems were growing more and more complex, tightly integrating mechanical, electrical and software components (Carr, 2000; Eriksson *et al*, 2008 and Sauser & Boardman, 2008).

  Complexity referred to in this research followed the understanding of these authors: Vanek *et al* (2008) identified an aircraft or automobile as a complex system, whereas a unit of packaged food products was not, although the initial development, manufacture, distribution, and marketing of the food product may constitute a complex system when taken as a whole. Among complex systems, Oppenheim (2004, quoted in Vanek *et al*, 2008) defined complex systems and classified technological product development programmes into four types: (1) complex large open systems (e.g. the Internet), (2) complex frontier systems (a groundbreaking aerospace application, e.g., Mars Rover), (3) complex legacy-based systems (commercial passenger aircraft), and (4) smaller complex systems (light aircraft).

Vanek *et al* (2008) advised that in order to remain competitive it was important to find ways to reduce inefficiencies.

2.2.3 Characterisation of roles

This section is aimed at classifying the unique roles of the PM and the SEnr. One must first understand the concept of a project. A project could be defined as "a complex, coherent, interdependent group of activities, which combined to deliver common, novel objectives in a finite duration within a fixed amount of resource. Projects can be viewed as the interaction of three types of abstraction: time, cost and quality" (Emes *et al*, 2005: p. 172). Dasher (2003, Sage and Cuppan, 2001) described the function of the PM and the chief engineer (CE) as being "joined at the hip" or as one not being able to function without the other. The PM and CE were supported by a multidiscipline team led by the SEnr. He characterised SE into two disciplines: technical knowledge domain and the management domain.

Emes *et al* (2005; Eveleigh, Mazzuchi, and Sarkani, 2006) articulated that tension existed between the three abstractions (time, cost and quality) and stated that project management must balance and trade these off to achieve a successful project. Emes *et al* (2005) argued that traditional SE focused on delivering quality, while project management focused more on time and resource management. However, each role was important and should work together with effective communication. Hitchins (1992 quoted in Emes *et al,* 2005) found that many system practitioners did not believe that SE was a separate discipline; instead they preferred to think of it as common sense, although they admitted that such sense may be far from common.

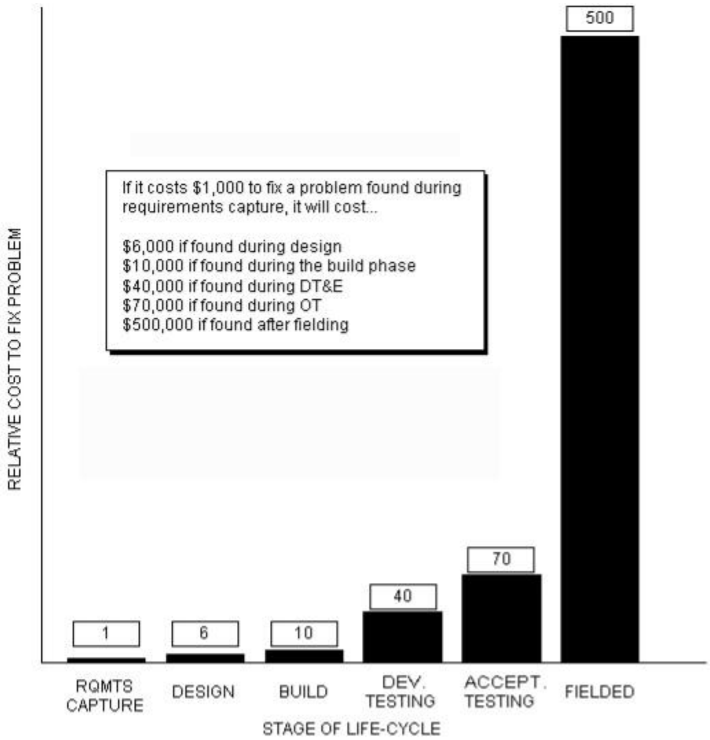
Pruitt, (1999) listed the basic responsibilities of a SEnr which were: 1) Create a clear definition of the URS; 2) Establish the system concept for the project; 3) Develop the system validation plan; 4) Develop the system performance specifications; 5) Develop the verification philosophy for all components; 6) Establish “design to” specification for all subsystems and contract items; 7) Control all design changes; ensure compatibility of all changes to the system integrity; 8) Ensure assignment and coordination of the various technical disciplines needed throughout the program; and 9) Coordinate all verification tests; ensure contract items meet design-to specifications. Meade & Farrington, (2008) added that each project required tailoring to satisfy the needs of the project.

2.3 Systems Engineering

This second step is to understand the effectiveness of SE and the factors that form part of effective SE.

2.3.1 System engineering effectiveness

The literature was examined for the effectiveness of SE. Major problems found on space/launch vehicles could have been rectified during early phases (i.e. requirements and design phases) if the level of effort, support, planning and maturity had been better (Nagano, 2008). Nagano (2008) found that the risks increased ten-fold when the verification programmes were not satisfactory. In Figure 2-1 below, Carr (2000) demonstrated the costs of fixing a problem in each phase as it was discovered.



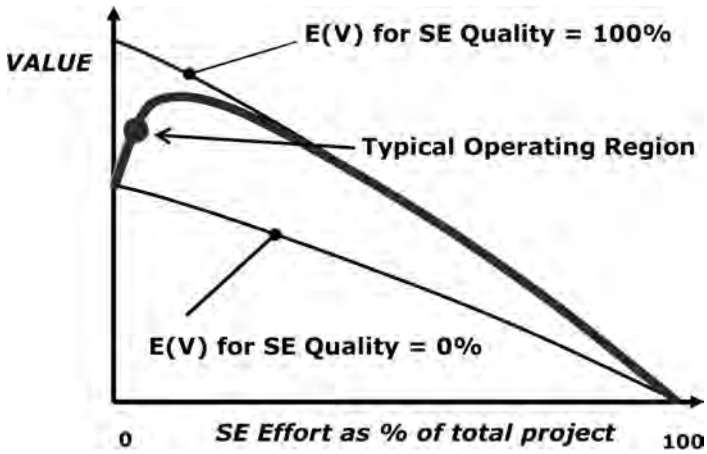
(Carr, 2000; p. 404)

Figure 2-1 : Cost ratio of fixing a problem in systems design

This view was enhanced by Nagano's (2008) investigation on secondary data of 133 cases of space/launch vehicles that failed between 1964 and 2003. The study showed that even a small mistake at the early stages of the system development could cause catastrophic failure.

Vanek *et al* (2008) believed that by using the tools and techniques of SE to execute the development process optimally will yield a superior product in shorter development time with less use of financial resources. However, proving the value of SE in the development of new products and processes in private industry, as in other sectors (e.g. government procurement of military and aerospace systems, investment in public works, etc.), was not an easy task.

Vanek *et al* (2008) also found complaints in their literature study with the notion that "SE was useful in general, but cannot identify which practices are useful under what conditions" (Vanek *et al*, 2008), or indeed that "it won't be possible to prove ROI from use of SE metrics for the foreseeable future" (Sheard and Miller, 2000 quoted in Vanek *et al*, 2008). Vanek *et al* (2008) described a method to measure SE effectiveness as presented in Figure 2-2.



(Vanek et al, 2008: p. 111)

Figure 2-2 : SE quality vs SE effort in relation to project outcome

A project with 0% SE effort (intersection of lower curve with y-axis) in Figure 2-2, was still able to achieve some value. Also, at very low percentages of SE effort, the quality of the SE effort would be poor, so that its effect on overall value was negligible. However, as the percentage of SE effort was added, its quality increased so that expected values rouse, as shown by the thick curve, toward some upper bound on achievable value (Vanek *et al*, 2008; p. 111).

Finally, once SE effort exceeded some optimal range, Gruhl's (1992 quoted in Vanek *et al*, 2008; Carr, 2000) study suggested a value of approximately 10%, SE effort no longer adds to overall expected value, even at 100% quality, so that the maximum expected value declines towards 0 as SE effort increased towards 100%.

2.3.2 User requirement statement (URS)

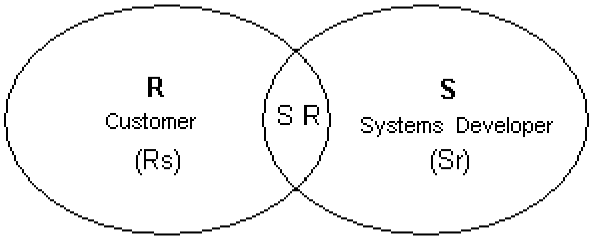
One of the first functions of a SEnr, brought out by Pruitt, (1999) above was to "create a clear definition of the URS". Therefore, this section describes the URS and the effect it has on the success of a project.

Carr (2000: p. 401 - 402) defined user requirements as the "descriptions of properties, attributes, services, functions, and/or behaviours needed in a product to accomplish the goals and purposes of the system: If it mandated that something must be accomplished, transformed, produced or provided, it was a requirement". Carr (2000) pointed out that some people erroneously believed that they could fix problems with requirements during a design review.

By the time the design review occurred major decisions affecting design had been made and there was little chance of significant change unless both cost and schedule could be adjusted (Carr, 2000). Carr (2000) also stated that project teams tended to short-live the requirements engineering and management process due to the "tyranny of urgent". It sometimes seemed that programmes were willing to spend huge amounts of time and money to fix things later on, rather than 'doing it right the first time' (Carr, 2000; Al-Karaghouli, Alsahwi and Fitzgerald, 2005).

Alshawi & Al-Karaghouli, (2003) demonstrated the different areas of knowledge and understanding in the two circles of the set diagram in

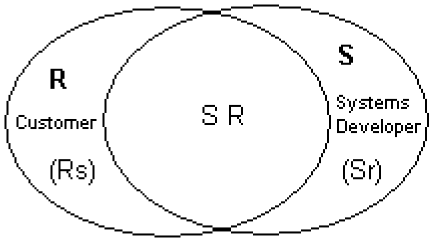
Figure 2-3: Initial overlapping of customer requirements and systems developer (SD) specifications; one circle represented the understanding of the SD, the other the customer. The matching or common understanding of the requirement was where the two circles overlapped (RS). The diagram illustrated that in this case the customer and the developer had different perceptions and understandings of what the system was to deliver and what it would be like as the area of overlap was very small (Alshawi & Al-Karaghouli, 2003).



(Alshawi & Al-Karaghouli, 2003: p. 346)

Figure 2-3 : Initial overlapping

The agreed mapping after the second stage was shown in the new set diagram, Figure 2-4: Greater overlapping of customer requirements and systems developer specifications, below. The diagram helped the parties to focus on those instances that were not mapped in each set. These were then reviewed, discussed and negotiated for clarity on the definition and the purpose of their appearance.



(Alshawi & Al-Karaghouli, 2003: p. 348)

Figure 2-4 : Greater overlapping

In Mckeen *et al*, (1994) analysis of 151 independent systems development projects in eight different organizations indicated that there was a positive relationship between user participation and user satisfaction.

Sahraoui (2005) found that designing systems was highly sensitive to two main issues: (1) requirement development and elicitation; and (2) requirement management and traceability. He stated that the traceability approach was first developed for describing connections between different layers of requirements descriptions. It aimed at an improved understanding of requirements and easier determination of the impact of a changed requirement (Sahraoui, 2005).

Keating, Padilla and Adams (2008) identified the attributes of system requirements to have several important characteristics that were considered critical to their effectiveness. These characteristics were: unique, complete, consistent with other requirements, implementable, achievable, and verifiable (ISO 15288, 2002 quoted in Keating *et al*, 2004). While in respect to judgment concerning the quality of specified requirements, Keating *et al* (2004; Anderson, Compton and Mason, 2004) also found the following characteristics: unambiguous, ranked, understandable, traceable, modifiable, and correct.

2.3.3 Skills shortage

Skills shortage has become a global problem, therefore this section describes the effect this problem has on SE and the SE workforce. Davidz and Nightingale (2008) described how the global skills shortage, which includes SE professionals, was further hampered by the retirements of an aging aerospace workforce.

SA was also faced with similar challenges (Griffiths, 2006). Griffiths (2006) explained that the aging workforce in the defence industries was exacerbated by the aging defence hardware and systems. Organizations tended to recruit skilled systems workers from each other or desperately try to fill systems roles with junior personnel who lacked the requisite skills, systems capability suffered at a time when these skills were in high demand (Davidz and Nightingale, 2008).

Although systems thinking definitions differ, there was union on instruments that enabled and obstructed systems thinking development. These instruments include experiential learning, individual characteristics, and a supportive environment (Davidz and Nightingale, 2008). Data sourced from Davidz and Nightingale (2008) interviews with high-performance employees proved that there was a need for a supportive environment to develop systems thinking. Their research results had specific implications for government, industry, and academia.

A growing number of systems educational degree programmes were offered in the USA and internationally, which was an indication of the increase in systems thinking requirement. One of the key points of their research was that experiential learning was an important mechanism to develop systems thinking in engineers (Davidz and Nightingale, 2008).

Córdoba and Farquharson (2008) articulated that an overabundance of policies and initiatives was developed, including the definition and implementation of partnerships between government agencies, educational institutions and representatives of economic sectors. Over a decade after the first democratic elections in 1994 in SA, unemployment and low skills levels still constituted major challenges (Córdoba and Farquharson, 2008). However, skills development was emerging and rapidly developing into domain of knowledge and practice in SA, broadly speaking, it belonged to what was commonly known internationally as 'Vocational Education and Training' (VET) (Córdoba and Farquharson, 2008).

Checkland, (1992) believed that the SE scholarship was still too young. He had argued that it was a good idea to make the systems movement less primitive and more scholarly; what was needed was more hard-thought scrutiny of the ideas and to be more intellectually disciplined than before in this field. The SE workforce needed to pay more attention to mapping this particular epistemology onto the real world (Checkland, 1992).

2.3.4 Systems thinking

This section tackled systems thinking which was deemed to be a specific skill that SEnr should possess. Becoming aware that “reality is made up of circles but we see straight lines” (Senge, 1990: p. 73) leads to the adoption of a new paradigm. Senge (1990) refers to this new paradigm as systems thinking. The concept was not a new one. It flourished in the 1990s, stimulated by Senge’s (1990) *The Fifth Discipline* and countless other publications, workshops, and websites. The result was a compelling vision of an organisation made up of employees skilled at creating, acquiring and transferring knowledge.

In systems thinking it was an axiom that every influence was both cause and effect. “Nothing was ever influenced in just one direction” (Senge, 1990: p. 69-75). According to Senge, (1990) “systems thinking was a discipline for seeing wholes”. It was a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static “snapshots” (Senge, 1990; Frank, 2002; Córdoba and Farquharson, 2008; Witte, 2008; Cook & Ferris, 2007; and Woodside, 2006). Systems thinking offered a flexible language that might have expanded, changed, and shaped the ordinary way of thinking in regard to complex issues (Senge, 1990).

2.4 Projects and the organisation

The third step was to describe the situation in the project environment and the organisation that can hinder or contribute positively to successful SE.

2.4.1 Project failure

This section explored the contributing factors of project failure as projects belong to the organisation and not to just one person. Alshawi & Al-Karaghouli (2003) argued that only 10 to 20 percent of projects met all success criteria and some of the main reasons for information technology system (ITS) project failure was: management was too focused on cost-cutting since most of these projects were technology led. That also led to inadequate attention given to the workforce and organisational issues that were needed for the project to be successful.

Also, McFarlan (1981, quoted in Baccarini *et al*, 2004) suggested that projects fail due to the lack of attention to individual project risks, aggregate risk of portfolio of projects and the recognition that different types of projects required different types of management, which was supported by Hartman and Ashrafi's (2002, quoted in Baccarini *et al*, 2004; Cervone, 2006b) observations that most software problems were of a management, organisational or behavioural nature, and not technical.

In relation to these observations, three of the key factors that influenced the eventual breakdown of the systems identified by Maguire & Ojiako (2007) were: lack of viable customer experience strategy; lack of viable user experience strategy, and training and people. Al-Karaghouli *et al* (2005) maintained that one reason for systems development project's poor performance, or even failure, was the mismatch between the customer and the developer's technical knowledge/understanding instigated by the differences in the cultural background of both sides.

2.4.2 Risks

Risks not properly handled or if ignored, could be the main cause of project failure. "Risk in projects can be defined as the chance of an event occurring that is likely to have a negative impact on project objectives and is measured in terms of likelihood and consequence" (Baccarini *et al*, 2004: p. 287). Risk analysis was found to be similar to the SE process and it consisted of the following processes (Baccarini *et al*, 2004): (1) establish the context; (2) identify risks; (3) analyse risks; (4) evaluate risks; (5) treat risks; (6) monitor and review; and (7) communicate and consult (Baccarini *et al*, 2004).

Baccarini *et al* (2004) pointed out the following consequences if risks surfaced:

- Commercial and legal: Inadequate third party performance; litigation in protecting intellectual property; friction between clients and contractors.

- Economic circumstances: changing market conditions; harmful competitive actions; software no longer needed.
- Human behaviour: Personnel shortfalls; poor quality of staff.
- Political circumstances: Corporate culture not supportive; lack of executive support; politically-motivated collection of unrelated requirements.
- Technology and technical issues: Inadequate user documentation; Application software not fit for purpose; poor production system performance, technical limitation of solution reached or exceeded; incomplete requirements; inappropriate user interface.
- Management activities and controls: unreasonable project schedule band budget; continuous changes to requirements by client; lack of agreed-to user acceptance testing and signoff criteria; failure to review daily progress; lack of single point accountability; poor leadership; developing wrong software functionality; lack of formal change management process.
- Individual activities: Gold plating (over specification); unrealistic expectations (salesperson over sells product).

Witte (2008) articulated that risk necessitated a systematic method of dealing with it. However, Cervone (2006b) reminded us that it was easier and less costly to avoid risk than attempting to fix or remediate problems once they had occurred. Jones (1994, quoted in Cervone, 2006b) stated that projects involving information technology were also particularly subject to the following additional risk factors: creeping user requirements; excessive schedule pressure – i.e. doing too much in too little time; low quality work as a result of undue pressure; cost overruns; and inadequate configuration control.

2.4.3 Organisational culture

Organisational culture was cited more than once as a reason for projects failing, further reviewing of the literature revealed significant information about organisations and the impact on the workforce. Briggs and Little (2008) explored the background activities of decision-making in organisations and how the hierarchy of senior manager's decisions affected the future of the organization as a whole. Briggs and Little (2008) also articulated that bad decision-making affected the culture of the organization across all functional departments/groups.

Organisations that worked on large complex technical programmes/projects inadvertently made costly mistakes when they did not include all relevant specialists during brainstorming sessions (Briggs and Little, 2008). Conflicting cultures and personalities resulted in disabling environments (Briggs and Little, (2008). Often team members lacked formal training in "soft skills" such as the basics of group process, because everyone assumed everyone else knew how to do 'it' (Cervone, 2006a).

2.4.4 Learning Organisation

This section suggested a remedy for the dilemma faced in section 2.3.3 and section 2.4.2. Organisations needed to learn more than ever as they confront these mounting forces of complexity, competition and rapid evolution. Each company must become a learning organisation. Senge (1996) made it clear that no significant change would occur unless it was driven from the top. One reason to take a new view of top management trend was the difference between compliance and commitment, when genuine commitment was needed, hierarchical authority became problematic. Later Senge (1997: p. 17) pointed out that "dynamic learning organisations were built and maintained by servant leaders who lead because they chose to serve."

Senge (1997) also described learning organisations as people that were always inquiring into the systematic consequences of their action, rather than just focusing on local consequences; they understand the interdependencies underlying complex issues and act with perceptiveness and leverage; they were patient in seeking deeper understanding rather than striking out to 'fix' the problem symptoms. Owing to their commitment, openness, and ability to deal with complexity, people found security not in stability but in dynamic equilibrium between holding on and letting go of beliefs, assumptions and certainties. However, "often it was preferred to fail again and again rather than let go of some core belief or master assessment" (Senge, 1997: p. 18).

2.5 Conclusion

The chapter started with many definitions of SE. Various authors have unique definitions of SE, however the definitions are all related in some way. It is evident from the literature that the industry for SE has become complicated. The issue of complexity required clarity as it was sometimes underestimated by project team members that did not look at the system as a whole. Complexity was used interchangeably with other concepts such as ambiguity, uncertainty, and lack of structure. This caused some confusion, so it was concluded that complexity arouse from ambiguity and lack of structure in the tasks and subtasks involved.

For the characterisation of roles, it was pointed out that to create and manage large-scale complex systems, management and engineering functions began merge, which was expressed as SE. However, one of the most important functions of a PM was to link all the supportive roles in the project team and the critical importance of the SEnr was not in possessing unique knowledge, but in possessing a diversity of knowledge from several different domains that allowed that person to make holistic tradeoffs and judgments that no other individual in the team could make. The authors have proved that SE is a unique function compared to that of other project teams members and should be treated as such.

A summary of effective SE would be to: reduce system risks so that the "right system is built". Also, one of the management characteristics identified was "common terminology", were everyone "speaks the same language", which was especially important for communication, and was directly related to the issue of complexity mentioned earlier.

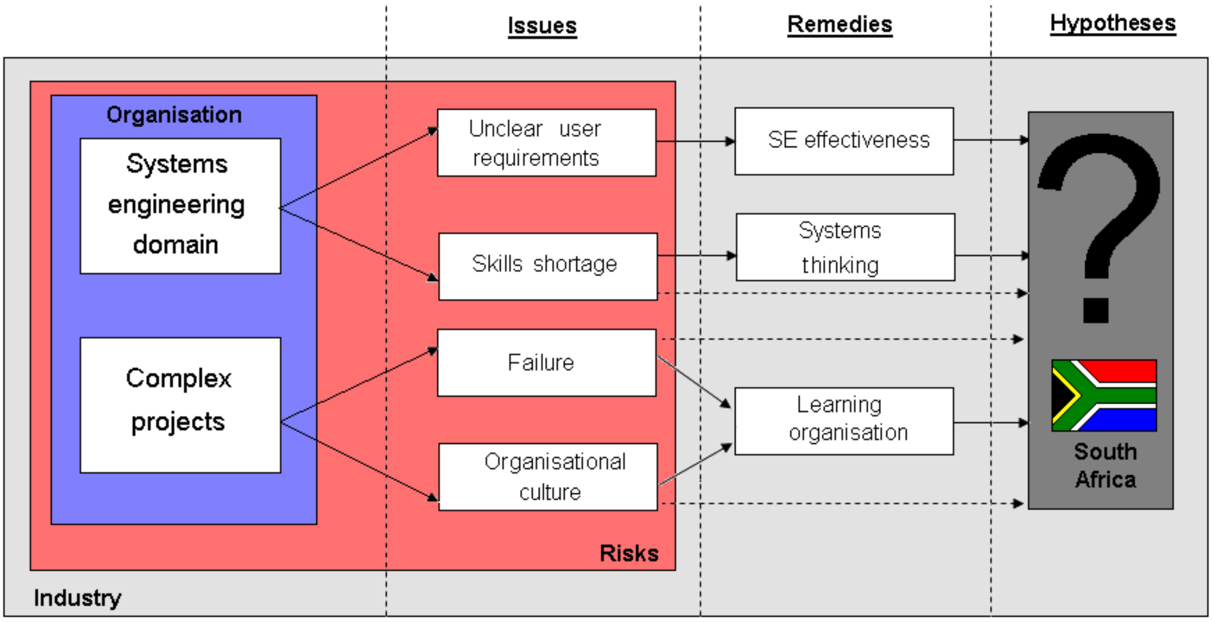
It was obvious from Figure 2-1 that the earlier an error occurred, and the later it was discovered, the more expensive it was to fix. Although it was difficult to measure the effectiveness of SE, some authors were able to deduce from their studies that SE was most effective in the early stages of the project life cycle. Often, the project was a failure due to unclear URS as the client, the project team had different interpretations, and no SE was used.

Lack of SE skills was a common reason for unclear requirements and project failures. It was observed that similar to other developing countries, skills development initiatives in SA were embedded in a complex historical, socioeconomic and legislative context.

In order to be a successful SEnr, the authors believed that the engineer must be able to think systematically, or rather, be able to see the 'big picture' instead of the parts individually. Research in the project environment revealed that organisational culture could share the blame for projects failing.

By turning the organisation into a learning organisation, systems thinking would be promoted and management would create an enabling environment. There were many risks identified and associated with projects that could be reduced by applying the SE process correctly.

This chapter is concluded graphically in Figure 2-5. The diagram indicates the issues that unfolded as the domain was researched. Possible remedies also emerged from the review. The last block on the right leads to the purpose of this research and the formulation of the research questions and hypotheses that are captured in the chapters to follow.



(Diagram drawn by the author of this research project)

Figure 2-5 : Summary of chapter 2

3 RESEARCH QUESTIONS AND HYPOTHESES

This chapter defines the purpose of the research. It presents research questions that were under-researched specifically in SA, although the literature review proposes generic solutions studied in other countries for the objectives of the research. The chapter also includes the hypotheses that will be tested and discussed in chapters 5 & 6. The research questions and hypotheses emanated from the aim and motivation for this research presented in chapter 1.

Research Q1: *Do the respondents understand what systems engineering is?*

The hypothesis states

H_0: Respondents understood what systems engineering was

H_a: Respondents did not understand what systems engineering was

Research Q2: *Are projects more successful with systems engineering processes?*

The hypothesis states

H0: Projects were not more successful with systems engineering processes

Ha: Projects were more successful with systems engineering processes

Research Q3: *Are organisations and/or their workforce constrained in utilising systems engineering in projects?*

The hypothesis states

H_0: Organisations and/or its workforce were not constrained in utilising systems engineering in projects

H_a: Organisations and/or its workforce were constrained in utilising systems engineering in projects

Research question Q4: *Could organisations do more to improve systems engineering in projects?*

The hypothesis states

H_0: Organisations could not do more to improve systems engineering in projects

Ha: Organisations could do more to improve systems engineering in projects

The next chapter discusses the research methodology used to find answers to the research questions and to test the hypotheses.

4 RESEARCH METHODOLOGY

4.1 Introduction

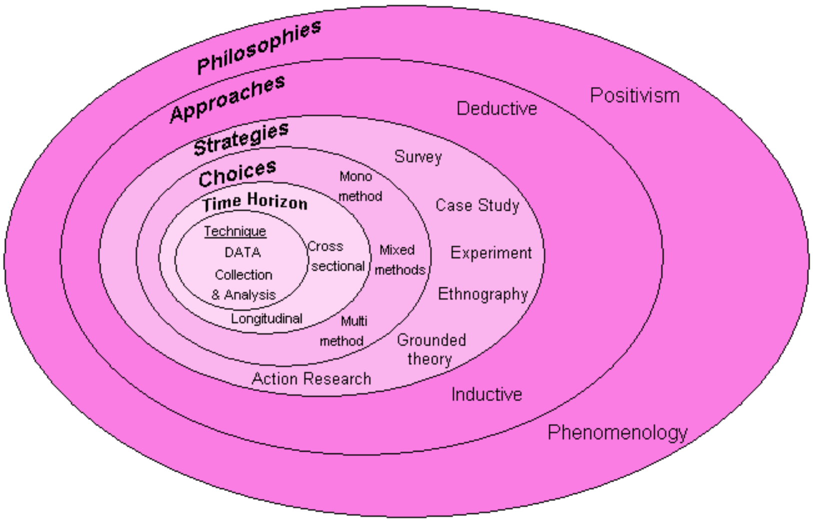
Having studied the broad outline of the research on SE and the SE workforce as presented in the introduction and the literature review, the research proceeded to define the boundaries of this research project, namely the objectives and scope of this study: research philosophy, approach, strategies, choices and time horizon. It further discussed the data collection and analysis techniques, arriving at the research limitations and the conclusions of the research.

The purpose of this chapter is to:

- discuss the research philosophy in relation to other philosophies;
- expound the research strategy, including the research methodologies adopted;
- Introduce the research instruments that were developed and utilised in the pursuit of the goals.

Research was defined by Saunders as: “the systematic collection and interpretation of information with a clear purpose, to find things out” (Saunders, Lewis and Thornhill, 2007: p. 610). Hence, the ‘things’ to find out in this research were the value of SE and the challenges experienced by organisations in using SE.

This chapter followed Saunders *et al’s* (2007) onion layer method. Figure 4-1 was a replication of the onion, edited to show the relevant areas of this research. The centre of the research method lay in the technique that was chosen to conduct the research. However, there were layers that needed to be 'peeled' away in order to select the most appropriate method (Saunders *et al,* 2007). These layers are the research philosophy, approach, strategy, method choice, time horizon and finally the technique.

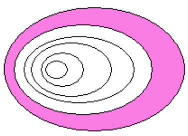


(Saunders et al, 2007)

Figure 4-1 : Research onion

4.2 Research Method

Research philosophy



First layer

Research philosophy was described by Saunders *et al,* (2007: p. 101) as the development of knowledge and the nature of the knowledge. A research philosophy is a belief about the way in which data about a phenomenon should be gathered, analysed and used. The term epistemology (what was known to be true) as opposed to doxology (what was believed to be true) encompasses the various philosophies of research approach. The purpose of science, then, was the process of transforming things 'believed' into things 'known'. Two major research philosophies have been identified in the western tradition of science, namely positivist (sometimes called scientific) and interpretivist (also known as antipositivist) (Galliers, 1991 quoted in Davison, 1998). The epistemology laid in either positivism or phenomenology paradigm for this research.

Positivism holds a position that the goal of knowledge was simply to describe the phenomena that was experienced. The purpose of science was to stick to what one can observe and measure (Trochim, 2006). Positivists believed that reality was stable and can be observed and described from an objective viewpoint, i.e. without interfering with the phenomena being studied. They contend that phenomena should be isolated and that observations should be repeatable (Davison, 1998). This often involved manipulation of reality with variations in only a single independent variable so as to identify regularities in and to form relationships between, some of the constituent elements of the social world predictions could be made on the basis of the previously observed and explained realities and their inter-relationships. Positivism research emphasised a highly structured methodology for replication purposes (Saunders *et al,* 2007).

Phenomenologists (or Interpretivists) contend that only through the subjective interpretation of and intervention in reality could this reality be fully understood. The study of phenomena in their natural environment was the key to the interpretive philosophy, together with the acknowledgement that scientists cannot avoid affecting those phenomena that they study. They admit that there might have been many interpretations of reality, but maintain that these interpretations were in themselves a part of the scientific knowledge they were pursuing. Phenomenology research was based on a social world and was difficult to theorise by definite relationships and laws (Saunders *et al,* 2007).

To conclude, this layer was important to the research and the positivism philosophy was used which allowed for quantifiable observations that could be analysed statistically.

Research approach


Second layer

Research approach was a general term for inductive and/or deductive reasoning (Saunders *et al,* 2007: p. 610).

Deductive reasoning worked from more general to more specific. Sometimes this was informally called a "top-down" approach. A researcher might begin with thinking up a theory about the topic of interest. It was then narrowed down to specific hypotheses that could be tested. It was further narrowed when observations were collected to address the hypotheses. This ultimately led to testing the hypotheses with specific data - a confirmation (or not) of the original theories (Trochim, 2006). Zikmund (2003, p. 46) added that deductive reasoning concerned the process of arriving at a “conclusion about a specific instance based on a known general premise”.

Inductive reasoning worked in the opposite way, moving from specific observations to broader generalizations and theories. Informally, it was sometimes called the "bottom up" approach. Inductive reasoning began with specific observations and measures, it then detected patterns and regularities, formulated some tentative hypotheses that could be explored, and finally resulted in developing some general conclusions or theories (Trochim, 2006). Zikmund (2003, p. 47) stated that inductive reasoning concerned the process of “establishing a general proposition on the basis of observation of particular facts”.

Further characterisation of deductive and inductive approaches revealed that they have similar properties to positivism and phenomenology, respectively. Deductive reasoning was important in this research as the topic was general when it was selected and only specific issues within the topic were researched. The process followed for this research was highly structured quantitative data that was aligned to the deductive reasoning approach.

Research design/strategy


Third layer

Research design provided the glue that held this research project together. Design was used to structure the research, to show how all the major parts of the research project - the samples or groups, measures, treatments or programmes, and methods of assignment - work together to try to address the central research questions (Trochim, 2006). From Zikmund (2003:741) the research objectives defined what the research was to achieve. He described it as 'the purpose of the research, expressed in measurable terms'. A large number of research methodologies were identified, as mentioned in Saunders *et al's*, (2007) onion diagram (Figure 4-1):

1. Experimental design: was often touted as the most 'rigorous' of all research designs or, as the 'gold standard' against which all other designs were judged. It was probably the strongest design with respect to internal validity. The researcher generally wanted to assess a proposition (Trochim, 2006).
2. Survey research: was one of the most important areas of measurement in applied social research. The broad area of survey research encompassed any measurement procedures that involved asking the respondents questions. A 'survey' was anything from a short paper-and-pencil feedback form to an intensive one-on-one in-depth interview (Trochim, 2006).
3. Case study: was a strategy for doing research which involved an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence (Saunders *et al*, 2007: p. 139).

Other methods include: action research; grounded theory; ethnography and archival research that were not suitable for this research.

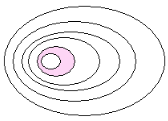
Surveys were the most common way to collect primary data (Zikmund, 2003). Data was gathered and assembled specifically for this research and it was used to describe what happened in the SE workforce and the reasons for a particular business activity, which in this case was SE in projects (Zikmund, 2003).

Research choices

Fourth layer

The chosen method was descriptive research in the form of surveys to quantify factual information about SE and the SE workforce. It is important to note that a mixture of methods was not used as it would have affected the time allocated for this research. The chosen method was also known as 'mono-method' in Saunders *et al*, 2007. The research was a quantitative design since SE was well researched by numerous authors and secondary data was available from the literature review.

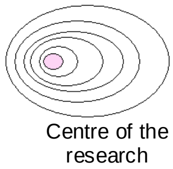
Time horizon



Fifth layer

The research was aimed at exploring the SE field and the SE workforce. The research was carried out in part fulfilment of an academic course, therefore the time allocated was constrained. Hence, the research followed a 'cross-sectional' study also known as a 'snap–shot' in the South African geographic location. Snap-shot refers to a study of a phenomenon at a particular time (Saunders *et al*, 2007). This layer was not fully applicable to the research due to the limited time to conduct the research.

Technique



Finally the most suitable technique emerged and the nature of the sample design and procedure was as follows. A probability sampling method is any method of sampling that utilised some form of random selection. In order to have a random selection method, the researcher must set up some process or procedure that assures that the different units in his/her population have equal probabilities of being chosen. There is a tendency to use computers as the mechanism for generating random numbers as the basis for random selection (Trochim, 2006).

Saunders *et al* (2007: p. 604) defined non-probability sampling as a selection of sampling techniques in which the chance or probability of each case being selected was unknown. Non-probability sampling did not involve random selection and it could not depend upon the rationale of probability theory. Since the research was targeting PMs, engineers and clients of projects, the technique deemed suitable was non-probability sampling.

<u>Population and sample frame</u>

The research was customised for the South African environment, and there were thousands of PMs, engineers and clients in SA could be identified as the population of this research; however, the actual size was unknown. Given the time frame for this research and the size of the population, it was unreasonable to survey the entire population or to locate them. For pragmatic reasons samples were used as it cut costs, reduced labour requirements, and gathered vital information quickly (Zikmund, 2003: 369).

In purposive sampling, sampling was done with a purpose in mind. Usually one or more specific predefined groups were sourced. Respondents were 'sized-up' or pre-identified before the questionnaire was distributed. Respondents for this research were first verified in the demographic section (e.g. position; years of experience and qualification) of the questionnaire.

Data collection method

The mono-method was a single data collection technique. Thus, it was the method used in the form of a questionnaire (see APPENDIX 2: List of Companies). The questionnaire was chosen because of its advantages towards quick, inexpensive, efficient and flexible means of assessing information about the population (Zikmund, 2003). The questionnaire was first pre-tested with a PM and an engineer with germane experience. The choice of selected professionals as respondents was influenced by Mckeen *et al*, (1994) and Baccarini *et al* (2004).

The author selected e-mail addresses of PMs and engineers that were available at that time. The survey was then e-mailed and some hand delivered to more than 360 people in various industries (see Appendix 2: List of companies).

The exact number of people that received the questionnaire was not known, taking into account that respondents were invited to forward the survey to other PMs and engineers. Alshawi & Al-Karaghouli (2003) and Mckeen *et al* (1994) used similar industries in their research. The e-mails and hard copies contained a consent section, for ethical purposes and the due date which was three weeks after distribution. The e-mails had a Microsoft WORD survey and the ADOBE PDF format of the survey for convenience, should the respondent experience any problems with the Microsoft WORD format. After week two a reminder e-mail was also sent.

The questionnaire

Style: The data format was a mixture of category scales, a simple-dichotomy ('yes/no' answer), determinant-choice and frequency-determination questions (Zikmund, 2003). There were Likert scales in the project and organisation sections. The analytical objective was to quantify variation and describe characteristics of the population. The questionnaire consisted of 16 closed ended questions. There was provision for comments after each section. Frank (2002) and Baccarini *et al* (2004) had divided their questionnaires into sections and a similar approach was followed for this research were the questionnaire was divided into four sections: 1) Demographics; 2) Systems engineering; 3) Projects, and 4) the Organisation.

Demographics

The respondents had to specify whether he or she was a PM, project engineer or the client. Defining who qualifies as a PM and an engineer could become complex, therefore there were three questions which included their title, years of experience and their qualifications. The classification of PMs, engineers or client was not critical to the purpose of this research and it was found that it was not necessary to compare the responses of PMs versus the responses of engineers.

Systems engineering

There were two questions outlining the definition of SE and one asking the respondent to rate his/her knowledge of SE. Questions 4 and 5 were to determine whether respondents could provide the correct definition and functions of SE. Section 2.2.1 provided definitions by various authors. A simplified definition was used in question 4. Question 4 provided six possibilities – the first four being different areas of SE, the fifth being the correct definition and the last one stating that none of the first five were correct. If respondents chose more than one of the first four (but not the fifth one) they were categorised as giving a partial definition; if they chose only one of the first three they were categorised as giving a limited definition, and if they chose the last one they have been categorised as giving no definition. . It also served to give the respondent an idea of what SE was, should the respondent use it under a different name.

Projects

The respondents were questioned on his/her knowledge of why projects they worked on were a success or a failure. No names or technical details of the projects were requested. This section consisted of five questions.

The organisation

Here, respondents had an opportunity in four questions to indicate what and where challenges laid in using SE, intrinsically and in the organisation.

The questions were carefully structured to facilitate ease of response and eliminate ambiguity.

Data analysis approach

Saunders *et al* (2007: p. 591) advised that the analysis process was the ability to break down data and to clarify the nature of the component parts and the relationship between them. In most social research, the data analysis involved three major steps, conducted roughly in the following order (Trochim, 2006; Saunders *et al*, 2007):

- Cleaning and organizing the data for analysis (Data preparation)
- Describing the data (Descriptive statistics)
- Testing hypotheses and models (Inferential statistics)

Data preparation: involved checking or logging the data in; checking the data for accuracy; entering the data into the computer; transforming the data; and developing and documenting a database structure that integrated the various measures.

Descriptive statistics: were used to describe the basic features of the data in a study. It provided simple summaries about the sample and the measures. Together with simple graphics analysis, they formed the basis of virtually every quantitative analysis of data. The descriptive statistics simply described what the data showed.

Inferential statistics: this investigated the research questions and hypotheses. In many cases, the conclusions from inferential statistics extended beyond the immediate data alone. For instance, it was able to deduce from the sample data what the population thought. Thus, inferential statistics was used to make inferences from the data to general conditions; descriptive statistics was used to describe what's going on in the data.

4.3 Research limitations

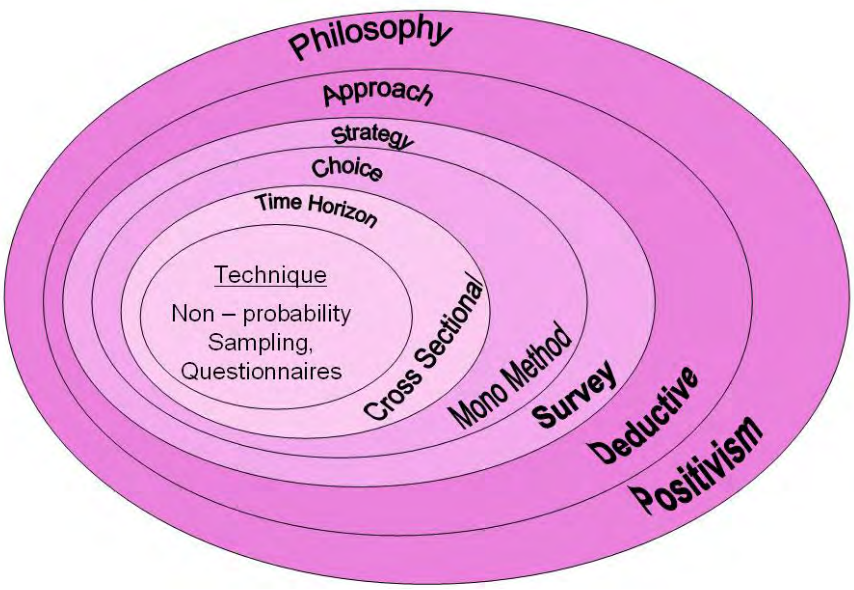
The following limitations were expected of this research:

- The majority of the respondents were from the Gauteng region, the research needs to expand into other geographic regions.
- Purposive sampling was used to reach a targeted sample quickly and where sampling for proportionality was not the primary concern. With a purposive sample, it was likely to get the opinions

of the target population, but it was also likely to overweight subgroups in the population that are more readily accessible. In this case, Armscor respondents were easily accessible as the author was an employee at Armscor. The sample consisted of PMs, engineers and clients from various companies.

4.4 Conclusion

This chapter described in detail the methods used and the reasons for using each one. The methods, namely the research philosophy, approach, strategy, choices, time horizon and technique, stemmed from Saunders *et al*'s (2007) onion layer method. After unpacking each layer, the final methodology for this research is shown in Figure 4-2:



(Saunders et al, 2007)

Figure 4-2 : Customised Research Onion

The next chapter provides a graphic representation of the results from the data of the respondents.

5 RESULTS

5.1 Introduction

This chapter presents a description and analysis of the data obtained from the survey. The layout of this chapter follows the order of the questionnaire, see APPENDIX 1. The chapter describes the target population, response rate and the response bias. It also presents exploratory and descriptive data analysis of the response to the survey. In addition to the graphical data, cross analysis of some questions were produced to reflect relationships between responses. Chi–square tests were carried out on other questions to examine any interdependencies between responses.

The purpose of this chapter is to present the facts that were discovered in the research, while the next chapter interprets the findings (Saunders *et al*, 2007). The chapter was concluded with a summary of the findings.

5.2 Preliminary data analysis

Target population

The target population were project managers, engineers and clients.

Response rate

Approximately 360 questionnaires were sent out (most through e-mail and some hard copies); of which 105 were completed. This represents a response rate of 29,17%. Those that received the e-mail were invited to forward the survey to other PMs and engineers.

Response bias

Saunders *et al* (2007) articulated that in semi-structured or in-depth interviews where the researcher wanted to extract explanations or explore events, interviewees may decide not to answer some aspects as he/she did not want the interviewer to ask more information on this particular aspect. To protect these aspects the interviewee responded with partial information and portrayed themselves in a 'socially desirable' role or the organisation in a negative/positive light (Saunders *et al,* 2007).

The quantitative method chosen for this research has favoured a highly structured, closed ended questionnaire. The structure of the questionnaire demonstrated to the respondents that the questions were short, to the point, and not probing them to disclose information, they did not want to. Since no names were requested, there was no reason to distort information, portray a 'socially desirable' role or portray the organisation negatively/positively.

5.3 Exploratory data analysis

Saunders *et al* (2007) identified exploratory data analysis as a favourable technique for it represented the data graphically. Such techniques are recognised as the best way to ensure that all possible avenues of analysis are explored.

The first question in the demographic section requested the organisational position of the respondent which was represented in a pie chart (Figure 5-1) below:

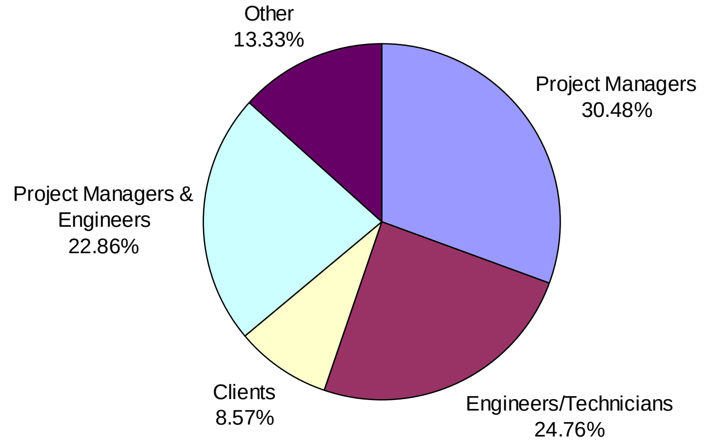


Figure 5-1 : Demographics Q1

For question 2, only 102 out of 105 respondents revealed their qualifications. The analysis was conducted on 102 as 100%, Figure 5-2. The responses confirmed that a large portion of the respondents were technically qualified (± 47% were engineers or technicians).

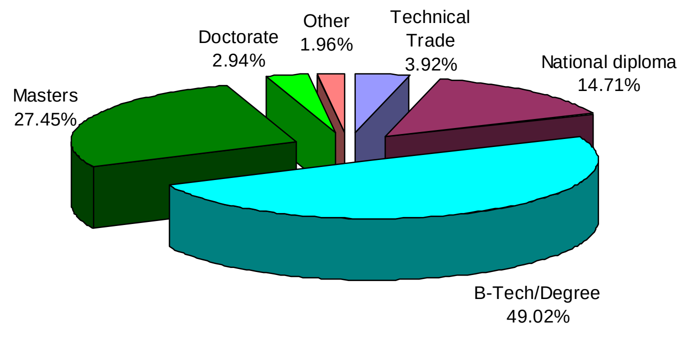


Figure 5-2 : Demographics Q2

For question 3, more than 95% of the respondents had over 3 years experience as shown in Figure 5-3. The largest group had 8 to 15 years experience.

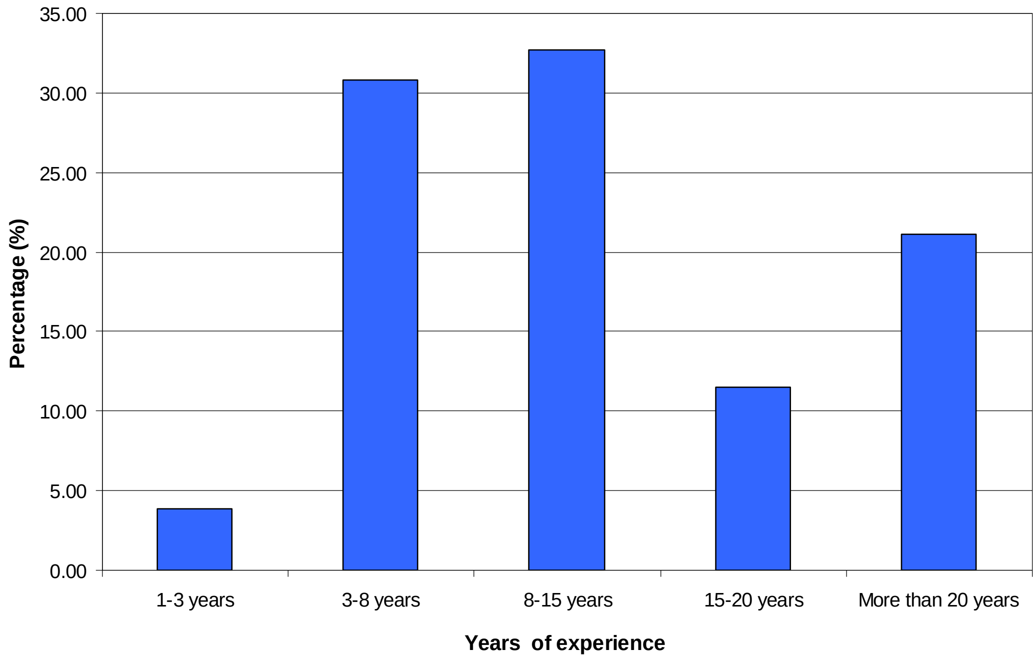


Figure 5-3 : Demographics Q3

5.4 Descriptive data analysis

Descriptive statistics and statistics to examine relationships were performed using the statistical data analysis package, SAS, version 9.2, where appropriate.

5.4.1 Systems engineering

Respondents were tested on the definition of SE in question 4 represented in Figure 5-4 The question had six options divided into groups of complete, partial, limited and no definition.

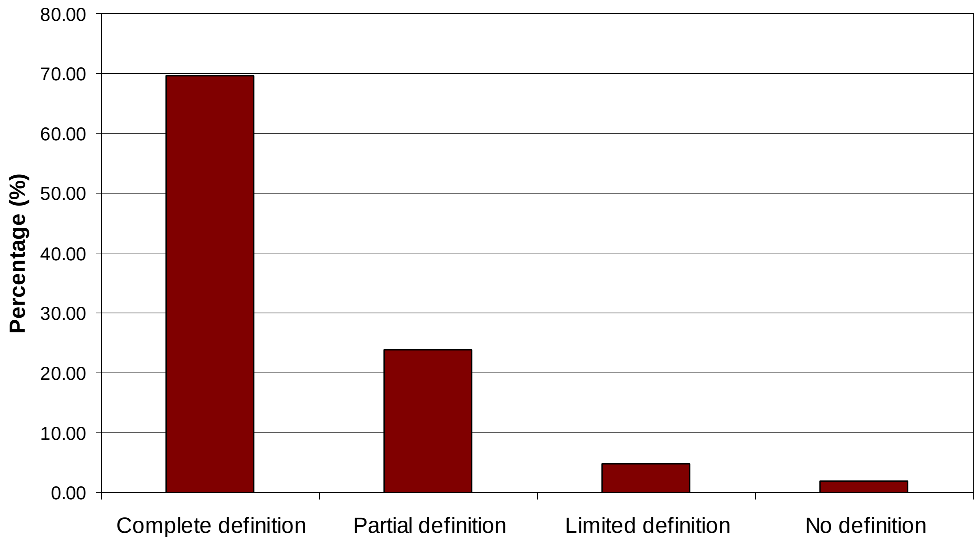


Figure 5-4 : Q4 Systems engineering definition

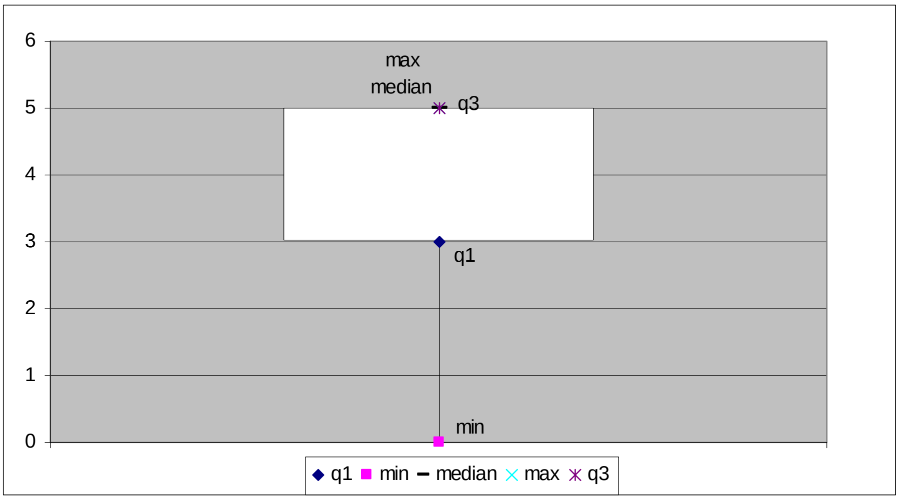


Figure 5-5 : Q4 Box plot

70% responded with the correct definition, see Figure 5-5: Q4 Box plot. The distribution was negatively skewed, denoting that most responded with a partial or complete definition.

Question 5, Figure 5-6 was aimed at determining whether respondents knew the functions of SE. Just over 50% were completely correct in giving all the functions of SE. The distribution was negatively skewed in Figure 5-7 .

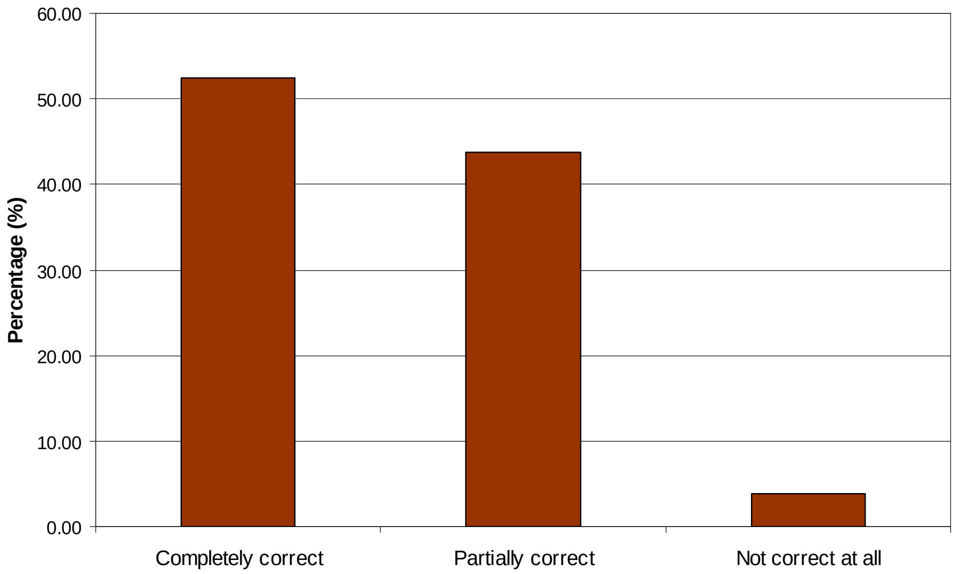


Figure 5-6 : Q5 Functions of SE

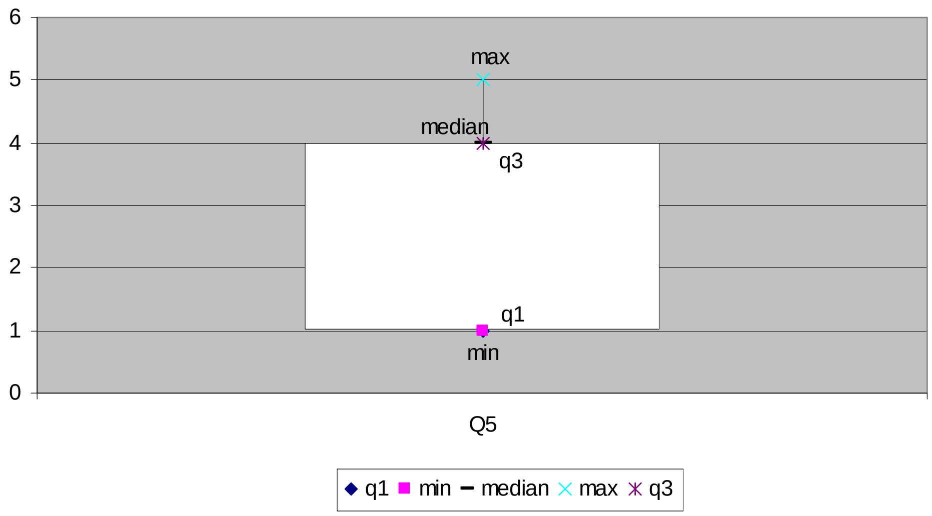


Figure 5-7 : Q5 Box plot

Question 6 requested respondents to rate their knowledge of SE. Almost 64% of the respondents perceived themselves as having the basic knowledge, see Figure 5-8. The distribution was negatively skewed; see Figure 5-9 denoting that most of the respondents had basic or full knowledge of SE.

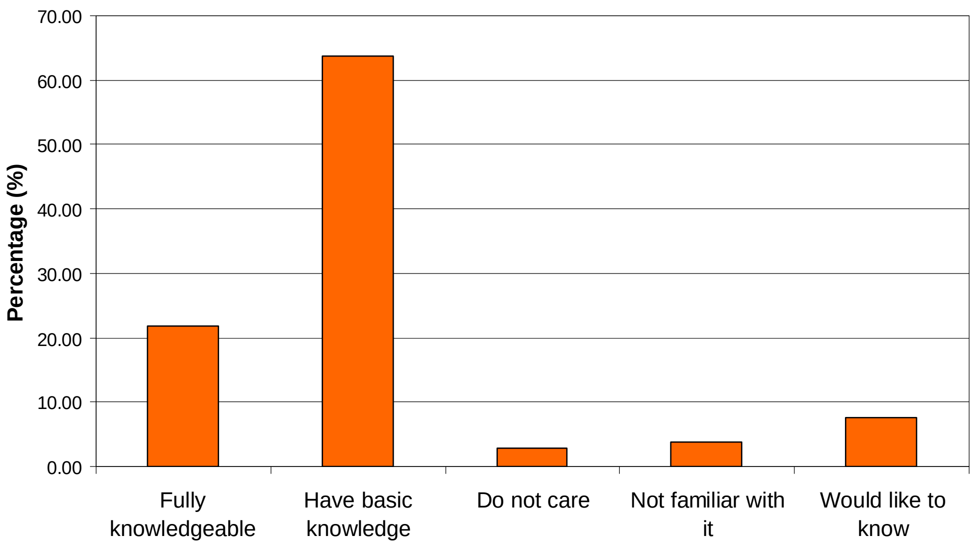


Figure 5-8 : Q6 Knowledge rating

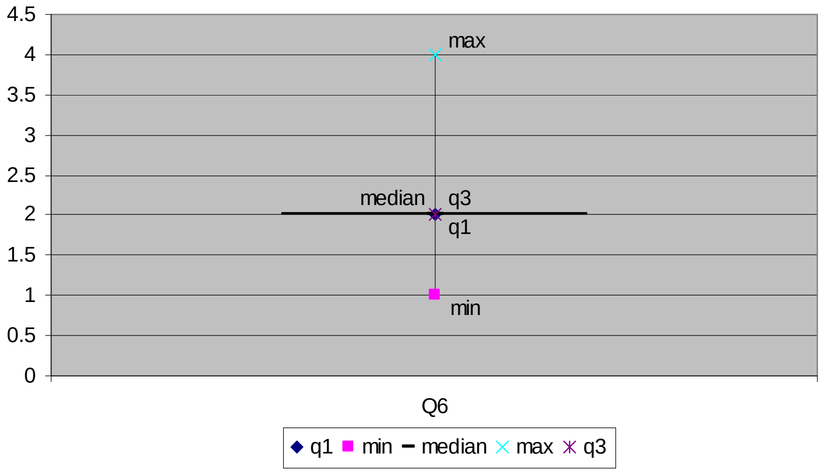


Figure 5-9 : Q6 Box plot

5.4.2 Projects

Question 7, Figure 5-10 asked respondents to identify the projects they worked on. The majority of the respondents reported on engineering projects which was ~59% and ~23% were from IT projects. Note that some respondents reported on more than one type of project.

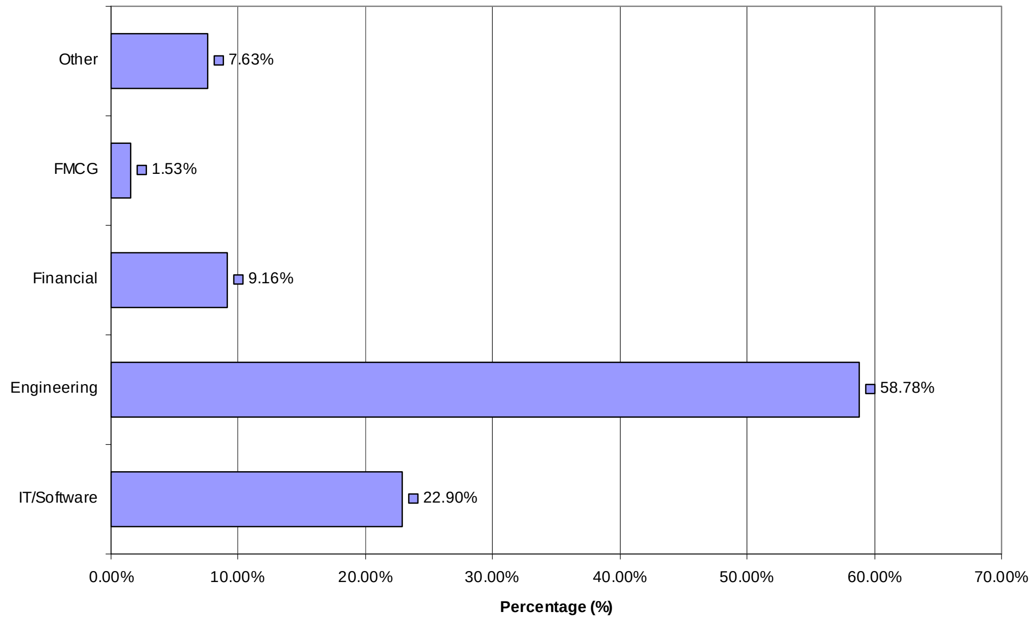


Figure 5-10 : Q7 Types of projects

For question 8, success of projects see Figure 5-11, various statements were made regarding different potential contributors to the success of projects, such as; the use of SE processes, good leadership and non complex projects.

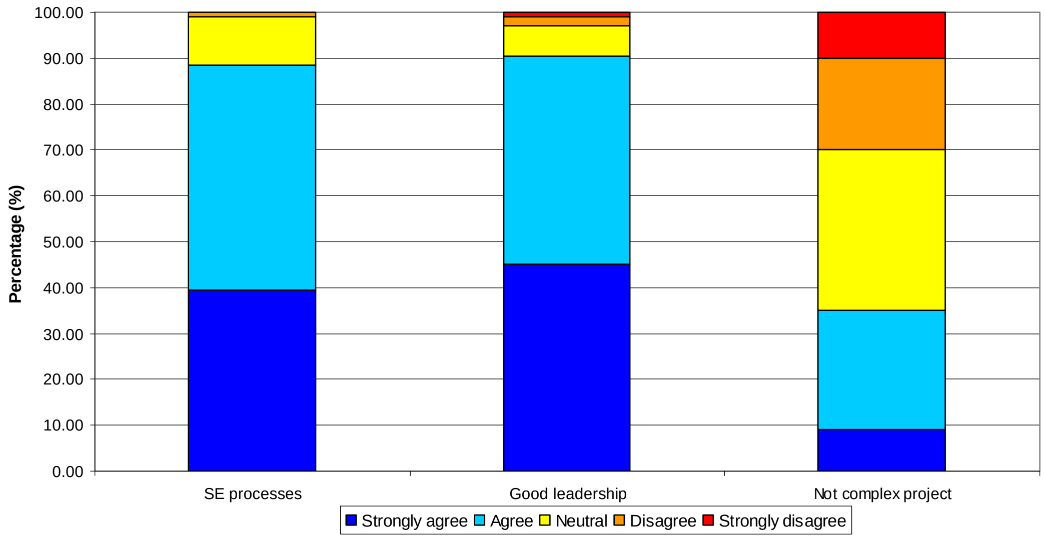
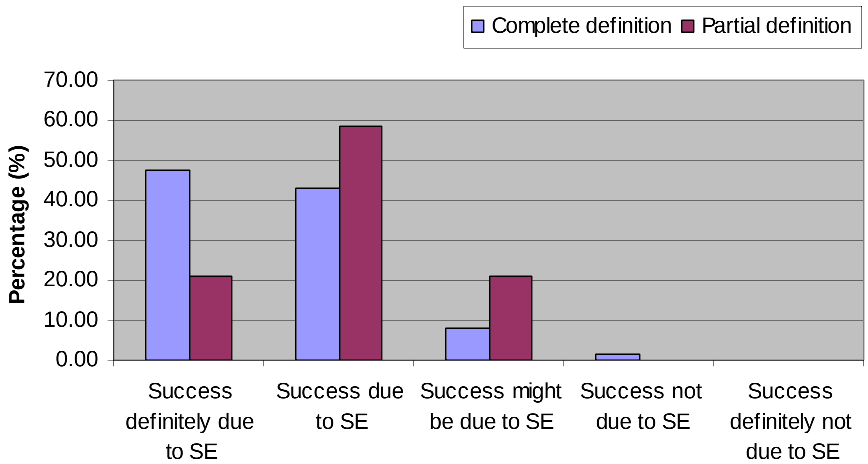


Figure 5-11 : Q8 Success of projects

Between 88% and 91% of respondents related the success of projects to the use of SE processes and good leadership. Only about 30% indicate that projects were successful because they were not complex.

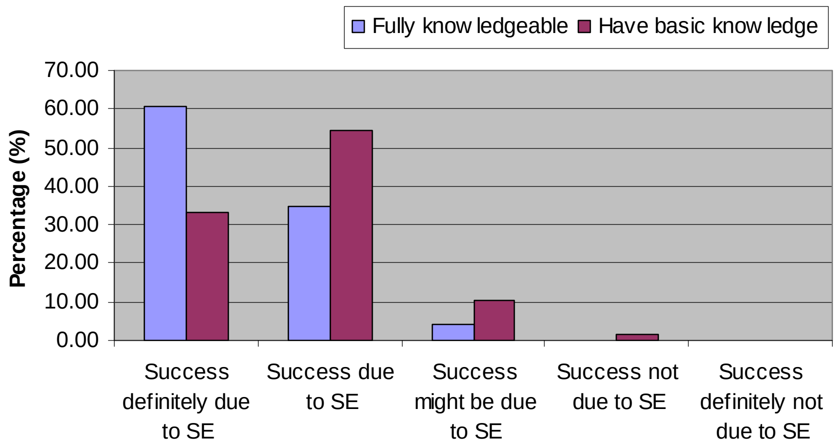
A cross analysis was drawn of the respondent's knowledge (i.e. correct definition chosen in question 4) and their view on what makes a project successful. See Figure 5-12



Note: The analysis was only performed on the two classes "Complete definition" and "Partial definition" as the other categories had very limited responses.

Figure 5-12 : Q8 Knowledge vs. project success

A similar cross analysis was drawn using the respondent's personal rating (i.e. rating given in question 5) of SE knowledge and their view on what makes a project successful. See Figure 5-13



Note: The analysis was only performed on the two classes "Fully knowledgeable" and "Have basic knowledge" as the other categories had very limited responses.

Figure 5-13 : Q8 Perceived knowledge vs project success

A hypothesis and a Chi-square test were formed; Chi-Square lets you know whether two groups have significantly different opinions (Steyn, Smit, Du Toit and Strasheim, 1996). Table 5-1 was used to test the hypotheses for any dependencies between SE knowledge and attributing project success to SE. The analysis will follow in chapter 6.

H_0: Having knowledge of systems engineering was independent of acknowledging systems engineering's contribution to project success

H_a: Having knowledge of systems engineering determines whether one can acknowledge systems engineering's contribution to project success

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Statistics for Table of A by B

                     Statistic                     DF       Value      Prob
                     ffffffffffffffffffffffffffffffffffffffffffffffffffffff
                     Chi-Square                     2      5.9033    0.0523
                     Likelihood Ratio Chi-Square    2      6.1289    0.0467
                     Mantel-Haenszel Chi-Square     1      5.7199    0.0168
                     Phi Coefficient                       0.2454
                     Contingency Coefficient               0.2384
                     Cramer's V                            0.2454

                                 Statistics for Table of A by B

                     Statistic                     DF       Value      Prob
                     ffffffffffffffffffffffffffffffffffffffffffffffffffffff
                     Chi-Square                     2      5.5639    0.0619
                     Likelihood Ratio Chi-Square    2      5.5930    0.0610
                     Mantel-Haenszel Chi-Square     1      5.0839    0.0241
                     Phi Coefficient                       0.2500
                     Contingency Coefficient               0.2426
                Cramer's V                            0.2500
```

Table 5-1 : Chi-square test 1

Question 9; see Figure 5-14, showed the following percentages of respondents who strongly agreed/agreed to the contributing factors to the failure of projects: ~ 85% unclear user requirements; ~56% no SE, ~72% lack of management support and ~68% lack of client involvement.

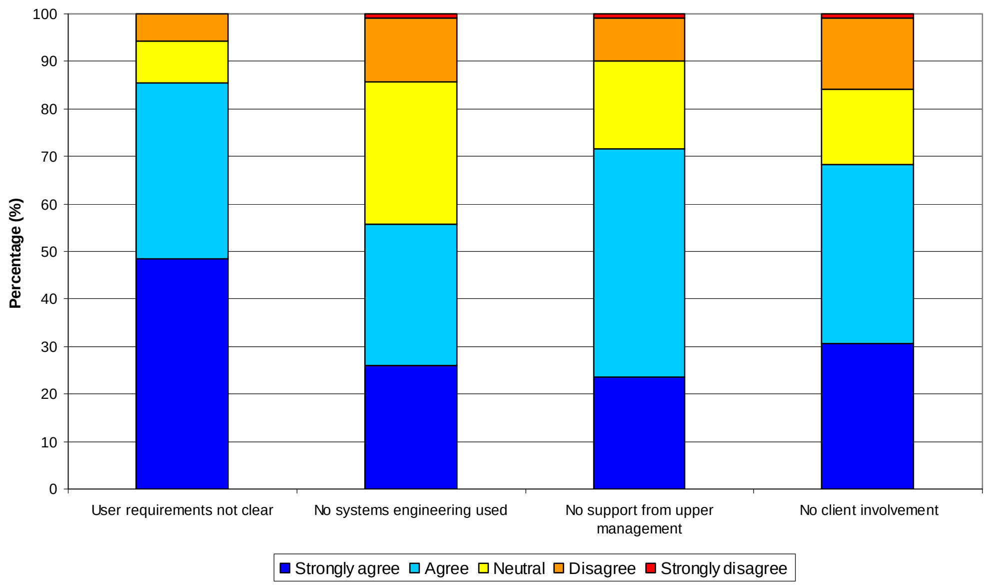
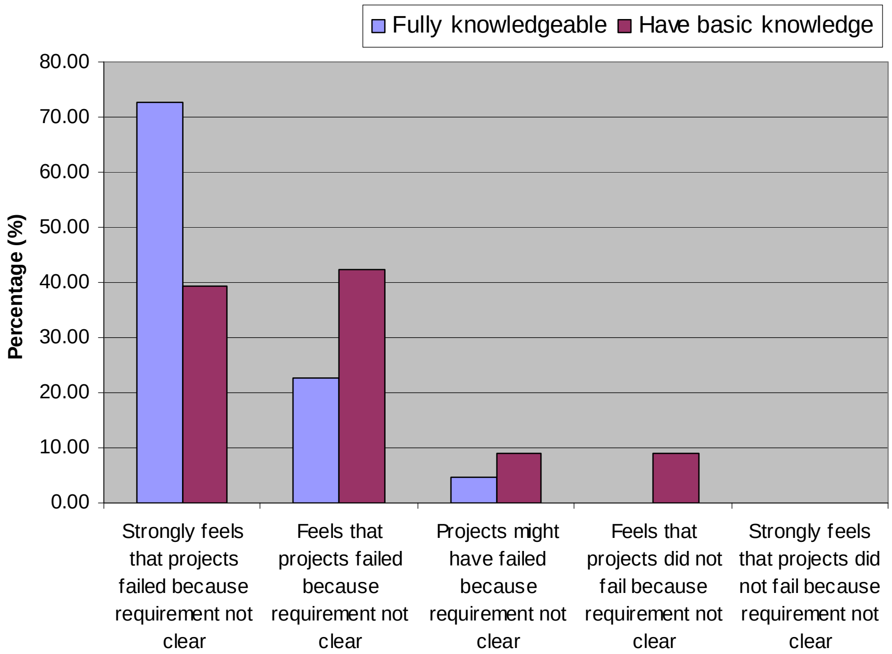


Figure 5-14 : Q9 Project failure

A cross analysis was drawn using the respondents personal rating (i.e. rating given in question 5) of SE knowledge and their view on the clarity of the user requirement. See Figure 5-15



Note: The analysis was only performed on the two classes "Fully knowledgeable" and "Have basic knowledge" as the other categories had very limited responses.

Figure 5-15 : Q9 Perceived knowledge vs. user requirement

A hypothesis and a Chi-Square were formed. Table 5-2 was used to test the hypothesis for any dependencies between SE knowledge and the importance of clear user requirements. The analysis follows in chapter 6.

H_0: Having knowledge of systems engineering was independent of relating project failure to unclear user requirements.

H_a: Having knowledge of systems engineering is dependent on relating project failure to unclear user requirements.

Statistics for Table of A by B

Statistic	DF	Value	Prob
Chi-Square	2	7.6253	0.0221
Likelihood Ratio Chi-Square	2	8.0280	0.0181
Mantel-Haenszel Chi-Square	1	6.9690	0.0083
Phi Coefficient		0.2944	
Contingency Coefficient		0.2824	
Cramer's V		0.2944	

Table 5-2 : Chi-square test 2

Question 10 requested respondents to select the phases where they use SE. See Figure 5-16. Respondents were allowed to choose more than one option. A trend line was drawn.

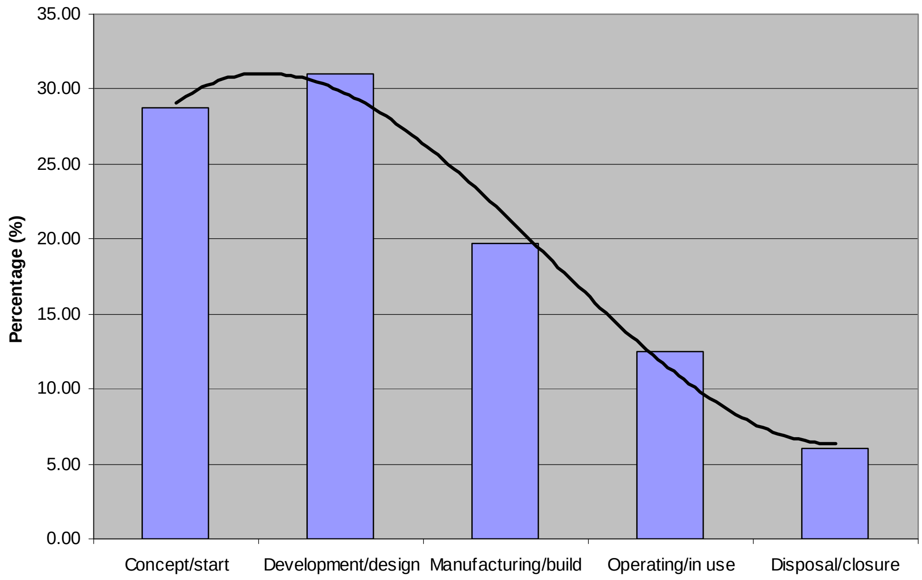


Figure 5-16 : Q10 Phases of projects

A cross table was drawn of the phases where SE was used (i.e. phases chosen in question 10) and their view on projects that failed due to the lack of SE (i.e. from question 9iii) (Steyn *et al*, 1996). See Figure 5-17

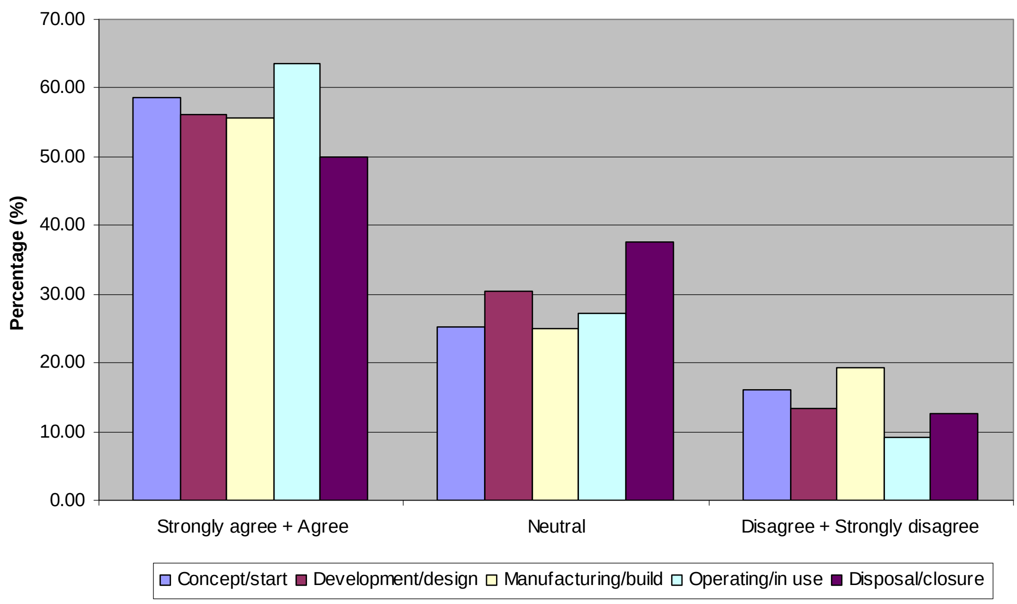


Figure 5-17 : Q10 Phases vs. project failure without SE

Question 11, Figure 5-18 determined if the projects had systems engineering plans as part of the project documentation.

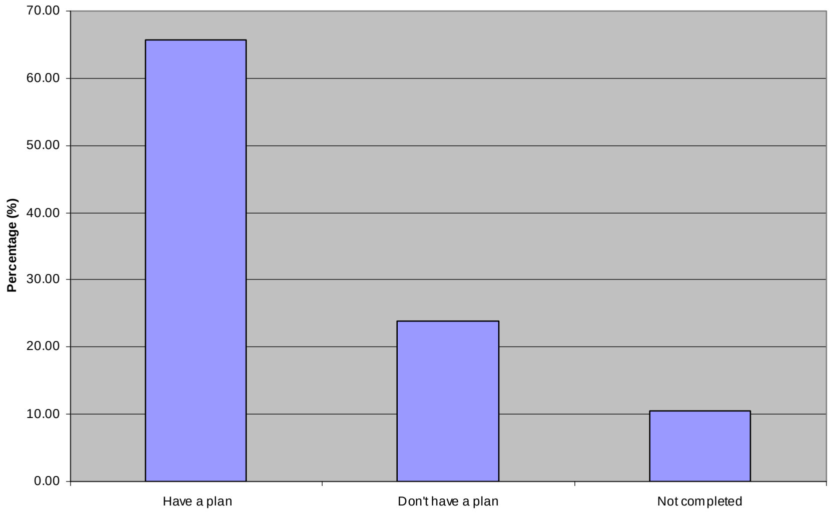


Figure 5-18 : Q11 SE plan

In question 12, Figure 5-19 respondents had to indicate who performed SE on their projects. Most of the respondents indicated that a systems engineer was used; many indicated that systems engineers in combination with the others were used.

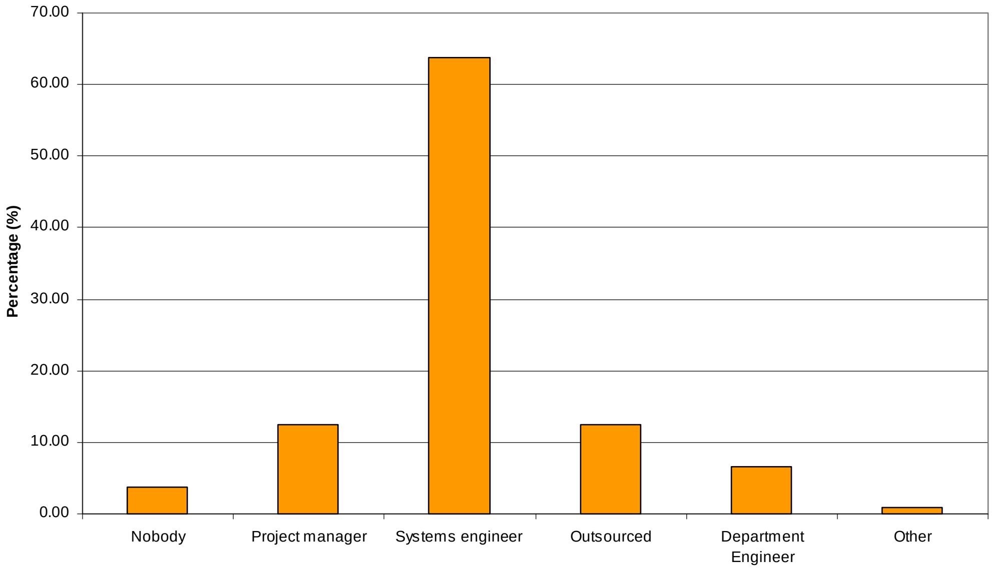


Figure 5-19 : Q12 SE facilitator

5.4.3 The organisation

Question 13; see Figure 5-20, showed the following percentages of respondents who strongly disagreed/disagreed to the factors that did not allow for utilising systems thinking in their day-to-day activities: ~ 55% lack of time; ~66% lack of skill, ~88% saw no value and ~78% too costly.

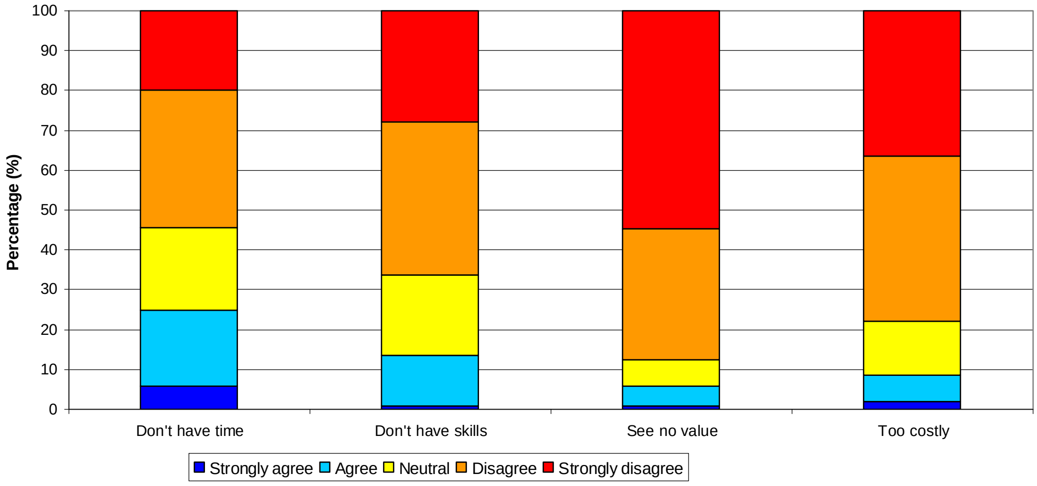


Figure 5-20 : Q13 Systems thinking

Respondents were asked to identify where their systems thinking originated from in question 14, see Figure 5-21

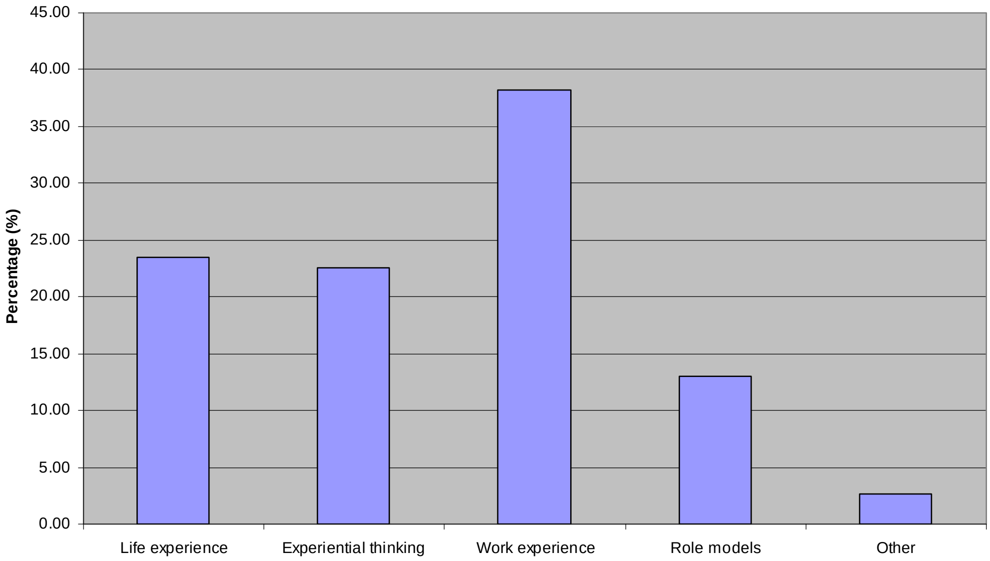


Figure 5-21 : Q14 Origins of systems thinking

In question 15, Figure 5-22 information was requested on the organisation and at its part in supporting SE. Most of the respondents felt their companies saw value in systems engineering and had the resources for it.

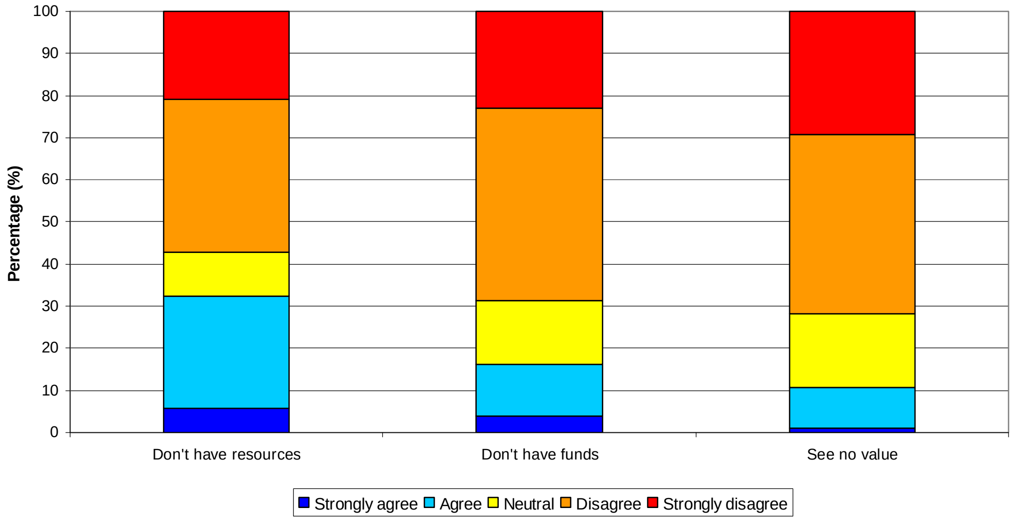


Figure 5-22 : Q15 Organisational support

In question 16, Figure 5-23 respondents had to indicate whether they felt their companies should provide SE courses. Most respondents felt that companies should provide SE courses.

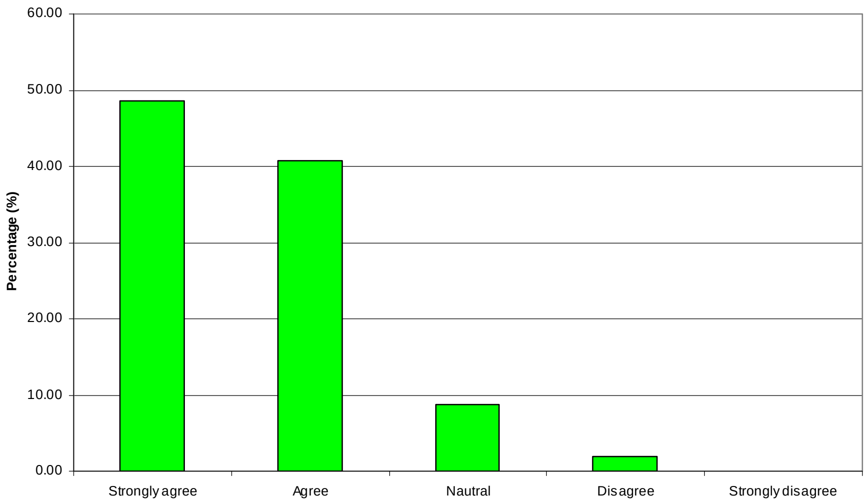


Figure 5-23 : Q16 SE courses

5.5 Conclusion

This chapter presented the data as it was collected from the survey. The overall response rate of 29,17% was satisfactory as it was equivalent to 105 respondents. Although respondents at times did not answer all questions, none of the questions had below 101 responses, except for question 11 which had 94 responses. The exploratory data analysis described the characteristics of the sample in terms of their position, years of experience and the qualifications.

The descriptive data analysis examined and described the SE field and the respondent's knowledge of it. It unpacked the project environment and factors that contributed to the success and failure of projects. Cross analysis was conducted on the respondents' ability to utilise systems thinking and their internal knowledge of SE. Cross analysis was also conducted on organisational involvement in SE and the enabling environment. The next chapter analyses and discusses the findings in relation to the research hypotheses.

6 DISCUSSION OF RESULTS

6.1 Introduction

This chapter provides a discussion of the results and empirical data presented in chapter 5. This chapter aims at finding answers to the research questions and hypotheses of the research problem, therefore the layout follows the order of chapter 3, the research questions. The discussion centred on the respondent's knowledge of SE, the reasons projects were successful and why they failed. It also analyses the respondent's level of systems thinking and the organisation's role in the SE domain. The chapter was concluded with a summary of the deductions from the results and discussions.

6.2 Empirical data collection process

Response Rate

Analysis and interpretations were done on completed questionnaires received. Neuman (1997) points out that the reliability of results was a frequently asked question, as a general rule of thumb a researcher needed a sampling ratio of about 30% for populations of below 1 000 respondents. In this case a response rate of 30% or above will be seen as large enough to ensure that results are accurate and should be representative of the whole population. The actual response rate of 29,17% was synonymous with the low online response rate that Saunders *et al* (2007) predicts. In order to receive more than 100 responses, the survey had to reach more than 350 people.

Scope/limitations

One must note that there was a risk that the perceptions of the people who do not respond may differ from those who do. Unfortunately, this cannot be measured and it was, therefore, of the utmost importance to try and optimise the response rate.

Sample characteristics

The target sample size for this research was 100. However, an actual sample size of 105 was achieved. The aim was to receive a mixture of respondents from a variety of project environments. The most common project environments for SE are the engineering, IT, fast moving consumable goods (FMCG) and financial industries. Figure 5-10: Q7 Types of projects, indicated a mix of 58,7% engineering, 22,9% IT, 9,16% financial, 7,63% other and 1,53% FMCG. This represented a well distributed mix in terms of the industries that use SE.

6.3 Demographics of the respondents

It was important for the purposes of this study that the respondents be experienced respondents. It was clear from Figure 5-2: Demographics Q2, that ± 98% had a formal qualification and the majority had more than three years of experience. More than five respondents gave comments in this section emphasising their years of experience and detailing their qualifications. Examples of comments were: 1) “36 years experience” and “B.Eng (Electronics), B. Eng (Homs)(Bio-Eng & Electro-optics); Eloptro, Kentron, Armscor”. This suggested that the respondents were proud of their career accomplishments and took pride in their response.

6.4 Systems engineering

Almost 70% of the respondents had the correct definition and ~24% had a partial definition, see Figure 5-4 : Q4 Systems engineering definition. While in question 5, ~ 54% had correct functions and ~ 24%, partial functions, see Figure 5-6 : Q5 Functions of SE. The results suggested that many respondents knew what SE was by definition; there was evidence from question 5 that many were unclear of the functions of SE.

Overall, there was an indication of uncertainty about the SE field. This view was supported by the results of question 6 where respondents were requested to rate their knowledge on SE. Most of the respondents perceive themselves as having the basic knowledge. Although most of the respondents did not classify themselves as being fully knowledgeable, most of them did understand the concept of SE.

These results also suggest that respondents were not fully confident in their knowledge of SE. Some of the comments made in this section of the questionnaire related to respondents explaining their field of work and their limited involvement in SE. An example comment was: “I have spent a lot of time doing maintenance related engineering activities and little design & development projects”.

An important observation was found in question 10. The trend line of the graph, Figure 5-16: Q10 Phases of projects resembles Figure 2-2: SE quality vs. SE effort in relation to project outcome, in section 2.3.1, which was developed by Vanek *et al,* (2008) in their attempt to measure the effectiveness of SE at different phases of the project.

The result suggested that, even though SE was fairly young to the companies used in this research, SE tended to be most used in the early stages of projects. It was not surprising to note from Figure 5-17: Q10 Phases vs. project failure without SE that about 10% less respondents felt that projects succeeded in the disposal phase because of SE involvement. That fact that each phase was selected shows that SE could be relevant in all phases of a projects, but varies in effectiveness.

Research question and hypotheses 1

Research question one posed was, “Do the respondents understand what systems engineering was?” The null hypothesis stated that respondents understood what SE was while the alternate hypothesis stated that respondents did not understand what SE was.

From the results of questions 4, 5 and 6, it was clear that a significant number only had basic knowledge, and could not supply the full definition and describe the functions. Therefore, the null hypothesis was rejected and the alternate hypothesis, respondents did not understand in full what systems engineering was, was accepted.

To answer the research question: the respondents did not fully understand what SE was; they have basic knowledge and they were young in the SE field. However, those companies seemed to be following the trend that the more experienced companies have followed, found by researchers in section 2.3.1.

6.5 Projects

Question 8 explored if projects were successful due SE processes, good leadership and non complexity. A large percentage, see Figure 5-11 : Q8 Success of projects, of respondents attributed success of projects to the use of SE processes and having good leadership. Only about 30% indicated that projects were successful because they were not complex.

In section 2.2.2, Eriksson *et al* (2008) and other authors gave many dimensions of complexity. It was not surprising that there was a small number that felt their projects was not complex. However, five did not answer the question and 20% were neutral, suggesting that they had issues with defining what ‘complex’ meant.

This point went back to the findings in section 6.4 that the respondents have basic knowledge of SE. Therefore, two cross tables: Figure 5-11: Q8 Success of projects and Figure 5-13: Q8 Perceived knowledge vs. project success, were drawn to see if there was any relationship. The graphs showed that those who gave the correct/partial definition and perceived themselves as having full/basic knowledge had a tendency to attribute success of their project to SE processes.

Further, Table 5-1: Chi-Square test 1, was used to test the null hypothesis that having knowledge of SE was independent of acknowledging SE’s contribution to projects success. The result was that the null hypothesis was rejected. Having knowledge of SE determined whether one could acknowledge its contribution to project success. The respondents who defined SE in full and have knowledge of SE felt that project success was dependent on SE involvement.

Moving on to project failures, question 9, Figure 5-14: Q9 Project failure, had different potential contributors to the failure of projects such as: no SE, unclear URS; management support and client involvement. Failure of projects was ascribed to all four of these contributors. Almost 72% strongly agreed/agreed that projects failed due to lack of management support which was also stressed by Davidz and Nightingale (2008) in section 2.3.3 and the bad decisions of senior managers that Cervone (2006a) pointed out in section 2.3.4. 68% strongly agreed/agreed that the lack of client involvement was a contributor, which matched Mckeen *et al*'s (1994) findings in section 2.3.2.

Most respondents were neutral on the contributor stating that projects fail because no SE was used. This response was inconsistent with ~85% who strongly agreed/agreed to unclear URS. One of the main functions of SE was to clearly define the URS (Pruitt, 1999). Respondents could not see the link between the URS and no SE involvement which also highlights that they lack the knowledge. Therefore a cross table, Figure 5-15: Q9 Perceived knowledge vs. user requirement, was drawn to find a relationship. The graph showed that those who perceived themselves as having full/basic knowledge had identified that the project failed due to unclear URS.

Further, Table 5-2: Chi-Square test 2, was used to test the null hypothesis that having knowledge of SE was independent of relating project failure to unclear URS. The result was that the null hypothesis was rejected. The ability to define SE determined whether one felt projects fail because the URS was not clear. The respondents who were fully knowledgeable in SE felt that projects failed because URS was not clear. Results of questions 8 and 9 suggested that the respondents who understood the concept of SE could identify the usefulness of it in their projects. They could also identify when they were lacking the functions of SE.

Another observation made in this section was of question 11, Figure 5-18: Q11 SE plan. Only 65% of the project had SE plans. A SE plan was part of the project documentation that was used to implement SE. The results show that 35% did not have SE plans, which suggests that no SE was used in those projects.

Research question and hypothesis 2

The second research question read: “Were projects more successful with systems engineering processes?” The null hypothesis stated that projects were not more successful with systems engineering processes and the alternate hypothesis stated that projects were more successful with systems engineering processes.

From the results of questions 8 and 9 it was evident that respondents saw SE processes as a large contributor to the success of projects. This statement was reinforced by the cross tables. The more knowledgeable respondents were in SE the more significant the perception that project success was dependent on SE involvement. Therefore, null hypothesis was rejected.

To answer the research question: Projects were more successful with SE processes, one needed to understand the concept of SE to understand the value it adds to a project.

6.6 The organisation

Question 12, Figure 5-19: Q12 SE facilitator, respondents indicated that someone in the project team was performing SE. However it was often found that more than one person performed SE. According to Dasher (2003) and Pruitt (1999), the PM and SEnr had clear defined separate roles and the results suggested that there was confusion of roles or members playing more than one role.

This was inline with the issue of skills shortage in section 2.3.3. Most of the comments in this section led to the respondent acknowledging that SE was a specialised function. Example comments were: “Some more specialised functions are outsourced to expert companies, with clear user requirements specs”, and “Depending on the project size, systems engineers can be contracted in to support the in-house team. However, we will not subcontract all the SE work for a project without in-house engineer participation. This is also utilised as an on-the-job-training opportunity."

Question 13, Figure 5-20: Q13 Systems thinking, showed that more than half did not feel that they did not have the time, two thirds did not disagree that they had the skill, close to 90% disagreed that there was no value in SE, and almost 80% did not feel it was too costly to practise systems thinking. The results show that except for time, the respondents ultimately felt that they have the skill, there was value in SE and it was not costly to apply systems thinking.

Davidz and Nightingale (2008) in section 2.3.3 found that systems thinking originated mainly from experiential training and individual characteristics. In question 14, Figure 5-21: Q14 Origins of systems thinking, ~38% work experience, ~24% life experiences and ~23% experiential training. The results suggested that respondents learnt from their day-to-day work and that more emphasis on SE must be incorporated in experiential training.

For question 15, Figure 5-22: Q15 Organisational support, most of the respondents felt that their companies saw value in SE and had the funds for it. What was of concern was that almost 32% felt that there were not enough resources for SE. This is in line with section 2.3.3 and the issue of skills shortage, brought out by Griffiths (2006).

Research question and hypothesis 3

The third research question stated: "Were organisations and/or its workforce constrained in utilising systems engineering in projects? The null hypotheses stated that organisations and/or its workforce were not constrained in utilising systems engineering in projects while the alternate hypothesis stated that organisations and/or its workforce were constrained in utilising systems engineering in projects

Different potential constraints were identified, namely: cost; funding by company; support by higher management; skills; company resources; value for company and time. The more SE knowledgeable the respondents were, the more they felt systems thinking was not too costly; companies had the necessary funding and resources and see the value for the company. They also felt that the workforce had the necessary skills and time to apply systems thinking.

Therefore, the null hypothesis was accepted. To answer the research question: Organisations and/or its workforce were not constrained in utilising SE in projects. However, there was the issue of skills shortage that was affecting the resources of the companies. Although people felt that they did have time for systems thinking, there were still a large percentage of people who felt that they did not have enough time.

Research question and hypothesis 4

The last research question was: "Could organisations do more to improve systems engineering in projects?" The null hypotheses stated that organisations could not do more to improve systems engineering in projects while the alternate hypothesis stated that organisations could do more to improve systems engineering in projects.

From the results of question 16, Figure 5-23: Q16 SE courses, it was clear that respondents believed that companies should provide systems engineering courses. This also suggested that the workforce was willing to learn. Some of the comments in this section showed their enthusiasm for SE.

Example comments were: "It would definitely benefit the organisation" and "To get a basic understanding of SE, a course is mandatory. Furthermore, a more advanced course should be attended after working some time as a systems engineer. However, my experience is that on-the-job training is the way to go if you are really striving for excellence. I regard tailoring as fundamental part of the SE process and that can not be taught in courses! During execution of real projects, a feeling for the level of formal SE will be developed and valuable lessons learnt. A course assignment can not have the same effect, because the outcome of the tailoring decisions can only be guessed."

Therefore, the null hypothesis was rejected. Organisations could do more to improve systems engineering in projects. To answer the research question: Organisation could make a start by providing courses and transforming into a learning organisation. The organisations also required buy-in from senior as managers as in question 9, Figure 5-14: Q9 Project failure, ~72% felt that there was a lack of management support.

6.7 Conclusion

This chapter contained an analysis and discussion of the results presented in chapter 5. The results revealed information of the respondents that proved to be valuable to this research. There were a satisfactory number of PMs and engineers in the response. The mixture of industries from where the responses were received was also satisfactory.

The respondents were able to partially and fully define SE, which showed that they did understand the basic concept of SE. As the questions probed deeper into the functions of SE, there was uncertainty displayed by the respondents. This was all in line with the basic knowledge ratings that the respondents gave themselves. Therefore, it was concluded that the respondents were fairly knew to the SE domain and not experts.

Respondents felt that SE processes and good leadership was necessary for the success of projects. They attributed the lack of management support, lack of client involvement and unclear URS to the failure of projects. Although the SE field was young, the trend of more companies using SE at the early stages of projects was found in the results.

Only two thirds of the respondents admitted to having a SE plan, which suggested that one third may not be using SE at all. There also seems to be confusion in the roles for performing SE work which was due to the problem of skills shortage. Many respondents felt that they had the skill to practise systems thinking as it was not too costly to do so and they saw value in SE. However, many have time constraints. They attributed their systems thinking ability to work experiences and the results suggested that SE must play a bigger role in experiential training.

The respondents admitted that their companies saw value in SE and had the funds to support it, but may be constrained with limited resources due to the skills shortage problem. ~92% strongly agreed/agreed that the company should provide courses on SE, suggesting that the respondents were willing to learn. In summary of research question one, two, three and four:

- Respondents did not understand in full what SE was.
- Projects were more successful with SE processes.
- Organisations and its workforce were not constrained in utilising SE.
- Organisations could do more to improve SE in projects

The analysis in this chapter has addressed the research objectives that were outlined in chapter 1. The next chapter offers recommendations and concludes this research with suggestions for future research.

7 CONCLUSION AND RECOMMENDATION

7.1 Introduction

The empirical data analysed and discussed in chapter 6 addressed the research problem outlined in chapter 1. It also provided possible solutions to the research questions and hypotheses posed in chapter 3. This chapter summarises the research problem and concludes the analysis of the findings. It also presents recommendations from the findings and future research ideas from this research.

The Research Problem

Although many authors such as Nagano (2008), Briggs and Little, Cook and Ferris (2007) and others had researched SE in many countries, it was difficult to find research papers of SE studies carried in SA, which implied that the SE field was under-researched in SA. This research was customised for South African industries as environmental conditions (such as: political; economic; social; technological; legal and ecological) were different from country to country.

When large-scale systems began to emerge, they became highly-complex. This resulted in more complex development and management roles. Projects had large costs associated with them and failure at a later stage of a project caused costs to escalate exponentially. One major reason for failure was unclear URS owing to no SE processes. Skills shortage became a problem and industry, government and academia were scurrying to establish programmes to develop systems skills (Davidz and Nightingale, 2008). In addition to the complexity of projects, the organisation culture and management support hindered the use of SE. The workforce also lacked the ability to apply systems thinking in their day-to-day work.

The results

The research sort to investigate the influence SE has on projects and the constraints the SE workforce and organisations face in SA. From the results, the following key observations were made which answered the research problem:

- SE added value towards the successful completion of projects. It provided constant monitoring and assessment of the project through the phases, minimising risks at each phase, saving costs and improving on quality.
- SE is a unique function and should be treated as an individual role in a project team. This eliminates the confusion of roles in a project team.
- Organisations can hinder the progress of projects by lack of management support and training of personnel.
- The skills shortage problem exists in this environment and has to be addressed
- The workforce does not feel constrained to practise SE and systems thinking. However, they have basic knowledge at this stage and want to learn more.

These findings were closely correlated to the literature review in chapter 2. Nagano (2008), Vanek *et al* (2008) and at length demonstrated the value of SE in projects. Pruitt (1999), Dasher (2003) and other authors characterised the roles of a SEnr. Briggs and Little (2008) and other authors explained the effect the organisation has on the workforce and Davidz and Nightingale (2008) described the skills shortage situation. However, the results revealed that the respondents were not constrained in terms of resources and funding within the organisation in practising SE, which was not the same as some authors, such as Alshawi & Al-Karaghouli (2003); Briggs and Little (2008) and Cervone (2006a), that found funding and resources for SE a problem.

7.2 Recommendations

This section makes recommendations for projects, organisations, government and academia. There were three main areas that required attention from the findings: application–training–support of SE.

<u>Application</u>

According to many authors from the literature review, the following best practises existed for acceptable SE application:

- Frank (2002) recommended that some of the SE best practises were to understand the whole system; the synergy of the system; the system from different perspectives and the implications of modifications to the system. He also articulated that the SEnr should be able to easily understand new systems; the system complexity level and interconnectedness. The SEnr must be able to provide remedies for failures and system problems but at the same time he/she must not get stuck on details (Frank, 2002)

- Cervone (2006a) recommended an 11 step approach to achieve better results; 1) the project team should develop a methodology for problem analysis, brainstorming or mind mapping, which will make it easier for team members to understand the process; 2) Define the problem – and all team members must reach consensus on what the problem really is; 3) Identify goals/outcomes to eliminate individual team members ideas conflicting; 4) Analyze cause and effect – often the consequences of a solution is overlooked, this must be done with all teams members; 5) Each solution should have a qualifying criteria; 6) Generate possible solutions – by means of brainstorming or mind mapping; 7) Analyze solutions – asking relevant questions; 8) Suggest a solution; 9) Guide the final decision process; 10) Design implementation; 11) Develop ways to measure the results.

Training

- A brief desktop study showed that most SE courses offered in SA are facilitated by private consultants and a few tertiary institutions, while in other countries there was evidence that many tertiary institutions were offering SE courses. Córdoba and Farquharson (2008) also showed that educational institutions have been developing rapidly in SA. Academic institutes, including business schools in SA, have the opportunity to offer SE programmes for post graduates, similar to that of project management programmes. Basic introductory modules could start at first semester for undergraduates.

- An opportunity also exists for industry to structure systems thinking interventions to emphasise experiential learning, offer systems programmes to teach systems skills and systems thinking, filter and foster identified individual characteristics in systems organizations, provide an environment supportive to the development of systems thinking, and clearly communicate how the strength of systems thinking is assessed (Davidz *et al*, 2008). Training courses can be coordinated with work tasks to enhance key learnings.

Support

- Frank (2002; Witte, 2008) recommended that additional manpower must be employed when projects become large. Use a value system when selecting partners and not to compromise on development budgets.

- The department of defence heavily impacted the aerospace industry in USA (Davidz *et al*, 2008). The same observation was made in SA. Therefore, government agencies have the ability to accelerate the development of SEnr by providing incentives to promote strong systems thinking, adjusting policies to emphasise experiential learning for systems thinking development, providing more programmes and opportunities for engineers to develop systems thinking when possible.

To summarise the recommendations and the concept of ‘application – training – support’ for SE. Correct application of SE processes will result in the successful completion of projects. Creating an enabling environment for the workforce by training and supporting them will result in competent project teams.

7.3 Future Research Ideas

This research concentrated on the overview status of the SE field. Owing to the time limit for the research, these specific areas were chosen: the concept of SE, the value of SE in projects, the organisational and workforce constraints. There are a few areas that can be expanded from this research, for instance:

- The true value of SE in projects was not clear and it was difficult to quantify. However, each measure sheds a little more insight on the value. Future research of projects, the costs and failure or success rates will provide organisations and senior management with information on the feasibility of using SE.

- Systems thinking was a grey area in the workforce from the results of the survey. Future research on the level of systems thinking within the individual will provide organisations with the competency levels of their workforce in SE. This may require the creation of a mental assessment measurement tool.

- Owing to the limited time for this research, only ~360 people received the survey and the response was predominantly from the Gauteng region and the defence industry. Further research is required in other geographic locations in SA, preferably with larger samples. This will generate a clearer picture of the SE field in SA.

7.4 Conclusion

This research provided an overview of the SE field in SA. The results proved to be valuable in offering insight into the status of the SE workforce. The findings of this research can assist industry in making decisions with regard to SE processes and the workforce. It demonstrates that by using SE in their projects, projects can be completed successfully in terms of time, cost and quality. Organisations will also realise that the workforce requires skills development and their management support. The SE workforce has basic knowledge and they are willing to learning. It is up to the organisations to create an enabling and learning environment. Academia can also play a role in developing the SE field by providing programmes for post-graduates and including basic introductory courses for undergraduates.

By acknowledging the results of this research and implementing the recommendations, industry, government and academia have the opportunity to improve on their project success rate and skills development, respectively.

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APPENDIX 1: Systems Engineering Questionnaire

DEMOGRAPHICS

1. I am a

☐ Project Manager ☐ Eng/Tech ☐ Client ☐ (Both)Project Manager & Eng ☐ Other

2. I have the following qualification

☐ Technical Trade ☐ National diploma ☐ B-Tech/Degree ☐ Masters ☐ Doctorate or higher ☐ other

3. I have ______years experience in technical field

☐ 1 - 3 ☐ 3 - 8 ☐ 8 - 15 ☐ 15 - 20 ☐ 20>

Comments:

SYSTEMS ENGINEERING

4. Systems Engineering is: (you may choose one or more)

☐ i) To design a system in detail with drawings and calculations.
☐ ii) The main integrator between all tasks in the projects.
☐ iii) Used in complex technology projects to write all documentation in a systematic way for record purposes should the project fail
☐ iv) A secondary skill of a project manager in his day to day functions that he/she uses if required by the client
☐ v) That part of the technical management process that coordinates and oversees the translation of an operational need into a system designed to meet that need.
☐ vi) None of the above.

5. A function or some functions of systems engineering is:

☐ i) To clearly define the user requirement statement
☐ ii) To minimise risk throughout the life of the project
☐ iii) Most applicable at the starting phases of the project
☐ iv) All of the above
☐ v) None of the above.

6. How would you describe your knowledge of systems engineering?

☐ Fully knowledgeable ☐ Have basic knowledge ☐ Do not care ☐ Not familiar with it ☐ Would like to know

Comments:

PROJECTS

7. What types of projects do you work with: (you may choose more than one)

☐ IT/Software ☐ Engineering ☐ Financial ☐ FMCG ☐ other

8. Some projects were successful because:

i) Of System Eng processes	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree
ii) Of good leadership	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree
iii) It was not a complex project	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree

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9. Some projects failed because

i) The user requirement was not clear:	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree
ii) No systems engineering was used	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree
iii) No support from upper management	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree
iv) No Client involvement	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree

10. Which phase is system engineering used in your projects: (you may choose more than one)

☐ Not used ☐ Concept/ start ☐ Development/ design ☐ Manufacturing/ build ☐ Operating/ in use ☐ Disposal/ closure

11. Do you have a systems engineering plan at the start of a project? ☐ Yes ☐ No

12. Who performs the systems engineering in your projects: (you may choose more than one)

☐ Nobody ☐ Project manager ☐ Systems engineer ☐ Outsourced to contractor ☐ Department Engineer ☐ other

Comments:

THE ORGANISATION

13. Do you include systems thinking in your day to day functions?

i) I do not have the time	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree
ii) I do not have the skill	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree
iii) I see no value	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree
iv) It is too costly	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree

14. My systems thinking comes from:

☐ Nowhere ☐ Life experiences ☐ Experiential Training ☐ Work experience ☐ Role models ☐ other

15. Does your company/department/client support system engineering?

i) They do not have the resources	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree
ii) They do not have the funds	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree
iii) They see no value	☐ Strongly agree	☐ agree	☐ neutral	☐ disagree	☐ Strongly disagree

16. I believe that the company should provide systems engineering courses:

☐ Strongly agree ☐ agree ☐ neutral ☐ disagree ☐ Strongly disagree

Comments:

I want to take this opportunity to thank you for your time and contribution to my research on systems engineering. It is highly appreciated.

MS MANJU SURJU
(You can save or scan and e-mail it directly to: manjus@armscor.co.za)

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APPENDIX 2: List of Companies

E-Mailed to	Response received
Armscor	Aardme
BMW	Alexandra Forbes
Vodacom	Alkantpan,
SAB miller	AMB Group
Sasol	Armscor
Investec	BMW
First National Bank	CSIR
South African Reserve bank	Defence Institute
Nissan SA	Denel Dynamics
Denel Dynamics	Denel Land Systems
Denel Land Systems	Dimension Data
IST	Fisher and Packel
Kumba Iron Ore	Flamengro
Telkom	FNB
Standard Bank	Gerotek
Eskom	Gijima
BAE Land Systems	Huletts
VW SA	IST
Alexandra Forbes	Kumba
Alkantpan,	Mitak
AMB Group	Necsa
Aardme	Nissan
CSIR	Optocon systems
Defence Institute	PMP
Dimension Data	Pronex
Fisher and Packel	SA Army
Flamengro	SA Reserve Bank
Gerotek	SAAF
Gijima	Sasol
Huletts	Transnet
Mitak	TWP
Necsa	Vodacom
Optocon systems	VWSA
PMP	ZA innovation-group
Pronex	
SA Army	
SAAF	
Transnet	
TWP	
ZA innovation-group	