Critical Success Factors (CSF) for the future economic and developmental needs of the South African engineering industry

YC Davids

orcid.org/0000-0002-0422-4437

Thesis accepted in fulfilment of the requirements for the degree *Doctor of Philosophy in Business Management* at the North-West University

Promoter: Prof P.D. Gerber

Co-promoter: Prof S. Swanepoel

Graduation July 2018

Student number: 12309109

ACKNOWLEDGEMENTS

I would like to thank all the engineering professionals for their participation in the survey who supported my work in this way and helped me get results of better quality. I am also grateful to the members on the university colloquium committee who advised and guided me through the numerous phases on the thesis.

I would like to express my sincere gratitude to my promoter Prof PD Gerber for the continuous support of my PhD study, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis.

In addition, a sincere thank you to my co-promoter Prof Sonia Swanepoel for her support and words of encouragement.

Lastly, I would like to thank my family, especially my late father, my mother and brothers for believing in me.

DEDICATION

For my daughter……..

DECLARATION

I, Yolanda Crisanda Davids, declare that this dissertation, entitled: "**CSF for the future economic and developmental needs of the South African engineering industry**", is hereby submitted to the North West University in the fulfilment of the degree, **Doctor Philosophiae**, in Business Management, and has not been submitted in any form for a degree at any other university. This is my own work in design and execution, and all materials and other sources of information have been duly acknowledged and cited.

Signature: ______________________

YC Davids

Date: 24 November 2017

ABSTRACT

It is identified that training and development of young engineering professionals and retention of skilled engineers are urgently required. The study therefore aimed to identify the critical success factors in the engineering industry and the development of a conceptual framework to meet the future economical and development needs of South Africa. Firstly, a suggested conceptual framework using the Engineering Systems Framework as a theoretical base was developed through a review of the literature. An exploratory analysis was conducted to understand the variety of connections and relationships between independent and dependent variables, focusing on dependent variables where a significant difference in opinion between groups exists. A conceptual framework was derived from a Component Factor Analysis which produced four (4) latent constructs and 14 observed variables. Lastly, a Structural Equation Model illustrating the directional relationships between the latent and observed variables as the conceptual model for the future economic and developmental needs of the South African engineering industry.

Keywords: *Critical success factors; engineering systems framework, engineering industry, quantitative analysis, conceptual framework.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

AsgiSA:	Accelerated and Shared Growth Initiative
BCI:	Black, Indian and Coloured
BEng:	Bachelor of Engineering
BRICS:	Brazil, Russia, India, China, South Africa consortium
BTech:	Bachelor of Technology
CAD:	computer aided system
CEO:	Chief Executive Officer
CFI:	Comparative Fit Index
CI:	Continuous improvement
CQM:	Centre for Quality Management
CSF:	Critical success factors
DWA:	Department of Water Affairs
ECSA:	Engineering Council of South Africa
EEA:	Employment Equity Act
ES:	Engineering Systems
GDE:	Gauteng Department of Education
HEI:	Higher education institutions
HR:	Human resources
IEA:	International Engineering Alliance
ISO:	International Standard Organisation
JIPSA:	Joint Initiative on Priority Skills Acquisition
MDG:	Millennium Developmental Goals
NQF:	National Qualifications Framework
PCA:	Principle component analysis
R&D:	Research and Development
RMSEA:	Root Mean Square Error of Approximation
RTS:	Russian Technical Society
SEM:	Structural equation model
SETA:	Sector Training Authority
SET:	Science, Engineering and Technology
STEM:	Science, technology, engineering and mathematics
SPSS:	Statistical Package for the Social Sciences
TLI:	Tucker-Lewis Index
TQM:	Total quality management
UNESCO:	United Nations Educational, Scientific and Cultural Organisation
UK:	United Kingdom

USEA: International Union of Scientific and Engineering Public Association

WFEO: World Federation of Engineering Organisations

CHAPTER 1: INTRODUCTION

1.1 Background

Engineering drives social, economic and human development and underpins the knowledge societies and infrastructure. The world is facing major social and economic challenges including wide-spread poverty, sustainable development and climate change. Many of the world's problems can be solved by applying ethical engineering principles and practices.

However, the engineering industry faces specific challenges, such as the shortages of engineering capacity, especially female engineers, the "brain drain" of engineering professionals in developing countries, lack of public policy in the engineering industry and the reliance on technology in engineering (UNESCO, 2010).

Within the South Africa context, a key limiting factor to achieve economic and social development is the lack of engineering capacity and the scarce skills crisis (Case, 2006). According to Du Toit and Roodt (2008), South Africa has a critical skills crisis and requires engineers of all disciplines. This is exacerbated by that fact that South African is developing economically and socially through a boom in the construction industry and the improvement of service delivery at municipal level. South Africa is in a period of extensive capital expenditure through the upgrade of its road and rail networks, power stations and major infrastructure development. In spite the achievement of widespread social upliftment such as improved water and waste management, electricity, power and housing provision that serves the poorer sector of the population and service delivery is still inconsistent and unreliable. This is evident in the recurring service delivery protests across the country.

A shortage of engineering capacity is not only a South African phenomenon, but a world-wide trend. According to Du Toit and Roodt (2008) shortages in engineering capacity hamper economic development and impede service delivery at a municipal and national level.

The above discussion outlines the challenges that hinder economic development for South Africa. This chapter provides an overview of the thesis. It gives the background to the study, the research rationale and the problem statement is identified. It identifies the research aims and objectives and presents the research questions that the researcher attempts to answer through the research. It discusses the scope of the study and finally briefly explains the study outline.

1.2 Research problem statement and rationale

Kraak (2009) observed that the South African government does have a strong consensus in terms of promoting growth and development. To resolve the shortages in suitably skilled labour in the engineering industry, the government has implemented economic and industrial policies such as the Accelerated and Shared Growth Initiative (ASGISA) and the Joint Initiative on Priority Skills Acquisition (JIPSA) (Kraak, 2009). ASGISA aims to identify medium- and long-term interventions and bottlenecks in the system in order to address skills shortages that prevent the 6% growth rate the government aims to achieve. JIPSA defines the priority skills in the labour market (Kraak, 2009). Although there has been a marginal increase in the number of engineers and significant increase in other engineering professionals such as engineering technicians qualifying from university of technologies (Lawless, 2008) and the low uptake of black students into engineering still remain a major problem. Another area of concern is the mass exodus of white, skilled engineering professionals resulting in a fewer experienced, professional engineers who are able mentor newly-qualified engineers. South Africa being part of the global, competitive society requires the training and development of young engineering professionals and the retention of skilled engineers to meet global needs.

Past and recent research on critical success factors in the engineering industry has failed to address industry-wide problems and focusses on sector specific issues. Wong, Ng and Chan (2010) and (Rezgui, Boddy, Wetherill & Cooper, 2009) investigated CSF in the construction sector, whereas Lawless (2017) based most of her research on the industrial and civil engineering sectors. Research has also explored the CSF of specific processes such as the implementation of enterprise resource planning and process re-engineering (Tarhini, Ammar, Tarhini, & Masa'deh, 2015), product development (De Medeiros, Ribeiro, & Cortimiglia, 2014), project management (Monteiro de Carvalho, Patah, & De Souza Bido, 2015), relationship management (Zou, Kumaraswamy, Chung, & Wong, 2014) but necessarily within a specific sector or industry.

Case (2006) and Francis (2009) note that the research conducted on the current state of engineering in South Africa has been underpinned by little systematic investigation and thus insufficient academic debate. After numerous database searches the researcher was unable to refute the claim of insufficient systematic investigations and academic debate of engineering in South Africa as stated by Case (2006) and Francis (2009). This research would therefore make a valuable contribution to understanding the CSF for the engineering industry in South Africa and moving the current debate forward.

The research therefore aims to identify the critical success factors in the engineering industry and developing a conceptual framework for meeting the future economical and development needs of South Africa. The thesis will do so through exploring the following questions:

1.2.1 Investigative questions

1) What are the factors and sub-factors driving the needs of the South Africa engineering industry as identified in the literature?
2) What are the significant factors and sub-factors impacting on the needs of the engineering industry in South Africa?
3) What is the underlying structure for the proposed engineering systems framework of the South African engineering industry?
4) What would a conceptual framework for the South African engineering industry look like?

1.3 Research objectives

1.3.1 Primary objective

The primary objective of this research is to develop a literature-based conceptual framework validated through an empirical investigation and producing a framework that enables the engineering industry to use these factors of success to meet South Africa's future development and economic needs.

1.3.2 Secondary objective

The secondary objective is to identify key factors of success and investigate their interrelatedness.

1.4 Scope of the study

n exploratory analysis was conducted determine the CSF and sub-factors and develop a framework for the South African engineering industry. The analysis in this chapter is based on the data collected from 705 engineering professionals consisting of professional engineering technologists, professional certified engineers and professional engineering technicians. A pilot study was conducted at Eskom and the Department of Water Affairs (DWA) with 42 people participating in the pilot study. Afterwards the research instrument was distributed to the entire population of 16 526 engineering professionals registered on the ECSA database. A total of 663 people responded. The study is focused on the perceptions of the 705 engineering professionals, engineering technologists and engineering technicians in Aerospace Engineering (4), Chemical Engineering (41), Civil Engineering (256), Electrical Engineering (221), Engineering Management (37) and Mechanical Engineering (140). Six (6) respondents failed specify their engineering disciplines.

1.5 Study outline

Chapter 1 introduced the study and provided the rationale for the proposed research to be undertaken. It outlines the problem statement and the research questions this study attempts to answer.

Chapter 2 contains the theory that underpins this study, the suggested conceptual framework developed through a review of the literature on the engineering systems theory, the International Engineering Association and a comparative study on the engineering related to BRICS.

Chapter 3 contains the literature review. It discusses the five factors and sub-factors identified in the suggested conceptual framework for the needs of the engineering industry in South Africa. These include environmental factors, social factors, social-environmental factors, cross-functional process factors and technology factors and their associated sub-factors.

Chapter 4 describes the research methodology employed. It gives an overview of the research philosophy, research strategy and approach. It discusses the research instrument and the method of data collection. It describes the research population, sampling techniques and the sample. Additionally, it described the measures and statistical analytical techniques used to answer the research questions. Finally, it addresses issues such as ethics, voluntary participation, consent and confidentiality and anonymity. The reliability and the validity of the measuring instrument are also discussed.

Chapter 5 presents the research findings. The analysis presented is based on the data collected from the 705 respondents. Different statistical methods were employed to answer the research questions. The outcomes of the statistical analysis endeavoured to answer the research questions.

Chapter 6 addresses the interpretation of the findings. Relationships are identified and highlighted. The findings are linked to the literature cited in the literature review. The conceptual framework addressing the needs of the South African engineering industry is developed. A summary of the research objectives and major findings are noted. Recommendations are made as to how the identification of appropriate critical success factors of the needs of the South

African engineering industry can be addressed. The limitations of the study are noted. Possible areas of further research are suggested.

CHAPTER 2: THEORETICAL FRAMEWORK

2.1 Introduction

According to Clinton and Jones (2010) developing countries can become economically viable through enhancing their human, institutional and infrastructure capacity (Mbanda & Chitiga-Mabugu, 2017) along with developing a solid base of technically skilled people. Clinton and Jones (2010) explain that 'technically skilled people are developed through educating, training, mentoring and investing resources in the economy, governments and institutions". A UNESCO report (2010) on the state of engineering in developing countries, suggests various strategies to increase engineering capacity in developing countries: strengthening engineering education, training and professional development, developing engineering standards, quality assurance and accreditation, developing engineering curricula, learning and teaching materials and methods, developing interactive distant learning in engineering, developing engineering ethics and a code of good practice, promoting a public understanding of engineering and technology, developing indicators, information and communications systems, addressing women and minority participation in engineering, increasing inter-university and institutional cooperation and developing an engineering and technology policy and planning to promote the above.

Based on the above-mentioned strategies, critical success factors (CSF) can be extrapolated for engineering. The concept of success factors were first developed by Daniel in 1961 which was refined into critical success factors by Rockart (Bullen & Rockart, 1981). Bullen and Rockart (1981:7) define CSF as "the limited number of areas in which satisfactory results will ensure successful competitive performance for the individual, department or organisation". Critical success factors are the few key areas where 'things must go right' for the business to flourish and for the manager's goals to be attained." The use of CSF by Bullen and Rockart (1981) is intended to explain business strategy which they see as an optimal match between environmental conditions and business characteristics. The surrounding environment has certain fundamental requirements, limitations, threats and opportunities to which a business must align their strategy, skills and resources to achieve success.

Bullen and Rockart (1981) identify five sources of CSF as the industry, where the organisation operates and include the technology employed, the characteristics of the products which can affect all competitors within an industry, the competitive strategy and industry position of the business in question, environmental factors which are the macroeconomic influences that affect all competitors within an industry, and over which the competitors have little or no influence, the temporal factors, which are areas within a business causing a time-limited distress to the implementation of a chosen strategy, e.g., lack of managerial expertise or skilled workers, and the managerial role, i.e., each manager's position within the organisation. Each of these sources has their generic set of associated critical success factors.

The researcher will use the following methods to identify the engineering success factors to investigate:

1. current management theories such as (a) institutional theory and (b) Porter's five forces framework to investigate their applicability in the study;
2. the Engineering systems (ES) framework as the theoretical base;
3. identify the various domains of the ES framework as CSF; and
4. and identify the sub-factors for each CSF.

This will be done though a comprehensive literature review and a comparative study of the BRICS consortium.

2.2 Institutional Theory

Literature (Kipping and Üsdiken, 2014) suggest that field of management has an 'idolisation of theory' which inhibits our ability to understand the world. This view is echoed by Suddaby, Hardy and Huy (2011) who are of the opinion that a new, preferably original, management centred theory has to be generated. Institutional theory is such a theory which takes into consideration how organisations are variably interpenetrated by wider societal forces. Institutional theory is popular within management theory paradigm as it is able to explain organisational behaviours and defying economic reasonableness (Suddaby, 2013). It explains why some managerial innovations become adopted by organisations or diffuse across organisations in spite of their inability to improve organisational efficiency or effectiveness. The adoption and retention of many organisational practices are often more dependent on social pressures for conformity and legitimacy than on technical pressures for economic performance. According to Suddaby (2013) there are six key concepts that form the basis of institutional theory, i.e. the infusion of value, diffusion, rational myths, loose coupling, legitimacy, and isomorphism. These concepts are explained below:

(a) Infusion of value

Suddaby (2013) state that infusion of value is the process by which, over time, routine tasks, organisational structures, or functional positions acquire additional meaning or value beyond their intended function. Suddaby (2013) concludes that organisations become infused with significance (meaning and value) that extends beyond their bare functional utility and as a result of this infusion of meaning and value, there are often unintended consequences of an action regardless of any planning or design.

(b) Diffusion

Diffusion is explained as an adoption of new practices not because of their technical outcomes but because they resonate with social and community values. Suddaby (2013) observes that the adoption of an innovation often depends less on the objective or technical attributes of the innovation and more on the subjective interpretations of the innovation by the adopter. The adoption of practices frequently depends on the subjective perceptions of conformity to shared values in within which adoptive organisations operates.

(c) Rational myths

Organisational activities are mostly unrelated to economic productivity. Organisations, Suddaby (2013) argues, exist within social contexts in which the rules of appropriate behaviour are defined not by economic prudence but rather by prevailing myths about what constitutes economic reasonability. The assumptions of what a successful organisation should be are therefore taken for granted by the adopters.

(d) Loose coupling

Organisations often separate and buffer their core productive functions (their technical activities) from functions adopted as a result of institutional pressures and often adopt some practices only ceremonially. Suddaby (2013) refers to this as loose coupling, separating the formal adoption of a practice from its implementation. The failure to implement occurs because the firm recognises that it would be unable to maintain its current productivity if it fully conformed to institutional pressures.

(e) Legitimacy

Organisations adhere to rational myths and adopt isomorphic practices out of a desire to appear to be a legitimate organisation since organisations that appear to be legitimate are more likely to access resources than those that do not. Within a South African context, organisations with a formal transformation and equity programme may be more likely to obtain government contracts than an organisation without one. Legitimacy is obtained by adhering to the explicit rules and implicit norms of the social environment within which it exists (Suddaby, 2013).

(f) Isomorphism

Isomorphism is when organisations who share a common social field, are subjected to similar institutional pressures become more similar or isomorphic. Suddaby (2013) indicates that conformity to an institutional environment is, mainly, signaled by adopting structures, practices, and behaviours similar to other leading organisations. Suddaby (2013) mention three types of isomorphism, discussed below:

- Coercive isomorphism is largely political in nature and arises from organisations' need to appear legitimate to other, more powerful actors, such as the state. These rules of conformity are often, but not necessarily, explicitly articulated in the form of rules or laws.
- Normative isomorphism is the need to adopt practices assumed to be right or proper by morally significant actors, such as the professions. These rules of conformity are often, but not necessarily, implicit.
- Mimetic isomorphism refers to the tendency of some organisations to copy other organisations that are perceived to be successful or legitimate under conditions of ambiguity, i.e. when the criteria for or path to success is not apparent.

Mahalingam and Levitt (2007) describe this framework is a rough guide to academics and practitioners to identify unique areas of risks in engineering project, but in its current state fail to estimate the magnitude of the risks and their impacts on these projects. Players in the industry tend to take institutional pressures for granted and behave in a relative regular and predictable way and for the most part abide by these institutional forces. Organisations that follow procedures that deviate from institutional pressures in an environment usually encounter increased transaction costs in conducting business within that environment. They are then likely to develop structures and policies that align with the institutional pressures they face, since such practices lead to legitimacy and a competitive advantage in their home environments (Mahalingam & Levitt, 2007).

2.2.1 Research methodology for institutional theory

Although institutional theory could also serve as an underpinning body of knowledge for this study as it has the ability to answer the research question posed, the proposed research trajectory in institutional theory is usually longitudinal in nature (Mahalingam & Levitt, 2007). Research on sociocultural and institutional issues on engineering projects is still in its early stages, which requires an initial qualitative research approach through a case study of different industry players in order to better understand the institutional dynamics that occur most frequently and have a larger impact on the industry. The identities of major players within the engineering space in South Africa (Careers24, 2018) and which case studies can be performed include:

- Aurecon, a multinational in Engineering, Management, Design, Planning, Project Management and Consulting, has a presence in 28 countries all over the world. They offer a range of Mechanical, Electrical, Chemical, Structural and Environmental engineering jobs.
- BHP Billiton is the biggest mining company in the world. The enterprise focusses mostly on the mining of coal, copper, iron ore and petroleum. In addition, they pride themselves on their social and environmental responsibility.
- Eskom generate, transport and distribute around 95% of all the electricity in South Africa. The company is the world's eleventh-largest power utility when it comes to generating capacity, it's the world's ninth-largest in terms of sales and the firm holds the largest dry-cooling power station in the world.
- Sasol tried to be a pioneer in innovation and have improved their methods, facilities and products often to make sure they keep up with the market's expectations. They develop and commercialise technologies, and build and operate facilities to produce a range of product streams like liquid fuels, low-carbon electricity or high-value chemicals for instance.
- Transnet Engineering focuses on manufacturing, upgrading conversion, repair and maintenance of railway rolling stock and transport equipment. Many of the Transnet Engineering plats have received Centres of Excellence Awards and accreditation by Original Equipment Manufacturers.

Morse and Krivian (2017) in their report of the best global universities for engineering in South Africa can ranked the following universities:

- The University of Pretoria as one of the best universities in South Africa. It's Faculty of Engineering, Built Environment and Information Technology (IT) is home to students who aim to become engineers. It offers Bio Systems, Civil, Chemical, Electronic and Computer Engineering and many other degrees.
- The University of Witwatersrand Faculty of Engineering and Built Environment offer many degrees in the fields of Electrical and Information Engineering, Biomedical Engineering, Computational Sciences, Environmental Engineering and many others. The university has also made industrial links to facilitate, enhance and maximize the student's experience in their courses of study.
- The University of KwaZulu Natal School of Engineering is accredited by ECSA. Students of engineering can specialise in eight areas offered by the institute such as Land Surveying, Civil, Electronic, Electrical, Computer, Agricultural, Chemical and Mechanical Engineering.

- The University of Cape Town is renowned for being the best public research engineering school of Africa. Founded in 1829 this popular institute offer courses in Chemical, Civil, Electrical and Mechanical Engineering as well as Architecture, Planning and Geomatics and Construction Economics & Management all under the Faculty of Engineering & Built Environment.
- Stellenbosch University Faculty of Engineering was established in 1944. The university was one of the best research institutes in 2010. The university offers Civil, Electrical & Electronic, Process and Mechanical and Mechatronic Engineering. The degrees of BEng are accredited by the Engineering Council of South Africa (ECSA).
- UNISA has many departments in the School of engineering and many degrees are offered such as Electrical, Mining, Civil, Mechanical & Chemical Engineering and many other degrees. This gigantic top engineering School of the African Continent was founded on June 26, 1873.

These institutions are sites where institutional theory can be used to explain why some managerial innovations adopted or diffuse across organisations in spite of their inability to improve organisational efficiency or effectiveness and why organisational practices are often more dependent on social pressures for conformity and legitimacy than on technical pressures for economic performance.

After careful observations of practices within these sites hypotheses can be constructed and rigorously tested using questionnaires and quantitative analysis. Techniques of data collection, coding, and analysis should then be done. The proposed methodology could provide a wealth of information to the CSF affecting the economic and development needs of the South African engineering industry, but it is deemed not applicable for this study because of constraints in time and resources.

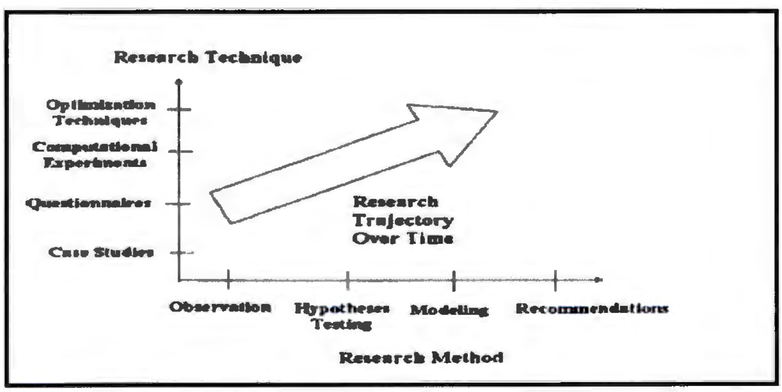


Figure 2.1 Adapted from Mahalingam and Levitt (2007) research method for intuitional theory

2.3 Porter's five forces

Porter's five forces theory (2008) shaped a generation of academic research and business practice by creating a model that helps to analyse the attractiveness of the industry. It allows you to access the current strength of your organisation's competitive position as well as the strength of the position that you are planning to attain. The model assumes that there are five competitive forces in a business situation. It identifies it as:

- Threat of substitute products
- Threat of new entrants
- Intense rivalry among existing players
- Bargaining power of suppliers
- Bargaining power of Buyers

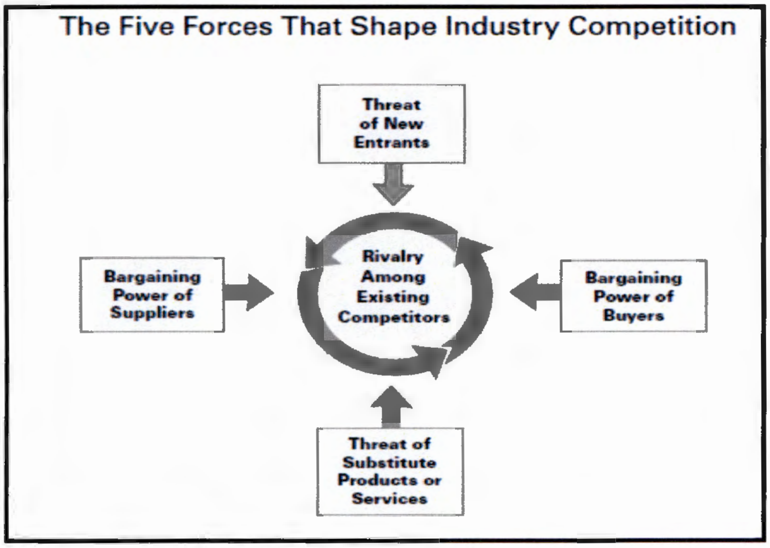


Figure 2.2 Porter's five forces theory

(a) Threat of substitute products

Porter (2008) describes the threat of substitute products as how easily your customers can switch to your competitors product. The threat of substitute is high when:

- there are many substitute products available;
- customer can easily find the product or service that you're offering at the same or a lower price;
- the competitors' product quality is better

- substitute products earn higher profits so it can reduce prices to the lowest level.

When actual and potential substitute products are available the segment is unattractive. In substitute industries, if competition rises or technology modernises, prices and profits usually decline. These trends should be closely monitored (Porter, 2008).

(b) Threat of new entrants

A new entry of a competitor into your market weakens your economic power. The threat of new entrants depends upon entry and exit barriers. According to Porter (2008) threats are high when:

- capital requirements to start the business are not readily available;
- fewer economies of scale are in place;
- customers can easily switch (low switching cost);
- the key technology is easy to acquire or not protected well; and
- the product is not differentiated.

Variability in the segment indicates that it has high entry barriers and low exit barriers. New firms may enter the industry easily and low performing companies may leave without difficulty. Porter (2008) is of the opinion that high entry and exit barriers increase profit margin but create higher risks as poor performing companies stay in it for the long haul. Additionally, when barriers are low, firms easily enter and exit the industry and profit margins are usually low. The worst condition is when entry barriers are low and exit barriers are high; indicating that when conditions are favourable firms easily enter but is difficult to exit unfavourable conditions.

(c) Industry rivalry

Porter (2008) defines industry rivalry as the intensity of competition among existing competitors in the market. Intensity of rivalry depends on the number of competitors and their capabilities. Industry rivalry is high when:

- there are number of small or equal number of competitors, but less when there's a clear market leader;
- customers have low switching costs;
- the industry is growing;
- exit barriers are high and rivals stay and compete; and

- fixed cost are high which result in huge production and reduction in prices

These situations create reasons for advertising wars, price wars, modifications and ultimately costs increase, making it difficult to compete in such an environment.

(d) Bargaining power of suppliers

Porter (2008) states that the bargaining power of supplier is apparent in the strength of its position to the seller and how much control the supplier has over the price increase of supplies. Suppliers are more powerful when:

- suppliers are concentrated and well organised;
- there are few supply substitutes available;
- their product is most effective or unique;
- the switching cost from one suppliers to another is high; and
- you are of less importance to supplier.

When suppliers have more control over supplies and its prices that segment is less attractive. The best way is to create a win-win relation with suppliers. Moreover its beneficial to have multi-sources of supply (Porter, 2008).

(e) Bargaining power of buyers

The bargaining powers of buyers demonstrate the control buyers have to drive down your products price (Porter, 2008). Buyers have more bargaining power when:

- few buyers chase too many goods;
- buyers purchase in bulk quantities;
- products are not differentiated;
- buyers' cost of switching to competitors' product is low';
- shopping cost is low;
- buyers are price sensitive; and
- there is a credible threat of integration.

Buyer's bargaining power is reduced when you offer a differentiated product. You have the power to dictate if you serve a few but a large quantity of ordering buyers.

Numerous challenges exist in applying Porter's five forces model to answer the research questions posed. Dobbs (2014) agrees that Porter's five forces model has challenges and mentions the following (a) the common misapplications of the framework and managerial difficulties, (b) the fact that many people only understand the five forces framework and its use in an inordinately shallow way and at its best can lead to incomplete, inaccurate, and unhelpful analysis and at its worst can lead to misanalysis, poor decision making, and disastrous organisational outcomes, (c) a lack of quantitative measures in the typical applications of the five forces framework and the devolution of the analysis into a series of qualitative lists, (d) a perception that the framework is primarily a tool to assess the attractiveness levels of industries rather than gain strategic insight as to how a firm can compete more effectively within its industry and (f) the framework preferred by millenniums who are very media-conscious and familiar with how technology contributes to an increasingly complex environment. They expect high levels of service, low levels of "busy work," and will not hesitate to voice their frustrations or dissatisfaction when those expectations are not met.

Although the framework will provide a critical view of the significant economic drivers in the engineering industry, the aim of the study was to identify the factors and sub-factors driving the needs of the South Africa engineering industry and how these factors and sub-factors impact both the economic and developmental needs of the South Africa engineering. This is inclusive, but not limited to the economic drivers as described in Porter's five forces model.

2.4 Engineering systems framework

Bartolomei, Hastings, de Neufville and Rhodes (2012) indicate that engineering system field, the modelling framework in which this research is embedded seeks solutions to an array of important large scale, complex and socio-technical problems. Engineering systems theory has its origins in the systems theory (Von Bertalanffy, 1968), aided by societal pressure on science calling for a development of theories capable of interdisciplinary application. The term "system" suggested by Ackoff (1981) is a set of two or more interrelated elements with the following properties: each element has an effect on the functioning of the whole, each element is affected by at least one other element in the system and all possible sub-groups of elements also have the first two properties.

Bartolomei *et al.* (2012) explained that engineering systems framework integrate behavioural, social, life science, and management sciences disciplines with an intention to discover the fundamental principles and properties of systems aimed at fulfilling important functions in society (large-scale), characterised by a high degree of technical complexity, social intricacy, and elaborate processes (complex). Engineering systems (ES) aim to address this challenge as it has its value in the fact that information can be visually arranged and simplify structure discourse in a clear and concise manner. It further provides a methodology to arrange and organise system information in ways that allow for better storage, processing and analysing system engineering data (Bartolomei *et al.*, 2012).

Engineering systems (ES) has its theoretical roots in two theories, i.e. socio-technical system theory (Trist & Bamforth, 1951) and large technological systems (Hughes, 1983). Trist and Bamforth (1951) developed a socio-technical systems framework to understand organisational behaviour by observing social interaction during work tasks and technical systems. Emery (1993) expanded it further by providing a basic theoretical concept that inspires socio-technical systems (STS). He (1993) indicates that STS consists of social/organisational and technical components that interact to achieve the purpose of the system. Larger technical systems (LTS) theory has been developed by Hughes (1983) and builds on concepts from the systems theory. Hughes (1987) defined it as focussed systems that exist to solve problems or fulfil goals, having mostly to do with reordering the physical world to make it more productive for goods and services. He (1987) sees these technological systems as changing society.

Engineering systems (ES) theory has developed because of a lack of existing theoretical knowledge to guide engineering professionals, engineering managers and policy makers responsible for the design and management of large-scale complex systems. Engineering systems defined as a large-scale complex system by Bartolomei *et al.* (2012) aim to fulfil a crucial function in society and are characterised by a high degree of technical involvedness, social complexity and intricate processes. Large-scale engineering systems include critical infrastructure, healthcare delivery systems, and manufacturing systems. According Bartolomei *et al.* (2012) ES theory identifies and defines domains common to all engineering projects.

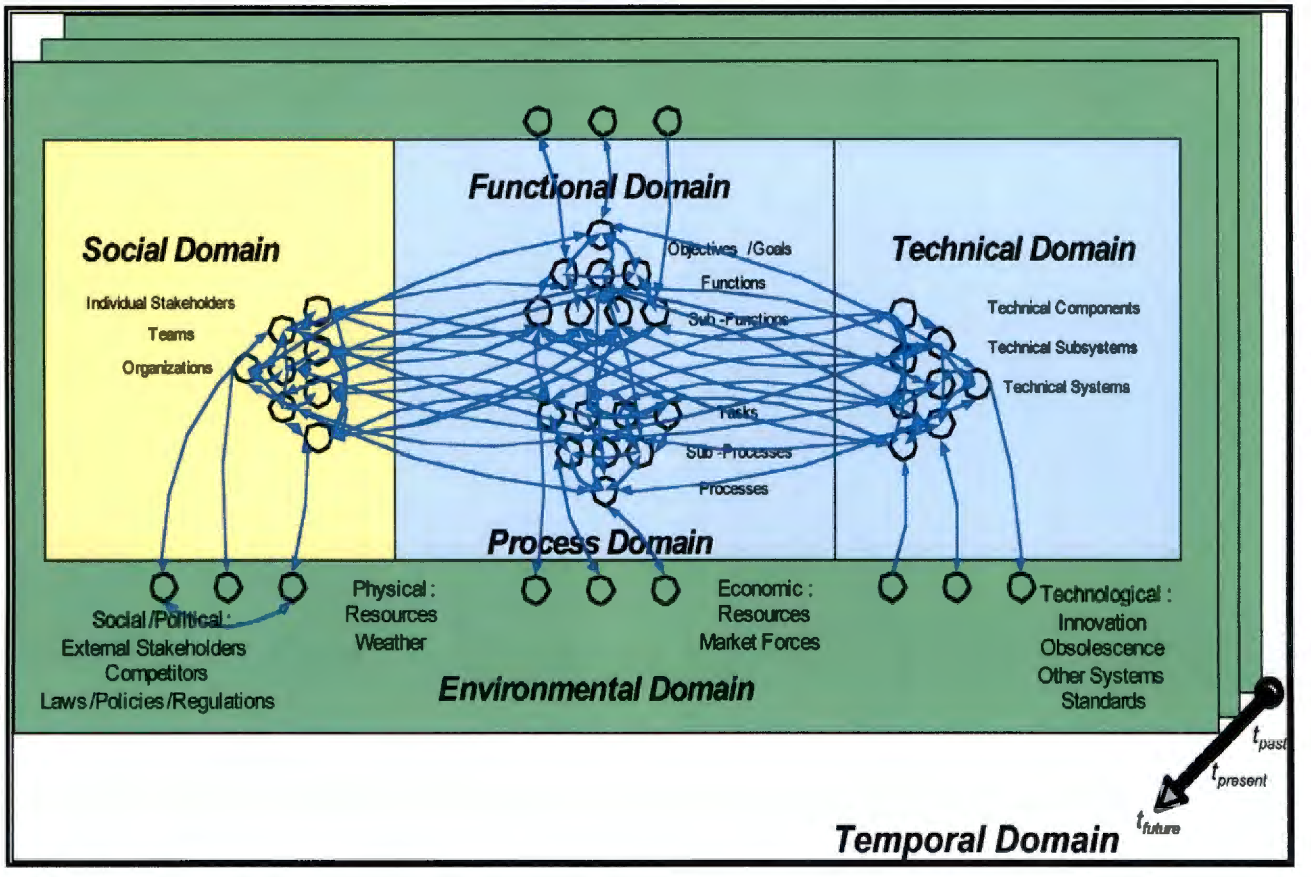


Figure 2.3 represents engineering systems domains, components and relationships

The Environmental domain consisting of external factors that affect or are affected by engineering systems; social domain consisting of the human factors and the relationships amongst them, the functional domain which includes the goals and purposes of the engineering system, as well as its functional architecture, technical domain, the physical, non-human components of the system to include hardware, infrastructure, software and information and process domain, the processes, sub-processes, and tasks performed within or by the system (Bartlomei *et al.*, 2012)

Other aspects included in the ES framework include time, system boundaries and path dependencies.

(a) *Time*

Bartolomei *et al.* (2012) are of the opinion that engineering systems components can change over time. The interaction between social and technical components causes certain properties to emerge, known as an emergent. The ease with which the system changes over time can only be understood by examining the social and technical aspects, the sources of change and who is responsible to authorising and managing the change.

(b) System boundaries

Engineering systems are complex, adaptive systems. If components of the system no longer contribute to the goal of the system and remain inactive, the system will self-regulate and adjust to bring the components of the system into alignment with the goals of the system (Bartolomei *et al.*, 2012).

(c) Path dependence

Engineering systems are socially constructed and involve thousands of human decisions over time. To understand the consequences of human decisions, unexpected events and other system behaviours a deep understanding of each domain and how human decisions affect it, is required (Bartolomei *et al.*, 2012).

2.4 Domain components

2.4.1 Environmental domain

Bartolomei *et al.* (2012) state that the environmental domain represents system drivers that act or are acted upon by the system. The system drivers include the economic, political, social and technical influences that constrain, enable or change the characteristics of components in the system.

2.4.2 Social domain

Bartolomei *et al.* (2012) describe the social domain as the basis for the level of complexity of an engineering system. The social domain or stakeholders are the human entities that contribute to the goals of the system or control components within the system. The social domain consist of different levels of complexities the individual and the group/team interacting with the technical components for some purpose, interacting groups or organisations whose contributions support the organisation's goals, interacting organisations or enterprise whose contribution supports the enterprise and enterprises, organisations and groups which support higher-level goals, To identify the stakeholders Bartolomei *et al.* (2012) suggest that the following four questions be asked; who benefits, who pays, who provides and who loses?

2.4.3 Functional domain

The functional domain consists of the objectives that include all expressed and unexpressed needs of the customer in the system. All functions must relate to an objective, either directly or indirectly and must measurable. This could include information flow, energy, material and spatial relations. Abstract and hierarchal relations are also examples of functional relations (Bartolomei *et al.*, 2012).

2.4.4 Technical domain

The technical domain (or objects) is the physical components of the system such as infrastructure, objects needed to carry out system functions, and physical entities used by internal stakeholders. These include software, hardware and infrastructure (Bartolomei *et al.*, 2012).

2.4.5 Process domain

Activities representing the process domain include processes, procedures, tasks and work units associated with an engineering system.

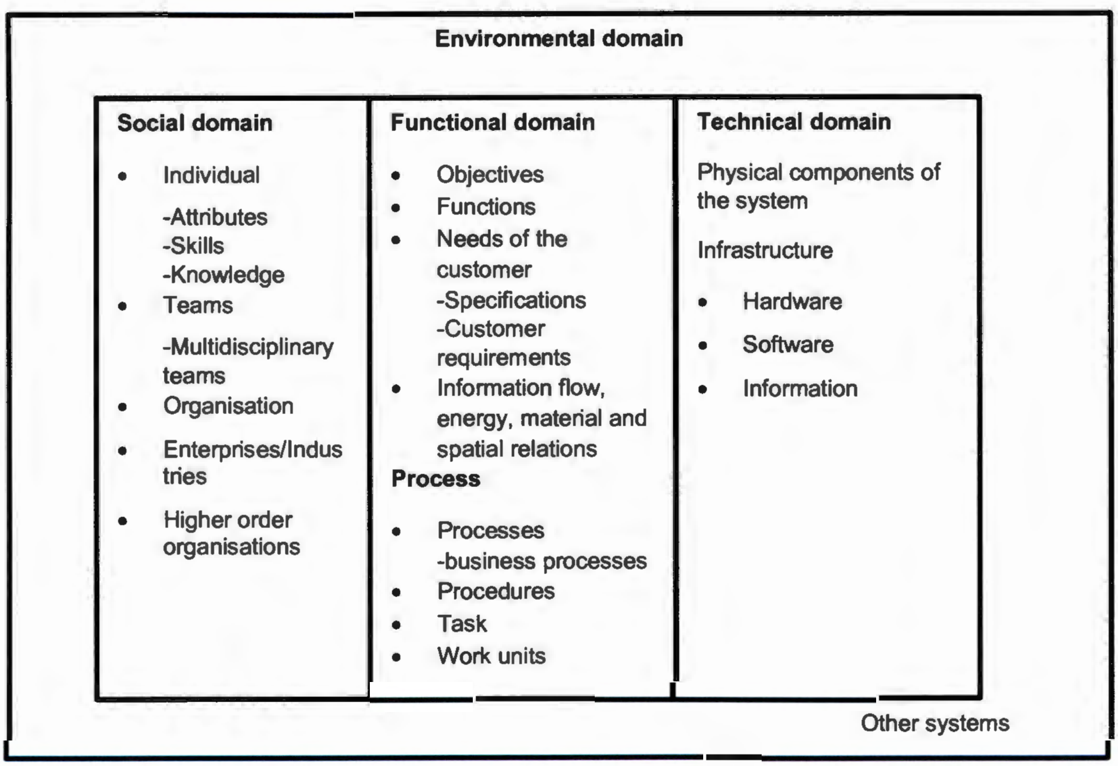


Figure 2.4 Engineering systems framework using the systems theory as basis

The ES theory is an applicable theoretical framework for this study based on the following: the study is investigating the engineering success factors most applicable to the South African engineering industry, all identified factors for the study fall within the five (5) domains, i.e. social, functional, process, technical and environmental domains of an engineering system, engineering systems are large-scale complex system characterised by a high degree of technical involvedness, social complexity and intricate processes, and all elements are interrelated, where each element has an effect on the functioning of the whole, additionally each element is affected by at least one other element in the system. Investigating how identified elements are related and how each element affect the system as a whole will give will usable framework for the South African engineering industry.

The ES framework defines domains and characteristics link to the domains. A review of the literature will enable the researcher to identify engineering CSF in each domain.

2.5 Review of the literature

The International Engineering Alliance (IEA) Report (2013) was consulted. The researcher analysed, compared and linked the skills, knowledge and attributes described in the IEA Report (2013) to factors identified in the literature.

The IEA Report (2013:1) on engineering graduates' attributes and professional competencies describes engineering as

> an activity essential to meet the needs of people, economic development and the provision of services to society. It involves the purposeful application of mathematical and natural sciences and a body of engineering knowledge, technology and techniques. Engineering seeks to produce solutions whose effects are predicted to the greatest degree possible in often uncertain contexts. While bringing benefits, engineering activity has potential adverse consequences. Engineering therefore must be carried out responsibly and ethically, use available resources efficiently, be economic, safeguard health and safety, be environmentally sound and sustainable and generally manage risks throughout the entire lifecycle of a system.

The IEA Report (2013) delineates engineering graduate attributes and professional competencies as key areas where 'things must go right' for engineering goals to be attained. Table 2.2 illustrates the factors identified in the literature and how it links to graduates attributes and professional competencies and the ES theoretical framework domains. An analysis of the literature substantiates the identified engineering success factors.

Table 2.1 CSF identified in the literature linked and link to the IEA skills, knowledge and attributes

Identification of CSF for engineering (IEA, 2013)	CSF identified in the literature and link to the International Engineering Associations skills, knowledge and attributes	Link to Engineering systems theory - Factors	Nguyen (1998)	Martin, Maytham, Case &Fraser (2005)	May & Strong (2006)	Chan and Fishbein (2009)	Male, Bush and Murray (2009)	Afida, Aini, Mohd, Muhd (2010)	Murphy (2010)	Zaharim, Md Yusoff, Omar, Mohamed, Muhamad& Mustapha (2010)	Mayorova (2011)	Sunthonkanokpong (2011)	Zhang (2011)	Yusoff, Omar & Zaharim (2013)	Laguador & Ramos (2014)
Engineering knowledge: *Apply knowledge of mathematics, natural science, engineering fundamentals and an engineering specialization respectively to the solution of complex engineering problems*	**Knowledge of technical terminology and skills, analytical skills, logical thinking, competence in engineering fundamentals and application, inclination to exact sciences, talent and inventiveness, fundamental education in mathematics and sciences,**	Technical	•	•	•	•			•		•	•	•	•	•
The engineer and society: *Apply reasoning informed by contextual knowledge to assess political, economic, societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex engineering problems.*	**Relationships with society, Economic and political issues, understanding different cultures**	Environmental	•			•	•	•		•	•			•	•

Identification of CSF for engineering (IEA, 2013)	CSF identified in the literature and link to the International Engineering Associations skills, knowledge and attributes	Link to Engineering systems theory - Factors	Nguyen (1998)	Martin, Maytham, Case &Fraser (2005)	May & Strong (2006)	Chan and Fishbein (2009)	Male, Bush and Murray (2009)	Afida, Aini, Mohd, Muhd (2010)	Murphy (2010)	Zaharim, Md Yusoff, Omar, Mohamed, Muhamad& Mustapha (2010)	Mayorova (2011)	Sunthonkanokpong (2011)	Zhang (2011)	Yusoff, Omar & Zaharim (2013)	Laguador & Ramos (2014)
Environment and sustainability: *Understand and evaluate the sustainability and impact of professional engineering work in the solution of complex engineering problems in societal and environmental context*	**Relationship with the environment, Impact of engineering on the environment**	Environmental	•			•	•		•	•		•			•
Ethics: *Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.*	**Code of ethics in engineering, Integrity**	Environmental	•			•	•					•		•	
Protection of society: *Recognise the reasonably foreseeable social, cultural and environmental effects of complex activities generally, and have regard to the need for sustainability; recognise that the protection of society is the highest priority*	**Social responsibility/awareness, Safety focus, principles of sustainable development**	Environmental				•									
Legal and regulatory: *Meet all legal and regulatory requirements and protect public health and safety in the course of*	**Quality control (Standards)**	Functional-Process	•						•						

Identification of CSF for engineering (IEA, 2013)	CSF identified in the literature and link to the International Engineering Associations skills, knowledge and attributes	Link to Engineering systems theory - Factors	Nguyen (1998)	Martin, Maytham, Case &Fraser (2005)	May & Strong (2006)	Chan and Fishbein (2009)	Male, Bush and Murray (2009)	Afida, Aini, Mohd, Muhd (2010)	Murphy (2010)	Zaharim, Md Yusoff, Omar, Mohamed, Muhamad& Mustapha (2010)	Mayorova (2011)	Sunthonkanokpong (2011)	Zhang (2011)	Yusoff, Omar & Zaharim (2013)	Laguador & Ramos (2014)
his or her activities															
Manage engineering activities: *Manage part or all of one or more complex activities*	**Business management, Commercial focus, Evaluate operational performance**	Functional-Process							•					•	
Project/Business Management and Finance: *Demonstrate knowledge and understanding of engineering management principles and economic decision-making and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.*	**Project Management, Commercial focus**	Process		•				•	•	•	•	•			
Investigation: *Conduct investigations of complex problems using research-based knowledge and research methods including design f experiments, analysis and interpretation of data, and synthesis*	**Conducting experiments, Competence in theoretical research engineering**	Process	•		•	•		•	•		•	•		•	•

Identification of CSF for engineering (IEA, 2013)	CSF identified in the literature and link to the International Engineering Associations skills, knowledge and attributes	Link to Engineering systems theory - Factors	Nguyen (1998)	Martin, Maytham, Case &Fraser (2005)	May & Strong (2006)	Chan and Fishbein (2009)	Male, Bush and Murray (2009)	Afida, Aini, Mohd, Muhd (2010)	Murphy (2010)	Zaharim, Md Yusoff, Omar, Mohamed, Muhamad& Mustapha (2010)	Mayorova (2011)	Sunthonkanokpong (2011)	Zhang (2011)	Yusoff, Omar & Zaharim (2013)	Laguador & Ramos (2014)
of information to provide valid conclusions.															
Design and development of solutions: *Design or develop solutions to complex problems*	**Design capabilities and conducting experiments, System approach to design and manufacturing**	Process	•	•	•	•		•	•	•	•	•		•	
Evaluation: *Evaluate the outcomes and impacts of complex activities*	**Evaluate operational performance,**	Process	•						•	•	•			•	
Judgement and responsibility for decision-making: *Recognize complexity and assess alternatives in light of competing requirements and incomplete knowledge. Exercise sound judgement in the course of his or her complex activities.*	**Decision-making capabilities**	Process				•			•						
Problem analysis: *Identify, formulate research literature and analyse complex engineering problems reaching substantiated conclusions using first*	**Problem identification, formulation and solution**	Process	•	•	•	•	•		•	•	•	•		•	•

Identification of CSF for engineering (IEA, 2013)	CSF identified in the literature and link to the International Engineering Associations skills, knowledge and attributes	Link to Engineering systems theory - Factors	Nguyen (1998)	Martin, Maytham, Case &Fraser (2005)	May & Strong (2006)	Chan and Fishbein (2009)	Male, Bush and Murray (2009)	Afida, Aini, Mohd, Muhd (2010)	Murphy (2010)	Zaharim, Md Yusoff, Omar, Mohamed, Muhamad& Mustapha (2010)	Mayorova (2011)	Sunthonkanokpong (2011)	Zhang (2011)	Yusoff, Omar & Zaharim (2013)	Laguador & Ramos (2014)
principles of mathematics, natural sciences and engineering sciences.															
Individual attributes	**Creativity and Innovation**	Social			•	•					•	•	•		
	Professionalism	Social				•				•					
	Entrepreneurial	Social				•		•			•			•	
	Leadership	Social			•			•		•	•	•	•	•	•
	Openness to change and flexibility	Social		•					•			•			

Identification of CSF for engineering (IEA, 2013)	CSF identified in the literature and link to the International Engineering Associations skills, knowledge and attributes	Link to Engineering systems theory - Factors	Nguyen (1998)	Martin, Maytham, Case &Fraser (2005)	May & Strong (2006)	Chan and Fishbein (2009)	Male, Bush and Murray (2009)	Afida, Aini, Mohd, Muhd (2010)	Murphy (2010)	Zaharim, Md Yusoff, Omar, Mohamed, Muhamad& Mustapha (2010)	Mayorova (2011)	Sunthonkanokpong (2011)	Zhang (2011)	Yusoff, Omar & Zaharim (2013)	Laguador & Ramos (2014)
	Precision and attention to detail	Social							•	•					•
	Integrity	Social								•					•
	Dynamic, agile, resilient	Social		•	•										
	Commitment	Social	•							•					
Team work: *Operate in diverse teams and in multi-disciplinary settings.*	**Teamwork (Interdisciplinary and multidisciplinary)/Collaboration**	Social		•	•	•	•	•	•	•	•	•		•	•
Lifelong learning: *Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.*	**Self-learning, lifelong learning and continuous improvement**	Social		•				•	•			•		•	

Identification of CSF for engineering (IEA, 2013)	CSF identified in the literature and link to the International Engineering Associations skills, knowledge and attributes	Link to Engineering systems theory - Factors	Nguyen (1998)	Martin, Maytham, Case &Fraser (2005)	May & Strong (2006)	Chan and Fishbein (2009)	Male, Bush and Murray (2009)	Afida, Aini, Mohd, Muhd (2010)	Murphy (2010)	Zaharim, Md Yusoff, Omar, Mohamed, Muhamad& Mustapha (2010)	Mayorova (2011)	Sunthonkanokpong (2011)	Zhang (2011)	Yusoff, Omar & Zaharim (2013)	Laguador & Ramos (2014)
Communication: *Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.*	**Communication skills, Written and spoken language fluency**	Social-Process	•	•	•	•	•	•	•	•	•	•	•	•	•
Modern Tool Usage: *Create, select and apply appropriate techniques, resources and modern techniques and IT tools, including prediction and modelling, to complex engineering problems, with an understanding of the limitations.*	**Using engineering tools, Knowledge of engineering software and application**	Technical	•			•	•		•	•					•
Comprehend and apply universal and local knowledge: *Comprehend and apply advanced knowledge of the widely-applied principles underpinning good practice specific to the jurisdiction in which he/she practices.*	**Deal with complexities and systems thinking**	Functional	•		•			•			•			•	

Additionally, a comparative study of the BRICS (Brazil, Russia, Indian, China and South Africa) consortium was done through a review of the literature to further elucidate on engineering success factors. The BRICS are a consortium of developing economies with fairly comparable issues and challenges in engineering.

2.6 The state of engineering within the BRICS (Brazil, Russia, India, China and South Africa) consortium

Science and engineering indicators (National Science Board, 2012) show that previously the developed countries such as United States, the United Kingdom, Germany and Japan produced the majority of the world's engineers, now the four largest emerging economies, Brazil, Russia, India and China, collectively known as the BRIC countries are now producing a significant fraction of engineering graduates. Loyalka, Carnoy, Froumin, Dossani, Tilak and Yang (2014) note that this increase in engineering graduates from the BRIC has the potential to affect the competiveness of developed countries by producing high value-add products and services. In contrast, it could increase innovation and push down the wage bill of highly talented engineers in developed countries (Loyalka *et al.*, 2014).

2.6.1 China

China is the second largest economy in the world, with its economic growth largely dependent on imported technology while producing the largest number of engineers in the world, i.e. approximately 600 000 engineering graduates per year (Chan, 2015). The Chinese government wants China to become an innovation-led nation by 2020. Chan (2015) states that Chinese leaders hopes to promote innovation in China through (a) a massive expansion in higher education, (b) more skilled workers and (c) heavy investment in research and development (R&D). Investing in engineering education will increase economic growth through innovation.

Loyalka *et al.* (2014) indicate that China, unlike other countries, does not have a problem with student enrolment numbers or female participation in engineering. Uriono-Maldonato *et al.* (2009) pointed out that China's main commodity is its large number of highly skilled human capital with the focus on developing only specific areas for research. However, Yixin (2010) and Loyalka *et al.* (2014) identify one of the major challenges in engineering is that Chinese graduates excel in the theoretical aspects, but lack practical training and innovation skills. Yixin (2010) says that only six months of the four-year engineering education is spent on a practical project. The OECD (2009) Report suggests that the low number of registered patents in certain arears may suggest a lack of practical training within these areas. Yixin

(2010) argues that in order to reform engineering education in China and become an innovation-led nation, the issues that should be addressed are: cover practical engineering training properly although most engineering students participated in an internship the quality of these internships is dubious, expose engineering students to leadership training, have more student-teacher interaction, encourage students to ask questions both inside and outside the classroom, provide opportunities for experiential training, recruit faculty members with more practical experience in engineering, address skills the industry requires such as creativity, risk taking behaviour, substandard English and communication skills, and improve university-industry partnership (Uriona-Maldonado, Maldonato, Chaim, Pietrobon& Varvakis, 2009).

2.6.2 India

Engineering has contributed substantially to India's economic growth. Over the past few years India has registered a Gross Domestic Product (GDP) of eight to nine per cent growth rate (Goel & Poothia, 2010:222). This growth rate is mainly due to the development in the high-tech industry like information technology (IT), IT-enabled services and nanotechnology, biotechnology while maintaining the advantage in low-end manufacturing such as textiles and clothing (Gereffi, Wadhwa, Rissing & Ong, 2008). Goel and Poothia (2010) further state that India has developed several critical technologies in space, defence and nuclear energy. India is now the exporter of innovative products to less developed countries. As a global player, India outsources its IT and engineering services to the developed world.

This growth can also be linked to the increased available talent pool. The number of engineering students exceeds 1.5 million, with 350 000 graduating each year. Although India has 1,290 engineering students per million of the population, this figure represents a low ratio compared to countries such as China, Russia and Brazil. While the engineering institutions and student enrolment in engineering education has significantly increased over the past few years, access to engineering education remains low as the main component of this significant expansion were in engineering education in private institution (Hiroshi & Saori, 2013). UNESCO (2013) states that for India to remain globally competitive, issues and challenges are: an increase demand for more innovation and entrepreneurship, international accreditation and quality assurance of engineering education, the lack of funding for engineering education, the production of easy-to-use and affordable technology for the developing world environment, an increase production of engineering PhD, internal brain-drain; engineering graduates who seek employment outside the engineering profession, employment preparedness of young engineering graduates, the large proportion of the population that is illiterate and poor and a severe shortage of qualified personnel in critical resources such as energy and water should be addressed

2.6.3 Russia

Engineering in Russia has long been characterised by the strong partnerships between the scientific community and the industrial and entrepreneurial community interested in the accelerated growth of the counties GDP (Sitsev, 2010). The Russian Technical Society (RTS) established in 1866, and approved by the emperor, supported wide participation in different areas of engineering such as chemical production, metallurgy, mechanical, construction, mining, etc. The RST scientific and technical activities led to the formation a number of engineering societies. After the fall of the Soviet Union, RST was replaced by the International Union of Scientific and Engineering Public Association (USEA) (Sitsev, 2010). The purpose of the USEA is to support the Russian federation's priority direction in the development of science, technologies and engineering. This was brought about by the fact that there was a 14 per cent decline in the labour force in industries that include engineering such as building, construction, transport and communication. After 2010, there was a significant increase in the number of students in higher education programmes in Russia, which increased the number of engineering students (Hiroshi & Saori, 2013).

In spite of the country's scientific and technological networks and technological innovations, there has been a decline in the interest in engineering amongst young people despite the increased infrastructure demands and the engineers and technologists needed to support this. Areas of focus include security, counter-terrorism, living systems, nanotechnology, information and telecommunication systems, environment, space systems, transport, aviation, power engineering and energy efficiency" (Sitsev, 2010:235). Danilova and Pudlowski (2010) and Hiroshi & Saori (2013) suggest that the following issues should be addressed with regard to engineering in the Russian Federation such as: communication skills of engineering professionals, the low demand for engineers in the labour market and the unpopularity of the engineering professions, the material and technical deterioration and obsolescence at educational institutions, a lack of receptiveness to innovation among engineering graduates, the improvement of the mathematics and science curricula at school level, the adjustment of engineering education by including emerging global requirements, industries imported technology and means of production from abroad rather than investing in training of engineers, the employability of engineers by adding foreign language and communication skills as part of the engineering educations curricula and the gaining of engineering know-how and expertise to improve knowledge, skills and attitudes.

2.6.4 Brazil

Engineering in Brazil is viewed as a vital component in economic growth. Scavarda do Carmo and Dali'Acqua (2010) state that Brazil is a major player in the manufacturing of automobiles and commercial airplanes and a world leader in deep water oil exploration. Scavarda do Carmo and Dali'Acqua (2010:241) note that 55 per cent of Brazil's annual exports are manufactured products. Brazil's focus is on aerospace and nuclear advancement and has introduced ambitious development programmes in these fields.

Brazil has made quite a few strides in technology and innovation, especially with the emergence of university incubators for start-up enterprises (South Asia Human Development Sector Report no.57, 2013). Currently the focus of engineering is on sustainability both socially and environmentally.

Although Brazil has impressive energy sources and telecommunications connectivity, it only has about 550 000 engineers in the economically active population (Scavarda do Carmo & Dali'Acqua, 2010). Scavarda do Carmo and Dali'Acqua (2010) note that the youth shows little interest in engineering which is evident in the lower enrolment in technical studies (Scavarda do Carmo & Dali'Acqua, 2010). Brazil's human capital is also under threat because of globalization. The country has suffered an increased brain drain of engineering professionals. Brazil faces the following challenges and issues: a significant inequality in population distribution, the internal inefficiencies of engineering education, i.e. students take six to seven years to complete a five-year degree. In addition, many students lack academic knowledge and practical skills, courses are too theoretical, engineering has an unpopular image and fail to attract talented students, insufficient railway networks, increased infrastructure demands, declining interest in engineering amongst young people, a brain drain of qualified professionals. Improved professional competence and increased exports of products with a higher technological content are cited as success factors

2.6.5 South Africa

Engineering is vital in addressing basic human needs, improving the quality of life and creating opportunities for sustainable prosperity on a local, regional, national and global level. The shortage of engineers is a major concern in Africa and across the world. There has been a declining interest and enrolment of young people, especially women in engineering. There is a need for more young people to take up engineering careers. However, making this choice depends on access to the necessary science, technology, engineering and mathematics (STEM) curriculum as well as having access to effective guidance, communication and role models. A common starting point in investigating the state of engineering in South Africa would be to examine the statistics representing engineers as a proportion of the population compared to other developing and developed counties (UNESCO, 2010).

Du Toit and Roodt (2008) claim that the training and education of a professional engineer in South Africa takes about ten to eleven years. It starts in Grade nine with a good grounding in mathematics and physical science education and ends when three years' workplace experience is completed. Hanrahan (2009) suggests that the development of a professional engineer to a level where the engineer can practice independently, require two processes, the engineer must satisfy the requirements of an accredited training programme, usually offered at a higher education institution and the trainee-engineer must follow a programme of workplace training in order to gain experience, knowledge and certain competencies to gain acceptance into a professional or licensed body. To address the skills shortages within the engineering sector and developing a sustainable solution, all levels of education have to be investigated.

Ms Naledi Pandor the Minister of Science and Technology indicated that "South Africa produces approximately 1500 engineering graduates per annum of which only half become professional engineers" (SAPA, 2014). Taylor (2008) states that economic growth depends on the production of high level science, engineering and technology (SET) skills, therefore the low number of engineering graduates impedes the country's ability to become a technological and economic world leader. A study done by Du Toit and Roodt (2008) indicates that in the last few years there was a shift in the demand from agriculture and mining engineers to those with expertise in manufacturing and service-related technology. They (2008) also note that although the economy shows expansion which should lead to the increase in engineering employment, the percentage of engineering professionals in the labour force shows a gradual decrease.

Lawless (2005) mentions the factors contributing to the low capacity of engineering in South Africa as the image of the engineering profession in relation to other more lucrative careers, lower remuneration for the engineering profession, the shortage of matriculants who meet the entrance criteria to engineering degree programmes, the high quality of the engineering degrees, low throughput rate of engineering graduates at higher education institutions, lack of experiential training opportunities, rigorous transformation policies, the failure to retain exceptional engineering talent irrespective of race and an increased demand for South African engineers abroad leading to a brain drain.

Table 2.2 summarises the challenges and issues facing engineering in the BRICS consortium and are delineated as CSF as these areas are described as the limited number of areas in which satisfactory results will ensure successful competitive performance for the individual, department or organisation (Bullen & Rockart, 1981).

Table 2.2 Success factors for the BRICS consortium

	Success Factor Framework for Engineering in BRICS -Adapted from ES Framework				
BRICS Countries	**Environmental**	**Environmental-Social**	**Social**	**Functional - Process**	**Technical**
Brazil		Fundamental education in mathematics and sciences Inclination to exact sciences	Creativity and Innovation Communication skills, written and spoken language fluency	Competence in engineering fundamentals Communication skills, Written and spoken language fluency within a work setting	Technical terminology and skills
India	Quality control (Standards) international accreditation Funding PhD production in engineering Brain-drain Literacy and poverty		Entrepreneurial Qualified personal Talent and inventiveness	Problem identification, formulation and solution Quality control (Standards)	Easy-to-use and affordable technology
Russia	labour market needs Global engineering requirements International market forces	Fundamental education in mathematics and sciences	Communication skills, Written and spoken language fluency Skills and attributes Talent and	Competence in engineering fundamentals	Technical terminology and skills

Success Factor Framework for Engineering in BRICS -Adapted from ES Framework

BRICS Countries	Environmental	Environmental-Social	Social	Functional - Process	Technical
			inventiveness		
China	University-industry partnership	Workplace training risk taking Student-teacher interaction	Leadership Communication skills, Written and spoken language fluency Creativity	Practical training	
South Africa	labour market needs Market forces High quality of engineering degrees Low throughput rates Transformation policies Immigration	Workplace training	Number of entrants in engineering education		

2.7 A suggested conceptual framework for the needs of South African engineering industry

A suggested conceptual framework delineating CSF and sub-factors (table 2.3) is suggested for the purpose of the study. It took the following into consideration, (a) the engineering success factors identified in the ES framework, sub-factors identified through a literature review, and a comparative study of the BRICS consortium.

Table 2.3 Suggested conceptual framework for the South African engineering

	CSF for the engineering industry in South Africa				
CSF aligned to ES framework	**Socio-Environmental**	**Social**	**Cross-functional process**	**Technical**	**Environmental**
CSF	**Education, Training and Development**	**Individual attributes**	**Engineering value-chain**	**Technology roadmap**	**Policy, legislation, market**
Sub-factors	Mathematics and Science education Engineering Education Experiential training; Mentoring; Talent Management	Communication Multi-disciplinary team-work Leadership Creativity and Innovation Entrepreneurial skills	Idea generation; Product design and development; New business process management Engineering project management Customer orientation	Technology needs and demands; Technology innovation Technology competence Engineering technology; Performance management of technological competence	Transformation in engineering, i.e. race and gender Engineering ethics Retention of engineering skills Engineering for sustainable development

2.8 Conclusion

The ES theory has been found to be the most applicable theory for this study. The ES theoretical framework's domains are identified as the CSF. The researcher considered the engineering sub-factors under each domain by reviewing applicable literature. A comparative study of the BRICS (Brazil, Russia, Indian, China and South Africa) consortium further elucidated sub-factors most applicable to the needs of the South African engineering industry. Each CSF and sub-factors will be explored in chapter three (3) through a further review of the literature.

CHAPTER 3: LITERATURE REVIEW

3.1 Introduction

As previously mentioned, the objective of the study is to identify the CSF for the needs of the South African engineering industry through identifying the relationship between variables, i.e. factors and sub-factors and developing a conceptual framework. The chapter investigates the literature that clarifies the five identified factors and its sub-factors. It will further identify casual relationships between identified and unidentified factors.

The first CSF is a socio-environmental factor focusing on education, training and development in engineering. Aspects such as science and mathematics education at school level, engineering education at higher education institutions (HEI), experiential training, mentoring and growing the engineering talent pool are sub-factors that will be discussed. The second CSF is a social factor, focusing on the individual attributes and skills of the 21st century engineering professional. The third CSF investigates the engineering value-chain and is informed by the cross-functional process domain of ES framework. It investigates aspects such as idea generation, product design and development, the business process and procedures used in the engineering industry and the customer orientation and satisfaction in the development of the product and/or services. The fourth CSF focusses on the technical domain or objects. These are the physical components of the system such as infrastructure, objects needed to carry out system functions, and physical entities used by internal stakeholders. In addition to the technical requirements, socio-technical aspects such as technological competence, and performance are also investigated. The fifth CSF investigates the environmental domain. This is the environment the engineer operates in. Issues pertinent to the South African context, such as transformation will be investigated. Policy issues such as engineering policy environment, regulatory issues including ethics in engineering and sustainability of engineering are investigated.

3.2 CSF 1: Socio-environmental domain: Education, training and development

The sub-factors identified under the CSF training and development are mathematics and science curricula in schools, engineering education at higher education institutions (HEI), experiential training, mentoring and talent management of engineering graduates

3.2.1 Mathematics and Science education

ECSA (2009) and DiFrancesca, Lee and McIntyre (2014) state that Physical Science, English and Mathematics are essential subjects for admission into the engineering programmes. With the advent of the National Senior Certificate which made it compulsory for all learners to do mathematics, either pure mathematics or mathematics literacy, an increased in the number of students taking mathematics has been observed, but this did not translate into more learners meeting the minimum requirement for entry into engineering programmes. Ojiako, Chipulu, Marshall, Ashleigh and Williams (2015) observed a correlation between learners pass rate in matric mathematics and the achievement levels of engineering students. Taylor (2008) and DiFrancesca *et al.* (2014) observed that an ineffective Science, Engineering and Technology (SET) skills pipeline from Grade R to 12 significantly decreases the production of crucial human resources in the engineering industry. Schutte, Kennon and Bam (2016) note that engineering programmes do not deliver sufficient numbers of candidates from previously disadvantaged groups and that most academic programme do not meet transformation expectations. ECSA (2009) suggests that the talent pool from which engineering skills are sourced should be expanded by sourcing potential candidates from BCI groups.

3.2.1.1 Factors contributing to the poor performance in mathematics and physical science.

Tsanwani, Harding, Engelbrecht and Maree (2014:42) note factors that contribute to the poor performance in mathematics and physical Science in previously disadvantage schools and consequently affecting the SET skills pipeline as "decisions taken at a political level that have impacted negatively on education such as the rapid pace at which the new curriculum was implemented (GDE, 2010), the legacy of apartheid, increasing and endemic poverty levels in society in general but in the black population in particular, vast differences in the quality and quantity of teaching and learning taking place in private and former Model C schools and public schools, inadequate training of many teachers in terms of both content knowledge and didactic knowledge, poor management of schools, poor infrastructure in many schools, insufficient time spent at schools and failure on the part of the education departments (national, provincial, district) to support schools adequately".

3.2.1.2 Rapid pace at which the new curriculum was implemented.

Phasha, Bipath and Beckmann (2016) maintain that there have been many curriculum changes in South Africa since 1994. They (2016) are of the opinion that the adoption of the new curriculum changes in South Africa was politically motivated, to remove the curriculum followed under apartheid and keep abreast with curriculum changes in other developing and developed countries. Phasha *et al.* (2016) believe that change should be properly planned and executed or else it will lead to ineffective implementation. The rapid pace of change in the curriculum make teachers feel uncertain about their level of content knowledge and necessitate professional development on content knowledge, teaching approaches and professional attitudes. Additionally, teachers continuously have to refresh and increase the subject knowledge to maintain their interest in the teaching profession.

3.2.1.3 The shortage of qualified and competent mathematics and science teachers.

Learners' performance can also be attributed to the shortage of qualified and competent mathematics and science teachers. When schools have a lack of mathematics and science teachers they often find teachers who do not have the efficient level of subject content knowledge and teaching methodology to ensure that pupils attain success in these subjects. This lack of content knowledge and pedagogical content knowledge is often a result of teachers teaching subjects they did not qualify in (Hobbs, 2013). With regard to practical work in science, Matoti and Lekhu (2008) point out that teachers desist from doing practical work, not only because of a lack of adequate training to use resources (Phasha *et al.,* 2016), but because they themselves were never exposed to practical work. Furthermore, many schools lack learning and teaching support materials, resources and have poor infrastructure (Phasha *et al.,* 2016).

3.2.1.4 The teaching and learning of science concepts.

Ramnarain (2014) believes that in order for teachers to guide learners in formulating an investigation question and planning the investigation, the teacher must have a deep understanding of science concepts. If this is lacking, it contributes to the unsatisfactory experience of school science. Lekhu (2013) identifies language deficiency as a barrier affecting the teaching and learning of science concepts. The majority of learners are taught in a language other than their mother tongue. Matoti and Lekhu (2008:128) state that students "formulate their thoughts in their own language and then literally translate those thoughts from their mother tongue into the language of instruction. This is called code switching. It is during code switching that the problem occurs". Lekhu (2013) notes that there is a direct correlation between language proficiency and science content knowledge.

3.2.1.5 The lack of instructional leadership and ineffective management of schools.

Another major problem in South African schools is the lack of instructional leadership and ineffective management of schools (Lekhu, 2013). Promotional appointments within schools and department of education are made based on union affiliation and do not necessarily take the person's competence into account (Zengele, 2013), resulting in insufficient classroom and school support by senior members and the department of education. Zengele (2013) suggest that the lack of leadership and ineffective educational management is a major contributor to the poor performance of schools.

3.2.1.6 Pass percentage for mathematics and science.

The abolition of the grade system is another major problem that faces the South African education system. All learners now write the same papers, irrespective of their cognitive ability. The national pass mark has also been reduced from 40 per cent for higher grade and 33.3 per cent for standard grade to 20 per cent (GDE, 2010). More learners are now able to pass mathematics and physical science. The consequence is that students are accepted into engineering diploma and degree programmes at HEIs (van Broekhuizen, van der Berg & Hofmeyr, 2016), but do not have an adequate foundation to do the engineering programme, resulting in a high drop-out rate at university level. The university authorities responded to this problem by implementing a compulsory bridging programme which increases the number of years to completion.

3.2.1.7 Engineering education at higher education institutions

A large number of engineers are required to develop a country's infrastructure and economy. A key limiting factor in South Africa to develop socially and economically is the lack of engineering capacity (Case, 2006). The World Higher Education Declaration of 1998 declared that an adequate higher education and research institution is needed to provide a critical mass of skilled and educated people to ensure genuine endogenous and sustainable development and reduce the gap separating less develop countries from developed ones (Kakuchi, 2014). Patel (2017) mentions need to invest in universities in general, and engineering in particular is critical as only universities can replicate in great measure the high-level scarce skills required to move South Africa forward and to foster development on the continent.

According to ECSA (2011) the international benchmark of engineers per population shows that South Africa lags behind globally and the country is not training enough engineers, artisans and technicians to deliver on government infrastructure projects (Burmeister, 2012). South Africa has one engineer per 2 600 people compared to international norms, where one engineer serves 40 people with over 16 000 registered professional engineers in the country (Patel, 2017). Adding further to the problem is the low enrolment and low throughput rates in engineering education.

Kootsookos, Alam, Chowdhury and Jollands (2017) are of the opinion engineering degrees required accreditation from national accrediting bodies. South Africa's national accreditation body, ECSA is a signatory of the Washington, Sydney and Dublin Accords which ensures that engineering, engineering technology degrees and technician diplomas offered in South Africa are internationally benchmarked and mutually recognised by all other countries that are signatories to these Accords.

A list of graduate attributes agreed by all signatories of the Accords (Kootsookos *et al.*, 2017 & Hanrahan, 2009) and part of the criteria for accredited engineering programmes are (1) the use of fundamental and specialist mathematical, natural science and engineering knowledge, to use contextual knowledge in solving problems and evaluate the social, economic and environmental impacts of solutions, to manage projects, to communicate and to work in teams and across disciplinary boundaries should be an outcome of programmes in engineering education. Danilova and Pudlowski (2010) and Litzinger, Lattuca, Hadgraft and Newsletter (2011) investigating the attributes of engineering graduates state that that engineering education has to ensure that the engineering students are able to face the challenges of the 21st century and meet emerging global requirements.

An ECSA Report (2011) refers to the preparedness of students entering engineering programmes, insufficient university resources (academic and infrastructure), escalating student enrolment (Case, Marshall, and Grayson, 2013) in engineering programmes and financial support for engineering students as issues that should be addressed to increase the throughput rate in engineering education.

3.2.2. The lack of preparedness of students entering engineering programmes

To increase the number of engineering professionals, the throughput rate of the previously disadvantaged groups at HEI has to increase, but both Lawless (2005, 2008) and Case *et al.* (2013) are of the opinion that poor mathematics and science teaching at school level discourages students from considering careers in engineering.

In developing appropriate engineering curricula that will guide university teachers in the training of engineering graduates it is paramount that engineering faculties, industry leaders and government agencies must get together. Senior members of academic staff should be employed on government engineering projects where they work with representatives of industrial sector in order to relate the subject matter to industrial needs and reinforce the subject matter with professional knowledge and local examples (Mafe, 2006). In support of this notion, Van Schalkwyk (2013) describes this as a supplementary educational method in order to bridge the gap between abstract lectures in universities and practical experiences required in the work place.

3.2.2.1 Insufficient university resources (academic and infrastructure)

Hanrahan, Beute, Fraser, Gosling, Lawless and Jandrell (2006), Case *et al.* (2013) are of the opinion that HEIs are under pressure to increase the throughput rate of students in engineering programmes. They note that there is a lack of academic staff that can provide expert teaching in each sub-discipline of its discipline. Another concern is the decrease in funding for HEI. Hanrahun *et al.* (2006) also point out that the when funding is reduced capital equipment allocation to faculties and departments will be affected. Many departments and faculties have outdated equipment and laboratories that cannot provide adequate support for teaching practically-based subjects.

According to Nel (2014) the Programme and Qualification Mix (PQM) is another factor limiting student uptake and throughput in engineering. The PQM allows universities to nominate the number of students in each engineering discipline it wishes to fund through the Department of Higher Education and Training (DHET) subsidy programme. The overall student enrolment at an institution provides an indication on the number of students the DHET can or is willing to subsidise (Nel, 2014). The number of subsidised students is based on student interest, national priorities and the job market.

3.2.2.2 Escalating student enrolment.

Student enrolment in engineering programmes had surged due to increases in funding becoming available, engineering being classified as a critical and scarce skill, therefore engineering is a national priority for government and there is a high demand for qualified engineers in the South African public sector. Universities are ill-prepared for the escalating student numbers, as most of its facilities are outdated and faculty members are overloaded (Falade, 2006; Grasso & Burkins, 2010, Richardson, 2014). To address these problems HEI should increase its investment in state of the art equipment, recruit new staff members or match enrolment with available facilities (Grasso and Burkins, 2010; Slavova, Fosfuri, & De Castro, 2016).

3.2.2.3 Financial support for engineering students.

Another dominating factor that affects student performance and throughput rate in engineering education is adequate financial resources (Horwitz, 2013). The majority of black (African, Coloured and Indian) students come from a more disadvantage background where financial resources are inadequate. South African higher education is extremely expensive and engineering students are depended on other parties to afford the cost of studying (Hanrahan et.al. 2006). Inadequate financial support will result in a low number of student take-up, low through-put of engineering students, few qualified engineers to meet the increasing labour market demand for this skilled labour force (Horwitz, 2013).

In addressing the factors mentioned South African may increase its critical mass of skilled and educated people, thereby creating a knowledge economy and improving sustainability.

3.2.3 Experiential training

Dhliwayo (2008:330) defines experiential training as "process whereby knowledge is created by transforming an experience". According to Dhliwayo (2008), Mandel and Noyes (2016) experiential training is a component of training where the theory can be applied in a real-life work-based situation. It enables the trainee to acquire specific competencies and skills for future employment as well as understanding the culture and structure of the working environment.

3.2.3.1 Experiential training for engineering technicians.

Experiential training of technicians (National Diploma) is a workplace training programme to improve practical skills and accelerate development. After doing experiential training the trainees are expected to have the necessary skills, knowledge and attitudes to enter and start working in the chosen engineering profession. Experiential training forms part of the technician's official qualification. The training period is usually for a year. Case (2010) explains that only a few students complete the engineering diplomas because they struggle to find the appropriate industrial placements. The JIPSA report (2008) identifies two reasons why students cannot find work-placement, i.e. the increased number of African students enrolled in the national diploma programmes at universities of technology and that companies have to bear the cost of training students. Case (2010) is of the opinion that companies are reluctant to train students because of a shortage of experienced professionals to act as mentors and that training students further creates additional work pressure. In addition, Erasmus and Breier (2009) are of the opinion that companies fail to see the immediate return on the time, effort and resources spent on experiential training programmes and is reluctant to invest in these programmes. To overcome this problem and increase access to experiential training programmes, Lawless (2010) suggests following the learnership route. Lawless (2010) propose that the relevant Sector Training Authority (SETA) be responsible for the learnership module. The SETA identifies the employer where the student will do the experiential training component, the student then obtains the diploma and the company is compensated for the training component. Learnership programmes should have a framework with guiding principles for the transfer of knowledge (Kruss, Wildschut, Janse van Rensburg, Visser, Haupt & Roodt, 2014) from older engineering professionals to the young trainees. In the absence of a framework knowledge transfer is not guaranteed. Another limiting factor is a cohort of aging technician and technologists, who are mostly white and a new cohort of technicians and technologists who are predominantly black. The language barrier may affect the efficient transfer of knowledge between these two groups (Du Toit & Roodt, 2008).

3.2.3.2 Workplace training for engineering graduates.

The training of engineering graduates (BEng and BTech degrees) takes three to five years after obtaining the engineering degree. The aim is to gain relevant workplace experience and obtain the professional engineering registration if they so chooses. The training of engineering graduates is usually technical in nature.

The Human Resource Development Review (2008) identifies the shortage of high-level skills, the pace of technology change and equity targets as some of the problems affecting the training of engineering graduates in the workplace.

3.2.4 Shortage of skilled mentors

If there is a shortage of skilled engineers, inadequate workplace training is offered (Detsimas, Coffey, Sadiqi & Li, 2016). Engineers with huge workloads do not have enough time to mentor young graduates.

3.2.4.1 Inadequate training.

Employees need specific capabilities to respond to the many and often changing project requirements. Companies concerned about their profit margins tend to train young graduates in one only aspect of the project cycle where they are required to perform only specific tasks (Lawless 2005). International training trends requires young graduates to be exposed to all aspects of the project life cycle (Detsimas, Coffey, Sadiqi & Li, 2016), to ensure the development of competent, independent professionals.

3.2.4.2 Lack of engineering skills.

Patil, Nair and Codner (2008) state that engineering graduates struggle to settle into workplace training programmes, because there is a gap between the engineering student's skills and what the workplace require (Detsimas, Coffey, Sadiqi & Li, 2016). Kraisuth and Panjakajornsak, (2017) identified several successful attributes an engineering graduate should possess; these are strong analytical skills, practical ingenuity, creativity, good communication, business, management and leadership abilities and has high ethical standards. Such a person should also possess a strong sense of professionalism, is quick–thinking, self-motivated, lifelong learners, and has the ability to frame problems and to put them in a socio-technical and operational context. Engineering education curriculum should ensure that the engineering student master these attributes. Patil, Nair and Codner (2008) state that universities are not meeting the industry needs and that the graduates they produce lack essential engineering skills.

3.2.4.3 The changing pace of technology.

Technology is an integral part of engineering. Ridley (2010:35) defines "technology as the employment and manipulation of science into concepts, processes and devices". Higher education institutions are unable to keep up with the rapid changes in technology and produces engineering graduates that are inaptly skilled when they enter the workplace. This places an added burden on mentors.

Chetty, Bird and Lawless (2016) suggest several methods that can be employed to solve the current problems with experiential and workplace training. These are pairing retired engineers with two or more graduates, to train graduate engineers on all aspects of the project life cycle to relieve boredom and increase retention, create a structured training programme that assess the graduate current skills level and the most appropriate training programme to follow, provide a tax incentive or skills levy to employers that are willing to train, and use skilled, professional engineers from foreign countries to expand workplace training initiatives as a short-term measure.

Experiential and workplace training should benefit both the industry and the individual who receives the training (Chetty, Bird & Lawless, 2016). The skills, knowledge and attitudes produced should satisfy the industry and most importantly everybody that requires the training should have access to these training programmes.

3.2.5 Mentoring

There are already short supplies of engineering graduates and finding the right calibre engineer is difficult. It is important to give graduate engineers responsibilities and develop their knowledge, skills and attitudes through direct work experience with the support of a mentor (Makki, Salleh, Memon & Harun, 2015). The mentoring approach is to enable the next generation of engineers to develop in an environment where weaknesses can be addressed early-on.

Lo and Ramayah (2011) define mentoring as a long-term process that is developmental in nature. It has a career development aspect where the mentor show the mentee how to advance within the organisation as well as aiding the mentee on a personal level to build a positive self-image and how to be effective in a professional role. Within the mentoring relationship the knowledge, skills and attitudes of the mentee is developed and aligned to the organisation's business objectives. O'Donnell, Karallis, Sandelands, Cassin and O'Neill (2008), San Miguel and Kim (2014) observe that mentoring is critical in the early career development phase of engineers. O'Donnell *et al.* (2008) are of the opinion that for effective mentoring to take place, the mentor should know the organisation well, understand and interpret the organisational culture and the rules of the game, familiarise the mentee with the organisation to enable the mentee to get ahead, build, guide and maintain the mentor-mentee partnership, monitor, supervise and give feedback to the mentee, create an enabling environment where the mentee concerns can be discussed and know the mentees developmental goals and career objectives.

Fleming, House, Shewakramani, Yu, Garbutt, McGee, and Rubio (2013) list the following competencies a mentor should possess as maintaining effective communication, aligning expectations, assessing understanding, addressing diversity, fostering independence, and promoting professional development.

According to Hudson (2016) the mentor-mentee relationship has to be reciprocal for it to work. The mentee's responsibilities are to be committed and exercise initiative, utilise the opportunity of the training and assistance offered, accept and take action on the mentor's advice, keep a logbook on all activities done and monitored, to be proactive and build qualities such as dedication, professionalism and co-operation within the relationship.

3.2.5.1 Mentoring programmes.

Mentoring programmes are needed because of the dire need for highly-skilled engineering professionals. Companies are competing for the same scarce resource and investing in the training as well as supporting the engineering graduate's career development will ensure that the organisation becomes the employer of choice. The employer must ensure that the knowledge construct of the training programme is aligned to vision, mission and strategies of the organisation and informs the mentee about the organisational culture and the business operations. For engineering mentoring programmes to be effective, managers and engineers across the entire organisation have to be involved. Mentoring programmes require mentees to create a portfolio of evidence of work done; employers must allow the mentee some time-off to undertake portfolio development. Employers must also provide opportunities for the mentees to develop outside the workplace. Providing personal counselling and advice will improve professionalism. It is imperative that the mentoring programme is supported by the organisation's systems and infrastructure. The selection and correct matching of mentees to mentors is vital for its success. The sustainability of the programme depends on measuring, reviewing and reporting the successes, failures, opportunities and threats to the programme (O'Donnell *et al.*, 2008).

3.2.5.2 Mentoring in the South African engineering industry

Mentoring in the South African industry is being regulated through the SETA. Mukora, Visser, Roodt, Arends, Molefe and Letseka (2008) state that in each workplace a qualified mentor must be registered with and trained by the SETA. However, Mukora *et al.* (2008) found that only a few mentors are registered. Mukora *et al.* (2008) explain that few members renew their registration when their registrations expire. Furthermore, lapsed memberships are not replaced by new members. This may be the result of the skills shortage that exists in the industry. Each mentee must be matched with a qualified mentor and a shortage of skilled mentors affects the training and development of the mentees.

Another problem that affects mentoring in the engineering industry is an understanding of the National Qualifications Framework (NQF) system. Training is linked to an NQF level. Mukora *et al.* (2008) suggest that most mentors do not understand the system.

The engineering industry needs high-level skilled professionals. Mentoring programmes are crucial since workplace training is a fundamental to the training and development of new engineering graduates and technologists. A well-constructed mentoring programme, supported by the entire organisation, ensures the development of well-rounded engineering professionals.

Mentoring programmes reflect a power relationship between a senior and a junior member of staff (Ramaswami, Huang & Dreher, 2013). For mentoring to be effective the hierarchical gap between mentors and mentees should be less important than the experience gap. In instances where the employers are less supportive of the mentoring programme, the power relationship makes it difficult for the mentees to address problems (Ramaswami *et al.*, 2013).

Another area of concern is application of the transformation policy where young, inexperienced black engineering graduates are appointed in management positions, subsequently forcing experienced staff with lesser qualifications and positions to act as mentors to young graduates. This created a reverse hierarchy that effects mentor-mentee relationship negatively (Chen, 2013).

3.2.6 Talent management

Al Ariss, Cascio and Paauwe (2014) see talent management as the strategies employed to identify, attract, retain and manage talent. The lack of engineering skills is a global phenomenon which undermines the industry growth and the South African engineering industry has to think of creative ways to attract and retain this scarce resource. Hornby (2014) defines skills as talent, expertise, dexterity, proficiency or handedness.

3.2.6.1 Talent management in the South African engineering industry

The lack of an available pool of talent in many engineering sectors can be ascribed to a perception that a career in engineering is hard work, dirty and boring. The lack of an available pool of talent results in an industry that has low productivity is globally uncompetitive. Additionally, the perception that it is difficult to gain entry into engineering education programmes makes this career choice unpopular amongst the youth.

Talent management is vital to the organisation's competiveness, but is neglected by most (Oosthuizen & Nienaber, 2010) Talent management can only be effective if it is part of the organisation's strategy and driven by senior management (Oosthuizen & Nienaber, 2010). It takes at least 10 000 hours of active working experience to become an expert in one's field, and Litzinger *et al.* (2011) see this as a reason why available talent should be retained. Oosthuizen and Nienaber (2010) believe that talent management is the responsibility of line managers and not the human resources (HR) department. They (2010) believe that organisations tend to spent most of their resources on one aspect of talent management, i.e. training and development and neglect the recruitment and retention of talented individuals.

South African municipalities have a huge shortage of engineering professionals. Kraak (2009) and Lawless (2017) mention that municipalities had lost many engineers including senior engineers through retrenchments and early retirements because of its transformation policies and restructuring and not only because of the pull of the private sector, resulting in a loss of scarce and critical skills. In an attempt to redress past inequalities, Kraak (2009) state that municipalities that push the transformation agenda misses out on the available talent. Erasmus and Breier (2009:91) note that "transformations should be managed responsibly by identifying, attracting and retaining exceptional engineering talent irrespective of race and gender". Van der Walt, Thasi , Chipunza, and Jonck (2016) state that organisations should develop strategies to identify the available talent, attract them, provide training and development and retain them in the long run.

3.2.6.2 Identifying talented individuals.

The identification of talented individuals is an important phase in talent management. Talented individuals can be identified through using numerous strategies and initiatives.

3.2.6.3 University-industry partnerships.

Kashinaa, Chudnovskiyb, Aleksandrovac, Shamovd and Borovayae (2016) assert that the university-industry partnership initiatives can be used to identify available talent. The identified individuals skills set is assessed and then matched to the required skills. This can then be used to identify the training and development needs of the individual.

3.2.6.4 Potential identification.

Potential identification is another talent identification strategy (Dries, 2013). Here the potential of the engineering graduate can be identified through observation, assessment and discussions. This informs the employer about the employee's potential future contribution.

3.2.6.5 Benchmarking existing talent.

Benchmarking existing talent to international skills available is a method that can be used to identify the talent needed as well as training and development strategies that should be formulated to up-skill individuals and creating a globally competitive skilled workforce (Martin, Jones, Benson, Murphy, Jamaluddin, Hoeksema, & Chibber, 2014).

3.2.6.6 Attracting talented individuals.

To attract talented individuals, the engineering industry should firstly address issues of access (Sonnenberg, van Zijderveld, & Brinks, 2014). The current educational quality of students entering the engineering education programmes has to be improved. Stringent entrance requirements of engineering programmes at HEI hinder access. The bursaries that are made available to engineering students are limited and without adequate financial support potential students are unable to enter engineering education programmes.

Clinton and Jones (2010) indicate that to grow the engineering pipe-line pool the industry should attract foreign expertise regardless of race and gender. In addition, regulations that make obtaining work permits cumbersome should be reviewed and adapted. Clinton and Jones (2010) believe that attracting emigrants from the diaspora will grow the talent pool.

3.2.6.7 Retaining talented individuals.

Creating job satisfaction is more than offering a good salary. In order to retain talent the industry should develop, mentor and effectively utilise its talent. Maalik, Ahmed and Nazir (2015) mention that in order to retain talent employers should focus on the employees' value proposition, namely reward and recognition, career and development, work environment and work-life balance.

Kraak (2009) suggests that new recruits be assigned to new start-up projects locally and abroad to accelerate training and development and growing the talent pool. He is of the opinion that organisations should recruit from within by identifying potential candidates and up-skilling them. Employers often overlook available talent and the potential of existing staff members. Kraak (2009) states that organisations which align its employees to the mission, vision and the strategic objectives of the organisation and create a culture that values people and their ideas; retain its staff. Kraak (2009) suggests investing in training facilities to grow the talent pool to ensure that they have an adequate supply of talent in the future. Maalik *et al.* (2015) mention a flexible workplace and attractive working conditions as means to retain talent.

Talent management is crucial for the identification, attraction and retention of talent in the engineering industry. With the severe shortage of engineering skills in all sectors, the industry can ill-afford to lose talented engineering professionals to other sectors. An effective talent management strategy should therefore be integrated into the human resources management strategy of the organisation, sector and industry.

3.3 CSF 2: Cross-functional process: Engineering value chain

A value chain is a set of activities needed to bring a product or service from conception to production to delivery to its customers and the final disposal after use (Porter, 1985). Zhang and Gregory (2011) state that engineering is a set of activities that contributes to the creation delivery of customer value. Porter's (1985) industrial value chain provides a foundation for the development of the engineering value chain (Zhang & Gregory, 2011). The different phases of the engineering value chain are that:

Engineers add value when they understand the engineering industry and how it operates. An understanding of the industry enables engineers and engineering activities to adapt to the changing environment. Knowledge of the engineering industry is the ability to understand the business functions within the industry. The CSF, engineering value chain consists of idea generation, product design and development, development of new processes, procedures and methods, and good management practice, i.e. business process management, the management of engineering projects, i.e. project management and customer satisfaction as sub-factors.

3.3.1 Idea generation

Idea generation is the first step in the development of an innovative solution to an engineering problem. Within idea generation, a problem is defined and researched until a solution is found. The solution will then be tested to realise a product. According to Hansen and Birkinshaw (2007), idea generation happens inside a unit, across units in an organisation or outside the organisation. Hansen and Birkinshaw (2007) are of the opinion that truly innovative and creative ideas can only be generated when fragments of ideas are brainstormed by individuals across different units are put together or when organisations tap into external partners for ideas. Zhang and Gregory (2011) emphasise that in engineering it is important that generated ideas result in the development of a product or service. The literature discusses several idea generation techniques used by engineering professionals to find a solution to an engineering problem. Yang, Yu, Liu, and Rui (2016) see the generation of new ideas as knowledge-intensive activities. Yang and Rui (2009) describe three categories of knowledge used in the development of new products and services.

- General knowledge – This knowledge is gained through everyday experience which is independent of the field the person works in. This knowledge is also gained through the passive or active exploration of new technology and new market opportunities.
- Domain-specific knowledge – This is the knowledge gained through education and work experience in a specific field.
- Procedural knowledge – This knowledge is both general and domain specific and includes knowledge on product development processes used to accomplish tasks.

Shah, Kulkarni and Vargas-Hernandez (2000) suggest that the traditional idea generation methods using the logical and intuitive approach. The logical approach is when the engineer makes use of charts, databases, patent research and physical principle to define the solution space and the intuitive approach is using brainstorming, C-sketch to focus on research and expand the solution space. Another technique used to generate ideas is the cognitive mechanism as proposed by Dugosh and Paulus (2005). This technique entails that others' ideas serve as a stimulus that can help to retain task-relevant knowledge that would have not been available if the triggers were absent.

The different idea generation techniques are thus classified either as process-based, where the evaluation of the idea occurs during the cognitive process and is inherent in creative and novel thought processes or outcomes-based, where the idea is evaluated based on the design, products or outcomes produced.

Zhang and Gregory (2011) suggest that when screening for new ideas the following has to be considered:

- Market assessment – The assessment of the relevance of the product for the market as well as the competitive adeptness of the product/service.
- Technical assessment – The assessment of how well the product/service is able to adapt to changes in the external environment.

- Business analysis – An analysis of how the new product will fit in a market where the business has considerable influence and if the new product/service matches the organisation's core skills and resources and build on its strength?
- Financial analysis – An analysis of the seed funding available to bring this product to commercialisation as well as the commercial skills available to develop this product/service?
- Business case development – The development of the product has to improve the business's profitability, market share and competitiveness.
- Specification functional requirements – The fundamental mechanism to achieve the requirements of the product are taken into consideration.
- Negotiated amendments and customer requirements – Have the all the customer requirements been taken into consideration within the idea generation?
- Potential supplier assessment – In screening the idea have all potential suppliers of parts/components been considered?
- Resources viability confirmation – Assess the feasibility of the product and confirm other relevant management support and organisational resources.
- Service and support concept development – Compilation of the business rules, method processes, information models as well as instructions on how to apply the rules in practice.

Ideas are generated by people and rewarding individuals encourages the generation of new ideas which can create long-term effectiveness and a competitive advantage for the organisation (Yang & Rui, 2009). The reward system must positively encourage employees' performance levels and be a key motivator in creating innovative activities.

Within engineering, the generation of new ideas results in the development of a new product or service. Goel, Vatten, Wiltgen and Helms (2012) find experience and creativity as the attributes necessary to generate new ideas. Goel *et al.* (2012) believe that more experienced engineers are able to create concepts that have more variability, but that creativity may hamper the functional specification requirements being considered.

To generate new ideas, sustained and focused attention must be given to the idea generation process as small changes can have large economic and ecological impact.

3.3.2 Product design and development

Perttula (2006) and Atilola, Tomko and Linsey (2016) define designing as providing descriptions of physical structures that perform a specific function. Engineers are responsible for designing and developing whole new systems, products or a sub-system of a product. To gain an advantage over its competitors, the engineering team must be able to design and develop a product or sub-system of a product that is distinct in its feature and meaningful in its dimensions. Developing such a product will ensure its protection as intellectual property and as such enhance the organisation's competitive advantage. One of the main challenges in engineering is finding a novel solution for a particular sub-system of a product rather than creating an entire new system (Atilola *et al.*, 2016).

3.3.2.1 Design teams

For designs to be successful the insight from more than one person is required. The best designs are conceived by a group of diverse people with a variety of perceptions, brought together because of their innovative ideas (Pritchett & Strong, 2016). To prevent disasters, engineering designers usually work in teams. Wilson, Rosen, Nelson and Yen (2010) assert that within engineering team, engineers use ideation components, i.e. that each designer is responsible for designing a different component or a larger part of a component. A consensus amongst the design team on the unique theory to be employed or model of ideation to be used is important. Within this collaborative space time, space, disciplines and cultures must be taken into account. New designs knowledge usually builds on inherited knowledge of the engineering designers. New designs are usually generated from adapting, transferring and composing old design.

A study done by Brigham Young University colleagues Todd, Sorenson, and Magleby (1993) show a number of weaknesses of engineering graduates that enter the industry. They (1993:1) found that "engineering graduates are technically arrogant, lack understanding of manufacturing processes, desire complicated and "high-tech" solutions, lack in design capability and creativity, lack in appreciation for considering alternatives, have a poor perception of the overall project engineering process; have a narrow view of engineering and related disciplines, have weak communication skills, and have little skill or experience working in teams".

Wasson (2016) states that the problem with creating innovative designs within design teams is the lack design experience of entry level engineers. Lanzotti and Tarantino (2008) state that it is not uncommon for design teams to be geographically separated distributed could have problems with communication. In addition, complex engineering designs are fundamentally multidisciplinary and communication in a multi-disciplined team is often complicated and may pose a problem to the design. Lanzotti and Tarantino (2008) and

Taha, Alli and Abdul-Rashid (2013) identify the five (5) phases in producing a quality design concept:

1) Identification of quality elements

In this phase the quality elements in the design that will satisfy the customer's needs are identified through traditional methods such as market research, interviews and focus groups.

2) Classification of the identified quality elements

The elements are classified through the Kano model (CQM, 2003); the must-be elements are the essential ones, the one-dimensional and attractive, those elements that may be included in the design to increase customer satisfaction.

3) Generation of the product concept

The generation of the product concept or preliminary design is achieved by producing several design solutions, representing different combinations of quality elements. Both hand sketches, productions drawings and 3D concepts representations using a computer aided system (CAD) or prototypes can be used to design these preliminary structures (Perttulla, 2006 & McLeod, 2010). Perttulla (2006) describes the preliminary design or pre-inventive structures as visualized patterns and object forms. They are models, schemas, cases, conceptual combinations and parts.

Andreasen (1994) indicates that modelling is the visual and verbal expression of the design piece and Perttula (2006) defines modelling as hierarchical representation of a conceptual level attributes of a class of artefacts or sub-systems of the class. Perttula (2006) describes schemas as a more detained representation of conceptual models and cases as something similar to exemplars and are specific instances of a class of artefacts. Conceptual combinations on the other hand are the creation of new knowledge structure through the integration of previously distinct concepts and parts assembly is the process of assembling a new design from different parts.

4) Quality evaluation

Quality evaluation is the assessment of the quality level for the generated concept and associated elements is quantitatively measured during experimental session in a virtual environment. Atilola *et al.* (2016) mention four (4) key metrics to evaluate the product functionality in the design concept, they are: the novelty of the concept, the variety of the concept, the quality of the concept and the number of concepts.

5) Defining the optimal or winning concept

Based on the analysis of the results obtained from the evaluation, the designer or design team will choose the optimal concept. The results satisfy the original design hypothesis as well as the customer's needs. Lanzotti and Tarantino (2008) suggest that innovation can be improved by collecting and statistically analysing information obtained from the customer's experience of the quality of the design elements.

One of the key elements of engineering is product design and development. Complex innovative designs require a multidisciplinary approach and produced by a design team. Effective team work and communication is important to achieve the best results. Producing a quality design concepts happens in phases and requires a multitude of skills and attributes and technologies to be achieved.

3.3.3 Business process management

Businesses need to be agile in an ever-changing business environment. Modern theory on business process practices looks at performance standards, total quality management, lean principle, six sigma and engineering protocol, continuous improvement to improve business performance.

3.3.3.1 International Standard Organisation Certification (ISO 9000).

Bateman, Snell and Konopaske (2017) define standard as an expected performance for a given goal. Standards are the preferred performance level(s) and the benchmark against which actual performance is assessed. Standards can be set for any activity whether it is financial, operational or legal. Standards can also be set for employees as a goal setting for motivation. These standards are known as a measurable performance standard (Bateman *et al.*, 2017).

Standards are set by the International Standardisation Organisation (ISO) which has 157 member countries of which South Africa is one. According to Watermeyer (2010), De Almeida, Sousa, Dias and Branco's (2015) standards are the tool of engineers through which a framework of acceptable engineering practice is established to arrive at a solution. Watermeyer (2010) is of the opinion that standards should address the current challenges and be able to expedite the employment of the solutions. A problem with the setting of current standards observed by Watermeyer (2010) is that they are mainly set by developed countries which do not take developing countries' needs into consideration, with little participation from developing countries. There is a need for developing countries to participate more actively in the development of international standards. Within engineering, performance standards do not only apply to people in isolation, but reflects that integration of human, product, process and service systems performance (Bateman *et al.* 2017).

A country's economic development is usually dependent on the standards or performance targets of its processes, systems (procedures and methods) and products. Standards are set to reduce costs, increase business opportunities and the optimal use of resources.

3.3.3.2 Total quality management (TQM).

Total quality management focuses on customer satisfaction and the continuous improvement of the entire system (Malik & Blumenfeld, 2012). Small and Yasin (2011) state that TQM is the effective use of all the businesses resources to produce world-class quality products and services so as to increase customer satisfaction and gain a competitive advantage. Malik and Blumefeld (2012) conclude that human resources (HR), management structures, aligning business strategies to customer needs, employing quality tools as well as supporting contractors and service providers are the focus of TQM practices. TQM can only be successful if HR and organisational change are effectively addressed. TQM practices use sophisticated statistical techniques to monitor and evaluate the quality of the product or service provided.

3.3.3.3 Six-sigma.

The Lean Six Sigma approach is a management process to improve business performance. Six Sigma is a methodology to reduce the unpredictability of the product or service and increase customer satisfaction. Malik and Blumenfeld (2012) mention that Six Sigma quality management framework enables a business gain competitive advantage by improving internal business process inefficiencies and through product and service differentiation. Hahn, Doganaksoy, and Hoerl (2000) state that main features of the Six Sigma is a top-down management approach operating at a strategic as well as an operational or project level and using a structured control system of defining the performance standards, measuring the performance against set standards, analysing the data , improving performance and maintaining high performance. Malik and Blumenfeld (2012) mention that Six Sigma is achieved through organisational learning, through team work, education, training and development and multi-role participation.

3.3.3.4 Lean management principle.

Deshmukh (2017) is of the opinion that the lean management principle means the reduction of all types of waste throughout the entire value chain. According to Small and Yasin (2011) waste excludes minimum resources and working hours critical for the production of the product or the provision of a service. The lean management principle is dependent on effective communication throughout the value chain as well as a high degree of communication between business and its suppliers so as to eliminate possible defective supplies and work. Effective communication of information improves planning and real-time scheduling. The lean management principle is effective if the focus is on employees and the customer as well as technical aspects of the business process.

3.3.3.5 Continuous improvement (CI).

Singh and Ahuja (2015) indicate that CI is adoption of a programme where the quality of products and services are continuously assessed and improved. New methods, technology, processes should be researched, adapted and implemented in order to improve quality and reduce waste. Small, Yasin and Alavi (2011) state that CI is usually a prerequisite for other implementation of other business management processes. CI is the process whereby the organisation reduces waste by cutting back on time, activities and processes that do not add value.

Within the engineering industry the delivery of a satisfactory product or services to the customers' needs, expectations, on time, within budget and at the right price is important. Adopting effective business management processes is vital to eliminating waste, improve quality, improve and maintain business performance according to a set standard.

3.3.4 Engineering projects management

Project management is the standard operation of delivering products and services within the engineering industry. Project management is an engineering activity that span across the engineering value chain. Engineering activities are usually integrated and therefore requires the simultaneous thinking and management of these activities. Zhang, Gregory and Neely (2016) note that project management is particularly useful in long-life or complex engineering systems. The main objectives of managing engineering project are to meet or beat the engineering project budget costs, to satisfy customer requirements, to tender for contracts, meet qualifying criteria and win contacts and to satisfy legal requirements such as health and safety regulations, environmental requirements, taxations, etc. (Hall, Nousala & Kilpatrick, 2009).

Projects are managed by project teams. The team members of a project team are assigned roles, responsibilities and risks (Zhang *et al.*, 2016). Project teams with their team leaders are the decision-makers in the project. In an engineering consulting firm, there are decision makers off-site, the project director and on-site, the site project manager and his team. Off-site decisions involve the planning of the project, purchasing of resources, safety regulations as well as sub-contacting. On-site decisions include construction, engineering, sub-contracting and work-force management.

Hazir (2015) is of the opinion that engineering projects uses software packages to plan and model projects. The software package determines and sets the opening and closing sequence and indicates overlapping within the sequence. Project management is the management of the following aspects, i.e. project costs (budget), expected completion dates (scheduling), product/service quality and safety and monitoring and evaluating the project deliverables (Hazir, 2015).

3.3.4.1 Project costs.

To remain competitive in a global economy it is important that businesses reduce costs and increase profitability. When using a project management approach cost-planning starts during the conceptualisation of the project (Hazir, 2015). The project's costs may include labour, materials, overheads, technology, subcontractors and consultants, equipment and facilities rentals, subsistence and travel. A project is successful when the estimated cost meets or exceeds the cost performance measures (Zhang *et al.*, 2016). The completion of a project within the original budget is critical to the success of the project. It is important that the estimated project costs include the total costs over the entire life cycle of the product or service. The life cycle costs include the cost of research and development, production, support, operation and disposal. An understanding of the life cycle costs assists in choosing appropriate technology and supports strategic deliverable improvements (Nicholas & Steyn, 2017).

Zhang *et al.* (2016) indicate that project budgeting is calculated by allocating cost to the various work packages and then distributing the budget over the duration of the work package. All the budgets are then summed and that the summed budgets cannot exceed the total budgeted costs. It is important to ensure track actual costs (Vanhoucke, 2011), by establishing a system to collect data on funds actually expended per work package as well as the total cost expended at a specific time schedule to reduce the risk of overspending on the total budgeted costs. Nicholas and Steyn (2017) mention that the value of the actual work performed should be assessed by determining the percentage of completion for each work package and converting this to a money amount.

Nicholas and Steyn (2017) mention the ways to reduce costs of activities to decrease costs and increase profitability as use less expensive materials, use experts to perform or help with tasks, reduce the scope or the requirements of the project and increase productivity through improved methods and technology.

Regarding sub-contractors or consultants, Nicholas and Steyn (2017) indicate that the relationship should be clearly defined, such as agreed scope of work, unit costs, etc. Ways to mitigate risks should be identified and implemented.

3.3.4.2 Project scheduling.

Project scheduling is important to ensure that the project is completed by the scheduled date. An overrun of activities beyond the estimated completed date may result in an increased costs and an unhappy client. To ensure that a project finishes at the expected time, Nicholas and Steyn (2017) state that project scheduling should include the earliest and the latest start and the earliest and latest finish times for the entire project. Project scheduling includes the calculation of paths (Nicholas & Steyn, 2017). These are:

- total slack - the time available between the earliest finish time of the very last activity and the project required completion time,
- critical path - the longest path (time frame) for all the activities within the project. the critical path has the least slack,
- optimistic time - the time to complete an activity if everything is perfect,
- most likely time - the time to complete an activity under normal conditions, and
- pessimistic time - the time to complete an activity under adverse conditions.

Project management software packages can assist with project scheduling. Software packages that show a breakdown structure of the various activities, estimated times start and finish times, slack and critical path.

3.3.4.3 Product quality and safety.

The product delivered or developed has to meet all the client's requirements and specifications. Set standards are applied to develop a safe product of high quality. The ISO standard is one of the business management processes that may be applied in engineering practices. The ISO 9000 series are the standards set for quality management and quality assurance, whereas the 9001 series is a methodology to set for improving and controlling the quality of a product or a service (ISO, 2015b). The ISO 9001:2000 can specifically be applied in product realisation, customer requirements, and in the design and development of a product (Sivakumar, Devadasan & Murugesh, 2014). ISO set security standards to regulate the safety and security of products, e.g. ISO/IEC 17799 is a security standards used in the software development industry (Rebollo, Mellado, Fernández-Medina & Mouratidis, 2015). Mellado, Fernández-Medina and Piattini (2007) are of the opinion that upon completion of the project the following has to be assessed:

- has the technical specification provided by the client had been met or exceeded,
- has the envisioned functional goals of the client been met,
- has the workmanship met or exceeded the contracted standards,
- has a quality product or service been delivered and
- does the product meet all the required safety features?

3.3.4.4 Monitoring and evaluation of projects.

Nicholas and Steyn (2017) assert that successful projects have proper monitoring and feedback systems. The deliverables on the project has to be measured, appraised and reviewed on an ongoing basis. The actual progress has to be compared to the planned progress and if the progress or costs changes, immediate action should be taken. In addition, Nicholas and Steyn (2017) believe that the project objectives should always be aligned to the corporate strategic objectives and that the project manager must be able to adjust the project objective if there is any deviation from the corporate strategy.

When completing projects, it is important to evaluate the project performance, by evaluating the following variables, i.e. technical performance of the project, the costs performance, the schedule performance, project planning and control, customer relationships, team relationships, communication and problem identification and resolution and make recommendation for future projects (Nicholas & Steyn, 2017).

3.3.5 Customer orientation

According to Gummesson (2008, 2009) and Kärnä, Sorvala and Junnonen (2009) customers are individuals with special qualities, needs and wants. Customer-centricity is when a business learns about the needs of the customer and wants to satisfy those needs (Kärnä *et al.*, 2009). Gummesson, Kuusela and Närvänen (2014) indicate that customer orientation is essential for the continued existence and viability of the business. Womack and Jones (2015) identified several customer orientation principles to increase the customer's satisfaction, i.e.

- do not waste the customer's time,
- provide exactly what the customer wants,
- provide what the customer wants exactly where it is needed,
- provide what the customer wants, when it is needed, and
- continually provide solutions to reduce the customer's time and hassles.

The engineering industry consists of several role-players that have to ensure that a quality product or service is delivered and that the customer's expectations are met. These role-players may be different for each sector in the industry. The role-players are divided into external and internal customers, including but is not limited to the engineering project manager, the client, the engineering design team, contractors and sub-contractors, site manager as well as the support function teams, such as finance, marketing and human resource (HR).

3.3.5.1 Quality of the service provided.

Peter Drucker (1995) indicates that the quality of a product or a service is not what the supplier puts in, but what the customer gets out and is willing to pay for. Porter (1986), states that the quality of a product allows the business to charge a higher price per unit therefore ensuring a price advantage over its competitors. Businesses that follow a high quality and product differentiation strategy have an advantage over their competitors.

Zhang *et al.* (2016) are of the opinion that project management is the standard operation of delivering products and services within the engineering industry. Kärnä *et al.* (2009) believe that projects are only successful if customer's needs are met. Satisfaction arises when the customer or product expected requirements are met or exceeded. Chougule, Khare and Pattada (2012) believe that the quality and reliability of the product or service is based on the customer's own experience with that product or service. Therefore customer satisfaction, quality and reliability of a product are closely related. Wormack and Jones (2015) are of the opinion that customer satisfaction can be used as a product performance measurement and that one bad experience by a customer can be exaggerated to affect the quality related satisfaction of the product or service.

Raza, Ashi, Agusta, Jalal and Hasan (2016) state that quality management as a strategic objective also involves continuous improvement of business processes to the customer's requirements and that quality management practices in engineering firms requires a team-based approach to problem-solving, measuring performance continuously, increased employee involvement and team-work. To ensure that a quality product is delivered the following measures may be employed, implementing a service orientation culture within the organisation, apply business processes such as TQM, lean principle, six sigma which focusses on customer satisfaction and orientation, offer the customer different financing options and provide a product component upgrade Raza *et al.* (2016).

3.3.5.2 Quality assurance.

Adopting the ISO standards is essential in quality assurance. According to ISO (2015b), quality assurance standards are adhered to if the following are available,: Auditable documents that stipulate the product specifications and implement procedures as well as corrections to what was previously done, a continual flow of information to improve interaction and skills development, the production of a good quality, reliable product and service benchmarked against international standards, customised to the needs and wants of the customer, a regular quality control process as well as a description thereof; and various operational models of various services that give a description of the end-result.

3.3.5.3 Relationship management.

Grummesson *et al.* (2014) see customers as individuals with their own needs and wants. They (2014) believe that business must offer something the customer really wants and is prepared to pay a price for. With regard to value actualization, Grummesson *et al.* (2014) are of the opinion that it be determined whether consumption patterns and use of the product are analysed.

The supplier plays an important role in realiising the value proposition. Jajja, Kannan, Brah and Hassan (2017) define the supplier relations as an interactive relationship where the business produces a product or service through the input from the supplier. It is important to establish a close, long-term relationship with the supplier to prevent the delivery of defective parts and increased delivery times. In addition, they (2017) are of the opinion that suppliers can provide valuable inputs to the customer's requirements. Regarding contractor-sub-contractor relationships, Agusa and Hassan (2008) emphasise that contractor-sub-contractor relationships are formed on a project-by-project basis and are usually short-term. Relationships between contractors and sub-contractors are usually competitive in nature that can become antagonistic and threaten future collaborations between the parties. It is therefore important to maintain a healthy contractor-sub-contractor relationship as the delivery of a quality product is dependent on the performance of the sub-contractor. The sub-contractor's performance is measured by the proportion of rework that needs to be done. Rework by sub-contractors can be minimised by establishing closer relationships between the contractor and sub-contractor (Sarker, Egbelu, Liao & Yu, 2012).

Another important relationship that should be enhanced is the customer-business relationship. The relationship with the customer can be improved by ensuring a continuous flow of information between suppliers, customers, contractor, sub-contractors and other stakeholders (Bubshait, Siddiqui & Al-Buali, 2015), involving the customer in every phase of the project, providing continuous support to improve customer relations, offering a superior customer value, adjusting the support according to the needs of the customer, coordinating support planning with the customer, providing support at the customer location and offering a fast-response to customer's needs.

The relationships between the business and customers, suppliers, contractors and sub-contractors have to be maintained and improved to ensure that a superior product is delivered that meet the customer's specification. The continuous flow of information between all parties prevents misunderstanding and ensures that the business produces a high quality product in the end.

3.4 CSF 3: Social domain: Individual attributes

There are various skills, attribute and qualities an engineer must possess to practise effectively and in a professional manner. The following skills, attributes and qualities will be discussed for the purpose of this study: communication, multi-disciplinary teams, leadership, creativity and innovation and entrepreneurial skills.

3.4.1 Communication

Patel *et al.* (2012) refer to communication as the reciprocal transfer of information between two or more parties. Communication can be one-way, the process where information flows in one direction only with no feedback or two-way, the process of information flow in two directions, between the sender and the receiver (Bateman *et al.* 2017).

Mohamed, Radzuan, Kassim and Ali (2014) indicate that oral communication, which include face-to-face discussions, telephone conversations and formal presentation and speeches and written communication which include memos, letters, reports, and computer files are important modes of communication in engineering. Kassim and Ali (2010) identify translation, clarity, negotiation and listening as vital attributes of communication.

Communication can take place formally and informally, verbal or non-verbal, harmoniously or discordantly and occur through various media. Errors in communication can occur in all stages of the communication process.

- Encoding stage – words are misused, decimal points entered in the wrong places, facts left out or ambiguous phrases inserted.
- Transmission stage – a memo can get lost on a cluttered desk, the words on the screen are too small to read from the back of the room, or words spoken that are vague and unclear.
- Decoding stage – the receiver does not listen carefully, reads too quickly or overlooks a key point. The receiver may also misinterpret the message or draw the wrong conclusion from an unclear memo.

Additionally, Bateman *et al.* (2017) explain that a person's perception, the process of receiving and filtering information, may be affected by one's ego of attitude towards the sender, which may create subjective understanding. Filtering (Bateman *et al.*, 2017), the process of withholding, ignoring or distorting information is another communication pitfall.

3.4.1.1 Communication in multi-cultural, multi-disciplinary team.

South Africa is a multi-cultural, multi-lingual society. Engineers are not only required to effectively convey technical information but to have suitable social and communication skills. Organisations that support a multidisciplinary, multi-cultural, collaborative working environment therefore needs effective communication to achieve the common goals (Patel, Pettitt & Wilson, 2012). Effective cross-cultural communication can take place if people first become conscious of their biases and cultural influences, question them and reshape.

People from different cultural backgrounds attend to things differently and interpret the same things in different ways, creating problems in communication. Bateman *et al.* (2017) suggest that the receivers attend to the message they are receiving and should consider the other person's frame of reference and attempt to convey the message from that viewpoint in mind, take tangible steps to minimise perception errors and improper signalling, send consistent messages by saying only what is meant or not meant as a means to improve communication in a multi-cultural, multi-disciplinary collaborative team environment.

3.4.1.2 Communication tools.

A vital category of communication channel is the electronic media (Bateman *et al.*, 2017). The electronic media are used to reduce the social distance between members of a team. It can improve ease of communication, practicality, accuracy and richness of information. Electronic media such as computers are effectively used to gather and distribute quantitative data and talk electronically to others. Teleconferencing and video conferencing allow people to share views and work collectively. Electronic communication tools enable users to share information, and improve the speed and efficiency in delivering messages to a large number of people. One of the drawbacks of electronic communication tools is the difficulty of solving complex problems that require more face-to-face interaction (Bateman *et al.*, 2017).

3.4.1.3 Improving communication skills

Patel *et al.* (2012) reiterate that effective communication between team members is important to achieve the common goal. Patel *et al.* (2012) describe effective communication as, when the right information is conveyed to the right people at the right time, when information is provided through a variety of verbal and non-verbal channels, when nuanced information conveyed, is explained, when opportunities for spontaneous informal exchanges are provided; and when members of the organisation and team are made to understand the meaning of the word or expression depending on who is saying it and where they are.

Effective communication and the free access to information are vital. Information should move quickly and easily between the separate parts of the organisation and be available as it is needed.

3.4.2 Multi-disciplinary team-work

Bateman *et al.* (2017) describe a team as a number of people with complementary skill, committed to a common purpose, with a common set of performance indicators and methods for which they are mutually accountable for. The advantages of a team-based approach in the work environment are, increased productivity and quality at reduced costs, creating new products, faster, enhanced innovation and change and the acquisition of new skills and performance strategies from other team members.

3.4.2.1 Team-based approach in the engineering industry.

Work in the engineering industry is usually project-based, delivered by a project or development team. The success of the engineering project may depend on more than one team. Project teams have to interact to ensure the successful delivery of the project. These are known as cross-functional teams.

The projects are normally long-term, spanning a period of years. Within project teams, each team or team member is assigned a specific function, e.g. research, ideation and design, product delivery. In the idea creation and design and development phase, the tasks of the team members include decision making, viewing of sketches, modelling and designing, suggesting and carrying out alterations and drawing on reference materials with systems and data access. These multidisciplinary, collaborative teams can stretch across professional and organisational boundaries as well as be distributed locally, internationally or situated in mobile workstations (Patel *et al.*, 2012). The team members are required to contribute their expert knowledge and judgment to the project. The team works towards a one-time product and disband after their work is completed. New teams are then formed for new projects.

3.4.2.2 Developing effective teams

De O'Melo, Cruzes, Kon and Conradi (2012) state that team member characteristics are knowledge, skills, and personality and the team's characteristics are defined by size, diversity, shared beliefs, staff turnover and team capabilities. A group of people with a common goal comes together to form a team. Groups become effective teams over time through team development activities. Bateman *et al.* (2017) identified time as a vital feature in the development of the team. Groups have to pass through critical times before turning into an effective, high-performing team. The phases in team-development as mentioned by Bateman *et al.* (2017) are:

Forming – The group members establish desired norms, rules and roles.

Storming – Conflict arises, where people compete for positions of power and status.

Norming – Group members come to agree on their shared goals and closer relationships develop.

Performing – The group directs its energies into performing its tasks.

Groups develop into true teams if the team leader builds trust and inspires teamwork as well as facilitate and support team decisions, expanding on the capabilities of the team, create a team identity, make the most of the team differences and foresee and influence changes in the team. A managerial intervention to create cohesive, high-performing units, is team building. Team building activities include goal setting, dealing with interpersonal relationships and conflict, solving problems and role clarification (Salas, Rico & Passmore, 2017). Bateman *et al.* (2017) state that a participatory leadership approach is needed to create effective teams. High-performing, effective teams are teams where team members have complementary skills, team members are committed to a common purpose, performance goals and approach and team members hold themselves accountable to one another.

Bateman *et al.* (2017) are of the opinion that teams fail because group members do not share common goals, are not committed to the team, do not understand how a team works or fail to implement appropriate team practices.

3.4.2.3 Team-based performance

Melo *et al.* (2012) mention factors, effective team communication, the nature of the task, the organisational context and supervisory behaviours as affecting team performance and productivity.

Effective team communication improves the performance of the team. Complex task creates inherent uncertainty in its intermediary outcomes, which is diminishes through effective team communication (Kennedy, Sommer, & Nguyen, 2017).

Team productivity increases when there is certainty about

- the nature of the task - the task design, the duration of the task, the autonomy to execute the task and tasks interdependencies,
- the organisational context - the type of rewards, the culture of the organisation, training and resources available to execute the tasks and
- supervisory behaviour – the leadership style of the manager, and whether it guides the team directly or encourage self-management (Kennedy, McCombb, & Vozdolska, 2011).

To design a team-based performance measurement system, the purpose of the team has to be defined and translated into measurable team goals, after which team tasks and responsibilities are designed (Atanasova & Senn, 2011). Rewards must be provided for good performance. Awards are in recognition for what the teams accomplishes. The award structures should take the individual team member's contribution and the entire team performance into consideration. Collaboration amongst team members are enhanced if teams are rewarded for its successes (Sundaresan & Zhang, 2012).

3.4.2.3 Managing team conflict

Within a collaborative working relationships conflict often arises due to the number of people in the team(s), uncertainty, different team goals, competing for scarce resources or disagreement over resource allocation and team members' diversity. Lee, Lin, Huang, Huang and Teng (2015) are of the opinion that within cross-functional teams, conflict usually arises because of insufficient interaction. Members fail to understand each other's abilities, expertise, functional, social and educational background and style of work (Lee *et al.*, 2015). Bateman *et al.* (2017) mention collaboration as a strategy to minimise conflict. Collaboration can be achieved by expressing feelings and opinions, addressing all concerns raised and not letting personal attacks interfere with solving the problem. In addition, establishing high-level organisational goals that everybody need to strive for and which take priority over individual or team's preference.

Teamwork is important to deliver a high-quality, innovative product in the shortest time. To become effective teams, a group has to undergo several phases. Effective, high-performing teams are dependent on task, organisational context, leadership style and communication. Conflict in team arises because of the number of team members, uncertainty, different team goals, scarce resources and diversity within the team.

3.4.3 Leadership

True leadership is when a leader combines the strategic vision with interpersonal processes; articulate and implement organisational strategies that produce results and a sustainable competitive advantage.

Posner and Kouzes (2014) describe leaders as people that challenge traditional beliefs and practices and create change, inspire a shared vision and motivate them to care about an important mission, give people access to information and encourage them to perform to their full potential,, live by example and shows appreciation for others contribution, provide rewards and use various ways to motivate people.

Bateman *et al.* (2017) describe two types of leadership styles in organisations, supervisory leadership where the manager guides, support and give corrective feedback on day-to-day activities and strategic leadership, when the manager envision and work with others to create a sustainable future for the organisation.

3.4.3.1 Leadership traits.

The literature (Xuesheng & Wenbiao, 2012; Bateman *et al.*, 2017) describes the traditional approach to understand leadership as well as the contemporary perspective to leadership. Leadership traits of both traditional and contemporary approaches will be discussed.

- Drive – A set of characteristics that reflect a high level of effort. Drive is seen as a personality trait that a person should be born with or strive to acquire.
- Leadership motivation – Leaders must want to lead and have a high need for power and preference to be in a leadership rather than a follower position.
- Integrity – Leaders must correspond action with words, they must be honest and credible.
- Self-confidence – This allows a leader to overcome setbacks and make decisions despite uncertainty. It also instils confidence in others.
- Knowledge of the business – Leaders should have a high level of knowledge about the organisation and industry as well as technical matters.
- Task performance or transactional leadership – these are the actions that leaders take to ensure that the team or organisation reaches it goals.
- Group maintenance behaviours – The leader takes action to ensure the satisfaction of the team members and develop and maintain harmonious work relationships to preserve the stability of the group.
- Participation-in-decision-making - Leaders can be autocratic, i.e. make decisions and announce them to the group or democratic, solicit inputs from others before the final decision is made.
- Situational leadership – The leader first analyses the situation, before deciding the course of action to take.
- The path-goal theory – This theory is concerned with how the leader influences the sub-ordinates perception of their work goals and the paths they should follow to achieve those goals. The leadership behaviours most appropriate to this leadership approach are:
- Directive leadership – This type of leadership is appropriate for highly authoritarian people. It is inappropriate if tasks are already well structured or the task and authority

and rule system is already dissatisfying. This type of leadership is appropriate when subordinates ability is low.

- Supportive leadership – This type of leadership maintains the social cohesion of the team. If the team members provide social support to each other, this leadership is less important, but if the authority system is dissatisfying, it provides a positive source of gratification.
- Participatory leadership is appropriate for people who have an internal locus of control. People with an internal locus of control believe what happens to them is their own doing and not due to luck or faith.
- Achievement-orientated leadership – This type of leadership is geared towards motivating people, setting challenging performance goals and rewarding good performance.

3.4.3.2 Leading projects.

Engineering adopts a project management approach to provide a quality product or service. Project management style leadership requires certain competencies to ensure the successful execution of the project. Successful projects are led by people who possess technical and managerial knowledge and are able to motivate people in achieving the set goals (Byrne & Barling, 2015). Project leaders must be supportive as well as achievement-orientated to achieve the project goals within a set time frame.

Organisations often seek innovative ways to improve project performance. Kissy, Dainty and Tuuli (2013) suggest that the transformational leadership style is the individual leadership style that influences innovation and performance in the workplace. Transformation leadership is when the leader enables team members to look beyond their own self-interest to pursue the objective team (Kissi *et al.*, 2013). Team members have to adjust their morale, values and ideals to deliver extraordinary results. According to Kissi *et al.* (2013) the characteristics of a transformational leader are (a) able to articulate a vision, (b) provide an appropriate model to pursue the vision, (c) facilitate the adoption of team goals, (d) has high performance expectation and (e) support and stimulate individuals in pursuit of the goals.

3.4.3.3 Developing leadership skills.

Leadership skills can be developed through developmental experiences such as taking on project or task responsibilities, accepting international assignments, seek and learn about positive role models, increase your visibility to others, work with people of diverse backgrounds, take risks, try and learn from your mistakes, overcome ideas that fail, confront other's performance problems, take formal management and leadership courses, take on challenging job experiences, volunteer to be put in a position of responsibility that other people count on and experience other activities outside work.

Within leadership theory, the traditional and contemporary approach to leadership style exists. Engineering projects require leaders to adopt the situational leadership style, as different situations may arise that require different leadership style. The path-goal theory can be applied to project management leadership. Project management is the delivery of a high-quality product or service within a limited time-frame. Team goals have to be clear to deliver a successful product. Engineering requires the delivery of innovative products to maintain a competitive advantage. The transformational leadership approach encourages innovation and creativity from team members.

3.4.4 Creativity and innovation

Organisations respond to consumers' demands and new competitors by developing and introducing new products and services to the market. This is known as innovation. According to Bateman *et al.* (2017) developing innovative products and services had become critical to maintain a competitive advantage. Innovation is dependent on an organisation's human capital and their skills and knowledge. Bateman *et al.* (2017) indicate that new ideas develop when the organisation strategically focus on creativity. Burgelman, Maidique and Wheelwright (2000), state that innovation is a change in the way people do things, i.e. methods and the type of technology used to accomplish tasks. Burgelman *et al.*, (2000) indicate that there are two types of innovation:

3.4.4.1 Product and process innovation.

Process innovation is when an organisation changes the way it produces its products and services. Flexible business management processes such as Just-In-Time (JIT), TQM and Lean Processes, mass customisation and simultaneous engineering are examples of process innovations that have been introduced. Product innovation is changes in the actual product or services through the creation, development and replacement of technology had changed the actual products and services.

There can be no innovation without creativity. Creativity is the prerequisite for innovation. Sarkar & Chakrabarti (2014) express the view that creativity is flexible, effortless, original and sometimes elaborate. Creativity is that which produces a novel and appropriate product Sarkar & Chakrabarti, 2014). Innovative products are produced by creative individuals.

Nguyen and Shanks (2009); Bateman *et al.* (2017) state that creative individuals are open-minded, original ideas, restless with the status quo, persistent, able to learn quickly, highly, intelligent and adaptable, skilled at conceptualization, fluency in generating and has attention to detail. Sarkar and Chakrabarti (2014) state that engineering professionals must be creative individuals. Engineers are increasingly required to have a broad understanding of their profession to enable them to identify the customers' needs, initiate design and business process strategies, and make decisions regarding new products, production methods and sales strategies (Siu, 2012). Siu (2012) indicates that the current engineering curricula do not prepare students to be creative. Siu (2012) suggests that students should be offered design courses that nurture students' creative abilities and critical thinking and prepare them for this rapidly changing industry where traditional technical knowledge is no longer adequate.

3.4.4.2 Learning organisations.

March (1991) states that learning organisations are well positioned to develop innovative products. These organisations excel at problem solving, seeking and finding new approaches and sharing new knowledge with all members of the organisation. Learning organisations use their current competencies to improve their operations and increase market share. They learn how to set free people's creative energies and competencies to develop new products and processes. Learning organisations can nurture innovation by following these set of rules (Mitchel, 1989) set the goals for innovation, commit to research and development, inspire intrapreneurship, facilitate and don't obstruct, focus on the customer and tolerate failure.

3.4.4.3 Organisational culture and innovation.

Collaboration across different teams and partners outside the team environment can bring information and knowledge into the organisation and integrate it with existing knowledge to create innovation. Through collaboration current as well as future problems are solved, future opportunities are sought and different technologies can be developed. To develop such technologies a more flexible organisation is required and where the structure of the organisation does not restrict thoughts and actions. The cross-functional team structures are the ideal structure to solve problems and create innovation (Edmondson & Harvey, 2017). The cross-functional team is a structure where different teams with different expertise, skills and knowledge interact to realise the organisational goals. Cross-functional teams can be situated within the organisation or situated demographically.

Engineering teams following a cross-functional team structure can be constructed according to product decomposition into sub-components such as the employed design and development procedures, and the methods of final integration into a new product (Kratzer, Leenders & Van Engelen, 2010). The team develops new, innovative ideas based on existing knowledge and how information is disseminated through the interaction of the team(s) members (Kratzer *et al.*, 2010). Dissemination depends on the strength of the interaction of team members, the availability of time and energies, the number of teams that can be reached, the number of contacts maintained and the internal processes of and the work environment under which the teams operate. In some organisations temporary project structures are created that allows the project team to operate under a different set of rules. Bateman *et al.* (2017) see failure, learning, growing and succeeding as the key to innovation. Through many failures a few big ideas arise.

3.4.5 Entrepreneurial skill

Entrepreneurship is the pursuit of profitable opportunities by an enterprising individual. Bateman *et al.* (2017) suggest that entrepreneurship is essentially about innovation and the creation of new venture where none existed before. To be an entrepreneur it is to create new businesses, new systems, resources and processes to produce new goods and services to old markets or create and service new markets (Chandra, Styles & Wilkinson 2015).

Bateman *et al.* (2017) list the following characteristics that contribute to the success of an entrepreneur:

- Committed and determined – The entrepreneur is decisive, disciplined, willing to sacrifice and immerse themselves totally in their businesses and has an internal locus of control.
- Leadership - They are self-starters, team-builders, role models, superior learners, and teachers. They communicate a vision for the future of the organisation (Bygrave, 1995).
- Opportunity obsession - They have a good understanding of the customers' needs, are market driven and focused on value creation and enhancement.
- Tolerance of risks, ambiguity and uncertainty – They take risks, can tolerate stress and solve problems (Rauch & Frese, 2005; Bateman *et al.*, 2017).
- Creative, self-reliant and ability to adapt - They are open-minded, able to learn quickly, creative, highly adaptable, skilled at conceptualization and innovative.
- Motivated to excel - They set high, realistic goals for themselves, are results orientated, have a strong drive, know their own weaknesses and strengths, focused on what can be done (Farzaneh, Hassan, Gholamreza, Mirsalaldin, Parviz, Alireza, 2010).

- Prior knowledge – They have realistic knowledge of the customer, the market, the environment, governments, institutional frameworks, rules, norms and values, additionally they have experience of prior start-ups (Chandra *et al.*, 2015).

3.4.5.1 New ventures.

Dvir, Sadeh and Malach-Pines (2010) categorise new ventures in two groups derived from the classical definition of market-pull innovation and technology and push innovations. These ventures are either needs-driven or technology-driven ventures (Gimeno-Sanz, 2016). Needs-driven ventures are based on the needs of the customers, whilst technology-driven ventures are established because of the entrepreneur's desire to make technology accessible. Technology-driven ventures are high novelty, high technology or low novelty, low technology. High novelty, high technology ventures are more successful and have the potential to create new markets, product lines, new technological infrastructure and new knowledge. Low novelty, low technology ventures perform better in meeting the budgetary requirements and economic goals of the organisation. Entrepreneurs have a high propensity for risk taking and can operate well in an uncertain environment. They are usually drawn to high novelty high technology ventures (Dvir *et al.*, 2010). Dvir *et al.* (2010) state that the success or failure of new ventures depends on the following factors:

3.4.5.2 Risks.

The entrepreneur should be realistic about what the market demands and the costs of meeting these demands. The systematic deployment of resources reduces costs and eliminates risks.

3.4.5.3 The role of the economic environment.

In the current economic slump it is difficult to find funding for start-ups and new ventures. Business incubators can provide a nurturing, protected environment for new small businesses. Business incubators are often located in industrial parks where rent is low and costs are shared. Incubators are often associated with universities or can be a government initiative where technical and business services are provided for new, small businesses.

Highly profitable organisations believe that the best time to expand or introduce new ventures is when the economy is declining. In a declining economy, competitors usually cut back, being risk averse. It is also best time to recruit talent.

3.4.5.4 Common management challenges.

An entrepreneur may face several management challenges in a competitive environment, i.e. the more the business grows, the greater its challenges. Entrepreneurs may find it especially difficult to relinquish control and delegate authority when the business has grown. Businesses often fail because resources are used incorrectly and unintelligently, lack formal controls and not enough public capital is sought when equity is scarce and expensive.

3.4.5.5 Intrapreneurship.

Innovation requires the implementation of ideas in an organisation. Intrapreneurs are individuals who work in organisations, have a good idea and must convince others to accept the idea by rallying support for the idea and get others to help implement the idea. Several steps can be followed to build support for a project idea:

1. Explain the idea to your superiors and seek approval.
2. Find people who will support your idea before formal approval is sought from higher authority.
3. Offer promises of payoffs from the project in return for support, time, money and other resources that others can contribute to the new idea.
4. Present the project's technical and political feasibility; seek higher level endorsement and the promise of resources.

Intrapreneurs are dependent on networks to support the idea and develop the innovation. The individual's power in the network enables him/her to influence others. Power may be conferred through the individual's status in the organisation (Piazza & Castellucci, 2014), but commonly through the position of the individual in the network (Kelley, Peters & O'Connor, 2009).

Entrepreneurs exhibit certain traits. New ventures are placed in two categories, high novelty, high technology and low novelty, low technology (Peng, Heim & Mallick 2014). An entrepreneur makes decisions about the type of venture he/she is willing to undertake and the factors that will affect the success or failure of the venture. For an organisation to maintain its competitive advantage, it needs intrapreneurs, who are able to come up with new ideas and have the ability to convince others to support their ideas (Baruah & Ward 2015).

3.5 CSF 4: Technology domain – technology roadmap

Technology is the systematic application of scientific knowledge to transform resources into new products, process or service. Technology is changing at a rapid pace and for organisations to remain competitive; they have to keep abreast of changes in technology. Today customers are demanding more technologically sophisticated products that have not been designed, as products life cycle is becoming shorter and shorter.

Organisations need an effective management of technology strategy to not only carry out basic tasks, but to ensure that the products and service on offer are of high quality and innovative. The engineering industry is dependent on technology and rapid innovation. It is important to understand how technology emerges, evolves and affects the way engineers do their work. Technology follows a distinct life-cycle pattern. Jeffrey, Sedgwick and Robinson (2013) identify this as a technology roadmap (TRM). Understanding what drives technology development and the pattern it follows enable organisations to manage technologies more effectively. Technology life-cycle is thus a predictable pattern from development, followed by a technological innovation to its entry into the market to market saturation and then replacement. The TRM describes where a need or a demand for the technology must exist. The TRM is described as follows (Jeffrey *et al.*, 2013):

- The technology must be theoretically able to meet the technology needs and the scientific knowledge must be available to do so. It must be possible to convert the scientific knowledge into practice.
- The time, resources, skills and human resource must be available to develop the technology.
- Business initiatives are needed to identify all elements and pull it together and develop the new technological innovation.
- After entering the market, improvements to the design are made to enhance the technology. Lowering the production costs will make the product more affordable to the customers. The new technology is technically more advanced and is used more widely.
- Any new developments to technology will take longer and be more costly.
- The market becomes saturated with only a few new customers entering the market and any new technology that now enters the market offers a superior performance or an economic advantage.

The CSF for technology innovation based on the technology road map are technology needs and demands, technology innovation in a competitive environment, technology competence, engineering technology and performance management of technological competence

3.5.1 Technology needs and demands.

Ngai, Chau, Poon, Chan, Chan and Wu (2014) identify technology push and need pull factors as factors that may influence an organisation or industry to adopt a certain type of technology. Ngai *et al.* (2014) claim that technology push factors result in the recognition and adoption of new technology after the business value as well as a performance gap had been established, whereas need pull factors result from the customer's need. Ngai *et al.* (2012:214) identify "relative advantage, compatibility, complexity, extendibility and cost of the technology as technology pull factors that may influence the adoption of the new technology".

Ngai *et al.* (2014) assert that the relative advantage of technology is the economic benefit of the new technology. Ngai *et al.* (2014) indicate that the new technology must be able to improve efficiency and productivity within the organisation. The compatibility is the degree to which the new technology satisfies the organisational requirements. The new technology should be aligned to the organisation's strategic objectives, infrastructure, needs and business processes. Ngai *et al.* (2014) explain the complexity of the new technology as how easy it is to operate the new technology. It is easier to adopt the new technology if the end user finds the technology to be user friendly. The extendibility of the new technology describes how well it supports other operational requirements other sub-modules (Ngai *et al.*, 2014). Technology is easily adopted if it is able to interface well with other systems.

The adoption of new technology is dependent on the cost of the technology. On the other hand, the organisation may compromise on the cost of the technology if the vendor support takes priority. Ngai *et al.* (2014) mention that in selecting a vendor, the vendor's experience, the support the vendor provides and the willingness to evaluate the technology after installation must be taken into consideration. It is important to build a long-term partnership with the vendor to ensure the success of the new technology.

Need pull factors that may influence the adoption of the new technology consist of customer and competitor pull factors. In the current economic conditions, customers are looking for affordable, high quality products and services and competitors may offer the same products at lower cost. Businesses may be reluctant to adopt the new technology when economic conditions are unfavourable, but to be competitive, businesses can use new technology to lower production and improve efficiency.

Top management has to support the adoption of new technology. They must be able to identify whether the new technology will enable the organisation to meet its strategic objectives. When the organisation decides to adopt the new technology, it is important to determine whether or not the staff accepts it and are able to adapt quickly to the new technology. The competencies needed to operate the new technology have to be established. Regular training programmes should be provided to ensure that the potential users do not have a problem in implementing and using the new technology. The adoption decision can also be informed by how well other organisations implemented the new technology.

Pichlak (2016) mentions three stages in technology adoption, i.e. initiation, adoption-decision, and implementation stage. The initiation stage includes; identifying the need for the new technology, gathering information and an awareness about the new technology, developing an attitude towards the new technology and proposing the adoption of the technology (Pichlak, 2016). The adoption-selection stage includes accepting the decision to adopt the idea. The organisation assesses the resources required and if the adoption of the new technology is aligned to its strategic objectives (Pichlak, 2016). The implementation stage takes into consideration the acquisition of the new technology, preparing the organisation for the new technology through communicating and training, the user acceptance of the new technology and the actual use of the technology (Hameed, Counsell & Swift, 2012).

Hameed *et al.* (2012) mention several factors that negatively affect the adoption of the new technology, i.e. business susceptibility, readiness, management support, organisational culture, stakeholder support, vendor support and user acceptability and attitude.

3.5.1.1 Assessing technology needs.

Clausing and Holmes (2010) maintain that technology innovation is one of the key factors for growth. Investing in new innovative technology increases the organisation's competitive advantage. Before organisations acquire or develop new technology it is important to assess their current technology base. A technology audit should be performed where the organisation identifies the key technologies it is dependent on. Clausing and Holmes (2010) identify the technology assets base as the most visible features such as (a) process, (b) product and support systems, (c) the organisational assets consisting of resources the organisation used to develop and set up its technical base, (d) external assets entailing the relationships the organisation set up with suppliers, (e) competitors and customers and projects which involve how technology and (f) organisational and external assets are used.

New technologies should be analysed and measured in terms of their competitive value. In scanning the technology landscape, new technologies should be first be categorised into emerging, pacing, key and base technologies before deciding which of these technology are strategically significant for the organisation.

- Emerging technologies - These are technologies that undeveloped and unproven. Organisation should monitor the development of these technologies as it can become potentially important.
- Pacing technologies – These are technologies that are in the market, but not currently used by the industry. One of the base or key technologies may be replaced by this technology. Adopting a pacing technology can lead to product or process efficiency and improve your competitive edge.
- Base technologies – These are the technologies needed to do the business. It does not provide a competitive advantage because the all competitors in the industry have equal access to it.
- Key technologies - These are the technologies that create a competitive advantage over other players in the industry.

The need or demand for new technology is dependent on technology-pull and customer-push factors. The adoption of new technology may bring improvements to the organisation and affect the performance. Before investing in new technology it is important to assess the organisation's technological assets and expand the vision to technologies beyond what the industry currently uses (Adomavicius, Curley, Gupta & Sanyal, 2013). The organisation has to be prepared for the adoption of new technologies. If an organisation is ill-prepared the endeavour can become expensive, adding little or no value to the organisation.

3.5.2 Technology innovation in a competitive environment

Skogstad (2009) and Vetterli, Brenner and Uebernickel (2013) describe technology innovation as the development of a new idea by an innovation community, who has to engage with others to implement the idea. Utterback's (1994) Dynamics of Innovation model depicted by Taylor and Taylor (2012) shows the three phases of innovation development, i.e. (a) the fluid phase, this is the early phases of technology development - innovation efforts are restricted to product development, (b) the transitional phase, the market has accepted the product and the dominant design had emerged - the innovation efforts are on both product and process, innovation efforts shifts to process technology to develop large scale efficient production and restricts product innovation and (c) the specific phase, a very specific product is produce at a high level of efficiency - during this phase there is a reluctance to make changes to the product or process because of the costs involved and this phase ends when a new technology emerges.

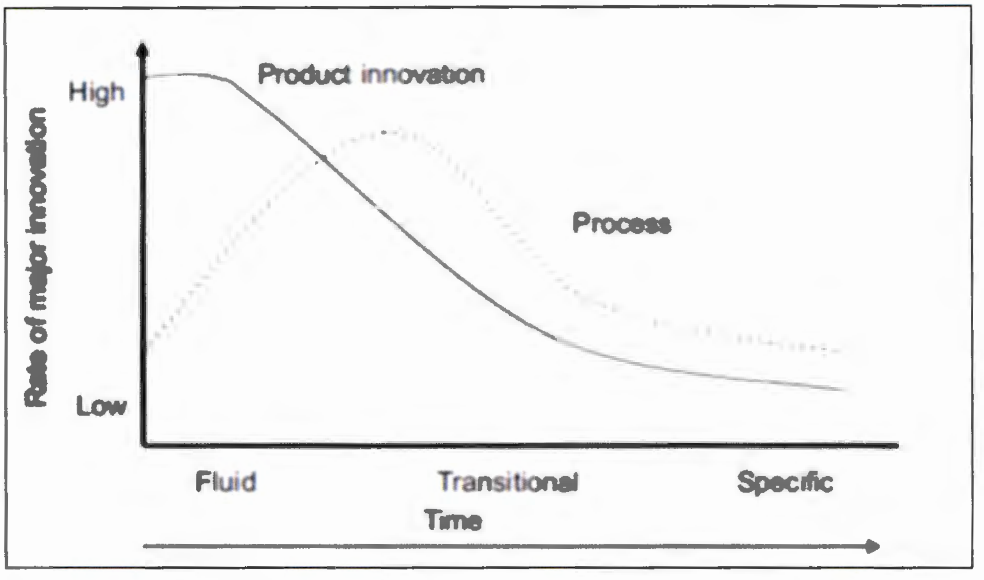


Figure 3.1: Dynamics of Innovation model reflecting the technology innovation life cycle, adapted from source (Utterback, 1994)

When deciding on the adoption of a new technology, organisations may consider (a) a low-cost strategy by lowering the costs of the product design, production or technology the cost of the product are lowered and (b) a differentiation strategy or the production of a unique product or service is offered and the customer is willing to pay a premium price.

3.5.2.1 Technology leadership.

Organisations that are willing to lead with a new technology have to take the costs and risks of technology leadership into consideration. Technology leadership can bring about high profits, because it creates a significant competitive advantage. The costs of the new technology may be reduced if the organisation achieves process technology efficiency related to its competitors. Technology leaders have a competitive advantage because it has the ability to attract more customers and make greater profits. In addition it can charge premium prices, because it has the first-to-market advantage. The technology leader may also be able to charge lower prices because of its large customer base.

Since technology leadership creates a significant competitive advantage, organisations should keep building on the lead to outpace its competitors. This can be done by making small incremental improvements to upgrade the products and processes continuously. Minor improvements are usually difficult to copy and incremental improvements will collectively provide a significant competitive advantage. Several techniques can be used to sustain technology leadership, i.e. building a reputation of being a quality differentiator or an innovator, creating institutional barriers such as patents to block competitors from replicating the new technology, creating a repeat customers base as the switching costs are too high for repeat users and creating and occupying niche markets.

The disadvantage of leading technology innovation is that the new technology may become too costly for the business. The cost is affected by buying unfamiliar, new technology, building infrastructure to support the new technology, developing complementary products to achieve the technology's full potential, obtaining regulatory approvals, using new equipment and raw material with unique specifications, stepping into an unproven and uncertain market and making existing investments such as infrastructure and businesses obsolete.

3.5.2.2 Technology followership.

Before making strategic technological decisions on whether to lead with new technology or follow existing technology. Adomavicius *et al.* (2013) suggest that the organisation assess their strength and weaknesses of their current technological base by identifying the current market needs, compare it with their current technology base, assess the functional specification of the future technology and decide whether to follow a low-cost, a differentiation strategy or both. Technology followership supports a low-costs as well as a differentiation strategy (Gehani, 2013). By learning from the leadership experiences, the risks and costs of leading technology innovation are avoided. The follower can differentiate the technology offering by adapting the available products and delivery systems to suit the customer's needs.

New technology introduced to the market always has the potential for further development and innovation. Further developments and improvements can make the technology easier to use, more adaptable to other technologies or produce complementary products and technologies. Complementary products and technologies combined with the technology lead can cause gradual diffusion progressing into a totally new technology to which users may likely switch. This may improve the organisation's competitive edge. New technologies are adopted when the benefits outweighs the switching costs and risks of the technology.

Technology innovation follows a distinct pattern illustrated as the technology innovation life-cycle. In deciding whether to develop or adopt a new technology, organisations are either technology leaders or followers. Technology leaders are willing to take considerable risks at huge costs with the aim of making a significant profit and be a market leader, whereas the technology follower improves on developed innovation in order to reduce costs and risks. The strategy the organisation follows depends on the characteristics as well as the competitive strategy of the organisation.

3.5.3 Technological competence

Duderstadt (2009, 2016) suggests that a knowledge-driven global economy requires a skilled technological competent workforce. Gerybadze (1998:5) defines technological competence in engineering as "the ability of the organisation to sustain the coordinated deployment of technological assets in a way that helps a firm achieve its goals". Adomavicius *et al.* (2013) describe the technological assets base as the skills, procedures, structure strategy and culture of an organisation. Huang (2011) explains that an organisation's technology competence include the ability to explore and exploit (a) technological opportunities, (b) technology skills, (c) core technology capabilities, (d) top management support for technology, (e) technology infrastructure and (f) technology investment.

According to Martín-Rojas, García-Morales and Bolívar-Ramos (2013) there are two types of technological improvements that affect technological competencies, i.e. competence-enhancing improvements and competence-destroying improvements. Competence-enhancements improvements are enhancements in the specifications of the technology and rely on existing knowledge. Competence-destroying improvements are technologies that are fundamentally different from previous technologies and rely on new knowledge (Huang, 2011).

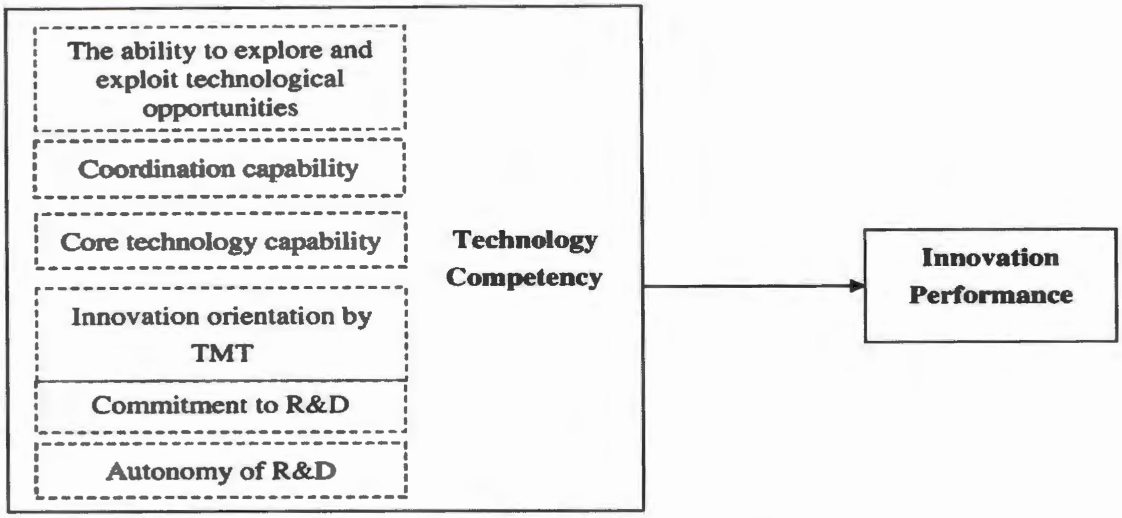


Figure 3.2 The relationship between the organisation's technology competency and innovation performance, adapted from source (Huang, 2011)

In order to further understand the relationship between technology competence and innovation competitiveness the following will be discussed: (a) the ability to explore and exploit technological opportunities, (b) coordination capabilities, (c) core technology capabilities, (d) innovation orientation by the top management team and (e) commitment and autonomy of research and development.

3.5.3.1 The ability to explore and exploit technological opportunities.

Banerjee (2012) explains that organisations can renew and rebuild adaptive technology capabilities to meet changing and uncertain market needs. This can be done by combining existing technological capabilities with new organisational knowledge resources (Banerjee, 2012). Cross application of technology is when technological capabilities that are invented to serve one purpose eventually find their use in another. Banerjee (2012) explains that research and development (R&D) intensive organisation are more willing to explore the cross application of technological capabilities than other organisations.

3.5.3.2 Coordination capabilities.

The coordination capabilities and the flow of information are important components that influence technology competencies. Technology teams should be able to communicate effectively with internal business units as well suppliers, buyers and competitors (Slater, Mohr & Sengupa, 2014). Slater *et al.* (2014) believe that effective, continuous communication with internal and external parties reduces operational costs. In addition, effective networking between the organisation's suppliers, buyers and competitors can enrich innovation activities. Haung (2011) asserts that organisations operating in an ever-changing, competitive environment and that have coordination capabilities can respond quickly to changes in that environment.

3.5.3.3 Core technology capabilities.

Organisations that use a superior core technology in product development and process enhancements usually possess core technology capabilities. These technologies are generally accumulated over the long term and are difficult for competitors to duplicate (Huang, 2011). Organisation that wants to employ a superior core technology should first understand their existing technology as well as the technology competence needed for the new technology. By employing a superior core technology, imitation barriers are created which ensure a competitive advantage.

3.5.3.4 Innovation orientation by the top management team.

A dynamic, unpredictable changeable environment is suitable for the development of new innovation. In such an environment top-management is more likely to support innovation. On the other hand, earlier technology choices may hinder technology opportunities as existing competencies and resources were developed around these technological specialisations (Huang, 2011) and the adoption of new technology may make existing competencies and resources obsolete. An increase in transaction cost will therefore influence management decision to adopt new technology.

3.5.3.5 Commitment and autonomy of research and development.

Previous research (Tuominen, Rajala & Möller, 2004) indicates whether the organisation's research and development adapt to a dynamic, ever-changing environment which must be applied if innovation is to be enhanced. The research and development team should be allowed to choose the problems they which to work and the freedom to pursue them independently (Huang, 2011). In this way the innovative performance will be increased.

Organisations that deploy their technological assets, explore and exploit different technological opportunities, coordinate its technological capabilities, are research and development intensive and have a management team that are committed to improved technology performance will have a sustainable competitive advantage.

3.5.4 Engineering technology

A knowledge-driven global economy requires a skilled technological workforce (Duderstadt, 2016) which has implications for engineering practices. The development of new technologies in the information, biotechnology and nanotechnology fields as well as the development of complex, mega systems such as urban, transportation and communication infrastructure is challenging traditional engineering practices. To adapt to an ever-changing environment, engineering practices must be able to develop innovative solutions to an array of social, environmental, cultural and ethical issues. Technological design and innovation must take into consideration the social, economic, environmental, legal and political climate (Duderstadt, 2009). Technological applications in the engineering value chain will be investigated and discussed.

3.5.4.1 Technology for engineering design.

The global economy is marked by rapid growth of new knowledge woven together by ever-evolving information and communication technologies. The consequences of a knowledge-driven global economy are particularly important for engineering practices (Dudersadt, 2016). May and Strong (2006:204) indicate that "engineering is a profession that uses information and communication technologies to create new and improved systems, processes and products to serve human needs". Hence the need for a technological advanced workforce is imperative.

Traditionally in the design, analysis and manufacturing of products, processes or systems engineers use engineering drawings and other manual methods. Today the industry uses computer technology because of its low cost and rapid developments. Computer technology and specifically the 3-D solid modelling computer assisted design (CAD) technology are used in the engineering graphic designs, analysis and manufacturing (Miller, 1999).

The use of computer-based technologies tools such as constraint-based modellers, the World Wide Web (WWW), graphical simulation technologies, virtual reality tools, and using graphical databases for file translation between systems and for product data management (PDM) are be vital in becoming a successful practicing engineer (Miller, 1999). The use of computer-aided design becomes vital in the current global economy, where multi-disciplinary teams situated in different locations across the globe.

Leahy and Oster (2012) explain that the design of products processes and systems become more innovative in the last 40 years. New design disciplines were developed as the complexity of systems evolved (Leahy & Oster, 2012). Design teams evolved to become more multi-disciplinary in nature to enable additional complexities to the products, processes and systems (Leahy & Oster, 2012). Vanio (2012) and Stark (2015) mention that in recent years, the use of computer software in the development of products, processes and systems become known as Product Lifecycle Management (PLM). The following are the latest computer software applications used in the design of products, processes and systems in different engineering disciplines (Vanio, 2012 & Stark 2015):

- Digital mock-up (DMU) and CAE software such as finite element method analysis or analytic element method allows engineers to create models of designs that can be analysed without having to make expensive and time-consuming physical prototypes Computational fluid dynamics (CFD) of the design;
- Computer-aided design (CAD) software like Autodesk Inventor, DSS Solidworks, or PRO Engineer which enables engineers to create 3D models, 2D drawings, and schematics of their designs;
- Computer-aided manufacture (CAM) software to generate CNC machining instructions and support specific engineering tasks;
- Manufacturing Process Management software for production engineering;
- EDA for printed circuit board (PCB) and circuit schematics for electronic engineers;
- MRO applications for maintenance management; and AEC software for civil engineering.
- Product data management (PDM) software stores, organize, provide access and distribute information.

Computer-aided design and manufacturing enable products and components to be (a) checked for flaws, (b) assessed for fit and assembly, (c) study ergonomics, and (d) analyse static and dynamic characteristics of systems such as stresses, temperatures, electromagnetic emissions, electrical currents, voltages, digital logic levels, fluid flows and kinematics, thus delivering a superior product.

An engineer has to possess a measure of technological expertise as well as soft skills, such as teamwork and communication abilities to be successful.

3.5.4.2 Technological prowess of engineering professionals.

Adomavicius *et al.* (2013) state that the single most important factor in an organisation's technological base is its skills set which has to include a mix of technical and managerial skills. Miller (1999) mentions five technological skills that are imperative for engineers to become successful in today digital world as (a) engineering professionals should have strong advancing visualisation abilities which will enable them to use applied scientific visualisation technologies as a communication tool, (b) they should possess creative problem-solving abilities which can be used and developed with modern technology innovation, (c) use open-ended and structured design exercises in conjunction with modern design tools such as constraint-based solid modelling and CAD simulations and analysis which can improve and develop design skills, (d) have an understanding and knowledge of engineering graphic standards and conventions and apply these standards by using the latest computer graphic tools and (e) have the ability to sketch using CAD technology which increases efficiency in the planning and communicating sketches.

De Gea, Nicolás, Fernández Alemán, Toval, Ebert and Vizcaíno (2012) are of the opinion that engineering software tools must be able to elicit, specify, analyse, commit, validate, and manage engineering requirements while considering user, technical, economic, and business-oriented needs and objectives. Since these tools are fast evolving and the demand for more agile, flexible, advanced and worldwide collaborative software is increasing, De Gea *et al.* (2012) are of the opinion that engineering software tools have to be evaluated for its suitability. De Gea *et al.* (2012) suggest that ISO/IEC TR 24766:2009 should be used to evaluate engineering software tools capabilities. The document is a type 2 technical report which shows future but not an immediate possibility agreement on an international standard. The ISO/IEC TR 24766:2009 supplements the more general ISO/IEC 14102:2008 standard which focuses on evaluating computer-aided software engineering tools.

May and Strong (2006) listed the engineering technology skills industry demands from graduating and practicing engineers. These include (a) engineering design specifications, (b) design for manufacturing, (c) the overall design process, (d) design for assembly, (e) creativity methods, (f) solid modelling, (g) team design projects, (h) open-ended problem-solving, (i) CAD solid modelling, (j) interdisciplinary design projects and (h) written design reports.

In today's global economy, engineers do not function in isolation, but as multi–disciplinary teams which could be geographically separated. Therefore, with the rapid increase of new knowledge, especially in information and communication technologies, engineering students, graduating engineers as well as practising engineers should be exposed to the latest engineering computer-based technologies.

3.5.5 Performance management of technological competence

Early socio-technical theorists such as Trist and Bamforth (1951) were of the opinion that an increase of new technology does not necessarily translate to an increase in productivity, but rather, that it brings about greater bureaucracy. Trist and Bamforth (1951) and Lewis and Siebold (1991) suggest that the effectiveness of sociotechnical teams is dependent on the individual members, the cohesion within the team, effective leadership and the regulatory environment. Socio-technical theory further exploits the issue of proximity. It suggests that when team members are not in immediate proximity and groups are semi-autonomous, the need for communication is vital for the success of the project.

Adapting to the changes in technology often requires that the job specifications of the user be redesigned to fit the demands of the technology and maximise technology processes. Technologies often fail to recognise the human aspect and social relationships of the task and hence fail to increase total productivity (Bateman *et al.*, 2017). The sociotechnical systems approach is a macro-ergonomic work system model developed by Smith and Carayon (2000) which attempts to redesign tasks to optimise operations of new technology while preserving employees interpersonal relationships and other human aspects of work (Bateman *et al.*, 2017).

Ghosh and Sahney (2010) state that sociotechnical systems consist of a social sub-system which includes the members of the organisations, their profiles and interpersonal relationships and in addition it also includes individual motivation, group performance, communication, flexibility, involvement, autonomy, commitment, and satisfaction. The technical sub-system includes the tools, work techniques and procedures, skills, knowledge, and devices used by members of the social subsystem to accomplish the tasks of the organisation. The technical subsystem holds the technology that affects the input, transform inputs into outputs and provide the outputs or services to internal and external to customers Davis, Challenger, Jayewardene and Clegg (2014) illustrate a socio-technical framework as a work system with a set of goals and metrics, which involves people with different skills and attitudes, that uses a range of technologies and tools, working within a physical infrastructure, operating with a set of cultural norms, and using sets of processes and working practices. They (Davis *et al.,* 2014) further maintain that the system operates within a regulatory framework, with sets of stakeholders (including customers), and an economic/financial environment.

3.5.5.1 Application of sociotechnical system approach to engineering project teams

As discussed earlier, engineering projects are delivered by a project or development team, in which the success of the engineering project is dependent on more than one team which is usually multi-disciplinary in nature. Team interaction falls within the social subsystem. The focus on the socio-technical aspects in engineering projects refers to the right mix of social and technical capabilities within a team. Social capabilities when aligned with the technical capabilities within project or development team can result in improved team performance and the production of superior products (Maheshwari, Kumar & Kumar, 2012). Adler and Shenhar (1999) list the various technical and social skills engineers should possess in a technological innovative organisation. They are (a) knowledge of planning procedures to use in technology forecasting, budgeting, project selection, and project management and (b) collaboration across different functional teams so as to keep people who are focused on the same types of tasks together as well as keeping them updated.

3.5.5.2 Job redesign and human resources in engineering technology.

Davis *et al.* (2014) are of the opinion that socio-technical systems approach has a significant impact on the design of jobs and reorganisation of work. Batman and Snell (2014) state that managers face several choices with regard to the application of new technology since technology has the ability to limit the tasks and responsibilities of the workforce, "deskill" the workforce to such an extent that they are turned into the servants of the technology; nonetheless managers must be able to train and empower the workforce to master the technology, achieve greater success and improve the competitiveness of the organisation. When new technology is introduced, employees' jobs have to be redesigned to complement the new technology. Additionally, the organisation's human resources system, i.e. the performance management, incentive, recruitment, training and development and has to take the introduction of the new technology into consideration. The redesign of jobs and work processes will help organisations to deliver an improved work experience for employees and more effective systems. The socio-technical system approach framework originally developed by Leavitt (1965) as cited in Davis *et al.* (2014) focuses on the relationships between people, tasks, structures and technologies and provides a basis to redesign jobs and work processes. Davis *et al.* (2014) explain that the framework show the relationships between people, tasks, structures and technologies, the interrelatedness of the system components embedded in the external environment and the need for their joint consideration. For example if an organisational change occurs, such as the acquisition of a new technology, all other system components will be affected. This will then have to translate in the redesign, reorganisation of work etc.

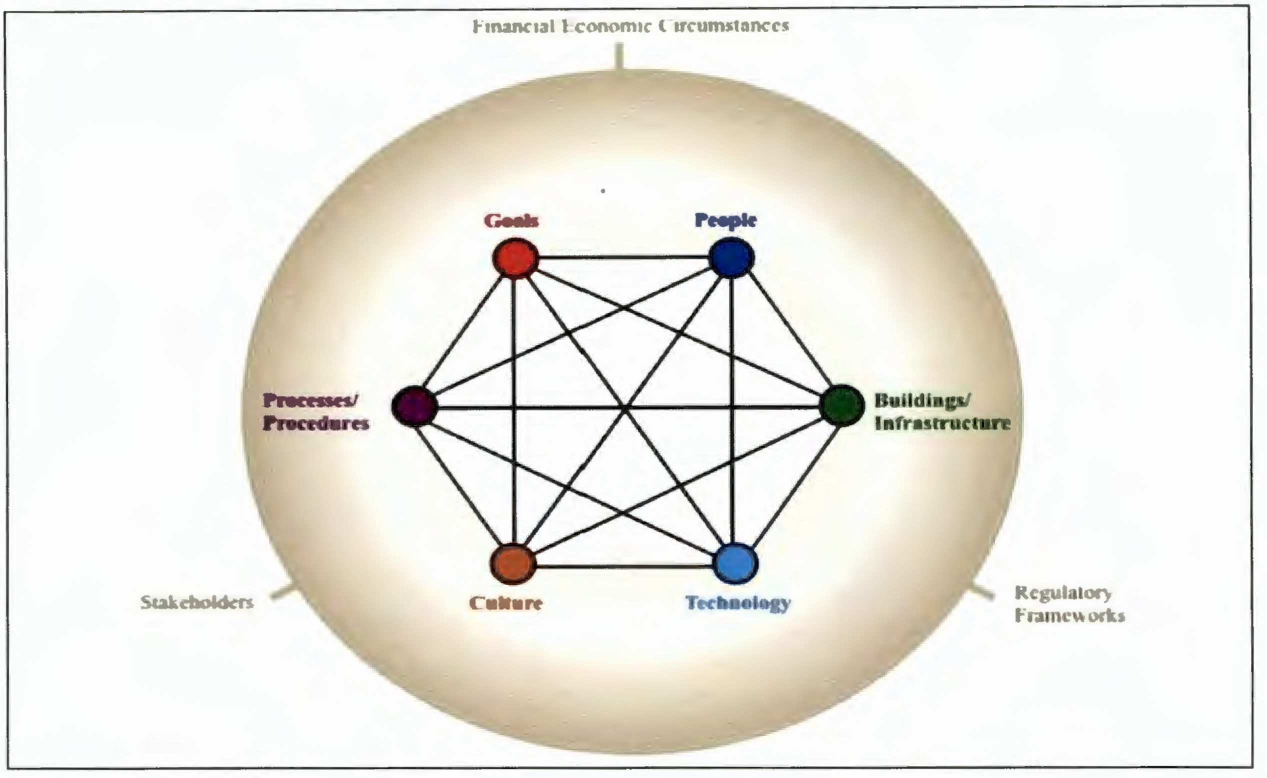


Figure 3.3 Socio-technical system and the interrelatedness between the system components, adapted from source, (Davis et al., 2014)

The acquisition of new technology does not necessarily bring about an increase in productivity. Changes in technology often require that the job specifications of the user be redesigned to fit the demands of the technology and the technology processes. The Socio-technical systems approach offers a framework that shows the interrelatedness of the different social sub-system which includes the members of the organisations, their profile and interpersonal relationships and how a change in one sub-system affects other sub-systems.

A knowledge-driven global economy requires a skilled technological workforce. Engineering is a profession that uses information and communication technologies to create new and improved systems, processes and products to serve human needs, engineers have to keep abreast with the changes in technology and remain competitive. The single most important factor in an organisation's technological base is its skills set which has to include a mix of technical, interpersonal and managerial skills. Adapting to the changes in technology often requires that the job specifications of the user be redesigned to fit the demands of the technology and maximise technology processes.

3.6 CSF 5: Environmental domain – policy, legislation, market

An ECSA (2011) briefing document states that South Africa, like many other developing countries is facing a severe shortage of high level engineering skills (Abimbola, 2016) therefore an urgent need to transform the profession and ensuring greater representivity exists. UNESCO (2010) mentions that in order for developing countries to become economically viable their human, institutional and infrastructure capacity should be developed. This requires a solid base of technologically skilled people. The World Federation of Engineering Organisations has therefore undertaken to build capacity in developing counties. UNESCO (2010) states that capacity building through education, training, mentoring and making resources available will strengthen economies, governments and institutions. UNESCO's strategies (UNESCO, 2010), to increase capacity in engineering are (a) transforming engineering i.e. addressing women and blacks participation in engineering (b) developing engineering ethics and a code of good practice (c) developing an sustainable engineering and technology policy and (d) the retention of engineering skills.

3.6.1 Transformation in the engineering industry

Table 3.1 Race breakdown of professional engineers in SA

White	African (A)	Coloured (C)	Indian (I)	Total Black (A, I and C)
13 657	1 671	175	1 023	2 869

Adapted from source: ECSA (2014)

The 2014 ECSA annual report states that there are a total number of 16 526 professional engineering registrations of which 17.4% are black and 82.6% white (table 2.1).

With regard to the increased participation of blacks in the engineering profession, Watson and Froyd (2007) suggested that one of the measures to recruit and retain blacks in the engineering profession is to (a) create supportive climate (Rice & Alfred, 2014) and (b) a sense of belonging. Within a group situation, individuals observe others in the group to achieve a sense of belonging, but also look for difference to maintain their identity (Rice & Alfred, 2014). A majority member has a sense of belonging without necessarily noticing the lone minority. The minority members notice instantly his/her minority status, and this is especially true in the engineering industry in South Africa where black South Africans are a minority and lack a sense of belonging. Creating a mentoring network can bring minorities together to create a greater sense of belonging and will enhance the recruitment and the retention of blacks in this profession (Watson & Froyd, 2007).

To address the low levels of blacks' participation in the engineering industry especially in leadership positions, transformation policies and practices such as the Employment Equity Act (EEA) were introduced but seemingly impacted negatively on the transformation of the engineering industry. Du Toit and Roodt (2008) found that the aggressive pursuit of affirmative action was costly and undermines the institution. These policies resulted in the migration of white, skilled engineering professionals which further contributed to the skills shortages. Another transformation policy directive is the implementation of an employment scorecard which measures representivity at management and board level. This resulted in the acceleration of transformation where inexperienced candidates are appointed into leadership positions which in turn affected the engineering standards and the quality of work produced. Du Toit and Roodt (2008) state that affirmative action policies can be counter-productive and can negatively affect the quantity and quality of professional engineers in the economy.

3.6.1.1 Women in engineering.

Table 3.2 Gender breakdown of professional engineers in South Africa in 2014

Male	Female
15 753	773

Adapted from source: ECSA (2014)

Table 2.2 shows 773 (4.7%) female registered engineering professionals compared to 15 753 (95.3%) males. Du Toit and Roodt (2008:91) are of the opinion that female participation in engineering can increase if career choices and the barriers that prevent full participation and success are addressed. Saavedra, Araújo, de Oliveira and Stephens (2014) point out that women are underrepresented in the engineering profession and that the industry had been trying numerous methods to increase the participation of women in an often male-dominated environment. Not only is recruitment of women engineers problematic, but also the retention and promotion of women in the profession presents a challenge.

Roodt (2012) states that women remains a minority in engineering and that several factors impacts on the representivity of women and black engineering professionals in South Africa. Du Toit and Roodt (2008) mentioned a few reasons for the lack of female participation in the engineering profession as (a) females regarding engineering as man's job, (b) traditionally; females are not attracted by technology and (c) a leakage of females in the engineering pipeline. Although women may be attracted to studying engineering, fewer enter the engineering profession (Faulkner, 2007).

Faulkner (2007, 2009) mentions poor work-life balance and the lack of family-friendly policies of organisations as some of the more observable difficulties women face in the workplace but also mentions other subtle undercurrents that make the workplace less comfortable for women than men. Faulkner (2007, 2009) investigated these dynamics in an ethnographic study in the United Kingdom (UK). She (2007) mentions (a) attracting women, (b) good practice to help women become engineers and (c) nurturing a more inclusive workplace culture as issues that can make the engineering workplace environment more suitable for women.

3.6.1.2 Stereotyping women in engineering.

Saavedra *et al.*, (2014) state that in the engineering world male engineers as still seen as the norm, being a woman is thus seen as uncommon and the reaction by others towards women engineers is a testimony of this fact. Often too, men are viewed as brilliant at and passionate about technology, and not too good at social interaction. The perception about women is that they have better people skills than their male counterparts and are often not technology savvy. However, the gendering of the technical-social divide (Buse, Hill & Benson, 2017), associating men with technology and women with social things are often incorrect and affect the recruitment of women engineers (Faulkner, 2007, 2009b). Recruitment should rather focus on enthusiasm about maths, science and technology and the desire to be practical, which are shared by both men and women.

3.6.1.3 Good practices to help men and women become a better engineers.

Frize (2011) mentions several hiring criteria that employers can develop to increase the number of women engineers as (a) proactively seeking women applicants, (b) differentiate between appropriate and illegal questions during the interview process, (c) identify and fast-track women with management potential in order to provide mentorship to younger women, (d) institute flexible hours for better work-life balance, parental leave made available to both mothers and fathers with no negative impact on their careers, (e) create access to affordable childcare, (f) provide visible assignments to people who need to build their self-confidence and credibility, (g) ongoing strategic support and advice over career development for talented junior engineers (Rice & Alfred, 2014) and (h) facilitate networks between peers and other women (Rice & Alfred, 2014) and junior engineers.

3.6.1.4 Nurturing a more inclusive workplace culture.

Many practices/cultures in the engineering workplace operate like male spaces, and in so doing it marginalise women and make it difficult for them to feel a sense of belonging. Faulkner (2009) mention practices where the types of conversation are often a narrow range of 'admissible' conversations that include (a) football and family which may silence and disregard others, (b) humour in the workplace that are harsh and offensive and that include racist, sexist and homophobic jokes, (c) gendered language such referring to an engineer as a he, (d) men-only social circles which often determine how the work gets done and who gets promoted, (e) when women are expected to become one of the boys to fit in, but at the same time not lose their femininity (Saavedra *et al.*, 2014), (f) women are more visible as women than as engineers and often have to establish their credentials to other colleagues and (g) sexual harassment and heavy flirting.

When dealing with diversity and equality issues it is paramount to create a nurturing environment where everybody feels valued and have a sense of belonging. Sensitive diversity training to raise awareness which involve all staff, including management and geared to a particular workforce should be implemented.

3.6.2 Engineering ethics

3.6.2.1 Engineering ethics.

Martin and Schinzinger (1996:23) define engineering ethics "as the study of the moral issues and decisions confronting individuals and organisations involved in engineering; and (b) the study of related questions about moral conduct, character, policies, and relationships of people and corporations involved in technological activity."

To understand ethical behaviour, it is therefore important to understand morality. Morality is defined in terms of what people see to be right and good and the reasons for it, whereas ethics is the philosophical study of morality. UNESCO (2010) describes ethics as the balanced investigation into people's moral beliefs and behaviour, the study of right and wrong, and of good and evil of human conduct. Morality and ethics are governed by a set of rules or rules of conduct and it prescribes what people ought and ought not to do in various situations. Ethical theory are mostly religious based, but the ethical theories according to UNESCO (2010:187-188) such as "Kantianism Act, that describes that you should treat others as ends in themselves and never as a means to an end, the Social Contract theory that are based on the benefits to the community, governing how people are supposed to treat one another which is talks about individual rights and explains why rational people act out of self interest in the absence of a common agreement and the Rawls theory that explains how each individual may claim basic rights and liberties as long as these claims are consistent with everybody's claim to the same rights and liberties" are theories that are helpful in the decision-making related to engineering works.

The WFEO (n.d.) defines a code of ethics as a discipline or field of study dealing with a moral duty or an obligation. The moral duty and obligation typically give rise to a set of guiding or governing principles which are used to judge the correctness of a particular conduct or behaviour.

Most professional engineering associations provide their own ethical guidelines to help engineers avoid misconduct, negligence, incompetence and corruption. The UNESCO (2010) report states that a complaint against an engineer who displayed unethical conduct can lead to disciplinary action, resulting in a fine or losing the licence to practice. The report (UNESCO, 2010) expands on the treatment of underrepresented groups stating that ethical behaviour includes the fair treatment of underrepresented groups by employers, peers or employees. Any form of discrimination against a person based on his race, gender, sexual orientation and religious beliefs should not be allowed. Other unethical behaviours are plagiarism, conflicts of interest, fraud and corruption. Another modern day phenomenon and a key component of ethical behaviour is the impact of technology on society. Technology can bring major benefits as well as threats in its wake. Laws and ethical codes of conduct that guide the direction and impact of technological development should be instituted in order for engineers become socially more responsible (UNESCO, 2010).

3.6.2.2 ECSA rules of conduct for registered persons.

Registered engineers are guided by the rules of conduct for registered persons prescribed in the Engineering Professions Act (Act 46 of 2000, section 27), named the Schedule. The objectives for the registered person are "to apply their knowledge and skill in the interests of humanity and the environment, execute their work with integrity, sincerity and in accordance with generally accepted norms of professional conduct, respect the interests of their fellow beings and honour the standing of the profession, continuously improve their professional skills and those of their subordinates and encourage excellence within the engineering profession" (Act 46, 2000:27:1). The rules of conduct (Act 46 of 2000) defines and explains the ethical framework for engineering professionals which includes competence, integrity, public interest, environment, the dignity of the profession and administrative issues related to the engineering profession. The ethical aspects of competence, integrity and public interest will be further elaborated upon whereas the environment will be discussed as a separate sub-factor under sustainable engineering.

3.6.2.3 Competence.

According to the Act (Act 46, 2000) registered engineering professionals must discharge their duties with skill, efficiency, professionalism, knowledge, due care and due diligence, engage in work for which education and training and experience rendered them competent to perform and which adhere to acceptable engineering practices.

The work of an engineer frequently directly affects public safety and health and can influence business and even politics, the words ethical and professionalism is often synonymous with the engineering profession. In most countries the engineering profession is self-regulated, which means that it is governed by its own association of engineers. In order to join this association engineers that apply are screened for competence by examining that the degree that is held by the engineer comes from an accredited programme. If not, the engineers are asked to pass a number of technical exams. All applicants are also requested to complete an exam on ethical practices.

Lynch and Kline (2000) argue that it is important for engineers to understand engineering standards and procedures, the effect of incremental changes, and human error in engineering design to anticipate and prevent potential threats to public safety that may arise during routine engineering works. Therefore, engineers should be able to learn how to identify features in their engineering work that can potentially contribute to problematic ethical outcomes. Engineers may face moral dilemmas when ethics are in conflict with management cost-benefit calculation.

Negligence is described as the failure to exercise due care required by law for the protection of the persons that may be adversely be affected by the want of such care. Vee and Skitmore (2003) indicate that negligence occurs during the design, prototype development and production phases.

3.6.2.4 Integrity.

Registered engineering professionals must discharge their duties with integrity, fidelity and honesty according to acceptable engineering standards and should not engage in any act of dishonesty, corruption and bribery (Act 46, 2000).

Vee and Skitmore (2003) suggest that one of the most common reported unethical behaviour in business is bribery. According to Vee and Skitmore (2003) bribes are offers of payments or incentives to someone in a position of authority to get them to favour the bribe payer and to which the bribe payer is not entitled to. Legally, it is important to distinguish between "gift giving" and bribery. What transforms gift giving to the illegal practice of bribery is when (a) when the person receiving the gift favours the interest of the gift giver and (b) when the gift puts the interest of the giver in a privileged position when all else is equal.

Other frequently reported unethical behaviour in the industry relates to fraud, breach of confidence, deceit, trickery and negligence described as when the payer sought to gain some dishonest and unfair advantage (Vee & Skitmore, 2003).

Because of the rampant cases of fraud, whistle-blowing, a common breach of confidentiality is encouraged. However Vee and Skitmore (2003) advise that whistle blowing should be used as the very last resort only after (a) need (b) proximity (c) capability and (d) last resort option have been satisfied.

3.6.2.5 Public interest.

The Act (Act 46, 2000:3) states that a "registered engineering professional must have due regard and priority for public health, safety and interest and must be able to provide professional advice to clients and employers, however if the advice is not accepted must inform the client or employer of the consequences which may be detrimental to public health and safety and interest". Vee and Skitmore (2003) indicate that the engineering profession is a service profession where a group of people with specialised knowledge is organised to serve the interest of society or are entrusted to safeguard some matter that may significantly affect the health and safety of others.

3.6.2.6 Dignity of the profession.

The Act (Act 46, 2000) states that the registered professional must uphold the dignity, standing and reputation of the profession and must provide work and services of acceptable standards and practices required by the profession. All registered professionals are therefore bound by a set of principles, attitudes and types of character disposition that control the way the profession is practised. The type of unethical behaviour that may affect a person's professionalism is conflict of interest that if followed, which may prevent a person from meeting one of their obligations. Another is the action termed the Right of Conscientious Refusal (Vee & Skitmore, 2003) when the employee refuses to participate in unethical conduct if coerced by the employer.

When faced with ethical issues Andrews and Kemper (2003) suggest several steps that can be applied to the decision-making process, there are (a) recognising an ethical problem that needs to be solved and gather information about the problem, (b) defining the ethical problem, i.e. what is wrong and what codes or laws have been breached and how ethical theories define this situation, (c) generating alternate solutions by evaluating all approaches that may exist and approach a part of the evaluation process, (d) evaluating the solutions and their consequences with the help of the ethical theories and codes of ethical practice considering the legal aspects of the problem, (e) selecting the most appropriate solution for the situation, (f) implementing the solution keeping in mind that the solution may require several additional steps depending on the severity of the offence and (g) considering corruption and fraud where bribes have been accepted especially with regard to those in authority and especially public authority positions.

3.6.3 The retention of engineering skills

Skilled professionals can make a positive contribution to a country's development. Global talent is now more mobile than ever and Facchini and Lodigiani (2014) observed that many countries are developing policies and programmes to attract highly-skilled students, temporary workers and immigrants. Ellis (2008) and Gwaradzimba and Shumba (2010) see the movement of highly-skilled workers from one country to another as one of the greatest threats to socio-economic development in Africa. Labour market demands in developed countries have increased due to an aging labour force and a rapid decline in birth rates and skilled professionals from developing countries are filling these gaps (Maharaj, 2010). Maharaj (2010:97) is of the opinion that "skilled immigrant entering a country comes with the sum of past investment and a stream of future revenue rooted in the competencies of that individual". Gwaradzimba and Shumba (2010) maintain that the country of origin suffers a net loss because it funds the education and training of the skilled professional whereas the receiving country makes a net gain, by obtaining qualified workers without having to bear the cost of training them. The implications of losing skilled and talented professionals on an economy are (a) a decrease in job creation; (b) a decrease in foreign investment, (c) an increase in expenditure on education and training to compensate for the loss of skills; (d) hinder innovation and the adoption of new technologies; (e) reduce the quality of social services and (f) affect development targets and worsen inequalities between developed and developing countries (Maharaj, 2010).

3.6.3.1 Push and pull factors affecting immigration.

Maharaj (2010) explains that the factors affecting the immigration of skilled professionals to more developed countries are regarded as either push or pull factors. Pull factors are (a) higher salaries, (b) opportunities for research, (c) professional development and promotion, (e) improvement in the quality of life, (f) advanced higher education institutions, (g) attractive scholarships, (g) stable political environment and intellectual and academic freedom (World Migration Report, 2003). The World Migration Report (2003:218) mentions that push factors include "(a) poor socio-economic living conditions, (b) unemployment, (c) increasing the dependency burden of household wage-earners, (d) drops in real income, (e) currency devaluation and rising cost of living, (f) rigid government employment systems, (g) professional isolation, (h) tribal/ethnic discrimination in appointments and personnel policies, (i) corruption, employer discrimination against the qualifications held, (j) social unrest, political conflict, wars, (k) drop in education standards, competition with expatriates and (l) lack of freedom" that affect the immigration of skilled professionals from their countries of origin. Gwaradzimba and Shumba (2010) suggest that crime is the main reason why skilled professionals leave South African for other destinations. Other reasons include uncertainty about future leadership, better business opportunities elsewhere, racial discrimination, poor quality of education and poor quality of healthcare.

Table 3.3 International migration from South Africa

Total thousands	Percentage of total population	Percentage Female Migrants	Average annual rate of change (%)	Net migration among the foreign-born(thousands)	Remittance	
					Total (millions of US dollars)	% of total GDP
2010	**2010**	**2010**	**2005–10**	**2005–10**	**2007**	**2007**
1863	3.7	42.7	8.0	684.0	834	0.3

Adapted from source: United Nations (2010)

Table 2.3 indicates that in 2010, 1 863 000 (3.7 per cent) South Africans emigrated. The net migration from 2005 – 2010 is 684 000 individuals. The net migration figure is calculated as the total number of individuals leaving their country of origin minus those entering. Table 2.11 shows that between 2005 and 2010 South Africa experienced a positive net migration showing that the pull factors outweighs the push factor in this country. The positive net migration in South Africa is due to the influx of refugees from surrounding African countries, such as Zimbabwe seeking better employment opportunities. Based on Lee's theory of selectivity in migration (1966), people with lower level skills tend to migrate regionally because of barrier to mobility. The majority of migrants coming from surrounding countries to South Africa generally have a lower level skills base. Policies, such as the demand for high-end skills, eliminating barriers to entry for people with scarce skills are favoured, allowing students that have obtained their higher degrees in South Africa to stay after graduating as well as inviting professionals to settle here with their families.

3.6.3.2 Factors affecting the loss of engineering skills in South Africa.

Kraak and Press (2009) are of the opinion that South Africa is experiencing a loss of engineering skills through emigration. Ellis (2008) states that when a skilled worker emigrates the country incurs a loss in tax revenue, resulting in lower economic growth. Ellis (2008) concurs that the push factors for engineering professional of all races are (a) the high cost of living, (b) high taxation, (c) fear of crime, (d) high levels of corruption, and (e) the poor education system in South Africa.

3.6.3.3 Addressing the skills gap.

Over the past few years, South Africa has made major investments in huge infrastructural projects; these include the construction of the soccer stadiums, rail and road networks and power-plants. A lack of critical and scarce skills provided an opportunity to recruit foreign skilled labour into the country. Foreign workers were able to plug the skills gap in the domestic market (Hall & Sandelands, 2009). Hall and Sandelands (2009) found this was not without difficulty as many barriers to entry into the country exist, such as (a) difficulty in obtaining work permits and (b) the corrupt practices of some home affairs officials. Blockages in the system are being addressed by relaxing many of the immigration laws. Business processes in many home affairs department offices have become more efficient and corrupt practices are being addressed. Visas are now processed in record time to allow easy entry into the country. Hall and Sandalands (2009) are of the opinion that when skilled foreign workers are used, opportunities for the transfer of skills from foreign to local workers must be created and encouraged.

With South African labour laws and policies such as ASGISA JIPSA and the SETAs having the development of scarce and priority skills as a high priority, Kraak and Press (2008) suggest that turning towards immigration for the convenience of an already skilled workforce may create an impression that companies are less committed to train and develop their own.

3.6.4 Engineering for sustainable development

In addition to achieving the MDG, environmental sustainability is becoming one of the most critical matters for many countries, industries and citizens that should to be addressed. Morrell, Bash, Trucco and Patel (2013) mention that the world's population will exceed nine (9) billion by 2050 which will impact on the consumption of natural resources and put tremendous strain on economic growth of both developing and developed countries. A growing population will cause (a) a rise in prices for critical materials such as copper and steel, (b) a reduction of petroleum output around the world, (c) a limitation to city scale waste disposal, and (d) an increase in environmental costs associated with consumption and production. Extending the current infrastructure to meet the growing needs of society and address environmental concerns is not enough, more has to be done.

Morell *et al.* (2012) suggest that sustainable environmental concerns can be addressed through a universal approach of resource management of physical infrastructure using IT technology. With regard to sustainable and renewable energy resource, Morell *et al.* (2012) looked at the supply of energy resources suggesting that pools of available resources with design and management that reduce the requirements to extract, manufacture, mitigate, waste, transport, operate and reclaim components of energy be used. The use of scalable, flexible "micro-grids" which incorporate various sources of locally-sources energy such as solar electricity and wind turbines to complement centrally sources electrical energy. Additionally, Morell *et al.* (2012) suggest energy can be source from waste streams such as methane from waste water and methane derived from manure in local farms. In arid and water constrained areas the use of intricate water harvesting to enable a micro-grid of water can be used. To build these micro-grids professionally trained engineers should have, sound technical, design and IT experience, be able to work in a multi-disciplinary team and be capable of optimising solutions with input from many perspectives, such as technical, social, historical and economical.

The MDG aims to reduce global poverty and improve living standards of all human beings by 2050. Engineering is therefore vital in address the deficiencies identified in the MDG. Engineering is crucial to develop basic physical infrastructure, a precondition for creating a viable and sustainable economy. Engineering solutions must consider the use of natural resources and ensure that engineering solutions have positive or neutral effects on natural resource consumption (UNESCO, 2010). Sustainable environmental engineering should adopt a universal approach to resource management of physical infrastructure using IT technology solutions. The supply of energy resources should look at pools of available renewable and sustainable resources to ensure sustainability.

3.7 Conclusion

Globally the engineering industry is facing the same issues and challenges which impact on the capacity in engineering, the ability to address poverty and affect sustainable development of the environment and growth of the economy.

This chapter analysed and reviewed the state of engineering in the BRICS (Brazil, Russia, India, China and Brazil) nations, extrapolated CSF from this analysis and compared it with the current state as identified CSF for the engineering industry in South Africa. If addressed, the five (5) CSF and sub-factors identified, will improve their economic growth and global dominance.

The CSFs, training and development aim to create a critical skills pipeline to significantly increase the production of crucial human resources in the engineering industry from which engineering skills can be sourced. The skills, knowledge and attitudes produced should satisfy the industry. Additionally, the industry has to think of creative ways to attract and retain this scarce resource. An effective talent management strategy integrated into the human resources management strategy can be used to retain this much needed skill.

The CSF, engineering value chain examined how the engineering industry operates. An understanding of the industry enables engineers and engineering activities to adapt to the changing environment. Knowledge of the engineering industry is the ability to understand the business functions within the industry.

The CSF skills, attributes and qualities of an engineer consist of various skills, attributes and qualities an engineer must possess to practice effectively and in a professional manner and answer the demands of the 21st century.

The CSF technology innovation is based on the technology road map and investigates the technology needed to transform resources into new products, process or service. The engineering industry is dependent on technology and rapid innovation to become globally competitive. Engineers have to understand how technology emerges, evolves and affects the way they do their work and therefore has to keep abreast with rapid pace of changing technology. Engineering uses information and communication technologies to create new and improved systems, processes and products, a technological advanced workforce is therefore imperative.

South Africa is facing a severe shortage of high-level engineering skills consequently an urgent need to transform the profession to ensure greater representivity of previously disadvantage individuals, is needed in the industry. The CSF engineering issues and challenges looks at capacity building through education, training and mentoring in order to minimise the loss of skilled professional through immigration. Additionally, engineering being crucial to the development of basic physical infrastructure, a precondition for mitigating poverty and creating a viable and sustainable economy, engineering solutions must consider the use of natural resources with the minimum impact on the environment.

Chapter four (4) will discuss the methodology employed to create a conceptual framework of the CFS identified for the engineering industry in South Africa. The methodology will outline the research instrument, research sample and research methods.

CHAPTER 4: RESEARCH METHODOLOGY

4.1 Introduction

Research methodology is the strategy employed to scientifically resolve the research problem. The outline of the chapter entails (a) the philosophical worldview where researcher have to think through assumptions that they bring to the study, (b) the research design that is related to worldview, and (c) the specific methods or procedures of research that translate the approach into practice (Creswell, 2014).

In this chapter the researcher will therefore discuss the philosophical worldview, the research approach, the study design and the research methods which outline the framework for the collection, analysis, interpretation and validation of the data in an effort to answer the research questions of the study.

4.2.1 Research philosophy

The study follows a post-positivism worldview. Post-positivism subscribes to the quantitative method approach. According to Creswell (2014) post-positivism is a philosophical approach to the creation of knowledge and is characterised by the following, viz. (a) that knowledge is based on empirical observation, (b) testing of theories and (c) the development of universal laws.

4.2.2 Research approach

The study draws on a quantitative research approach. This approach is deductive in nature, where existing theories and an in-depth literature review are used to develop a suggested engineering conceptual framework for the South African engineering industry. The researcher thereafter hypothesised whether relationships exist between the chosen variables. This approach allowed the researcher to make use of a structured questionnaire and to perform statistical tests on quantified data. The outcome of the quantitative confirmed or rejected the hypotheses.

4.2.3 Research strategy

In this research, an exploratory analysis was conducted to understand the variety of connections and relationships between independent and dependent variables for the needs of the South African engineering industry, by focusing on specific variables of interest. This decision was arrived at after taking into consideration the objective of the study. The survey technique allowed the researcher to collect data from respondents who were geographically widely dispersed (engineering professionals within different sectors). The strategy also made possible the collection of data that could be used to create relationships between variables for further interpretation. Saunders, Lewis and Thornhill (2009) define the research strategy as the general plan on how the researcher will go about answering the following research questions:

1. What are the factors and sub-factors appropriate for the needs of the South Africa engineering industry through a literature review?
2. What are the significant factors and sub-factors impacting on the needs of the engineering industry in South Africa?
3. What is the underlying structure for the proposed engineering systems framework for the South African engineering industry?
4. What will the conceptual framework for a South African engineering industry look like?

4.3 Theoretical framework

A suggested conceptual framework was developed after review of the documents. Bryman (2008) mentions that documents can be a source of data, although the reliability and validity of such documents are rarely perfect. The review of documents in this study occurred concurrently and sequentially. The ES theory suggested by Bartolomei *et al.* (2012), IEA Report (2013), and literature on state of engineering in the BRICS consortium were reviewed to develop the suggested conceptual framework which will be tested in the research.

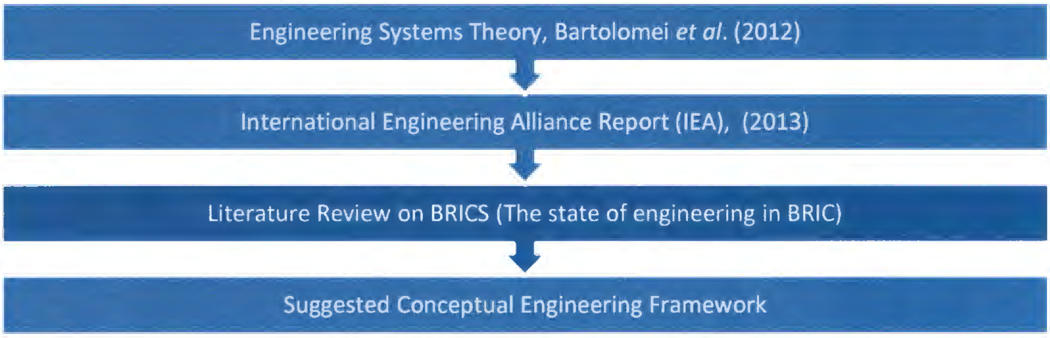


Figure 4.1 Steps in the development of the suggested conceptual framework

According to Sekaran (2003), a variable is anything that can take on differing or varying values. The literature survey (Chapter 3) investigated the factors and sub-factors (dependent variables) suggested in the framework. This framework made logical sense and shows relationships between variables. The independent variables in this research comprised of engineering disciplines, engineering categories (levels), age, gender, nationality, registered with a professional engineering body and professional engineering status. In developing the theory, the researcher hypothesised relationships between independent and dependent variables so as to understand the dynamics of the problem.

4.4 Quantitative research method

According to Williams (2007), quantitative research is a scientific, systematic investigation of data and their relationships to one another. The aim of quantitative research is to construct and use numerical forms, philosophies and hypotheses relevant to natural phenomena, through the use of statistics (Williams, 2007). Quantitative research is concerned with verifying hypotheses and/ or being able to estimate the size of a phenomenon of interest.

According to Williams (2007) quantitative research has the following characteristics:

- It is deductive, the researcher tests the hypotheses and theory with the data;
- It measures attitudes, opinions and behaviour;
- It is objective; where the researchers should as far as possible remain distanced from what they study so findings depend on the nature of what was studied rather than on the personality, beliefs and values of the researcher;
- It collects quantitative data based on precise measuring using structured and validated data collection instrument (close-ended items, rating scales, behavioural responses)
- It establishes relationships and causation among variables;
- A literature review must be done early in the study.
- The sample should be representative of a large population.
- All respondents are asked the same questions.
- It offers true characteristics of the particular individuals, circumstances or groups.
- It reports statistical analysis used to summarise and describe quantitative data. Figures and/or tables are used to visualise present raw data.

4.5 Research instrument

The study uses a cross-sectional survey design (Bryman, 2008). In order to do this a carefully constructed questionnaire with closed-ended questions, and ranking options was used. A closed-ended question limits respondents to a specified number of answers. By deploying this research approach delineated by Hofstee (2006), the researcher will be able to (a) identify the factors/variables that influence an outcome, (b) test the suggested conceptual framework, understanding the best predictors of outcomes through identifying casual relationships and (d) establish an intervention strategy, a conceptual framework

4.5.1 Questionnaire design

Hofstee (2006) and Creswell (2014) indicate that the basic purpose and rationale for the questionnaire design is to 1) generalise from a sample of to a population so that inferences can be made about some characteristics, attitudes, or behaviour of this population; 2) create the questions through the literature; 3) pose questions related to the observable behaviour, allowing the respondents to draw on first-hand experience and not inference; 4) measure behaviour and opinions linked to the CSF for the needs of the South African engineering industry; 5) not set the questions in ranking order as persons tend to remember the first and the last items on a list, which may bias the answers to the questions; 6) have economy of design and the rapid turnaround in the data collection; and 7) ensure that the survey could be completed in 15 minutes.

4.5.2 Pilot study

The questionnaire used in this research was pre-tested before being distributed. A pilot study was conducted to ascertain 1) how well the respondents understood the questions, 2) whether the questions were leading or loaded, 3) whether the selected respondents, i.e. engineering professionals had the necessary information at their disposal to answer the questions, 4) whether the layout was designed in such a way that it would be easy for the respondents to read, 5) how long it took to complete the questionnaire, 6) whether the questions were too long, and 7) whether there were any ambiguous questions.

4.5.3 Sampling

Stratification as a sampling technique was employed in the pilot study. The population was stratified using academic levels, i.e. individuals with an engineering qualification were asked to participate through an e-mail request to the heads of the engineering departments of Eskom and the Department of Water Affairs (DWA). Twelve (12) people from the DWA responded and 30 in Eskom. This brings the response rate in the pilot study to 5.9% of the total sample (705).

The respondents indicated that some engineering categories were omitted and that the online questionnaire prevented them from selecting certain Likert items. This was corrected; and additionally two questions were adjusted because of ambiguity. Clarification was also provided to respondents who could not understand some key concepts.

4.6 Statistical measures

A five-point Likert scale was applied (McLeod, 2008). According to McLeod (2008) the advantage of a Likert scale is that it is quick and easy to construct, is easy to administer, there are several variants of the Likert scale that are commonly used, it varies from a four to a nine-point scale, each item meets an empirical test for discriminating ability, is reliable and provides a huge volume of data and can be analysed by virtually a full range of statistical procedures. A balanced rating scale with an odd number of categories and a neutral point (Malhotra, Krosnick, & Thomas, 2009) was used. The researcher was of the opinion that some respondents would not have an opinion or be reluctant to disclose an opinion; hence to ensure the accuracy of the data, a non-forced scale that included "unable to provide a response" category was included. This is confirmed by Malhorta *et al.*, (2009) and Drummond and Ensor (2005) who are of the opinion that if a neutral or indifferent response is possible from at least some of the respondents, an odd number of categories should be used.

As stated by Likert (1932) attitudes towards any object or issue varies along the same underlying negative to positive- dimension. Johns (2010) states that this has three significant implications (a) his method is universally applicable measuring opinions on subjects, (b) it provides that the response options covered the negative-to-positive dimension and (c) responses are comparable across different questions and could be assigned the same numerical codes. Likert (1932) indicate that with multiple items on the same broad object codes could be summed or averaged to give an indication of each respondent's overall positive or negative orientation towards that object. The five-point Likert-type scale included 1 = strongly agree; 2 = agree; 3 = disagree; 4 = strongly disagree and 5 = unable to provide a response. The codes were summed or average to give an indication of each respondents positive or negative orientation towards the object, therefore the data were reduced to the nominal level by combining strongly agree and agree and strongly disagree and agree responses into two categories of "agree" and "disagree".

4.7 Census and sampling techniques

The term *census* includes all members of a defined group or object (the 16 526 registered members on the ECSA database) are under study and from whom information were requested for data-driven decisions (Sekaran, 2003). Since only a few units (705) responded to the survey, this is called a sample. A sample possess the same characteristics as the population.

4.7.1 Census

The census comprised the 16 526 registered engineering professionals consisting of professional engineers, professional engineering technologist, professional certified engineers and professional engineering technicians. Table 4.1 indicates the distribution of engineering professionals in each specified category registered on the ECSA database.

Table 4.1 Engineering professionals in specified categories

		Engineering Category			
		Professional Engineers	**Certified Engineers**	**Engineering Technologist**	**Engineering Technicians**
Gender/Race	**Total Registration**	**16526**	**1076**	**5491**	**5214**
Gender	**Male**	15753	1069	5145	4509
	Female	773	7	346	705
Race	**African**	1671	71	1487	2434
	White	13657	952	3311	2299
	Indian	1023	40	474	283
	Coloured	175	13	219	198

Source: Adapted from ECSA (2014)

4.7.2 Sample

Fowler (2013) defines a sample as a set of data gathered from the population whose properties are studied to gain information about the whole. When dealing with people, it can be defined as a set of respondents selected from a larger population for the purpose of a survey (Mugo, 2002).

4.7.3 Random sampling technique

The researcher used the random sampling technique, which is a systematic or probabilistic sampling technique where each individual in the population has an equal probability of being selected. With randomisation, a representative sample forms a population and provides the ability to generalise to a population (Creswell, 2014).

The survey was distributed to the 16 526 engineering professionals registered on the ECSA database. A total of 663 people responded. The total sample of 705 includes the respondents at Eskom (30) and the respondents from the Department of Water Affairs (12) who responded in the pilot study.

Fowler (2009) suggests that the sample size determination relates to the analysis plan. Research Advisors (2014) uses a table that suggests the optimum sample size for a given a population size, at specific margin of error and a desired confidence interval. The margin of error in this table varies from 5.0% to 1.0% on a confidence level of 95% and 99%. The population of 16 526 was included in the table, and the required sample size at a 95% and 99% confidence level at different error margins was calculated.

Table 4.2 Required sample size for a given population

Population size(N)	Confidence = 95% Margin of Error 0.05	Confidence = 95% Margin of Error 0.01	Confidence = 99.0% Margin of Error 0.05	Confidence = 99.0% Margin of Error 0.01
10	10	10	10	10
20	19	20	19	20
30	28	30	29	30
50	44	50	47	50
75	63	74	67	75
100	80	99	87	99
150	108	148	122	149
200	132	196	154	198
250	152	244	182	246
300	169	291	207	295
400	196	384	250	391
500	217	475	285	485
600	234	565	315	579
700	248	653	341	672
800	260	739	363	763
900	269	823	382	854
1,000	278	906	399	943
1,200	291	1067	427	1119
1,500	306	1297	460	1376
2,000	322	1655	498	1785
2,500	333	1984	524	2173
3,500	346	2565	558	2890
5,000	357	3288	586	3842
7,500	365	4211	610	5165
10,000	370	4899	622	6239
16,526	375	6074	638	8279
50,000	381	8056	655	12455
75,000	382	8514	658	13583
100,000	383	8762	659	14227

Source: Adapted from the Research Advisors (2014)

From table 3.4 it is clear that n = 375 is an adequate sample size for N = 16 526 at a 95% confidence level with a 5% error margin. The response rate of n = 705 is therefore adequate for this study.

4.8 Research site

The research site refers to the place where data was collected. The Engineering Council of South Africa (ECSA) maintains a database of registered engineering professionals comprising of professional engineers, professional technologist, certified engineers and professional technicians. Since the target group for the study was engineering professionals across all engineering disciplines, the researcher decided to collect data via the ECSA database by making use of a web-based survey, SurveyMonkey ™. A formal e-mail was sent to the Acting CEO of ECSA, Mr Edgar Sabelo, requesting permission to access the database. Access was granted. An e-mail request with a link to the web-based survey was developed and distributed by ECSA to all registered engineering professionals.

4.9 Data collection

The data used in the research was collected from two different sources, 1) an in-depth literature review and 2) an online survey.

Table 4.3 Data-collection sources

Data required	**Source**	**Strategy**	**Primary/Secondary data**
Suggested ES theoretical framework	Literature	ES theory suggested by Bartolomei *et al.* (2012), International Engineering Alliance (IEA) Report (2013) on the attributes of the 21st century engineer and a literature review on state of engineering in the BRIC consortium	Secondary
Identified factors and sub-factors to be investigated	Literature	Extensive literature review	Secondary
Quantitative data: Perceptions about the future needs of the engineering industry	ECSA database	Web-based survey	Primary

Creswell (2014) explains that a self-administered questionnaire sent to a sample of a population via electronic means is an accepted method of data collection. Creswell (2014) is of the opinion that conducting an online survey is economical and ensures rapid turnaround in data collection. It is also an effective method when a large number of people are surveyed.

Rubin and Babbie (2011) state that when an online survey is conducted, is important to obtain the consent of respondents. Their anonymity and confidentiality should be guaranteed. To ensure the above, a cover letter explaining the aim of the research, the process that had to be followed as well as consent from the acting CEO, Mr Edgar Sabelo, were compiled and attached to the questionnaire. The cover letter assured the respondents of anonymity and confidentiality and stated that they can complete the questionnaire on a voluntary basis.

The data was collected once and over a specified period of time, from October 2014 to February 2015. The respondents were guided to click on the web link provided. The questionnaire consisted of 50 questions, which were formulated in such a manner that it would be easy for the respondents to comprehend and complete. Respondents could click on the option they mostly agreed with. The questionnaire was open and accessible for a period of four months. The researcher downloaded the completed surveys using the SPSS tool available on SurveyMonkey ™ and made it available for statistical analysis.

4.10 Statistical analysis

The responses and measures of location of the 50 items in the questionnaire were summarised. Analytical techniques were applied. These include the following:

4.10.1 Descriptive statistics

Descriptive statistics are defined by Schreiber (2008) as a mathematical summary of the data where frequency distributions are numerically converted to a few numbers. Descriptive statistics were performed to give a general view of the data in this study. A descriptive analysis of each data element uses frequency counts and mean and standard deviations. According to Manikandan (2011:54), a frequency distribution is an 'organised table or figure of the number of individuals or objects in each category on the scale of measurement'. A frequency distribution organises and presents frequency counts in summary form so that the data could be easily interpreted and be used to determine subsequent steps in the analysis (Punch, 2009).

4.10.2 Univariate analysis

A univariate analysis was performed. A univariate analysis examines each variable in a data set separately. It looks for central tendency of the values and describes the pattern of responses to the variable (Manikandan, 2011). The univariate analysis can be descriptive or inferential. For the purpose of this study a five point he Likert scale were used, i.e. strongly agree, agree, strongly disagree and disagree and unable to provide a response. The variables are categorical and the tendency of the respondents was determined.

4.10.3 Cross-tabulation analysis

Cross-tabulation is a method that has been identified as a contingency table. It is a combined frequency distribution based on more than one categorical variable (Michael, n.d.). This test helped the researcher to measure scale data and compare variables with one another. It provided more information about the connection between factors.

4.10.4 Chi-square analysis

Chi-square measures whether a significant difference between two variables exists or whether they are related (Cochran, 1952). The method together with cross-tabulation analysis helped with the testing of the hypotheses.

4.10.5 A component factor analysis

A component factor analysis examines the underlying structure for the proposed engineering systems model for the South African engineering industry, it explores whether the factors such as training and development/social-environmental, individual attributes/social of an engineer, engineering value chain/process-function, technical and environmental factors model the needs of the South African engineering industry as suggested in the engineering systems model.

4.10.6 A structural equation modelling

A structural equation modelling represents, estimates and tests a network of relationships between variables (Suhr, 2000). It tests (a) hypotheses about relationships among observed and latent variables, (b) represents, estimates and tests a theoretical network of linear relationships between variables and (c) to test hypothesised patterns of directional and non-directional relationships amongst a set of observed (measured) and unobserved (latent) variables. With an SEM the researchers aim to understand the pattern of correlation/co-variance and to explain their variance as possible with the model specified.

4.11 Ethical considerations

The design, conduct and research were conducted in accordance with recognised standards of scientific competence and ethics, by:

- minimising the possibility that the results would be misleading by testing reliability and validity of the research instrument;
- ensuring that all materials used are cited and acknowledged properly;
- obtaining appropriate consent from the Acting CEO of ECSA to use the existing database;
- obtaining appropriate consent from the respondents;
- protecting the identities and interests of the respondents through an anonymous questionnaire.

4.12 Voluntary participation

Participation in all studies should be voluntary. Although participation in the study can be coerced, the researcher should not force respondents to participate in the study. All respondents participated out of their own free will and were under no obligation to do so. The respondents participated with an understanding that there would be no negative consequences for them.

4.13 Informed consent

Another significant problem in research concerning social interference is to make sure that respondents who participated in a research study were fully aware of the aims and objectives of the study and are informed if there are any possible negative impacts. In this case, the researcher attached an information/request letter (see Appendix A) to the online survey when the online survey were distributed to all the potential respondents. This letter helped the researcher to increase the response rate.

4.14 Confidentiality and anonymity

In the information letter, the respondents were assured that their answers would be confidential and/or anonymous. Anonymity was accomplished through random surveying.

Confidentiality was assured; through the online survey only participants' IP addresses were known, but did not appear anywhere in the report.

4.15 Possibility of harm

Respondents can be physically, psychologically and emotionally harmed. In an effort to mitigate potential harm, anonymity and treating confidential information with sensitivity and respect ensures that no harm would come to respondents as a result of their participation in the research study. Other potential harmful practices were identified and mitigated. No harm was reported during the collection of the data.

4.16 Communicating results

During the completion of the research project, the researcher minimised plagiarism, academic fraud, and misrepresentation of the findings. The participants were informed that on completion of this study, they would receive feedback.

4.17 Plagiarism

The researcher was very careful not to present someone else's work as her own and cited appropriate references where necessary.

4.18 Academic fraud

Academic fraud is classified as being worse than plagiarism. It is the intention to misrepresent what has been done by other researchers (Schrimsher, Northrup, & Alverson, 2011). Academic fraud usually occurs during the collection, analysis and interpretation phases of any research (Schrimsher, *et al.*, 2011). The researcher avoided any false techniques in analysing and interpreting the data collected via the use of questionnaire.

4.19 Reliability and validity

4.19.1 Reliability

Reliability is the consistency of a set of measurements of a measuring instrument. A measure is considered reliable if it would give us the same result over and over again. The inter-item reliability, or Cronbach's alpha reliability coefficients of the fifty dependent variables were obtained. An illustration of the outcome for Cronbach's alpha test for the dependent variables are represented in table 4.4 The closer the reliability gets to 1.0, the better. Generally, reliabilities less than .60 are reflected to be poor, those in the .70 range, satisfactory, and those over .80, good (Creswell, 2014).

Table 4.4 Cronbach's alpha reliability coefficients

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.867	.871	50

The consistency of measurements for the 50 items can be categorised as good since they were all above .80 (.867).

4.19.2 Validity

Validity implies reliability (consistency). A valid measure is one that measures what it is supposed to measure. A valid measure must be reliable, but a reliable measure need not necessarily be valid. Validity refers to obtaining results that accurately reflect the concept that is measured (Watkins, 2006). Construct validity ensures that the abstract concepts are measured adequately and logically and that the relationship between variables are identified with the research instrument based on theory and clear definitions (Burns & Grove, 2009).

A Cronbach Alpha was conducted to test construct validity of the measuring instrument. The test shows adequate validity of 74.5%, it can therefore be assumed that the measures used in this study are valid and effective for what they were intended.

Table 4.5 Cronbach Alpha testing validity of the measuring instrument

Items	N	%
Valid	527	74.5
Excluded	178	25.5
Total	705	100.0

4.20 Conclusion

This chapter provided the reasons for selecting the chosen methodology and how the methodology was implemented. The study follows a post-positivist worldview. The research strategy is exploratory in nature. A cross-sectional, survey-based research approach as a method for measuring perceptions was used to collect data from employees registered as engineering professionals on the ECSA database. The data was statistically analysed to interpret the meaning of respondents' perceptions. The validity and reliability of the research instrument were measured to check if the findings were reliable.

CHAPTER 5: RESEARCH FINDINGS

5.1 Introduction

In this chapter the researcher analysed the data and interpreted the results for the CSF for the South African engineering industry. An exploratory analysis was conducted to determine the CSF and sub-factors and develop a framework for the South African engineering industry. The analysis in this chapter is based on the data collected from 705 engineering professionals consisting of professional engineering technologist, professional certified engineers and professional engineering technicians from Eskom and Department of Water Affairs (DWA) and those registered on the ECSA database.

Each variable was analysed for significance using descriptive (frequency analysis) and inferential (component factor analysis (CFA)) and structural equation modelling (SEM) statistical methods.

The first section of this chapter will focus on the demographic information of the respondents, the second section at the frequency distribution or classification variables. A component factor analysis was performed to answer the following research question:

"What are the underlying structures for the proposed engineering systems model for the South African engineering industry, i.e. do training and development/social-environmental, individual attributes/social of an engineer, engineering value chain/cross-functional process, technical and environmental factors model the needs of the South African engineering industry as suggested in the engineering systems model. A SEM was performed to estimates and tests a network of relationships between variables and to investigate relationships amongst observed and latent variables.

5.2 Demographic information

The descriptive statistics were used to analyse the personal information of the total sample. According to Creswell (2014), descriptive statistics describe the characteristics of a sample or relationships among variables in a sample. The frequency distribution for all personal information obtained is represented.

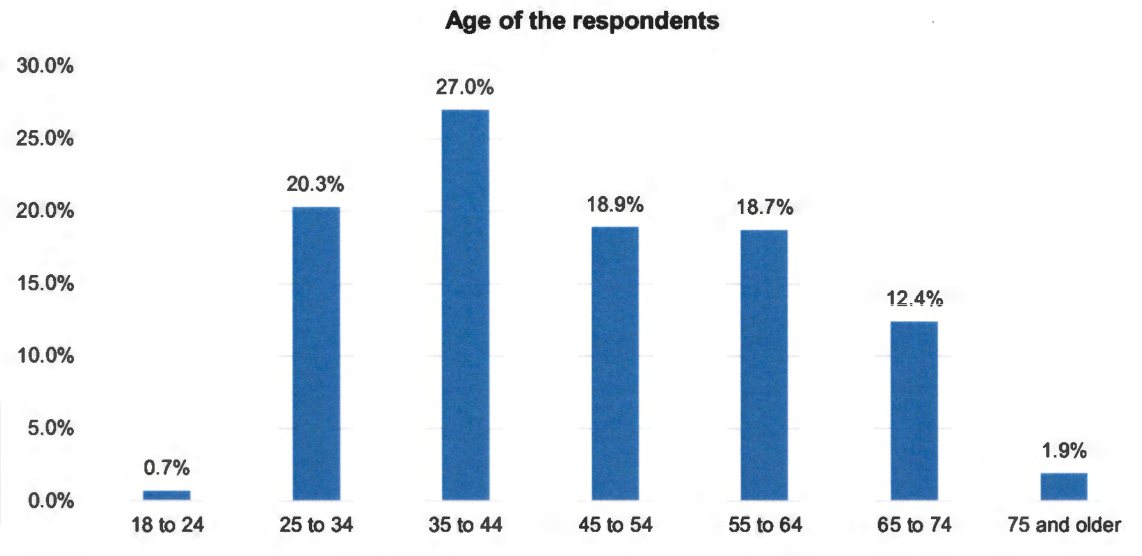


Figure 5.1 Age of the respondents

The age distribution (figure 5.1) shows that 35 to 44 (27.0%) and the 25 to 34 (20.3%) age groups had the highest response rate whereas the youngest, 18 to 24 (0.7%) and the oldest age groups, 75 and older (1.9%), had the lowest response rate.

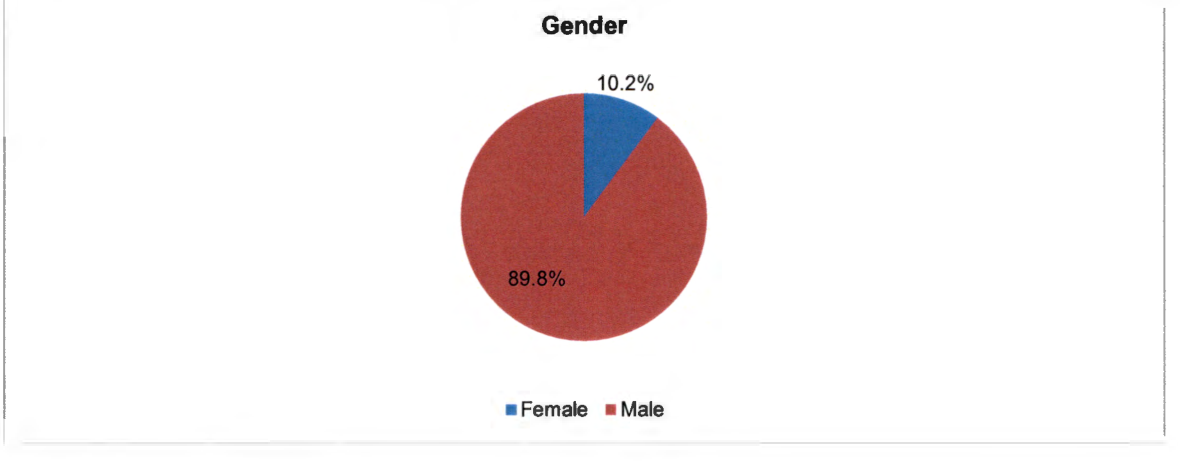


Figure 5.2 Gender of the respondents

The gender distribution (Fig. 5.2) shows that 89.8% of the respondents are males and 10.2% are females.

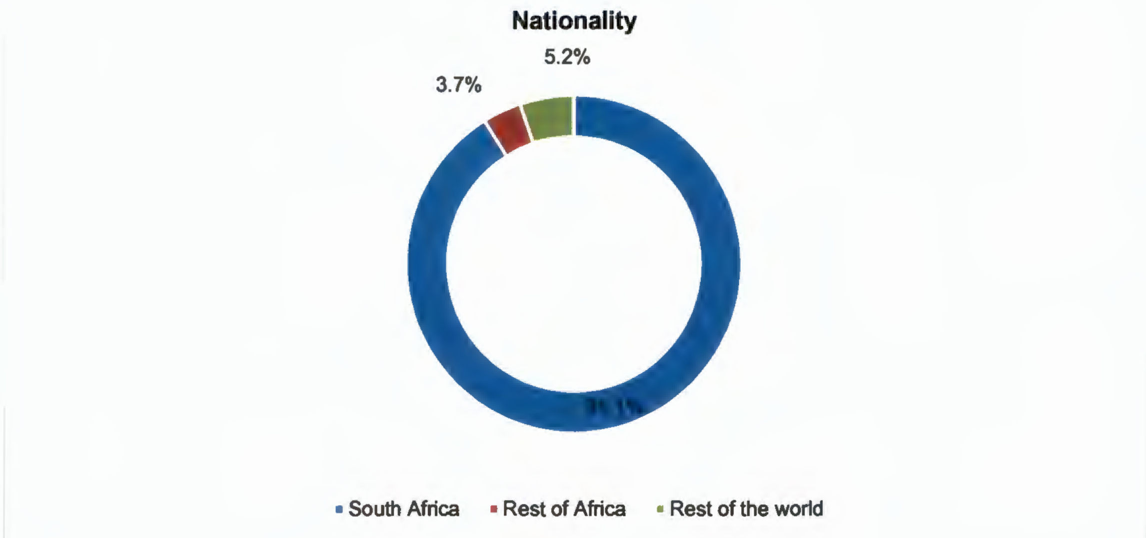


Figure 5.3 Nationality of the respondents

The nationalities of the respondents as indicated in figure 5.3 show that 91.1% of the respondents are South Africans, 3.7% are from the rest of Africa and 5.2% from the rest of the world.

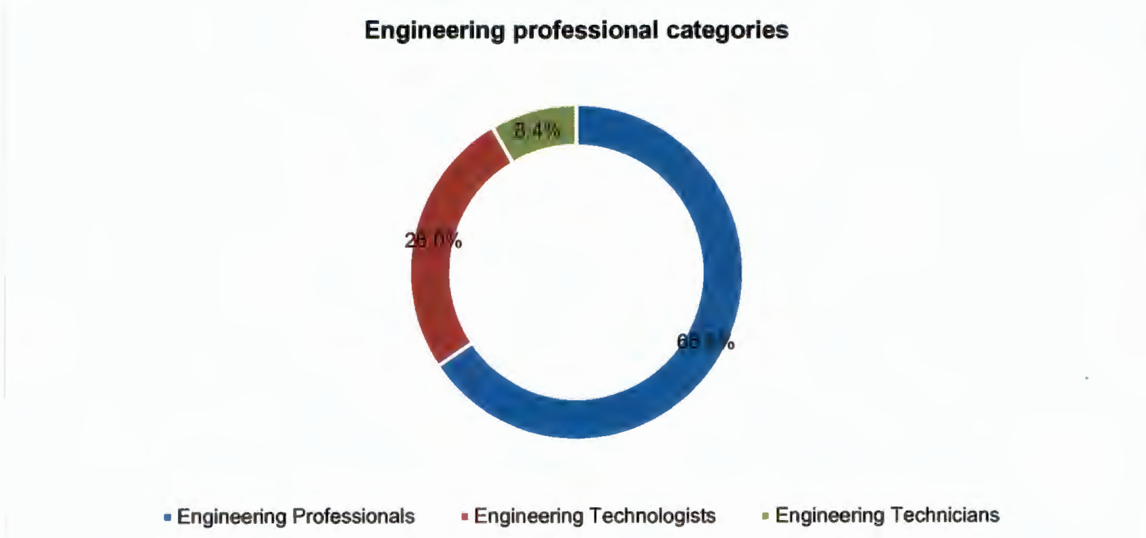


Figure 5.4 Engineering professional categories of the respondents

The respondents are divided in the following engineering professional category, engineering professionals (65.7%) engineering technologists (25.9%) and engineering technicians (8.4%).

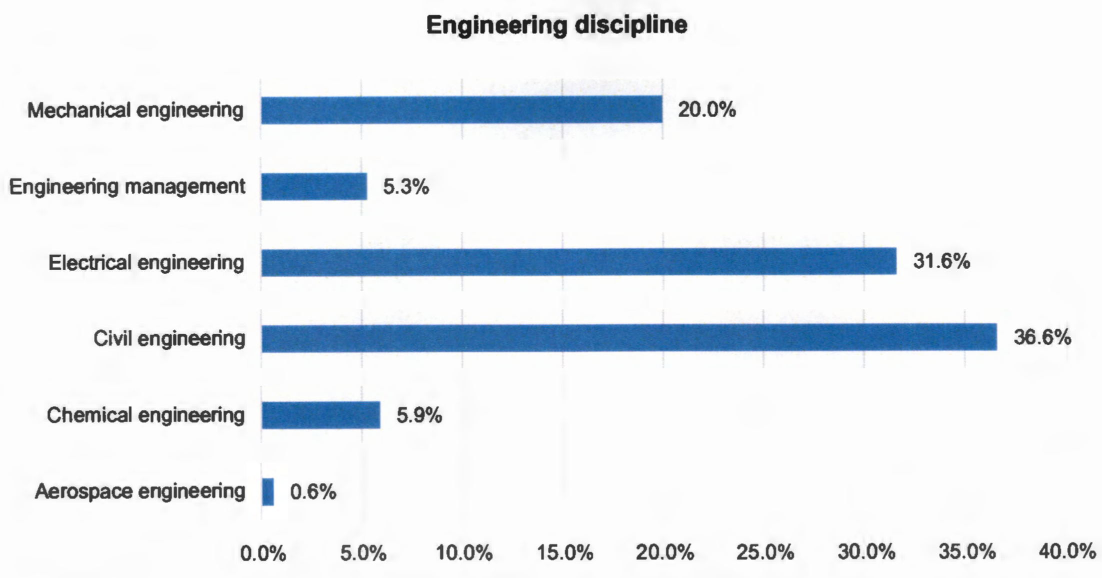


Figure 5.5 Engineering disciplines of the respondents

The highest numbers of respondents are from the civil (36.6%) and electrical (31.6%) engineering disciplines. Aerospace engineering and engineering management account for 0.6% and 5.3% respectively.

Table 5.1 Demographic frequencies for professional affiliation and practicing engineering professional

Professional affiliation	Categories	Percentage (%)
Professional body affiliation	Yes	79.5
	No	20.5
	Total	**100.0**
Professional body affiliation outside South Africa	Yes	19.9
	No	80.1
	Total	**100.0**
Practicing engineering professional in South Africa	Yes	90.2
	No	9.8
	Total	**100.0**
Practicing engineering professional outside South Africa	Africa	22.6
-Where are you practicing	Asia	18.9
-If not what are you currently doing	Australia	3.8
	Europe	9.4
	USA	7.5
	Consulting	9.4
	Retired	28.3
	Total	**100.0**

Seventy-nine-point five per cent (79.5%) of the respondents indicated that they were affiliated to a professional engineering body or voluntary organisation and 19.9% are affiliated to an international professional engineering body. Of the respondents, 90.2% indicated that they were engineering professionals currently practising in South Africa. Of the fifty-three (7.5%) non-practicing engineers, 28.3% are retired and 9.4% are consulting.

One of the objectives of the study is to explore the factors that influence the economic and developmental needs of the South African engineering industry. A cross-tabulation was performed which analysed and described the relationships between the categorical variables. This statistical analysis highlighted significant connections between the dependent and independent variables.

5.2.1 Cross-tabulation: Gender

A statistical analysis using frequency counts and chi-square tests was carried out to explore the relationship between gender and other independent variables with $\alpha < .05$ indicating significance.

5.2.1.1 Gender and age.

The results in Figure 5.6 show that the majority of male respondents (26.4%) fall within the 35 to 44 age group, whereas the females (44.9%) are in the 25 to 34 age group. The results of a chi-square goodness of fit test (table 5.2) shows that response options between gender and age have not been selected equally χ2 (6, N = 686) = 51.009; p < .05). There is a significant difference between the gender and age of the respondents.

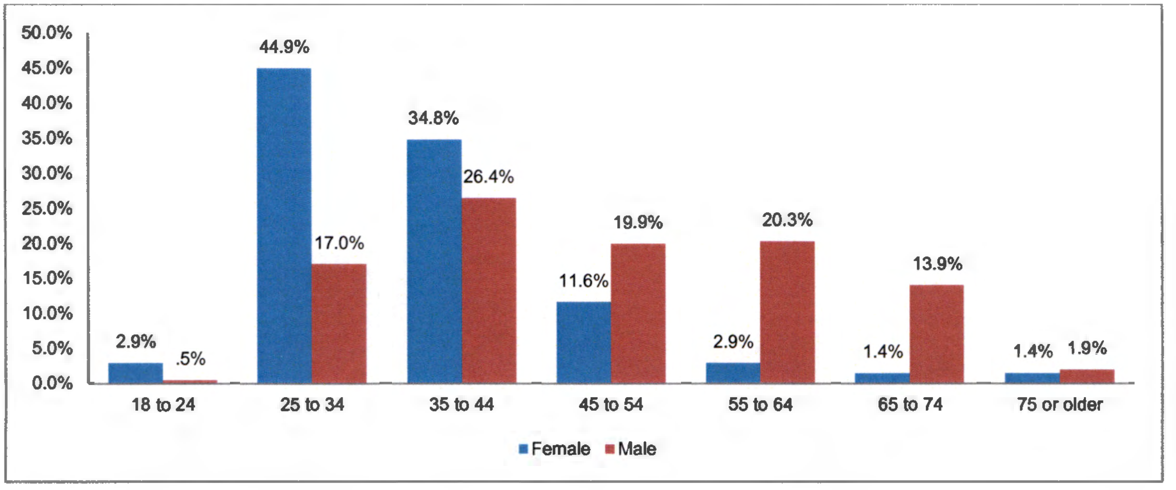


Figure 5.6 Cross-tabulation gender and age

Table 5.2 Chi-Square Tests between gender and age of the respondents

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	51.009[a]	6	.000
N of Valid Cases	686		

a. 3 cells (21.4%) have expected count less than 5. The minimum expected count is .50.

5.2.1.2 Gender and engineering disciplines.

The top engineering disciplines for males (37.6%) and females (31.9%) are civil engineering and electrical engineers (males, 31.4% and females, 31.9%). Males (6%) occupy engineering management roles whereas females (0%) do not. There are more females (14.5%) than males (4.7%) in the chemical engineering disciplines. There are no females (0%) in engineering management. The results of a chi-square goodness of fit test (table 5.3) between gender and engineering disciplines shows that response options have not been selected equally χ2 (5, N = 683) = 15.682; p < .05). There is a significant difference between the gender and engineering disciplines selected by the respondents.

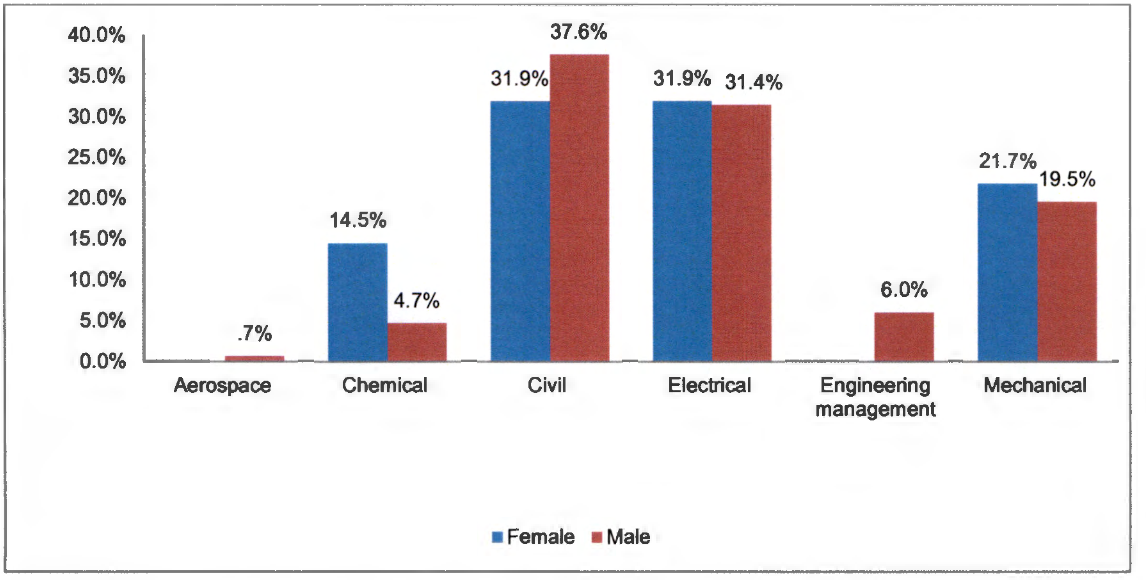


Figure 5.7 Cross-tabulation: gender and engineering disciplines

Table 5.3 Chi-Square Tests between gender and engineering disciplines of the respondents

	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson Chi-Square	15.682[a]	5	.008
N of Valid Cases	683		

a. 4 cells (33.3%) have expected count less than 5. The minimum expected count is .40.

5.2.2 Cross-tabulation: Nationality

A statistical analysis using frequency counts and chi-square tests was carried out to explore the relationship between nationality and other independent variables with $\alpha < .05$ indicating significance.

5.2.2.1 Nationality and age.

Figure 5.8 identifies that majority of South Africans (26.3%) and those from the rest of Africa (57.7%) are in the 35 to 44 age group. The majority of respondents outside Africa are in the 55 to 64 (30.6%) and 65 to 74 (27.8%) age groups. Table 5.4 shows that response options between nationality and age have not been selected equally $\chi 2$ (12, N = 696) = 33.848; $p < .05$). There is a significant difference between the nationality and age of the respondents.

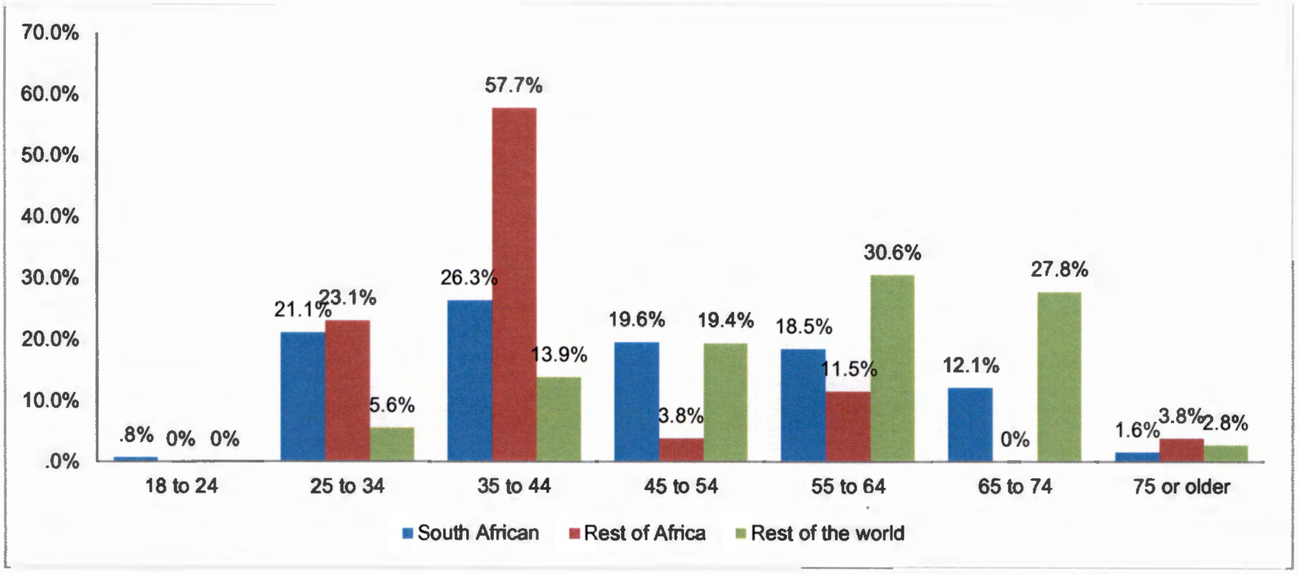


Figure 5.8 Cross-tabulation nationality and age

Table 5.4 Chi-Square Tests between nationality and age of the respondents

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	33.848[a]	12	.001
N of Valid Cases	696		

5.2.2.2 Nationality and engineering disciplines.

Figure 5.9 depicts that the top engineering discipline for respondents from South African (35.9%), Rest of Africa (42.3%) and Rest of the World (41.7%) is civil engineering. There is no significant difference between the nationality and engineering disciplines of the respondents.

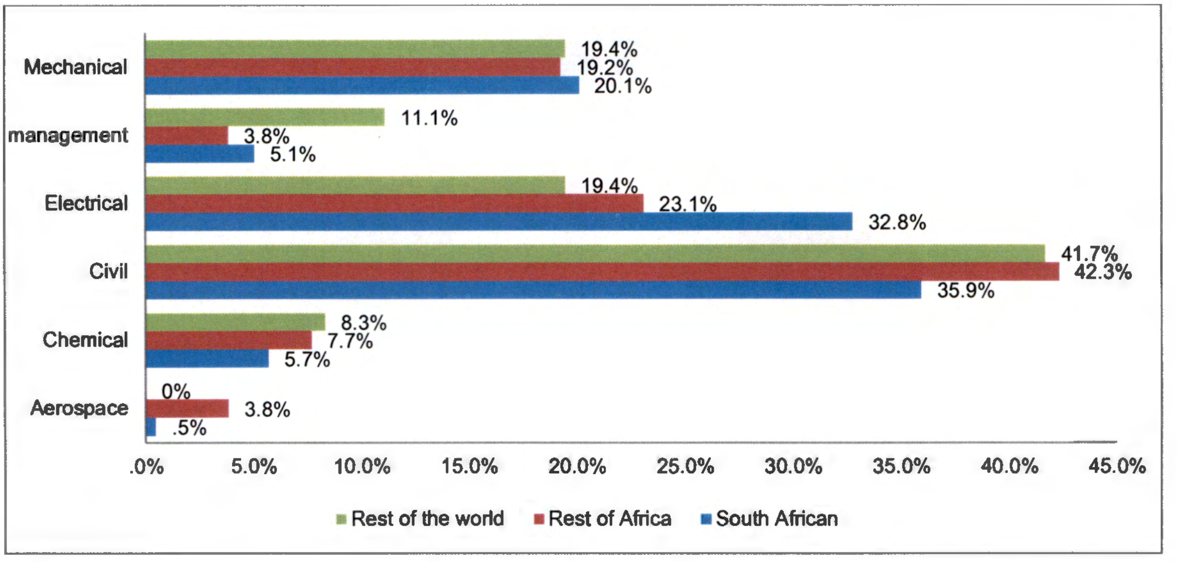


Figure 5.9 Cross-tabulation nationality and engineering disciplines

5.2.3 Cross-tabulation: Engineering category

A statistical analysis using frequency counts and chi-square tests was carried out to explore the relationship between engineering category and other independent variables with $\alpha < .05$ indicating significance.

5.2.3.1 Engineering category and age.

Figure 5.10 indicates that majority of engineers (25.5%) and engineering technologists are in the 35 to 44 age group and the majority of technicians (30.6%) are in the 25 to 34 age group. There are only technicians (5.6%) in the 18 to 24 age group. Table 5.5 shows that response options between engineering category and age have not been selected equally $\chi 2$ (12, N = 586) = 54.743; $p < .05$). There is a significant difference between the engineering category and age of the respondents.

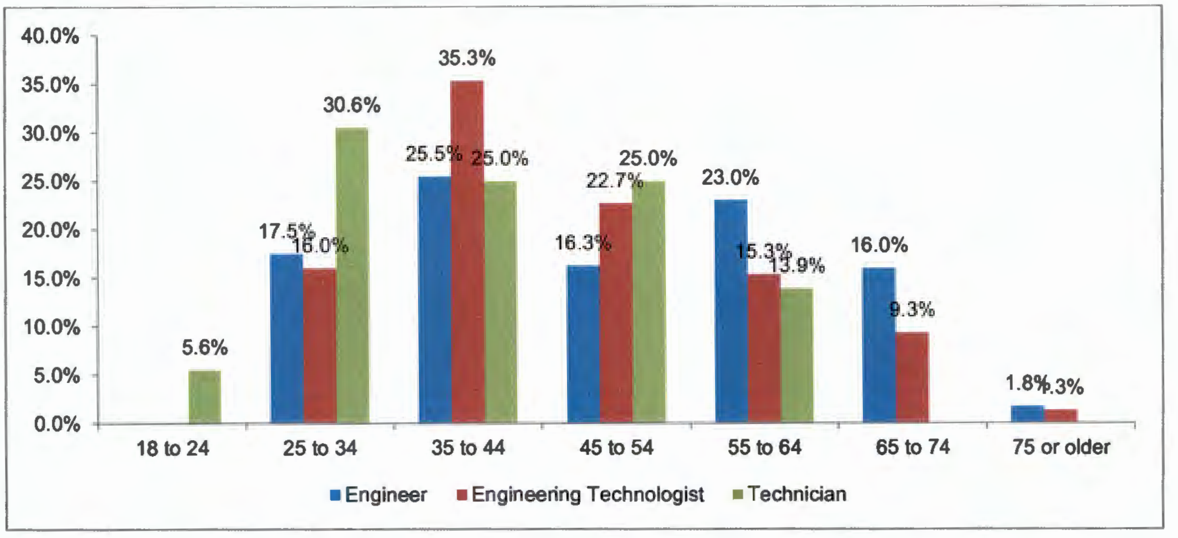


Figure 5.10 Cross-tabulation engineering category and age

Table 5.5 Chi-Square Tests between engineering category and age of the respondents

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	54.743[a]	12	.000
N of Valid Cases	586		

6 cells (28.6%) have expected count less than 5. The minimum expected count is .12.

5.2.3.2 Engineering category and engineering discipline.

Figure 5.11 depicts that the majority of engineers (35.7%) and engineering technologists (39.1%) are in civil engineering and technicians (55.6%) are in electrical engineering. More engineering technologists (8.6%) than engineers (4.2%) occupy managerial positions. Table 5.6 below shows that response options between engineering category and engineering disciplines have not been selected equally $\chi 2$ $(10, N = 588) = 21.615$; $p < .05$). There is a significant difference between the engineering category and engineering disciplines of the respondents.

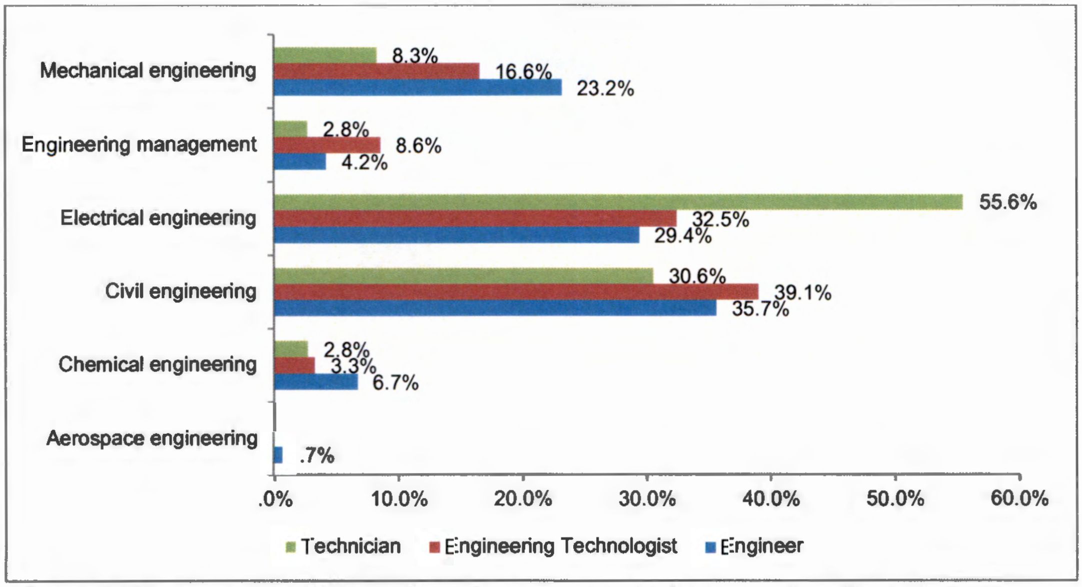


Figure 5.11 Cross-tabulation engineering category and engineering discipline

Table 5.6 Chi-Square Tests between engineering category and engineering disciplines

	Value	df	Asymp. Sig.(2-sided)
Pearson Chi-Square	21.615[a]	10	.017
N of Valid Cases	588		

a. 5 cells (27.8%) have expected count less than 5. The minimum expected count is .18.

5.2.4 Engineering discipline

A statistical analysis using frequency counts and chi-square tests was carried out to explore the relationship between engineering discipline and other independent variables with α < .05 indicating significance.

5.2.4.1 Engineering discipline and age.

Figure 5.12 shows that the respondents (66.7%) in aerospace engineering fall within the 65 to 74 age group. The 35 to 44 age group has the highest number of electrical engineers (29.6%), mechanical engineers (29.2%) chemical engineers (27.3%) and civil engineers (26.8%). The majority in engineering management (29.0%) fall within the 45 to 54 age group. The 18 to 24 age group are in civil engineering (0.5%) and electrical engineering (0.5%).

Table 5.7 below shows that response options between engineering category and age have not been selected equally $\chi 2$ (10, N = 588) = 21.615; $p < .05$). There is a significant difference between the engineering discipline and the age of the respondents.

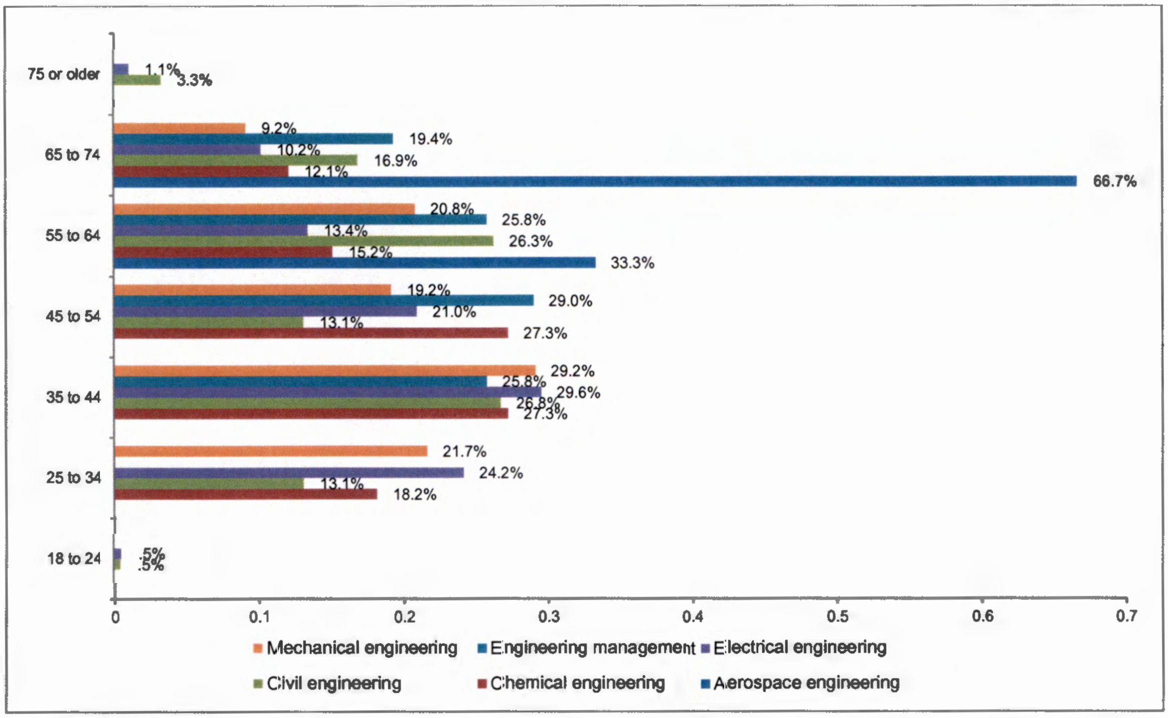


Figure 5.12 Cross-tabulation engineering discipline and age

Table 5.7 Chi-Square Tests between engineering discipline and age

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	52.557[a]	30	.007
N of Valid Cases	586		

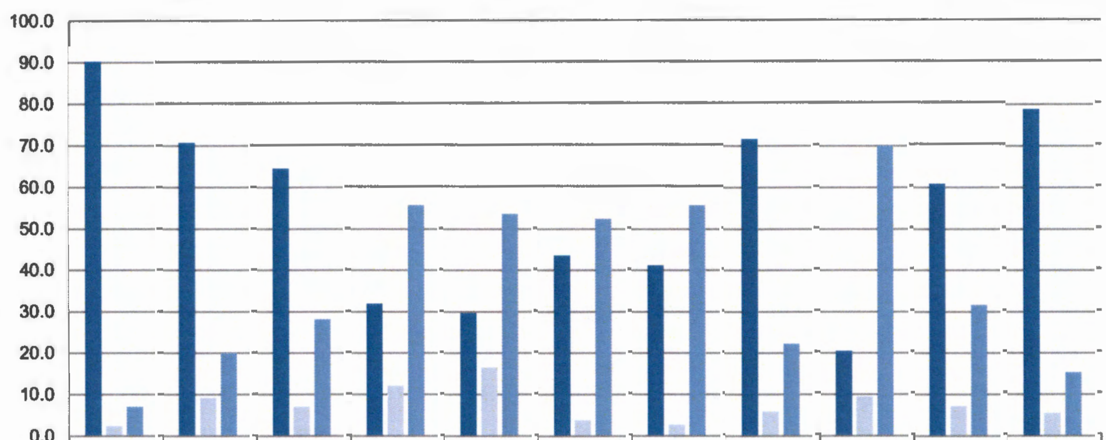
a. 19 cells (45.2%) have expected count less than 5. The minimum expected count is .01.

5.3 The CSF for the South African engineering industry

A descriptive analysis was performed to describe and summarise the dependent variables/factors in this study. It shows frequency counts, means and standard deviations. Additionally, inferential analysis was performed to determine the impact of the age, gender and engineering categories of the respondents on CSFs for the engineering industry in South Africa. The objective of these analyses was to establish relationships by examining the connection between the independent and dependent variables, and to identify patterns and trends.

5.3.1 CSF Environmental - Social domain: Education, training and development

Figure 5.13 explains the environmental-social factors that influence the needs for the South African engineering industry. It shows that with regard to Mathematics and Science Education, 90.4% of respondents agree that the effective learning of Science and Mathematics are influenced by the availability of adequate teaching and 70.8% agree that leaners poor performance in Mathematics and Science is due to a shortage of qualified teachers. The majority (55.8%) of the respondents disagreed that the engineering education curriculum at higher education institutions enables engineering students to deal with socio-economic challenges and 53.8% are of the opinion that insufficient financial support is provided to most engineering students. With regard to experiential training, 55.8% of the respondents disagreed that engineering graduates possess the necessary skills the workplace requires. Regarding the mentoring engineering graduates, 71.7% agree that the knowledge construct of workplace training programmes teaches the engineering graduate about the business operations, however, 70.1% disagreed that the hierarchical gap is more between mentors and mentees are more important that the experience gap. Concerning talent management, 79.0% agree that talent management entails the training and development of staff members.



	Teaching resources	Qualified Maths and Science teachers	University resources (academic and infrastructure)	Engineering education curriculum	Finacial support for engineering students	Adequate workplace training	Workplace readiness	Workplace training programmes	Mentor-mentee relationship	Benchmarking training/development strategies	Retention strategies
Agree	90.4	70.8	64.6	32.0	29.6	43.6	41.3	71.7	20.5	61.0	79.0
Unable to provide a response	2.5	9.2	7.2	12.2	16.6	3.9	2.8	6.0	9.4	7.3	5.6
Disagree	7.1	20.0	28.3	55.8	53.8	52.5	55.9	22.3	70.1	31.7	15.5

Figure 5.13 Frequency counts for each training and development sub-factor

5.3.2 The impact of independent variables on the education, training and development CSF

Cross-tabulation and chi-square tests were performed to establish the impact of the independent variables, age, gender and engineering categories on the education, training and development CSF. Dependent variables where a significant difference in opinion between groups exists will be presented.

5.3.2.1 Engineering education.

a) Engineering education curriculum and age groups.

The cross-tabulation between age group and holistic engineering education (table 5.8) shows that the majority (27.5%) of the respondents are in the 35 – 44 age groups. Of these, 27.5% disagree and 30.9% agree that engineering education curriculum at higher education institutions enables engineering students to deal with socio-economic challenges. Although the majority (55.9%) of the respondents disagree that engineering education curriculum at higher education institutions enables engineering students to deal with socio-economic challenges, the standardised residuals indicate that more than the expected count of the respondents in the 25 to 34, 35 to 44 and 45 to 54 agree that engineering education curriculum enables the engineering graduate to deal with socio-economic challenges. This is confirmed through the chi-square goodness of fit test (Annexure B, Table 7.2) which shows that the responses of results in Table 5.8 have not been selected equally ($\chi 2$ (N = 597, 12) = 46.000; $p < .05$), indicating that a significant difference exists between age of the respondents and holistic engineering curriculum.

Table 5.8 Cross-tabulation: Engineering education curriculum and age groups

Age group and holistic engineering curriculum cross-tabulation		The engineering education curriculum at higher education institutions enables engineering students to deal with socio-economic challenges			N
		Disagree	Unable to provide a response	Agree	
18 to 24	Count	0	0	2	2
	% Within age groups	0.0%	0.0%	0.5%	0.3%
	% Within 18 to 24 age group	0.0%	0.0%	100.0%	100.0%
	Standardized Residual	-1.1	-0.5	1.7	
25 to 34	Count	52	5	50	107
	%Within age groups	15.6%	6.9%	26.2%	17.9%
	% Within 25 to 34 age group	48.6%	4.7%	46.7%	100.0%
	Standardized Residual	-1	-2.2	2.7	
35 to 44	Count	92	13	59	164
	% Within age groups	27.5%	18.1%	30.9%	27.5%
	% Within 35 to 44 age group	56.1%	7.9%	36.0%	100.0%
	Standardized Residual	0	-1.5	0.9	
45 to 54	Count	60	14	38	112
	% Within age groups	18.0%	19.4%	19.9%	18.8%
	% Within 45 to 54 age group	53.6%	12.5%	33.9%	100.0%
	Standardized Residual	-0.3	0.1	0.4	
55 to 64	Count	76	22	26	124
	% Within age groups	22.7%	30.5%	13.6%	20.8%
	% Within 55 to 64 age group	61.3%	17.7%	21.0%	100.0%
	Standardized Residual	0.8	1.8	-2.2	
65 to 74	Count	49	18	12	79
	% Within age groups	14.7%	25.0%	6.3%	13.2%
	% Within 65 to 74 age group	62.0%	22.8%	15.2%	100.0%
	Standardized Residual	0.7	2.7	-2.6	
75 or older	Count	5	0	4	9
	% Within age groups	1.5%	0.0%	2.1%	1.5%
	% Within 75 and older age group	55.6%	0.0%	44.4%	100.0%
	Standardized Residual	0	-1	0.7	
N	Count	334	72	191	597
	% Within age group	55.9%	12.1%	32.0%	100.0%

b) Engineering education curriculum and engineering categories.

The cross-tabulation (table 5.9) shows that the majority, 61.4% (n=245) engineers and 47.7% (n=70) technologist, disagree that the engineering education curriculum at higher education institutions enables engineering students to deal with socio-economic challenges. However, 67.6% of technicians are of the opinion that the engineering curriculum at HEIs does provide the engineering student to deal with socio-economic challenges. This difference in opinion is confirmed through the chi-square goodness of fit test (Annexure B, Table 7.3) which shows that the responses of results in Table 5.9 has not been selected equally ($\chi 2$ (N = 585, 4) = 30.803; $p < .05$), indicating that a significant difference exists between engineering category of the respondents and engineering curriculum.

Table 5.9 Cross-tabulation: Engineering education curriculum and engineering category

Engineering category and socio-economic challenges cross-tabulation		The engineering education curriculum at higher education institutions enables engineering students to deal with socio-economic challenges.			N
		Disagree	Unable to provide a response	Agree	
Engineer	Count	245	46	108	399
	% within engineering category	75.2%	65.7%	57.1%	68.2%
	% within engineer group	61.4%	11.5%	27.1%	100.0%
	Standardized Residual	1.5	-0.3	-1.8	
Engineering Technologist	Count	71	22	56	149
	% within engineering category	21.8%	31.4%	29.6%	25.5%
	% within engineering technology group	47.7%	14.8%	37.6%	100.0%
	Standardized Residual	-1.3	1	1.1	
Technician	Count	10	2	25	37
	% within engineering category	3.1%	2.9%	13.2%	6.3%
	% within engineering technician	27.0%	5.4%	67.6%	100.0%
	Standardized Residual	-2.3	-1.2	3.8	
N	Count	326	70	189	585
	%within engineering category	55.7%	12.0%	32.3%	585

c) Financial support and age groups.

Table 5.10 specifies that the 53.7% of the respondents disagree and 29.8% agree that sufficient financial support is provided for engineering students. The majority in the 45 to 54 (64.9%) and 55 to 64 (57.7%) age groups disagree. The standardised residuals for the 25 to 34, 35 to 44 and the 75 and older age groups show that more than the expected number of respondents agrees that sufficient financial support is provided for engineering students. This is confirmed through the chi-square goodness of fit test (Annexure B, Table 7.4) which shows that the responses of results in Table 5.6 have not been selected equally ($\chi 2$ (N =

594, 12) = 21.382; p < .05), indicating that a significant difference exists between age of the respondents and financial support for engineering students.

Table 5.10 Cross-tabulation: financial support and age

Age group and financial support for engineering students cross-tabulation		Sufficient financial support is provided to most engineering students.			N
		Disagree	Unable to provide a response	Agree	
18 to 24	Count	2	0	0	2
	% Within age groups	0.6%	0.0%	0.0%	0.3%
	% Within 18 to 24 age group	100.0%	0.0%	0.0%	100.0%
	Standardized Residual	0.9	-0.6	-0.8	
25 to 34	Count	54	11	41	106
	% Within age group	16.9%	11.2%	23.2%	17.8%
	% Within 25 to 34 age group	50.9%	10.4%	38.7%	100.0%
	Standardized Residual	-0.4	-1.6	1.7	
35 to 44	Count	78	32	54	164
	% Within age group	24.5%	32.6%	30.5%	27.6%
	% Within 35 to 44 age group	47.6%	19.5%	32.9%	100.0%
	Standardized Residual	-1.1	1	0.7	
45 to 54	Count	72	13	26	111
	% Within age group	22.6%	13.3%	14.7%	18.7%
	% Within 45 to 54 age group	64.9%	11.7%	23.4%	100.0%
	Standardized Residual	1.6	-1.2	-1.2	
55 to 64	Count	71	21	31	123
	% Within age group	22.3%	21.4%	17.5%	20.7%
	% Within 55 to 64 age group	57.7%	17.1%	25.2%	100.0%
	Standardized Residual	0.6	0.2	-0.9	
65 to 74	Count	39	19	21	79
	% Within age group	12.2%	19.4%	11.9%	13.3%
	% Within 65 to 74 age group	49.4%	24.1%	26.6%	100.0%
	Standardized Residual	-0.5	1.7	-0.5	
75 or older	Count	3	2	4	9
	% Within age group	0.9%	2.0%	2.3%	1.5%
	% Within 75 and older age group	33.3%	22.2%	44.5%	100.0%
	Standardized Residual	-0.8	0.4	0.8	
N	Count	319	98	177	594
	% Within age group	53.7%	16.5%	29.8%	100.0%

e) Financial support and gender.

The cross-tabulation (table 5.11) indicates that 90.4% males and 9.6% females responded to the question, "Sufficient financial support is provided to most engineering students". Of these, the majority (54.7%) males disagreed, and the majority females (46.4%) agreed that sufficient financial support is provided to most engineering students. The standard residual indicates that more than the expected count of females agreed and more than the expected count of males disagreed that sufficient financial support is provided to most engineering students. This is confirmed through the chi-square goodness of fit test (Annexure B, Table 7.5) which shows that the responses of results in Table 5.11 have not been selected equally ($\chi 2$ (N = 584, 2) = 9.064; $p < .05$), indicating that a significant difference exists between gender of the respondents and financial support for engineering graduates. Females are likely to agree whereas males disagree that sufficient financial support is provided to most engineering students.

Table 5.11 Cross-tabulation: Financial support and gender

Gender and financial support for engineering students cross- tabulation		Sufficient financial support is provided to most engineering students.			N
		Disagree	Unable to provide a response	Agree	
Female	Count	25	5	26	56
	% Within gender group	7.9%	5.2%	15.0%	9.6%
	% Within female group	44.6%	8.9%	46.4%	100.0%
	Standardized Residual	-0.9	-1.4	2.3	
Male	Count	289	92	147	528
	% Within gender group	92.0%	94.8%	85.0%	90.4%
	% Within male group	54.7%	17.4%	27.8%	100.0%
	Standardized Residual	0.3	0.5	-0.8	
N	Count	314	97	173	584
	% Within gender group	53.8%	16.6%	29.6%	100.0%

5.3.2.2 Experiential training.

a) Workplace training.

Table 5.12 indicates that the majority (52.4%) of the respondents disagreed that engineering graduates are provided with adequate workplace training. However the majority within the younger age groups, 18 to 24 (50%) and 25 to 34 (53.8%), agreed that engineering graduates are provided with adequate workplace training. The chi-square goodness of fit test (Annexure B, Table 7.6) shows that the responses in table 5.12 have not been selected equally ($\chi 2$ (N = 593, 12) = 26.631; $p < .05$), indicating that a significant difference exists between age of the respondents and mentors' availability.

Table 5.12 Cross-tabulation: age and workplace training

Age group and mentoring cross-tabulation		Engineering graduates are provided with adequate workplace training.			N
		Disagree	Unable to provide a response	Agree	
18 to 24	Count	1	0	1	2
	% Within age groups	0.3%	0.0%	0.4%	0.3%
	% Within 18 to 24 age group	50.0%	0.0%	50.0%	100.0%
	Standardized Residual	0	-0.3	0.1	
25 to 34	Count	45	3	56	104
	% Within age groups	14.5%	13.0%	21.6%	17.5%
	% Within 25 to 34 age group	43.3%	2.9%	53.8%	100.0%
	Standardized Residual	-1.3	-0.5	1.6	
35 to 44	Count	89	3	72	164
	% Within age groups	28.6%	13.0%	27.8%	27.7%
	% Within 35 to 44 age group	54.3%	1.8%	43. 9%	100.0%
	Standardized Residual	0.3	-1.3	0	
45 to 54	Count	58	2	51	111
	% Within age groups	18.6%	8.7%	19.7%	18.7%
	% Within 45 to 54 age group	52.3%	1.8%	45.9%	100.0%
	Standardized Residual	0	-1.1	0.4	
55 to 64	Count	70	5	49	124
	% Within age groups	22.5%	21.7%	18.9%	20.9%
	% Within 55 to 64 age group	56.5%	4.0%	39.5%	100.0%
	Standardized Residual	0.6	0.1	-0.7	
65 to 74	Count	43	8	28	79
	% Within age groups	13.8%	34.8%	10.8%	13.3%
	% Within 65 to 74 age group	54.4%	10.1%	35.4	100.0%
	Standardized Residual	0.2	2.8	-1.1	
75 or older	Count	5	2	2	9
	% Within age groups	1.6%	8.7%	0.7%	1.5%
	% Within 75 and older age group	55.6%	22.2%	22.2%	100.0%
	Standardized Residual	0.1	2.8	-1	
N	Count	311	23	259	593
	Expected Count	52.4%	3.9%	43.7%	100.0%

b) Workplace readiness and age.

Table 5.13 shows that the majority (56.1%) of the respondents disagreed that engineering graduates possess the necessary skills the workplace requires. However, 52.3% of the 25 to 34 and 77.8% of the 75 and older age groups agreed that engineering graduates possess the necessary skills the workplace requires. This is confirmed through the chi-square goodness of fit test (Annexure B, Table 7.7) which shows that the responses of results in Table 5.13 have not been selected equally ($\chi 2$ (N = 594, 12) = 22.439; $p < .05$), indicating that a significant difference exists between age of the respondents and engineering skills of engineering graduates.

Table 5.13 Cross-tabulation: age and workplace readiness

Age group and workplace readiness of engineering graduates cross-tabulation		Engineering graduates possess the necessary skills the workplace requires.			N
		Disagree	Unable to provide a response	Agree	
18 to 24	Count	1	0	1	2
	% Within age group	0.3%	0.0%	0.4%	0.3%
	%Within 18 to 24 age group	50.0%	0%	50.0%	100.0%
	Standardized Residual	-0.1	-0.2	0.2	
25 to 34	Count	49	2	56	107
	% Within age group	14.7%	11.8%	22.9%	18.0%
	%Within 25 to 34 age group	45.8%	1.9%	52.3%	100.0%
	Standardized Residual	-1.4	-0.6	1.8	
35 to 44	Count	89	6	69	164
	% Within age group	26.6%	35.3%	28.3%	27.6%
	%Within 35 to 44 age group	54.3%	3.7%	42.1%	100.0%
	Standardized Residual	-0.3	0.6	0.2	
45 to 54	Count	70	0	41	111
	% Within age group	20.9%	0.0%	16.8%	18.7%
	%Within 45 to 54 age group	63.1%	0.0%	36.9%	100.0%
	Standardized Residual	1	-1.8	-0.7	
55 to 64	Count	75	7	41	123
	% Within age group	22.5%	41.2%	16.8%	20.7%
	%Within 55 to 64 age group	61.0%	5.7%	33.3%	100.0%
	Standardized Residual	0.7	1.9	-1.3	
65 to 74	Count	48	2	29	79
	% Within age group	14.4%	11.8%	11.9%	13.3%
	%Within 65 to 74 age group	60.8%	2.5%	36.7%	100.0%
	Standardized Residual	0.5	-0.2	-0.6	
75 or older	Count	2	0	7	9
	% Within age group	0.6%	0.0%	2.9%	1.5%
	%Within 75 and older age group	22.2%	0.0%	77.8%	100.0%
	Standardized Residual	-1.4	-0.5	1.7	
N	Count	334	17	244	595
	% Within age group	56.1%	2.9%	41.0%	100.0%

c) Workplace readiness and gender.

The cross-tabulation (table 5.14) indicates that 90.4% males and 9.6% females responded to the question, "engineering graduates possess the necessary skills the workplace requires". Of these, the majority males (58.0%) disagreed and the majority females (58.9%) agreed that engineering graduates possess the necessary skills the workplace requires. The standardised residuals indicate that more than the expected count of females agreed and more than the expected count of males disagreed that engineering graduates possess the necessary skills the workplace requires. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.8) which show that the responses of results in table 5.14 have not been selected equally ($\chi2$ (N = 584, 2) = 8.384; $p < .05$), indicating that a significant difference exists between gender of the respondents and engineering skills of engineering graduates, females are likely to agree whereas males disagree that engineering graduates possess the necessary skills the workplace requires.

Table 5.14 Cross-tabulation: gender and workplace readiness

Gender and engineering skills of engineering graduates cross-tabulation		Engineering graduates possess the necessary skills the workplace requires.			N
		Disagree	Unable to provide a response	Agree	
Female	Count	22	1	33	56
	% Within gender	6.7%	5.9%	13.8%	9.6%
	% Within female group	39.2%	1.8%	58.9%	100.0%
	Standardized Residual	-1.7	-0.5	2.1	
Male	Count	307	16	206	529
	% Within gender	93.3%	94.1%	86.2%	90.4%
	% Within male group	58.0%	3.0%	38.9%	100.0%
	Standardized Residual	0.6	0.2	-0.7	
N	Count	329	17	239	585
	% Within gender	56.2%	2.9%	40.9%	100.0%

5.3.2.3 Mentoring.

a) Workplace training programmes and engineering categories.

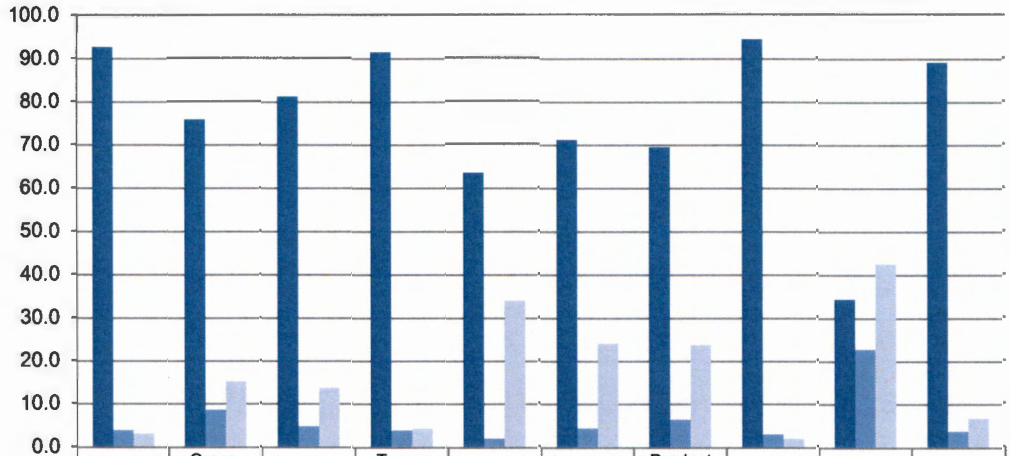
The cross-tabulation (table 5.15) indicates that 68.2% engineers, 25.4% engineering technologist and 6.4% technicians responded to the question "the knowledge construct of workplace training programmes teaches the engineering graduate about the business operations". Of these 72.5% of the respondents agreed that the knowledge construct of workplace training programmes teaches the engineering graduate about business operations. However, the standardised residual indicates that more than the expected count of engineers disagreed that the knowledge construct of workplace training programmes teaches the engineering graduate about the business operations. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.9) which shows that the responses of results in table 5.15 have not been selected equally ($\chi2$ (N = 582, 4) = 22.017; $p < .05$), indicating that a significant difference exists between the professional engineering categories of the respondents and workplace training programmes.

Table 5.15 Cross-tabulation: engineering category and workplace training programmes

Engineering category and workplace training programmes cross-tabulation		The knowledge construct of workplace training programmes teaches the engineering graduate about the business operations.			N
		Disagree	Unable to provide a response	Agree	
Engineer	Count	97	31	269	397
	% Within engineering category	78.2%	86.1%	63.7%	68.2%
	% Within engineer group	24.4%	7.8%	67.8%	100%
	Standardized Residual	1.3	1.3	-1.1	
Engineering Technologist	Count	27	5	116	148
	% Within engineering category	21.8%	13.9%	27.5%	25.4%
	% Within engineering technologist group	18.2%	3.4%	78.4%	100.0%
	Standardized Residual	-0.8	-1.4	0.8	
Technician	Count	0	0	37	37
	% Within engineering category	0.0%	0.0%	8.8%	6.4%
	% Within technicians group	0.0%	0.0%	100.0%	100.0%
	Standardized Residual	-2.8	-1.5	2	
N	Count	124	36	422	582
	% Within engineering category	21.3%	6.2%	72.5%	100.0%

5.3.3 CSF Social domain – individual attributes

Figure 5.14 and the univariate Table 1.2 in Annexure **B expla**ins the social factors that influence the needs of the South African engineering industry indicates that with regard to communication the 92.8% of the respondents regards electronic media as a vital form of communication in the engineering industry and 76.0% are of the opinion that effective cross cultural communication happens when people start questioning their own biases. Concerning effective teams, 81.4% agree that high level strategic goals should take priority over individual goals and 91.6% are of the opinion that incorrectly designed team activities affect the productivity within the team. On leadership, 71.3% of the respondents agree that most successful engineering projects are led by people with a high technical knowledge. Product and process innovation related to creativity and innovation 69.6% agree that design courses in the engineering curriculum nurture students' creative abilities and 94.6% are of the opinion that innovative solutions are found when team members share information. Relating to entrepreneurship, 42.6% are of the opinion that entrepreneurs are risks averse as new business owners do not prefer to invest in high novelty (new) business ventures and 89.3% agree that most engineering business owners aim to meet the demands in the market.



	Communication tools	Cross-cultural communication	Effective teams	Team-based performance	Situational leadership	Project leadership	Product and process innovation	Organisational culture	Risk taking	Entrepreneurial skill
Agree	92.8	76.0	81.4	91.6	63.7	71.3	69.6	94.6	34.4	89.3
Unable to provide a response	4.0	8.7	4.9	4.0	2.2	4.5	6.5	3.2	22.9	3.9
Disagree	3.2	15.2	13.8	4.4	34.1	24.2	23.9	2.2	42.6	6.8

Figure 5.14 Frequency count: Social perspective sub-factors

5.3.3.1 Communication

a) Cross cultural communication and gender

The cross-tabulation table 5.16 indicates that 9.4% females, 90.6% males responded to the question "Effective cross cultural communication can only take place when people start questioning their own biases". Of these 76.4% of the respondents agreed that effective cross-cultural communication can only take place when people start questioning their own biases. However, the standardised residual indicates that more than the expected count of males disagreed and more than the expected count of females agreed with this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.10) which shows that the responses of results in table 5.16 have not been selected equally ($\chi 2$ (N = 584, 2) = 7.237; $p < .05$), indicating that a significant difference exists between the gender of the respondents and cross cultural communication.

Table 5.16 Cross-tabulation: gender and cross cultural communication

Cross cultural communication and gender cross-tabulation		Effective cross cultural communication can only take place when people start questioning their own biases.			N
		Disagree	Unable to provide a response	Agree	
Females	Count	6	0	49	55
	%Within Gender	6.8%	0.0%	11.0%	9.4%
	% Within Females	10.9%	0.0%	89.1%	100.0%
	Standardized Residual	-0.8	-2.2	1.1	
Males	Count	81	51	397	529
	%Within Gender	93.1%	100.0%	89.0%	90.6%
	%Within Males	15.3%	9.6%	75.0%	100.0%
	Standardized Residual	0.2	0.7	-0.3	
N	Count	87	51	446	584
	%Within Gender	14.9%	8.7%	76.4%	100.0%

5.3.3.2 Creativity and innovation.

a) Product and process innovation and engineering categories

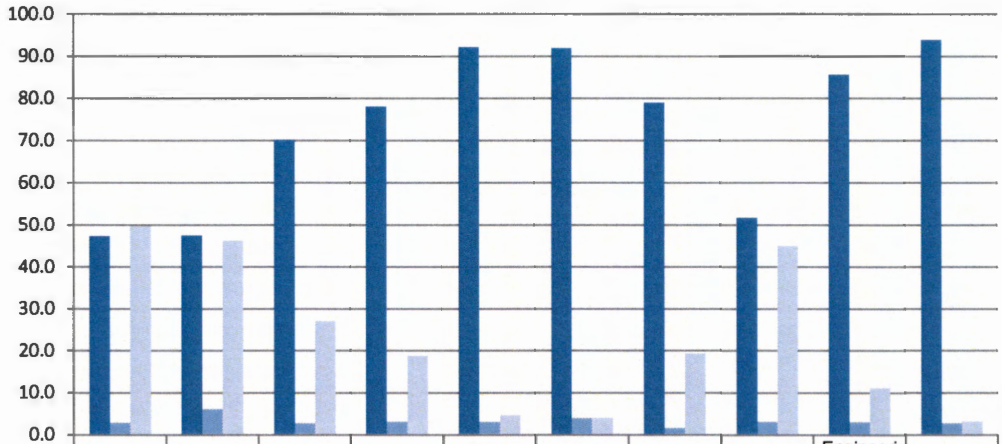
The cross-tabulation table 5.17 indicates that 68.2%% engineers, 25.5% technologists and 6.3% technicians responded to the question "Design courses in the engineering curriculum nurture students' creative abilities". Of these 69.5% of the respondents agreed that design courses in the engineering curriculum nurture students' creative abilities. However, the standardised residual indicates that more than the expected count of engineers also disagreed with this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 6.11) which shows that the responses of results in Table 7.17 have not been selected equally ($\chi 2$ (N = 584, 4) = 20.107; $p < .05$), indicating that a significant difference exists between the engineering category and product and process innovation.

Table 5.17 Cross-tabulation: engineering category and product and process information

Product and process innovation and engineering category cross-tabulation		Design courses in the engineering curriculum nurture students' creative abilities.			N
		Disagree	Unable to provide a response	Agree	
Engineer	Count	116	25	257	398
	%Within Engineering category	82.9%	65.8%	63.3%	68.2%
	%Within engineer group	29.1%	6.3%	64.6%	100.0%
	Standardized Residual	2.1	-0.2	-1.2	
Technologist	Count	20	12	117	149
	%Within Engineering category	14.3%	31.6%	28.8%	25.5%
	%Within Technologist group	13.4%	8.1%	78.5%	100.0%
	Standardized Residual	-2.6	0.7	1.3	
Technician	Count	4	1	32	37
	%Within Engineering category	2.9%	2.6%	7.9%	6.3%
	%Within Technician group	10.8%	2.7%	86.5%	100.0%
	Standardized Residual	-1.6	-0.9	1.2	
N	Count	140	38	406	584
	%Within Engineering category	24.0%	6.5%	69.5%	100.0%

5.3.4 CSF Cross-functional process domain – Engineering value chain

Respondents' opinions with regard to the engineering value chain, the cross-functional process domain of the suggested engineering system framework, were expressed as follows. With regard to product design and development, the majority of respondents, 70.1% agree that most engineering graduates lack design capabilities and 78.1% agree that high quality design concepts are usually produced by multi-disciplinary design teams. With regard to customer satisfaction, 92.2% of the respondents indicate that producing a reliable product creates a satisfied customer base and 91.9% agree that customer satisfaction improves when there is a continuous flow of information. Concerning project management, 79.0% of the respondents indicate that project management is the standard operations for delivering engineering products. The business process management, the majority (85.7%) of the respondents are in agreement that the engineering industry applies set standards to develop a safe, high quality product and 94.0% of the respondents are of the opinion that good business practices improve the quality of the product.



	Idea generation	Rewards and idea generation	Graduates design capabilities	Design teams	Product reliability	Communication strategy	Project management in engineering	Monitoring system	Engineering standards and quality products	Business practices and quality products
Agree	47.3	47.5	70.1	78.1	92.2	91.9	79.0	51.8	85.7	94.0
Unable to provide a response	3.0	6.2	2.8	3.2	3.2	4.0	1.7	3.2	3.2	2.9
Disagree	49.7	46.3	27.0	18.8	4.7	4.0	19.3	45.0	11.2	3.2

Figure 5.15 Frequency count of the cross-functional process factor

5.3.4.1 Product design and development.

a) Design teams and age.

A cross-tabulation (table 5.18) between age groups and design teams shows that the majority in the 25 to 34 (83.8%), 35 to 44 (80.4%) and 45 to 54 (80.4%), agree that high-quality designs concepts are usually produced by multi-disciplinary design teams. However, the standardised residual indicates that more than the expected count respondents in the 55 to 64 and 65 to 74 age groups disagree with this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.12) which shows that the responses of results in table 5.18 have not been selected equally ($\chi 2$ (N = 594, 12) = 23.115; $p < .05$), indicating that a significant difference exists between the age group and design teams.

Table 5.18 Cross-tabulation: age and design teams

Design teams and age group cross-tabulation		High quality designs concepts are usually produced by multi-disciplinary design teams.			N
		Disagree	Unable to provide a response	Agree	
18 to 24	Count	0	0	2	2
	%Within age groups	0.0%	0.0%	0.4%	0.3%
	%Within 18 to 24 age group	0.0%	0.0%	100.0%	100.0%
	Standardized Residual	-0.6	-0.3	0.4	
25 to 34	Count	15	2	88	105
	%Within age groups	13.5%	10.5%	19.0%	17.7%
	%Within 25 to 34 age group	14.3%	1.9%	83.8%	100.0%
	Standardized Residual	-1	-0.7	0.7	
35 to 44	Count	18	6	139	163
	%Within age groups	16.2%	31.6%	30.0%	27.4%
	%Within 35 to 44 age groups	11.0%	3.7%	85.3%	100.0%
	Standardized Residual	-2.3	0.3	1	
45 to 54	Count	18	4	90	112
	%Within age groups	16.2%	21.1%	19.4%	18.9%
	%Within 45 to 54 age groups	16.1%	3.6%	80.4%	100.0%
	Standardized Residual	-0.6	0.2	0.3	
55 to 64	Count	34	4	86	124
	%Within age groups	30.6%	21.1%	18.5%	20.9%
	%Within 55 to 64 age groups	27.4%	3.2%	69.4%	100.0%
	Standardized Residual	2.2	0	-1.1	
65 to 74	Count	23	3	53	79
	%Within age groups	20.7%	15.8%	11.4%	13.3%
	%Within 65 to 74 age group	29.1%	3.8%	67.1%	100.0%
	Standardized Residual	2.1	0.3	-1.1	
75 or older	Count	3	0	6	9
	%Within age groups	2.7%	0.0%	1.3%	1.5%
	%Within 75 and older age group	33.3%	0.0%	66.7%	100.0%
	Standardized Residual	1	-0.5	-0.4	
N	Count	111	19	464	594
	%Within age groups	18.7%	3.2%	78.1%	100.0%

b) Graduate design capabilities and engineering categories.

A cross-tabulation (table 5.19) between engineering categories and graduate design capabilities shows that the majority in the engineer (67.2%), technologist (78.0%) and technicians (71.8%), agree that most engineering graduates lack design capability. However, the standardised residual indicates that more than the expected counts of engineers are also of the opinion that most engineering graduates have design capabilities. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table

7.13) which shows that the responses of results in table 5.19 have not been selected equally ($\chi2$ (N = 588, 4) = 10.129; $p < .05$), indicating that a significant difference exists between engineering categories and graduate design capabilities.

Table 5.19 Cross-tabulation: engineering categories and graduate design capabilities

Graduate design capabilities and engineering category cross-tabulation		Most engineering graduates lack design capability.			Total
		Disagree	Unable to provide a response	Agree	
Engineer	Count	120	11	268	399
	%Within Engineering category	75.9%	64.7%	64.9%	67.9%
	%Within engineer group	30.1%	2.8%	67.2%	100.0%
	Standardized Residual	1.2	-0.2	-0.7	
Engineering Technologist	Count	30	3	117	150
	%Within Engineering category	19.0%	17.6%	28.3%	25.5%
	%Within technologist group	20.0%	2.0%	78.0%	100.0%
	Standardized Residual	-1.6	-0.6	1.1	
Technician	Count	8	3	28	39
	%Within Engineering category	5.1%	17.6%	6.8%	6.6%
	%Within technician group	20.5%	7.7%	71.8%	100.0%
	Standardized Residual	-0.8	1.8	0.1	
N	Count	158	17	413	588
	%Within Engineering category	26.9%	2.9%	70.2%	100.0%

5.3.4.2 Business process management.

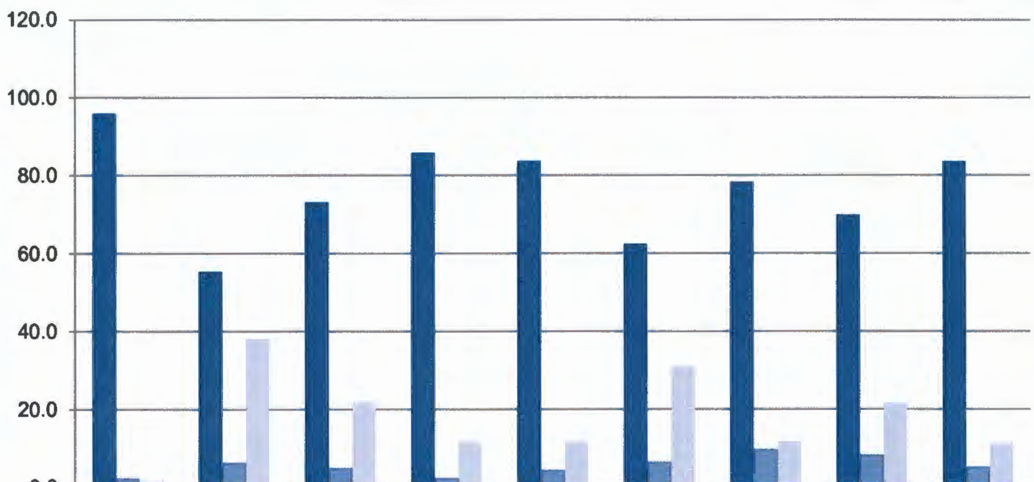
a) Good business practices for quality products development and engineering categories

A cross-tabulation (table 5.20) between engineering categories and quality products shows that the majority of engineers (68.1%), technologists (92.6%) and technicians (100.0%), agree that good engineering business practices improve the quality of the product. However, the standardised residual indicates that more than the expected counts of engineers disagree with this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.14) which shows that the responses of results in table 5.20 have not been selected equally ($\chi2$ (N = 581, 4) = 11.410; $p < .05$), indicating that a significant difference exists between engineering categories and business practices and quality products.

Table 5.20 Cross-tabulation: engineering categories and quality products

Good business practice for quality product development and engineering category cross-tabulation		Good engineering business practices improve the quality of the product.			N
		Disagree	Unable to provide a response	Agree	
Engineer	Count	17	8	371	396
	%Within Engineering category	89.5%	47.1%	68.1%	68.2%
	%Within engineer group	4.3%	2.0%	93.7%	100.0%
	Standardized Residual	1.1	-1.1	0	
Engineering Technologist	Count	2	9	138	149
	%Within Engineering category	10.5%	52.9%	25.3%	25.6%
	%Within technologist group	1.3%	6.0%	92.6%	100.0%
	Standardized Residual	-1.3	2.2	-0.1	
Technician	Count	0	0	36	36
	%Within Engineering category	0.0%	0.0%	6.6%	6.2%
	%Within technician group	0.0%	0.0%	100.0%	100.0%
	Standardized Residual	-1.1	-1	0.4	
N	Count	19	17	545	581
	%Within Engineering category	3.3%	2.9%	93.8%	100.0%

5.3.5 CSF Technology domain – technology roadmap



	Technological expertise	Technology requirements	User job specification	Acquisition of new technology	HR competence	Cost effecivenes s in technology innovation	Technology innovation	Technology audit	Value-add of new technology
Agree	95.8	55.5	73.2	85.8	83.7	62.5	78.5	70.0	83.7
Unable to provide a response	2.5	6.4	5.0	2.5	4.5	6.5	9.8	8.4	5.2
Disagree	1.7	38.1	21.8	11.7	11.7	31.0	11.8	21.6	11.1

Figure 5.16 Frequency count for technology sub-factor

Respondents expressed their opinion on the technology perspective in the following way: With regard to engineering technology, the majority of the respondents, 95.8% agree that an engineer must possess a measure of technological expertise. On the performance management of engineering competence, 73.2% of the respondents are of the opinion that changes in technology require the job specification of the user to be redesigned and 85.8% agree that the acquisition of new technology affects the human resources requirements of the organisation. Regarding technology competence, 83.7% of the respondents agree that the adoption of new technology affects existing human resources competencies and concerning technology innovation, 78.5% of the respondents are of the opinion that most technology leading organisations tend to make small incremental improvements to its technology from time to time. Concerning technology needs and wants, the majority of the respondents 70.0% agree that a technology audit established an organisation's technology needs and 83.7% agree that adoption of new technology for which an organisation is ill-prepared, adds little value to the organisation.

5.3.5.1 Engineering technology.

a) Engineering software tools

Table 5.21 Cross-tabulation: engineering categories and engineering technology

Engineering technology and engineering category cross-tabulation		Engineering software tools manage engineering requirements.			N
		Disagree	Unable to provide a response	Agree	
Engineer	Count	170	27	200	397
	% Within engineering category	76.6%	77.1%	61.7%	68.3%
	% Within engineer group	42.8%	6.8%	50.4%	100.0%
	Standardized Residual	1.5	0.6	-1.4	
Engineering Technologist	Count	46	6	96	148
	% Within engineering category	20.7%	17.1%	29.6%	25.5%
	% Within technologist group	31.1%	4.1%	64.9%	100.0%
	Standardized Residual	-1.4	-1	1.5	
Technician	Count	6	2	28	36
	% Within engineering category	2.7%	5.7%	8.6%	6.2%
	% Within technician group	16.7%	5.6%	77.8%	100.0%
	Standardized Residual	-2.1	-0.1	1.8	
N	Count	22	35	324	581
	% Within engineering category	38.2%	6.0%	55.8%	100.0%

A cross-tabulation (table 5.21) between engineering categories and engineering technology shows that the majority of engineer (50.4%), technologists (64.9%) and technicians (77.8%), agree that engineering software tools manage engineering requirements. However, the standardised residual shows that more than the expected count of engineers disagree and more than the expected count of technologist and technicians agree with this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.15) which shows that the responses of results in table 5.21 have not been selected equally ($\chi2$ (N = 581, 4) = 17.307; $p < .05$), indicating that a significant difference exists between engineering categories and engineering software tools.

5.3.5.2 Performance management of technology competence.

a) User job specification.

Table 5.22 Cross-tabulation: engineering categories and user job specification

User job specification and engineering category cross-tabulation		Changes in technology require that the job specifications of the user be redesigned.			N
		Disagree	Unable to provide a response	Agree	
Engineer	Count	96	22	278	396
	% Within engineering category	75.0%	78.6%	65.3%	68.0%
	% Within engineer group	24.2%	5.6%	70.2%	100.0%
	Standardized Residual	1	0.7	-0.7	
Engineering Technologist	Count	30	5	114	149
	% Within engineering category	23.4%	17.9%	26.8%	25.6%
	% Within technologist group	20.1%	3.4%	76.5%	100.0%
	Standardized Residual	-0.5	-0.8	0.5	
Technician	Count	2	1	34	37
	% Within engineering category	1.6%	3.6%	8.0%	6.4%
	% Within technician group	5.4%	2.7%	91.9%	100.0%
	Standardized Residual	-2.2	-0.6	1.3	
N	Count	128	28	426	582
	% Within engineering category	22.0%	4.8%	73.2%	100.0%

A cross-tabulation (table 5.22) between engineering categories and user job specification shows that the majority of engineers (70.2%), technologist (76.5%) and technicians (91.9%), agree that changes in technology require that the job specifications of the user be redesigned. However, the standardised residual shows that more than the expected count of engineers disagree and more than the expected count of technologist and technicians agree with this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.16) which shows that the responses of results in table 5.22 have not been selected equally ($\chi2$ (N = 582, 4) = 9.704; $p < .05$), indicating that a significant difference exists between engineering categories and user job specification.

5.3.5.3 Technology needs and demands.

a) Technology audits.

Table 5.23 Cross-tabulation: age and technology audits

Technology audits and age cross-tabulation		A technology audit establishes an organisation's technology needs.			N
		Disagree	Unable to provide a response	Agree	
18 to 24	Count	0	0	2	2
	%Within age group	0.0%	0.0%	0.5%	0.3%
	%Within 18 to 24 age group	0.0%	0.0%	100.0%	100.0%
	Standardized Residual	-0.7	-0.4	0.5	
25 to 34	Count	20	14	71	105
	%Within age group	15.5%	28.0%	17.1%	17.7%
	%Within 25 to 34 age group	19.0%	13.3%	67.6%	100.0%
	Standardized Residual	-0.6	1.7	-0.3	
35 to 44	Count	25	16	123	164
	%Within age group	19.4%	32.0%	29.7%	27.7%
	%Within 35 to 44 age group	15.2%	9.8%	75.0%	100.0%
	Standardized Residual	-1.8	0.6	0.8	
45 to 54	Count	28	4	79	111
	Expected Count	21.7%	8.0%	19.1%	18.7%
	%Within 45 to 54 age group	25.2%	3.6%	71.2%	100.0%
	Standardized Residual	0.8	-1.8	0.2	
55 to 64	Count	40	8	75	123
	%Within age group	31.0%	16.0%	18.1%	20.7%
	%Within 55 to 64 age group	32.5%	6.5%	61.0%	100.0%
	Standardized Residual	2.6	-0.7	-1.2	
65 to 74	Count	14	7	58	79
	%Within age group	10.9%	14.0%	14.0%	13.3%
	%Within 65 to 74 age group	17.7%	8.9%	73.4%	100.0%
	Standardized Residual	-0.8	0.1	0.4	
75 or older	Count	2	1	6	9
	%Within age group	1.6%	2.0%	1.4%	1.5%
	%Within 75 and older age group	22.2%	11.1%	66.7%	100.0%
	Standardized Residual	0	0.3	-0.1	
N	Count	129	50	414	593
	%Within age group	21.8%	8.4%	69.8%	100.0%

A cross-tabulation (table 5.23) between age groups and technology audits shows that the majority (69.8%) of respondents in all age groups agree that a technology audit establishes an organisation's technology needs. However, the standardised residual indicates that more than the expected count of respondents in the 45 to 54 and 55 to 64 disagree with this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B,

Table 7.17) which shows that the responses of results in table 5.23 have not been selected equally ($\chi2$ (N = 593, 12) = 21.481; $p < .05$), indicating that a significant difference exists between the age group and technology audits.

Table 5.24 Cross-tabulation: engineering categories and technology audits

Technology audits and engineering categories cross-tabulation		A technology audit establishes an organisation's technology needs.			N
		Disagree	Unable to provide a response	Agree	
Engineer	Count	102	36	260	398
	%Within engineering category	81.6%	72.0%	64.0%	68.5%
	%Within engineer group	25.6%	9.0%	65.3%	100.0%
	Standardized Residual	1.8	0.3	-1.1	
Engineering Technologist	Count	20	12	115	147
	%Within engineering category	16.0%	24.0%	28.3%	25.3%
	%Within technologist group	13.6%	8.2%	78.2%	100.0%
	Standardized Residual	-2.1	-0.2	1.2	
Technician	Count	3	2	31	36
	%Within engineering category	2.4%	4.0%	7.6%	6.2%
	%Within technicians group	8.3%	5.6%	86.1%	100.0%
	Standardized Residual	-1.7	-0.6	1.2	
N	Count	125	50	406	581
	Expected Count	125	50	406	581

A cross-tabulation (table 5.24) between engineering categories and technology audits shows that the majority of engineers (65.3%), technologists (78.2%) and technicians (86.1%), agree that a technology audit establishes an organisation's technology needs. However, the standardised residual shows that more than the expected count of engineers disagree and more than the expected count of technologist and technicians agree with this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.18) which shows that the responses of results in table 5.24 have not been selected equally ($\chi2$ (N = 581, 4) = 14.829; $p < .05$), indicating that a significant difference exists between engineering categories and technology audits.

b) Value-add of new technology.

Table 5.25 Cross-tabulation: age and value-add of new technology

Value-add of new technology and age cross-tabulation		The adoption of new technology for which an organisation is ill-prepared, adds little value to the organisation.			N
		Disagree	Unable to provide a response	Agree	
18 to 24	Count	0	0	2	2
	%Within age group	0.0%	0.0%	0.4%	0.3%
	%Within 18 to 24 age group	0.0%	0.0%	100.0%	100.0%
	Standardized Residual	-0.5	-0.3	0.3	
25 to 34	Count	10	6	89	105
	%Within age group	15.2%	19.4%	18.0%	17.8%
	%Within 25 to 34 age group	9.5%	5.7%	84.8%	100.0%
	Standardized Residual	-0.5	0.2	0.1	
35 to 44	Count	20	10	133	163
	%Within age group	30.3%	32.3%	26.9%	27.6%
	%Within 35 to 44 age group	12.3%	6.1%	81.6%	100.0%
	Standardized Residual	0.4	0.5	-0.3	
45 to 54	Count	10	7	94	111
	%Within age group	15.2%	22.6%	19.0%	18.8%
	%Within 45 to 54 age group	9.0%	6.3%	84.7%	100.0%
	Standardized Residual	-0.7	0.5	0.1	
55 to 64	Count	17	4	102	123
	%Within age group	25.8%	12.9%	20.6%	20.8%
	%Within 55 to 64 age group	13.8%	3.3%	82.9%	100.0%
	Standardized Residual	0.9	-1	-0.1	
65 to 74	Count	7	1	70	78
	%Within age group	10.6%	3.2%	14.2%	13.2%
	%Within 65 to 74 age group	9.0%	1.3%	89.7%	100.0%
	Standardized Residual	-0.6	-1.5	0.6	
75 or older	Count	2	3	4	9
	%Within age group	3.0%	9.7%	0.8%	1.5%
	%Within 75 and older age group	22.2%	33.3%	44.4%	100.0%
	Standardized Residual	1	3.7	-1.3	
N	Count	66	31	494	591
	%Within age group	11.2%	5.2%	83.6%	100.0%

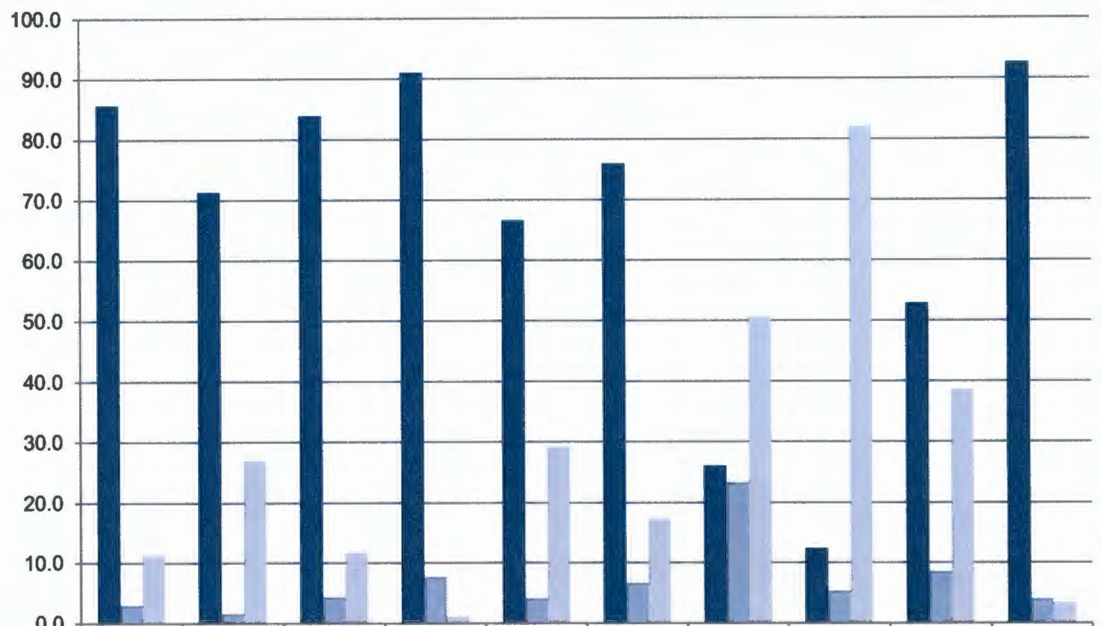
A cross-tabulation (Table 5.25) between age groups and value-add of new technology shows that the majority (83.6%) of respondents in all age groups agree that the adoption of new technology for which an organisation is ill-prepared, adds little value to the organisation. However, the standardised residual indicates that more than the expected count of respondents in the 35 to 44, 55 to 64 and the 75 and older age groups disagree with this statement. Additionally more than the expected count of 25 to 34 and 75 and older were unable to provide a response to this question. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.19) which shows that the responses of results in Table 5.25 have not been selected equally ($\chi 2$ (N = 591, 12) = 22.836; $p < .05$), indicating that a significant difference exists between the age group and value-add of new technology.

Table 5.26 Cross-tabulation: gender and value-add of new technology

Value-add of new technology and gender cross-tabulation		The adoption of new technology for which an organisation is ill-prepared, adds little value to the organisation.			N
		Disagree	Unable to provide a response	Agree	
Female	Count	2	0	53	55
	%Within gender	3.1%	0.0%	10.9%	9.5%
	%Within female group	3.6%	0.0%	96.4%	100.0%
	Standardized Residual	-1.6	-1.7	1	
Male	Count	62	31	433	526
	%Within gender	96.9%	100.0%	89.1%	90.5%
	%Within male group	11.8%	5.9%	82.3%	100.0%
	Standardized Residual	0.5	0.6	-0.3	
N	Count	64	31	486	581
	%Within gender	11.0%	5.3%	83.6%	100.0%

A cross-tabulation (Table 5.26) between gender and value-add of new technology shows that the majority of females (96.4) and males (82.3%) agree that new technology for which an organisation is ill-prepared, adds little value to the organisation. However, the standardised residual indicates that more than the expected count of males disagrees with this statement. Additionally more than the expected count of males was unable to provide a response to this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.20) which shows that the responses of results in table 5.26 have not been selected equally ($\chi 2$ (N = 581, 2) = 7.419; $p < .05$), indicating that a significant difference exists between gender and value-add of new technology.

5.3.6 CSF Environmental domain – policy, legislation, market.



	Ethical code of conduct	Engineering standards	Engineering for sustainable development	Engineering for sustainable economy	Emigration	Loss of skilled workforce	Immigration policy	Brain drain	Gender inclusion	Transformati on policy
Agree	85.7	71.3	83.9	91.1	66.6	76.0	26.0	12.4	52.9	92.6
Unable to provide a response	3.0	1.7	4.4	7.7	4.2	6.7	23.3	5.4	8.5	4.0
Disagree	11.2	27.0	11.7	1.2	29.2	17.3	50.7	82.2	38.5	3.4

Figure 5.17 Mean score per item for environmental factor

Respondents expressed their opinion on the environmental perspective in the following way. Relating to engineering ethics, the respondents (85.7%) agree that most engineers are guided by an ethical code of conduct. Regarding engineering for sustainable development, 83.9% of the respondents agree that engineering solutions have a positive effect on the consumption of natural resource and 91.1% are of the opinion that engineering is crucial in creating a sustainable economy. With regard to emigration in engineering, the respondents (66.6%) agree that the greatest threat to socio-economic development is the movement of highly skilled workers from one country to another and 76.0% agree that losing skilled professionals increases the expenditure on education to compensate for the loss of skills. On transformation policy in engineering, the majority (92.6%) of the respondents agree that a mentoring network creates a greater sense of belonging.

5.3.6.1 Engineering standards and ethics.

a) Engineering standards

Table 5.27 Cross-tabulation: age and engineering standards

Engineering standards and age cross-tabulation		Most engineers understand engineering standards.			N
		Disagree	Unable to provide a response	Agree	
18 to 24	Count	0	1	2	3
	%Within age group	0.0%	0.1	2.2	3
	%Within 18 to 24 age group	0.0%	33.3%	66.7%	100.0%
	Standardized Residual	-0.9	4.2	-0.1	
25 to 34	Count	31	1	74	106
	%Within age group	19.5%	1.8	76	106
	%Within 25 to 34 age group	29.2%	0.9%	69.8%	100.0%
	Standardized Residual	0.5	-0.6	-0.2	
35 to 44	Count	41	4	119	164
	%Within age group	25.8%	2.7	117.6	164
	%Within 35 to 44 age group	25.0%	2.4%	72.6%	100.0%
	Standardized Residual	-0.4	0.8	0.1	
45 to 54	Count	35	2	75	112
	%Within age group	22.0%	1.9	80.3	112
	%Within 45 to 54 age group	31.3%	1.8%	67.0%	100.0%
	Standardized Residual	0.9	0.1	-0.6	
55 to 64	Count	28	0	96	124
	%Within age group	17.6%	2.1	88.9	124
	%Within 55 to 64 age group	22.6%	0.0%	77.4%	100.0%
	Standardized Residual	-0.9	-1.4	0.8	
65 to 74	Count	23	2	54	79
	%Within age group	14.5%	1.3	56.6	79
	%Within 65 to 74 age group	29.1%	2.5%	68.4%	100.0%
	Standardized Residual	0.4	0.6	-0.4	
75 or older	Count	1	0	8	9
	%Within age group	0.6%	0.2	6.5	9
	%Within 75 and older age group	11.1%	0.0%	88.9%	100.0%
	Standardized Residual	-0.9	-0.4	0.6	
N	Count	159	10	428	597
	%Within age group	26.6%	1.7%	71.7%	100.0%

A cross-tabulation (table 5.27) between age groups and engineering standards shows that 71.7% of respondents agree that most engineers understand engineering standards. However, the standardised residual indicates that more than the expected counts of respondents in the 25 to 34, 45 to 54 and 65 to 74 age groups disagree with this statement. Additionally more than the expected count of 18 to 24 is unable to provide a response to this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B,

Table 7.21) which shows that the responses of results in table 5.27 have not been selected equally ($\chi 2$ (N = 597, 12) = 26.826; $p < .05$), indicating that a significant difference exists between the age group engineering standards.

Table 5.28 Cross-tabulation: engineering categories and engineering standards

Engineering standards and engineering categories cross-tabulation		Most engineers understand engineering standards			N
		Disagree	Unable to provide a response	Agree	
Engineer	Count	111	3	285	399
	%Within engineering category	71.6%	30.0%	67.9%	68.2%
	%Within engineer group	27.8%	0.8%	71.4%	100.0%
	Standardized Residual	0.5	-1.5	-0.1	
Engineering Technologist	Count	36	4	109	149
	%Within engineering category	23.2%	40.0%	26.0%	25.5%
	%Within technologist group	24.2%	2.7%	73.2%	100.0%
	Standardized Residual	-0.6	0.9	0.2	
Technician	Count	8	3	26	37
	%Within engineering category	5.2%	30.0%	6.2%	6.3%
	%Within technician group	21.6%	8.1%	70.3%	100.0%
	Standardized Residual	-0.6	3	-0.1	
N	Count	155	10	420	585
	%Within engineering category	26.5%	1.7%	71.8%	100.0%

A cross-tabulation (Table 5.28) between engineering categories and engineering standards shows that the majority of engineers (71.4%), technologists (73.2%) and technicians (70.3%), agree that most engineers understand engineering standards. However, the standardised residual shows that more than the expected count of engineers disagreed and more than the expected count of technologists and technicians are unable to provide a response to this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.22) which shows that the responses of results in table 5.28 have not been selected equally ($\chi 2$ (N = 585, 4) = 12.791; $p < .05$), indicating that a significant difference exists between engineering categories and engineering standards.

5.3.6.2 Retention of engineering skills.

a) Emigration.

Table 5.29 Cross-tabulation: gender and emigration

Emigration and gender cross-tabulation		The greatest threat to socio-economic development is the movement of highly skilled workers from one country to another.			N
		Disagree	Unable to provide a response	Agree	
Female	Count	9	0	48	57
	%Within gender group	5.4%	0.0%	12.1%	9.7%
	%Within female group	15.8%	0.0%	84.2%	100.0%
	Standardized Residual	-1.8	-1.6	1.6	
Male	Count	159	25	348	532
	%Within gender group	94.6%	100.0%	87.9%	90.3%
	%Within male group	29.9%	4.7%	65.4%	100.0%
	Standardized Residual	0.6	0.5	-0.5	
N	Count	168	25	396	589
	%Within gender group	28.5%	4.2%	67.2%	100.0%

A cross-tabulation (table 5.29) between gender and emigration shows that the majority of females (84.2%) and males (65.4%) agree that the greatest threat to socio-economic development is the movement of highly-skilled workers from one country to another. However, the standardised residual indicates that more than the expected count of females (1.6) agree and males (0.6) disagree with this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.23) which shows that the responses of results in table 5.29 have not been selected equally ($\chi 2$ (N = 589, 2) = 8.972; $p < .05$), indicating that a significant difference exists between gender and emigration.

Table 5.30 Cross-tabulation: engineering category and emigration

Emigration and engineering category cross-tabulation		The greatest threat to socio-economic development is the movement of highly skilled workers from one country to another.			N
		Disagree	Unable to provide a response	Agree	
Engineer	Count	135	17	247	399
	%Within engineering category	79.4%	70.8%	62.8%	68.0%
	%Within engineer group	33.8%	4.3%	61.9%	100.0%
	Standardized Residual	1.8	0.2	-1.2	
Engineering Technologist	Count	30	5	115	150
	%Within engineering category	17.6%	20.8%	29.3%	25.6%
	%Within technologist group	20.0%	3.3%	76.7%	100.0%
	Standardized Residual	-2	-0.5	1.5	
Technician	Count	5	2	31	38
	%Within engineering category	2.9%	8.3%	7.9%	6.5%
	%Within technician group	13.2%	5.3%	81.6%	100.0%
	Standardized Residual	-1.8	0.4	1.1	
N	Count	170	24	393	587
	%Within engineering category	29.0%	4.1%	67.0%	100.0%

A cross-tabulation (table 5.30) between engineering categories and emigration shows that the majority of engineers (61.9%), technologists (76.7%) and technicians (81.6%), agree that the greatest threat to socio-economic development is the movement of highly-skilled workers from one country to another. However, the standardised residual shows that more than the expected count of engineers disagreed and technologists and technicians agreed with this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.24) which shows that the responses of results in Table 5.30 have not been selected equally ($\chi 2$ (N = 587, 4) = 15.922; $p < .05$), indicating that a significant difference exists between engineering categories and emigration.

5.3.6.3 Sustainable development in engineering.

a) Immigration policies

Table 5.31 Cross-tabulation: age and immigration policies

Immigration policies and age cross-tabulation		South African immigration policies eliminate the barriers to entry for people with scarce skills.			N
		Disagree	Unable to provide a response	Agree	
18 to 24	Count	0	1	1	2
	%Within age group	0.0%	0.7%	0.6%	0.3%
	%Within 18 to 24 age group	0.0%	50.0%	50.0%	100.0%
	Standardized Residual	-1	0.8	0.7	
25 to 34	Count	38	36	33	107
	%Within age group	12.6%	25.7%	21.3%	17.9%
	%Within 25 to 34 age group	35.5%	33.6%	30.8%	100.0%
	Standardized Residual	-2.2	2.2	1	
35 to 44	Count	79	36	49	164
	%Within age group	26.2%	25.7%	31.6%	27.5%
	%Within 35 to 44 age group	48.2%	22.0%	29.9%	100.0%
	Standardized Residual	-0.4	-0.4	1	
45 to 54	Count	68	18	26	112
	%Within age group	22.5%	12.9%	16.8%	18.8%
	%Within 45 to 54 age group	60.7%	16.1%	23.2%	100.0%
	Standardized Residual	1.5	-1.6	-0.6	
55 to 64	Count	68	27	29	124
	%Within age group	22.5%	19.3%	18.7%	20.8%
	%Within 55 to 64 age group	54.8%	21.8%	23.4%	100.0%
	Standardized Residual	0.7	-0.4	-0.6	
65 to 74	Count	45	19	15	79
	%Within age group	14.9%	13.6%	9.7%	13.2%
	%Within 65 to 74 age group	57.0%	24.1%	19.0%	100.0%
	Standardized Residual	0.8	0.1	-1.2	
75 or older	Count	4	3	2	9
	%Within age group	1.3%	2.1%	1.3%	1.5%
	%Within 75 and older age group	44.4%	33.3%	22.2%	100.0%
	Standardized Residual	-0.3	0.6	-0.2	
N	Count	302	140	155	597
	%Within age group	50.6%	23.5%	26.0%	100.0%

A cross-tabulation (table 5.31) between age groups and immigration policies shows that 50.6% of respondents disagreed that South African immigration policies eliminate the barriers to entry for people with scarce skills. However, the standardised residual indicates that more than the expected count of respondents in the 25 to 34, 35 to 44 agreed and 45 to 54, 55 50 64 and 64 to 74 disagreed with this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.25) which shows that the responses of results in table 5.31 have not been selected equally ($\chi 2$ (N = 597, 12) = 22.625; $p < .05$), indicating that a significant difference exists between the age group and immigration policies.

Table 5.32 Cross-tabulation: engineering category and immigration policies

Immigration policies and engineering category cross-tabulation		South African immigration policies eliminate the barriers to entry for people with scarce skills.			N
		Disagree	Unable to provide a response	Agree	
Engineer	Count	214	90	95	399
	%Within engineering category	73.5%	64.7%	61.3%	68.2%
	%Within engineer group	53.6%	22.6%	23.8%	100.0%
	Standardized Residual	1.1	-0.5	-1	
Engineering Technologist	Count	63	35	51	149
	%Within engineering category	21.6%	25.2%	32.9%	25.5%
	%Within technologist group	42.3%	23.5%	34.2%	100.0%
	Standardized Residual	-1.3	-0.1	1.8	
Technician	Count	14	14	9	37
	%Within engineering category	4.8%	10.1%	5.8%	6.3%
	%Within technician group	37.8%	37.8%	24.3%	100.0%
	Standardized Residual	-1	1.8	-0.3	
N	Count	291	139	155	585
	%Within engineering category	49.7%	23.8%	26.5%	100.0%

A cross-tabulation (table 5.32) between engineering categories and immigration policies shows that the majority of engineers (53.6%) technologists (42.3%) and technicians (37.8%), disagreed that South African immigration policies eliminate the barriers to entry for people with scarce skills. However, the standardised residual shows that more than the expected count of engineers disagreed and technologist agreed with this statement. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table 7.26) which shows that the responses of results in table 5.32 have not been selected equally ($\chi 2$ (N = 585, 4) = 11.785; $p < .05$), indicating that a significant difference exists between engineering categories and immigration policies.

b) Brain drain

Table 5.33 Cross-tabulation: age and brain drain

Brain drain and age cross-tabulation		Engineering professional emigrate because of the high cost of living in South Africa.			N
		Disagree	Unable to provide a response	Agree	
18 to 24	Count	1	0	1	2
	%Within age group	0.2%	0.0%	1.4%	0.3%
	%Within 18 to 24 age group	50.0%	0.0%	50.0%	100.0%
	Standardized Residual	-0.5	-0.3	1.5	
25 to 34	Count	77	12	18	107
	%Within age group	15.8%	37.5%	24.3%	18.0%
	%Within 25 to 34 age group	72.0%	11.2%	16.8%	100.0%
	Standardized Residual	-1.2	2.6	1.3	
35 to 44	Count	135	8	20	163
	%Within age group	27.7%	8.8	20.3	163
	%Within 35 to 44 age group	82.8%	4.9%	12.3%	100.0%
	Standardized Residual	0.1	-0.3	-0.1	
45 to 54	Count	97	3	11	111
	%Within age group	19.9%	6	13.9	111
	%Within 45 to 54 age group	87.4%	2.7%	9.9%	100.0%
	Standardized Residual	0.6	-1.2	-0.8	
55 to 64	Count	107	3	12	122
	%Within age group	22.0%	6.6	15.2	122
	%Within 55 to 64 age group	87.7%	2.5%	9.8%	100.0%
	Standardized Residual	0.7	-1.4	-0.8	
65 to 74	Count	65	3	11	79
	%Within age group	13.3%	4.3	9.9	79
	%Within 65 to 74 age group	82.3%	3.8%	13.9%	100.0%
	Standardized Residual	0	-0.6	0.4	
75 or older	Count	5	3	1	9
	%Within age group	1.0%	0.5	1.1	9
	%Within 75 and older age group	55.6%	33.3%	11.1%	100.0%
	Standardized Residual	-0.9	3.6	-0.1	
N	Count	487	32	74	593
	%Within age group	82.1%	5.4%	12.5%	100.0%

A cross-tabulation (table 5.33) between age groups and brain drain shows that 82.1% of respondents disagreed that engineering professional emigrate because of the high cost of living in South Africa. However, the standardised residual indicates that more than the expected count of respondents in the 18 to 24, 25 to 34 agreed with this statement. Additionally, more than the expected count of 75 and older could not provide a response. This is further confirmed through the chi-square goodness of fit test (Annexure B, Table

7.27) which shows that the responses of results in table 5.33 have not been selected equally ($\chi 2$ (N = 593, 12) = 32.240; $p < .05$), indicating that a significant difference exists between the age group and brain drain.

Frequency and cross-tabulation analyses were performed to establish relationships by examining the connection between the independent and dependent variables, and to identify patterns and trends.

5.4 Component factor analysis

Pallant (2005) describes a factor analysis as an attempt to identify a limited set of factors that represents the underlying relationships among a group of related variables. A factor analysis was performed to answer the following research question: "What are the underlying structure for the proposed engineering systems model for the South African engineering industry, i.e. do training and development/social-environmental, individual attributes/social of an engineer, engineering value chain/process-function, technical and environmental factors model the needs of the South African engineering industry as suggested in the engineering systems model".

Pallant (2005) states that to perform a factor analysis, the following assumptions are made:

- The sample size should be 150 and more with a ratio of at least five cases for each of the variables;
- Items to be considered suitable for factor analysis the correlation matrix should show at least some correlations of $r = .3$ or greater. The Bartlett's test of sphericity should be statistically significant at $p < .05$ and the Kaiser-Meyer-Olkin value should be .6 or above.
- Since a factor analysis is based on correlation, it is assumed that the relationship between the variables is linear.
- Factor analysis can be sensitive to outliers, so as part of your initial data screening process either are removed or recoded to a less extreme value.

Firstly, the data was screened for univariate outliers and 131 out of range values due to administrative errors were identified and recoded as missing data. The minimum amount of data for a component analysis was satisfied, with a final sample size of 574, using listwise deletion, providing a ratio of over 11 cases per variable.

Initially, the factorability of the 50 items measuring the future needs of the South African engineering industry was examined. Firstly, criteria for the factorability of a correlation matrix were used. It was observed that only 14 of the 50 items correlated at least .35 with at least one other item, suggesting reasonable factorability.

Table 5.34 Correlation Matrix

Question		Mean	Std. Deviation	Analysis N	3	10	16	15	20	33	37	38	40	41	47	46	24	26	42
3	Project management in engineering	3.91	1.089	574	1.000														
10	Product reliability	4.41	.807	574	.170	1.000													
16	Creativity and innovation	3.63	1.083	574	.145	.154	1.000												
15	Workplace training programmes	3.65	1.099	574	.126	.127	.341	1.000											
20	Engineering education curriculum.	2.69	1.117	574	.154	.092	.264	.332	1.000										
33	Mentoring networks	4.29	.706	574	.165	.082	.063	.172	.138	1.000									
37	Technology audit	3.63	1.032	574	.176	.115	.157	.143	.158	.380	1.000								
38	Product quality	4.41	.720	574	.234	.167	.205	.092	.082	.183	.091	1.000							
40	Communication strategy	4.32	.735	574	.148	.224	.195	.193	.196	.133	.255	.201	1.000						
41	Creativity and innovation	4.47	.675	574	.184	.258	.130	.104	.091	.195	.205	.219	.281	1.000					
47	Market demands	4.08	.788	574	.188	.288	.105	.091	.028	.148	.148	.328	.225	.347	1.000				
46	Engineering software technology	3.26	1.166	574	.147	.177	.037	.100	.064	.227	.190	.322	.169	.360	.423	1.000			
24	Ethical code of conduct	4.10	.958	574	.189	.126	.243	.185	.237	.202	.294	.105	.189	.096	.110	.106	1.000		
26	Engineering standards	4.03	.885	574	.127	.168	.162	.125	.189	.093	.151	.112	.284	.127	.168	.063	.163	1.000	
42	Monitoring system	3.07	1.193	574	.183	.235	.118	.198	.087	.193	.215	.088	.071	.183	.122	.135	.287	.132	1.000

Table 5.34 shows the descriptive statistics for each variable and the Analysis N indicating the final sample size of 574. The correlation matrix indicates how each question is correlated with each of the other questions. Correlations $\geq$ .3 indicate that two items are associated and will probably group together by the PCA. Items with low correlations (e.g. $\leq$ .2) usually will not have high loadings on the same component. The diagonals of the correlation matrix were all 1.00.

Kaiser-Meyer-Olkin measurements of sampling adequacy, scree plot, variance and the rotated component matrix were investigated for a 14-item, four (4) component solution. This was found not to be adequate as only two (2) items loaded on the fourth component. The researcher decided to delete one (1) item, "Talent management is the training and development of staff members", and repeat the PCA on a 14 item, four (4) component solution. The results were adequate and are discussed below.

The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.790, above the commonly recommended value of 0.6, indicating sufficient items for each component. The Bartlett's test of sphericity was significant ($\chi2$ (91) = 1064.86, $p < 0.05$). Finally, the communalities were close to and above 0.3 (Annexure B, Table 7.28,) further confirming that each item shared some common variance with other items. Given these overall indicators, principal component analysis (PCA) was deemed to be suitable for the 14 items.

Table 5.35 KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.790
Bartlett's Test of Sphericity	Approx. Chi-Square	1064.859
	df	91
	Sig.	.000

5.4.1 Component extraction

Component factor analysis was used because the primary purpose was to identify and compute composite scores for the factors underlying the proposed engineering systems model. Table 5.36 shows that there are four components with an initial Eigenvalues more than 1.0. It should be noted that Eigenvalues for component fourth component is barely 1 at 1.001. After rotation the four components accounts for 49.12% of the total variance.

Although this is slightly less than 50% of the total variance we will continue to rotate four components.

The four component solution, which explained 49.12% of the variance, was preferred because of: (a) it develops a theoretical constructs; (b) it will be able to prove/disprove proposed theories; (c) the 'levelling off' of Eigen values on the scree plot after four factors; and (d) there were an insufficient number of primary loadings on five component solution and difficulty of interpreting the subsequent factors.

Table 5.36 Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.265	23.325	23.325	3.265	23.325	23.325	2.113	15.093	15.093
2	1.416	10.115	33.440	1.416	10.115	33.440	1.894	13.527	28.620
3	1.194	8.526	41.966	1.194	8.526	41.966	1.731	12.365	40.986
4	1.001	7.151	49.117	1.001	7.151	49.117	1.138	8.132	49.117
5	.983	7.024	56.142						
6	.879	6.281	62.423						
7	.794	5.670	68.092						
8	.760	5.428	73.521						
9	.691	4.935	78.456						
10	.688	4.911	83.366						
11	.647	4.624	87.990						
12	.636	4.541	92.531						
13	.563	4.019	96.550						
14	.483	3.450	100.000						

Extraction Method: Principal Component Analysis.

The Scree plot shows the initial Eigenvalues. A scree plot was examined to look for a change (or elbow) in the shape of the plot. Only components above this point will be retained. It is clear that a break between the fifth and six components, with the plot levelling off on the fifth component. A fourth component structure will therefore be explored. It should be noted that both the scree plot and the eigenvalues support the conclusion that the 14 variables can be reduced to four components.

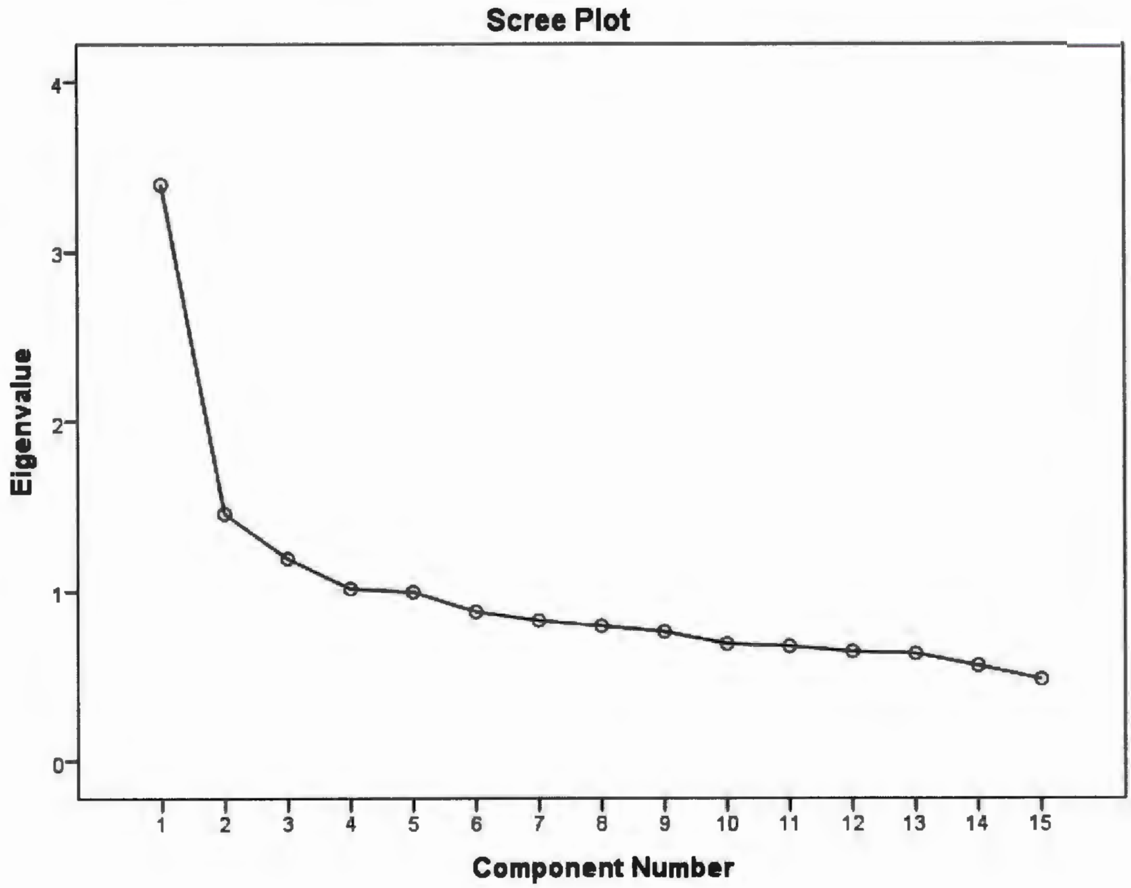


Figure 5.19 Scree Plot

Finally, a varimax rotation with Kaiser Normalization was used for the final solution.

Table 5.37 Rotated Component Matrix[a]

Items/Variables	Cross-functional process flow	Training and Development	Environment –Standards, ethics, monitoring and evaluation	Technology
Communication strategy	0.717	-0.066	0.071	0.176
Product reliability	0.632	0.187	-0.021	-0.08
Product quality	0.600	-0.033	0.223	0.197
Mentoring networks	0.589	0.08	0.018	0.137
Project management	0.427	0.216	0.218	-0.147
Creativity and innovation	0.072	0.701	0.088	0.013
Workplace training programmes	0.189	0.688	-0.051	0.093
Engineering education curriculum	-0.06	0.658	0.139	0.245
Engineering standards	0.072	0.089	0.773	0.185
Ethical code of conduct	0.112	-0.007	0.748	0.061
Monitoring system	0.087	0.441	0.478	-0.121
Technology audit	0.308	0.217	0.202	0.630
Market demands	0.33	0.282	0.393	-0.519
Engineering software requirements	0.189	0.272	0.127	0.483

Components are rotated so that they are easier to interpret. The rotated component matrix shows that all 14 items have a primary factor loading of .4 and above on the four components and three (3) or more items load on the four components which is adequate. The first component seems to index cross-functional process flow has strong loadings on five (5) items. The second component, index training and development, has strong loadings on three (3) items. The third component seems to index the environment, ethics, standards and evaluation of engineering products and processes has strong loadings on three (3) items and the fourth component seem to index technology has strong loadings on only three (3) items. The variable market demands has a strong negative loading of -0.519 indicating that if technology needs are not satisfied, the business owners will not be unable to meet the demands in the market.

The alpha coefficient (Annexure B, table 7.29) for the 14 items is .747, suggesting that the items have a relatively high internal consistency. A reliability coefficient of .70 or higher is considered "acceptable".

An interclass correlation coefficient (Annexure B, Table 7.30) was performed which indicates a high degree of reliability between the 50 items measured. The average measure ICC was .747 with a 95% confidence interval from .715 to 0.776 ($F (571) = 3.951$, $p<.001$). This evidence support the reliability of the measurement for the final sample, N = 574.

The CFA conducted prior to the Structural Equation Models (SEM) was performed to validate the measurements for the latent constructs and to separate out measurements and structural problems. The SEM model will examine the relations among latent constructs and assess the extent to which these relations are valid.

5.5 Structural equation modelling (SEM)

A Structural Equation Model (SEM) is a methodology that represents estimates and tests a network of relationships between variables (Suhr, 2006). An SEM was performed to test (a) hypothesis about relationships amongst observed and latent variables, (b) represent, estimate and test a theoretical network of linear relationships between variables and (c) to test hypothesised patterns of directional and non-directional relationships among a set of observed (measured) and unobserved (latent) variables. With an SEM the researcher's aim was to understand the pattern of correlation/co-variance and to explain their variance as well as possible with the model specified.

5.5.1 Advantages of SEM

Stein, Morris and Nock (2012) list the following as advantages of SEM as (1) factors and variables can be correlated, (2) it allows for multiple dependent variables or a single independent variable, (3) sub-group ability allows for the determination of the relationships between variables, and (4) Indicates the extent to which the theory is supported by the data.

5.5.2 Results of the SEM

As confirmed by the results in the CFA above, the latent variable, indexing cross-functional process flow has five (5) indicator or observed variables. The second latent variable, indexing training and development has three (3) indicator or observed variables. The third latent variable indexing the environment, ethics, standards and monitoring of engineering products and processes has three (3) indicator or observed variables and the fourth latent variable indexing technology has three (3) indicator or observed variables.

(a) The SEM will test this hypothesis that relationships exist between:

- The latent variable cross-functional process flow and observed variables communication strategy, product reliability, product quality, transformation policy and project management.
- The latent variable training and development and the observed variables, creative and innovation, workplace training programmes, and engineering education curriculum.
- The latent variable environment, ethics, standards and evaluation and the observed variables engineering ethics, ethical code of conduct monitoring system.
- The latent variable technology and the observed variables technology audit, entrepreneurship and engineering technology.

(b) The SEM will represent, estimate and test a theoretical network of linear relationships between variables.

(c) The SEM will test if a directional relationship exists between the latent variables and between the latent and measured variables (Suhr, 2006) and to understand the patterns of correlations/covariance amongst the set of variables (De Beer, Rothmann & Pienaar, 2014)

The SEM analysis used is an oblique confirmatory factor analysis (CFA) which assumes that all latent variables are correlated and is a priori model, in that the identified model is based on systems engineering theory as identified by Bartolomei *et al.* (2012).

First the overall model fit is determined. The goodness-of-fit test statistics are given below:

5.5.3 Fit statistics

Some of the criteria indicate acceptable model fit while others are close to meeting values for acceptable fit. An acceptable model fit is indicated by a chi-square probability greater than or equal to 0.05. Chi-square is a "badness of fit" index, smaller values indicate bad fit. The SEM analysis shows that chi-square $\chi 2$ (71) = 167.47; $p < .05$), indicates bad fit. Bentler and Bonnet (1980) says that chi-square test of absolute model fit is sensitive to sample size and non-normality in the underlying distribution of the input variables. If a sample size is large (N > 200), the model will most likely be rejected. Since the sample size exceeds 200 (N = 705 > 200), chi-square as an index will be ignored. A further investigation into alternative descriptive measures of fit such as CFI, TLI and RMSEA were performed.

- The Comparative Fit Index (CFI) is an incremental fit index and the value falls between 0 and 1. Siddiqui, Mirani and Fahim (2015) indicate that a value close to .90 reflect a good model fit. The value of .902 surpassed the rule of thumb of .90 (Hoyle, 1995),
- The TLI/NNFI value close to .90 reflects a good model fit (Hu & Bentler, 1999). TLI/NNFI is .875.
- RMSEA is based on the non-centrality parameter and indicates the amount of unexplained variance or residual. The .049 RMSEA value is below the guideline of .05 and also .10, which confirms good model fit (Suhr, 2012)

The SEM analysis has confirmed the factor structure of three (3) fit statistics; CFI, TLI and RMSEA indicate acceptable fit. A good fit means the variance in the variance-covariance matrix is well represented by the model.

5.5.4 Parameter estimates

Since acceptable model fit was found, the researcher determined significant parameter estimates. The path coefficient of communication strategy, creative and innovation, engineering ethics and technology audit are set as start value 1.0 or "fix". The ratio of each parameter estimate to its standard error is distributed as a z statistics and is significant at a 0.05 level if the t values exceed 1.96 and at the 0.01 level if the t value exceeds 2.56. The parameter estimates and statistical tests (z-values) for the model shows that it is significant at the .01 level. Measured/observed variables have "large" direct effect on the latent variable as the values of the path coefficients are all greater than .50. There is a positive relationship between the latent and measured variables illustrated by the statistically significant standardised regression coefficients. The coefficients reveal strong relationships.

Table 5.38 Standardised parameter estimates for the model

Path	Coef	Std. Err.	z	p>|z|	95% Conf. Interval		Result
Cross - Functional -> Communication strategy	1 (constrained)						
Cons	3.907666	0.045434	86.01	0.000	3.818617	3.996714	Significant
Cross - Functional -> Product reliability	0.891867	0.141094	6.32	0.000	0.6153276	1.168407	
cons.	4.409408	4.409408	131.09	0.000	4.34348	4.475335	Significant
Cross - Functional -> Product quality	0.749323	0.117451	6.38	0.000	0.5191242	0.979522	
cons.	4.287456	0.02944	145.63	0.000	4.229754	4.345159	Significant
Cross - Functional -> Mentoring networks	0.919133	0.138656	6.63	0.000	0.6473718	1.190894	
cons.	4.412892	0.030031	146.94	0.000	4.354032	4.471752	Significant
Cross - Functional -> Project management	0.982151	0.147778	6.65	0.000	0.6925123	1.27179	
cons.	4.324042	0.03066	141.03	0.000	4.263948	1.27179	Significant
Training and Development -> Creativity and innovation	1 (constrained)						
cons.	3.65331	0.045829	79.72	0.000	3.563486	3.743134	Significant
Training and Development -> Workplace training programmes	1.113846	0.142824	7.8	0.000	0.8339159	1.393776	
cons.	3.627178	0.045169	80.3	0.000	3.538648	3.715708	Significant
Training and Development -> Engineering education curriculum	0.986008	0.135816	7.26	0.000	0.7198123	1.252203	
cons.	2.691638	0.046566	57.8	0.000	2.600371	2.782904	Significant
Environment -> Engineering standards	1 (constrained)						
cons.	4.10453	0.039946	102.75	0.000	4.026238	4.182822	Significant
Environment -> Ethical code	1.148961	0.136798	8.40	0.000	0.8808412	1.41708	

Path	Coef	Std. Err.	z	p>|z|	95% Conf. Interval		Result
of conduct							
cons.	4.026132	0.0369	109.11	0.000	3.953811	4.098454	Significant
Environment -> Monitoring systems	1.228627	0.185559	6.62	0.000	0.864938	1.592315	
cons.	3.074913	0.049759	61.8	0.000	2.977386	3.172439	Significant
Technology -> Technology audit	1 (constrained)						
cons.	3.625436	0.043045	84.22	0.000	3.541069	3.709802	Significant
Technology -> Market demands	0.830063	0.129113	6.43	0.000	0.5770056	1.083119	
cons.	3.256098	0.048636	66.95	0.000	3.160773	3.351422	Significant
Technology -> Engineering software tools	0.609456	0.096172	6.34	0.000	0.4209622	0.79795	
cons.	4.078397	0.032847	124.16	0.000	4.014019	4.142775	Significant

The latent variable cross-functional process flow (functional) has a large direct effect on the following measured/observed variables, communication strategy, product reliability, product quality, monitoring networks and project management.

The latent variable training and development (training) has a large direct effect on the following measured/observed variables creativity and innovation, workplace training programmes and engineering education curriculum.

The latent variable standards, ethics and evaluation (evaluation) has a large direct effect on the following measured/observed variables engineering standards, ethical code of conduct and monitoring system.

The latent variable technology has a large direct effect on the following measured/observed variables technology audit, market demand and engineering software tools.

Table 5.39 Variances of exogenous variable

Path/Variance	Coef	Std. Err.
var(e.Q1- Communication strategy)	0.9984608	0.064891
var(e.Q2 - Product reliability)	0.5011963	0.034495
var(e.Q8 – Product quality)	0.3928511	0.026681
var(e.Q10 – Mentoring networks)	0.3602073	0.02683
var(e.Q11 – Project management)	0.3597973	0.028369
var(e.Q3 – Engineering curriculum)	0.8501921	0.067375
var(e.Q4 – Workplace training programmes)	0.7301826	0.067969
var(e.Q5 – Creativity and innovation)	0.8991121	0.0692059
var(e.Q6 – Engineering standards)	0.6784661	0.05079
var(e.Q7 – Ethical code of conduct)	0.4681043	0.047066
var(e.Q12 – Monitoring system)	1.062801	0.080037
var(e.Q9 – Technology audit)	0.8256884	0.062055
var(e.Q13 – Market demands)	1.193882	0.080267
var(e.Q14 – Engineering software tools)	0.5309447	0.033219
var(Cross-functional process)	0.1863934	0.046424
var(Training and development)	0.355398	0.067576
var(Environment)	0.2374368	0.047904
var(Technology)	0.2378458	0.055146

Note: level of confidence intervals = 95%;

In this model, the latent construct, training and development account for the highest percentage (35.5%) of residual of the variance and cross-functional process flow (18, 6%) the lowest. Standards and ethics and evaluation and technology account for 23.7% and 23.8% of the variances respectively.

All measured variables are affected by exogenous or unobserved variables. The path coefficient values that range between 0.3 and 1.2. The exogenous variables with the highest path coefficient values are ethical code of conduct (1.194) and monitoring system (1. 063). The dependent variable market demand (.359) has the lowest path coefficient score, in the model. Variances are significant at the 0.01 level for each error variance.

5.5.5 Covariance

The first test in SEM is obtaining the covariance and correlation between variables. These tests show relationships between variables that is not necessary causal (SAS/STAT 2010).

The covariance is an unstandardized form of correlation. It describes the pairwise relationships between a set of variables.

Table 5.40 Covariance between latent constructs

Covariance	Coef.	Std. Err.	z	P>|z|
Cross-functional process →Training	0.09925	0.024556	4.04	0.000
Cross-functional → Environment	0.105707	0.022592	4.68	0.000
Cross-functional → Technology	0.184676	0.031928	5.78	0.000
Training and development → Environment	0.149461	0.027662	5.40	0.000
Training and development → Technology	0.209975	0.035284	5.95	0.000
Environment → Technology	0.199011	0.029796	6.68	0.000

Note: level of confidence for confidence intervals = 95%;

Table 5.36 shows the correlation structure between the latent variables which are all less than 0.30, indicating that the latent constructs are all uncorrelated.

The structural diagram for the conceptual engineering systems framework for the South African engineering industry derived from the SEM shows the model shows acceptable fit on 3 fit criteria, CFI, TLI and RMSEA, has a strong positive relationship between the latent and measured variables illustrated by the statistically significant standardised regression coefficients, that the exogenous variables linked the training and development latent variable, variance accounts for the highest percentage (35.5%) and cross-functional process flow (18, 6%) the lowest. Environment and technology have share 23.7% and 23.8% of the variances respectively and the correlation structures between the latent variables are all uncorrelated.

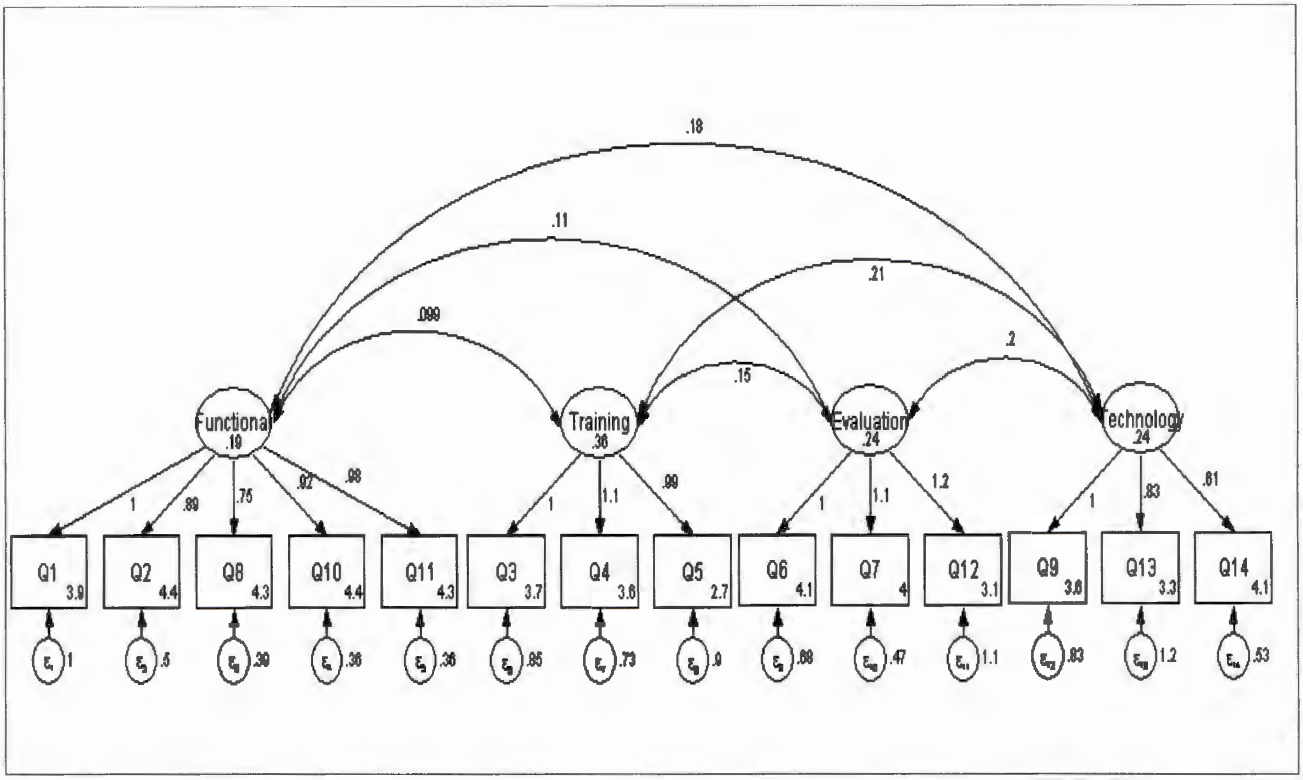


Figure 5.20 Path diagram for the needs South African engineering industry

5.6 Correlation matrix of the 14 dependent variables for the suggested model

A correlation matrix was again performed to shows the descriptive statistics for each of the 14 variable identified and shows the variables that correlate with other variables in the model. Correlations $\geq .3$ indicate that items are associated.

Table 5.42 Correlation matrix for the 14 dependent variables for the engineering conceptual model

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
.Technology audit	1													
. Market demands	0.24	1												
. Engineering software tools	0.27	0.19	1											
. Engineering standards	0.28	0.20	0.22	1										
. Ethical code of conduct	0.33	0.24	0.26	0.37	1									
. Monitoring system	0.27	0.20	0.22	0.31	0.37	1								
. Engineering education urriculum	0.25	0.18	0.20	0.19	0.23	0.19	1							
. Workplace training rogrammes	0.27	0.20	0.22	0.21	0.25	0.21	0.37	1						
. Creativity and innovation	0.24	0.17	0.19	0.19	0.22	0.18	0.32	0.34	1					
0. Communication strategy	0.28	0.20	0.22	0.19	0.23	0.19	0.15	0.17	0.14	1				
1. Product reliability	0.41	0.29	0.33	0.28	0.34	0.28	0.23	0.24	0.21	0.395	1			
2. Product quality	0.32	0.23	0.26	0.22	0.26	0.22	0.18	0.19	0.17	0.31	0.46	1		
3. Mentoring network	0.37	0.27	0.29	0.25	0.29	0.25	0.20	0.22	0.19	0.35	0.52	0.41	1	
4. Project management	0.35	0.25	0.28	0.24	0.28	0.23	0.19	0.21	0.18	0.33	0.49	0.39	0.44	1

$p > .0001$, $n = 705$

There is a relationship between ethical code of conduct, technology audit (r=.33) and engineering standards (r=.37). Monitoring systems correlate with engineering standards (r=.30) and ethical code of conduct (r=.37). Workplace training programmes correlates with engineering education curriculum (r=.37). Creativity and innovation correlates with education curriculum (r=.32) and workplace training programmes (r=.34). Product reliability correlates with technology audits (r=.41), engineering software tools (r=.33), ethical code of conduct (r=.33) and communication strategy (r=.39). Product quality correlates technology audit, communication strategy and product reliability. Mentoring network correlates with technology audit (r=.37), communication strategy (r=.35) and product quality (r=.41). Project management correlates with communication strategy (r=.33), product reliability (r=.49), product quality (r=.38) and mentoring network (r=.44)

5.7 Conclusion

The 50 variables were analysed for significance using univariate, i.e. descriptive and inferential statistics. The demographic information which forms the independent variables of the respondents was analysed and presented. The mean scores for the 50 items, showing central tendencies were calculated and analysed. A CFA was performed to determine the underlying structure for the proposed engineering systems model for the South African engineering. In conclusion an SEM was performed to answer the research questions (a) relationships amongst exists amongst observed and latent variables, and (b) are there patterns of directional and non-directional relationships amongst a set of observed (measured) and unobserved (latent) variables, as well as representing, estimating and testing a theoretical network of linear relationships between variables (conceptual framework).

CHAPTER 6: DISCUSSION AND RECOMMENDATION

6.1 Introduction

Based on the findings presented in chapter 5, the discussion will focus on the key findings made and recommendations following a quantitative or deductive research approach where existing theories and an in-depth literature review were used to identifying the CSF and sub-factors and suggest a conceptual framework for the South African engineering industry. The conceptual framework identified and groups the CSF into 5 factors, such as cross-functional process, social factors, environmental, technical training and development and to investigate their interrelatedness. This was tested through the use of a structured questionnaire and statistical tests on quantified data. The outcome of the quantitative confirmed or rejected or modified the theory. A conceptual framework based on the modification of theory was developed by determining the underlying structure of the proposed engineering systems framework for the South African engineering industry, and the main factors and sub-factors impacting on the needs of the engineering industry in South Africa

6.2 Findings of the quantitative study

The total population is 16 526 registered engineering professionals, consisting of professional engineering technologists, professional certified engineers and professional engineering technicians are registered on the ECSA database. Of these, 663 responded. The total sample size of 705 respondents included the respondents at Eskom (30) and the respondents at the Department of Water Affairs (12) who responded in the pilot study. The study examined the CSF and sub-factors for conceptual framework for the South African engineering industry and their interrelatedness, had the following findings:

6.2.1 Demographics of the South African engineering industry

Based on the analysis of the demographic factors the following is evident: the majority (27.0%) of the respondents are in the 34 to 44 age group, the majority (89.8%) of the respondents are males, the majority (91.1%) of the respondents are South Africans with 3.7% Africans and 5.7% foreigner nationals registered with the ECSA, the engineering professional categories are divided into engineering professions (65.7%), engineering technologist (25.9%) and engineering technicians (8.4%), Civil (36.6%) and electrical engineering disciplines (31.6%) have the highest number of respondents and engineering management (5.3%) and aerospace (0.6%), the lowest number of respondents and the total number of respondents, 90.2% are currently practicing professionals in South Africa.

6.2.1.1 Gender.

A further analysis was performed to establish the relationship between the gender and other independent variables. It is noted that the majority of male respondents (26.4%) fall within the 35 to 44 age group, whereas females (44.9%) are in the 25 to 34 age group; the top engineering discipline for males (37.6%) and females (31.9%) is civil engineering, there are more females (14.5%) than males (4.7%) respondents in the chemical engineering disciplines; and there are no females (0%) in engineering management.

Feminist theory (Crasnow, 2015) suggests that scientific knowledge is culturally constituted and a reflection of social structures and a way of thinking. In engineering this is embodied by a particular "culture of engineering" and is closely related to society's view on gender. Becker (2010) is of the opinion that the perceived image of engineering is strongly determined by traditions in society, prejudices of parents and teachers, which is largely moulded by gender stereotyping.

Evident to this fact is the male-dominated South African engineering industry, where only 658 (4.1%) females are registered as professional engineers (ECSA, 2014). Additionally, 70 (10.2%) of the 707 respondents to the online survey for this research were females.

Faulkner (2010) noted that South Africa, like many other developing countries, faces a severe shortage of high level engineering skills, which further highlighted by the underrepresentation of women in the engineering profession (ECSA, 2011). To promote and sustain the participation of women in engineering, it is important to understand how the culture of engineering sustains itself and then create a new engineering culture. Traditional activities of persuading women to try engineering and then help them fit into the engineering culture is no longer feasible. Becker (2010) states that a cultural revolution is needed to increase the number of women in science and technology.

Du Toit and Roodt (2008) identified several reasons for the low number of black female engineering professionals in South Africa as (a) females regards engineering as man's job; (b) traditionally, females are not attracted by technology; and (c) a leakage of females in the engineering pipeline. Faulkner (2007, 2010) is of the opinion that women may be attracted to studying engineering, but fewer enter the engineering profession. Moreover the recruitment, retention and promotion of women engineers remain a challenge.

A study done by Jawitz and Case (1998), analysing engineering disciplines at the University of Cape Town and Stellenbosch University showed that there is a sufficiently larger number of students in the civil, electrical, mechanical and chemical engineering disciplines. The reason cited for choosing civil engineering as a preferred discipline were the challenge, variety and career reward the discipline offers and chemical engineering attracts the high achievers in mathematics and science.

Jawitz and Case (1998) identified differences between males and females for choosing engineering as a career. For females it is involvement in human issues, the characteristics associated with the engineering career and their ability in mathematics and science. For males it is salary expectations, experience of engineering-related activities, scientific hobbies and fiddling with gadgets and wanting to be different.

6.2.1.2 Nationality.

The majority of engineers from South Africans and those from the rest of Africa are in the 35 to 44 age group. The majority of respondents from outside Africa are in the 55 to 64 and 65 to 74 age groups. The top engineering discipline for respondents from South African, rest of Africa and rest of the world is civil engineering.

Rasool and Botha (2011) noted that there is a severe shortage of engineers in South Africa with approximately a third of the engineers having left the country with 300 engineers leaving South Africa every year. Only seven hundred engineers join the economy every year from universities but 16 times more are needed. Problems with retaining engineers, combined with insufficient new graduates and an aging workforce, are affecting the South African engineering industry. Chronic skills shortages and the inability of the education and training system to meet the demand-driven needs of the economy major infrastructural projects such as the construction of the stadiums, transportation, road networks and power-plants constructions over the past few years, has caused South African engineering companies to recruit foreign skilled labour to South Africa (Hall & Sandelands, 2009). Skilled foreign workers are attracted to South Africa because it provides work opportunities which include competitive salaries and wages, professional opportunities such as promotions, education opportunities and good working conditions and quality family life (Rasool, 2010).

The data shows the highest percentage of respondents is in the civil engineering field. Case (2006) noted that there is a legislative requirement for the registration for certain types of engineering work. This legislative requirement is more enforced in the civil engineering fields. The data was collected from registered engineering professionals which shows that a relatively larger proportion of civil engineering professionals are registered compared to those in other disciplines (Case, 2006). ECSA has urged that that all employers of engineering professionals should understand and promote the benefits of registration. This is now evident in the increase in registration in disciplines such as electrical engineering and mechanical engineering.

6.2.1.3 Engineering category.

The data shows that the majority of engineers and engineering technologist are in the 35 to 44 age group and technicians in the 25 to 34 age group. The majority of engineers and engineering technologists are in civil engineering field and technicians are in the electrical engineering field.

According to Du Toit and Roodt (2008) engineering professionals are categorises into three groups: engineers, engineering technologist and engineering technicians. Engineers typically hold a BSc (Eng) or BEng/Ing degree from a recognised university, technologists hold a BTech from a recognised university of technology, and technicians hold a National Diploma (NDip) from a university of technology. Case (2006) states that there has been a dramatic increase in those studying towards engineering qualifications at the universities of technology at least in part due to the introduction of the BTech degree. This is confirmed in Reddy *et al.* (2016) who believe that the enrolments in engineering, both at university of technologies and traditional universities, increased by 16% from 71 000 in 2010 to 82 500 in 2014. He gave the reasons for the increase in student enrolment in engineering programmes as (a) increase in funding available, (b) the high demand for qualified engineers in the South African public sector and (c) engineering being classified as a critical and scarce skill, and priority skill in South Africa. Of concern is that the throughput rates for engineering programmes at institutions are particularly low, Reddy *et al.* (2016) indicate that the completion rate for qualifications in a Bachelor of Engineering is 23%, Bachelor of

Science, 23% and engineering diplomas is 5% (Reddy *et al.*, 2016). Research by Du Toit and Roodt (2008) shows that a significant number of engineering professionals employed as engineering technicians has a National Diploma and a NQF4 or less and are. The age pattern of employed individuals (StatsSA, 2014b) shows that 31.4% in the 25 to 34 age group and 30.9% in the 35 to 44 age group are in employment. This corresponds with our statistical analysis which shows that the majority of engineering professionals are in these age groups.

6.2.1.4 Engineering disciplines.

Aerospace engineering is noted as a scarce skills discipline with an ageing work force. Only 0.6% respondents indicated aerospace engineering as a discipline and the majority is in the 65 to 74 age group. It is important that the engineering sector should urgently look at the pipeline of skills to meet replacement demand in scarce areas. Perkins (2013) notes that engineering skills take a long time to develop, taking into account the time needed to develop the academic foundations of engineering by studying maths and science in school. In the short term, engineering can improve supply by investing in retaining those with engineering skills and encouraging them to return if they have left the profession or took a career break. In the longer term, the pipeline has to be prepared through (a) inspiring young people about engineering and giving them a strong academic foundation in school, (b) tackle leakage and capacity and quality issues throughout the pipeline, (c) improve the system's responsiveness to employer needs, (d) encouraging collaboration and engagement with educational institutions, (e) enhance employer ownership of skills; and (f) urgently address the lack of diversity in the system, by attracting more; and females and blacks into engineering.

Case (2006) confirms that traditionally BSc (Eng) graduate engineers moved more easily into management level positions than any other engineering professionals. The management function seemed to have evolved and now professionals are expected to perform and the management function is strongly rooted in the technical exposure that they have received in the earlier years of their training. This is evident in the fact that more engineering technologists than engineers now occupy managerial positions.

Case (2006) is of the opinion that engineers with about ten years' experience would likely be running large teams with specific technical goals, and those with approximately 20 years' experience would be at the helm of large corporate or public sector enterprises. Evidently, the 29.0% in the 45 to 54 and 25.8% in the 55 to 64 age groups are in engineering management.

6.3 CSF for the South African engineering industry

The five (5) CSFs were analysed to establish relationships by examining the connection between independent variables, age, gender and engineering categories and dependent variables with the aim was to identify patterns and trends.

6.3.1 Social-environmental factors - training and development

6.3.1.1 Engineering education.

a) Engineering education curriculum

Although the majority of respondents disagreed that the engineering education curriculum at higher education institutions enables engineering students to deal with socio-economic challenges, a perception amongst the younger age groups, 18 to 24 and 25 to 34 exists that higher education institutions do prepare engineering students to deal with socio-economic challenges. Case (2006) noted that ECSA had identified South African engineering degrees as narrowly scientific and technological. At the first Annual Engineering Summit in 2011 the resolution "ensuring the ongoing relevance and responsiveness of the engineering curriculum to the needs of society and the economy, taking into consideration international agreements, national quality standards and the needs of the diverse student intake" (Fisher, 2011:13), was captured which deals with transforming engineering education to meet the socio-economic challenges of the 21st century. Newberry, Miller, Johnson, Farber, Snieder and Kroes (2016) are of the opinion that although engineers play a crucial role in solving the enormous problems facing the world, most engineering schools are not preparing their students for the sociotechnical complexity or the global scale of the problems. They believe that the narrowness of engineering education provide few opportunities for students to develop substantive non-technical viewpoints and few opportunities to develop the personal attributes and understanding that might lead to become socially responsive and responsible.

b) Financial support

Although the majority of the respondents disagreed that sufficient financial support was provided for engineering students, more than the expected number of respondents in the 25 to 34 and 35 to 44 age groups are of the opinion that adequate sufficient financial support is provided for engineering students. A difference of opinion also exists between males and females, the majority of males disagreed and the majority of females agreed that sufficient financial support is provided to most engineering students. The literature (Hanrahan *et al.*, 2006) indicates that insufficient financial support is provided for engineering students. Hanrahan *et al.* (2006) state that South African higher education is extremely expensive and engineering students mostly depend on other parties to provide funding so as to afford the cost of studying engineering. They further state that inadequate funding result in low number of student take-up, low through-put of engineering students and a few qualified engineers to meet the increasing local and global demand for this skilled labour force. To address engineering skills shortage in South Africa, the JIPSA initiative skills deficit in engineering through three elements, (a) develop a framework for engineering acquisition, (b) provide funding, and (c) provide training, workplace placement and other support to students (JIPSA, 2010). JIPSA recognises that although there was increase in students enrolment in engineering disciplines such as electrical, civil, mechanical and industrial, there was also a high drop-out rate, especially amongst blacks students was evident. This is attributed to the fact that most black students lack fundamental and specialist mathematical, natural science and engineering knowledge due to historical inequalities (Hanrahan, 2009).

To increase engineering graduation rates and transform the engineering industry, the South African government adopted and implemented a multidimensional strategy of improved selection, academic support, academic development, pre-entry support, infrastructure improvement, hiring of additional staff, and the provision of student bursaries. The JIPSA report (2010) stated that the Department of Education made significant funding commitments to higher education institutions for engineering provision. The results in increasing the number of engineering graduates demonstrated that public funds can provide significant leverage in resource-poor institutions and learning environments. The inference can therefore be made that an increase investment to previously marginalised groups such as women and blacks would support the difference in opinion that exists. Although major strides had been made, the majority of respondents still believe that inadequate funding is provided to increase the local and global demand for this skilled labour force.

6.3.1.2 Mentoring.

a) Workplace training programmes

The majority of respondents indicated that engineering graduates are not provided with adequate workplace training. Lawless (2010) agrees with this notion and attributes this to a shortage of skilled engineers in the workplace. Armstrong and Wade (2015) state that the development of technical talent is important to become globally competitive an increase in new engineering graduates creates an uneven distribution by age within the industry. A gap of mid-level workers to move into more challenging positions in engineering exists. Armstrong and Wade (2015) reiterate that the training and development of engineering expertise takes about 10 years. They refer to the 10K rule as the amount of hours needed to develop a skill in an area to become an expert. It is therefore unlikely that adequate workplace training is provided to engineering graduates as perceived by the younger age groups. This is based on the following factors, (a) a shortage of skilled engineers and (b) an ageing skilled workforce and (c) expert performance is acquired slowly over a very long time as a result of intense practice.

6.3.1.4 Experiential training.

b) Workplace training

Although the majority of the respondents disagreed that engineering graduates possess the necessary skills the workplace requires, the younger age groups, 18 to 24 and 25 to 34 agree. A difference in opinion also exists between males and females, where the majority of females agreed that engineering graduates possess the necessary skills the workplace requires, the majority of males disagree. JIPSA (2010) and Lawless (2010) indicate that inadequate workplace training is provided to graduates engineers because of the shortage of skilled engineers in the industry resulting in a huge workload and not enough time to mentor young graduates. In an attempt to increase the number of skilled professionals who can mentor graduates, JIPSA (2010) requested the private sector to play an active role in the provision of priority skills and sought the support of organised labour for a shared priority skills agenda. The result was the introduction of a learnership programme which endeavours to close the skills gap by providing soft skills training or bridging courses to ensure not only workplace-readiness training, but also retrain graduates in the right study areas. A national placement strategy was introduced in most government departments and state-owned enterprises. These internships programmes aim to provide opportunities for intensive workplace training and experience, provide students with the work-based and experiential learning opportunities to meet requirements for graduation, improve the employment prospects of unemployed graduates and expose mid-career professionals, particularly women, to international best practice.

c) Workplace readiness

With regard to knowledge construct of workplace training programmes, the majority of the respondents agreed that the knowledge construct of workplace training programmes teaches the engineering graduate about the business operations, Niazi (2011) states that the employer must ensure that workplace training programmes are align to vision, mission and strategies of the organisation which informs the mentee about the organisational culture and the business operations. However, more than the expected number of engineers are of the opinion that workplace training programmes fail to teach the engineering graduate about the business operations. Mutereko and Wedekind (2015) postulate that workplace learning allows students to gain insight into the workplace for the purposes of qualification credits, regardless of its pedagogic site and it is primarily concerned with integrating classroom theory with industrial practice. Mutereko and Wedekind (2015) also suggest that the workplace learning curriculum is mostly work-directed theoretical learning, problem-based learning, project-based learning and workplace learning and it is not clear if WPL is able to bridge the theory/practice divide or allow the student to gain practical knowledge of industrial processes. Within South Africa, ECSA, does not make it mandatory for HEIs to include a workplace learning module in their degrees and therefore employers in South Africa are not obliged to provide workplace learning and integrate training as part of their business.

6.3.2 Social factors

6.3.2.1 Communication strategy,

a) Cross cultural communication

Patel *et al.* (2012) define South Africa as a multi-cultural, multi-linguistic society. The engineering industry is mostly a multidisciplinary, multi-cultural collaborative environment and for that reason needs an effective communication strategy to achieve the common goals. Engineers are required to effectively convey technical information and hence have suitable social and communication skills. Miscommunication can arise because of cultural differences and biases. Shachaf (2008) states that the varied cultural composition of many teams adds to their complexity as cultural biases can distort communication. Shachaf (2008) further reiterates that cultural and language differences may give rise to miscommunication, which can jeopardise trust, cohesion, and team identity. Patel *et al.* (2012) suggest that in order to communicate effectively, people must first become aware of their own biases and cultural influences, question it and reshape it. Hahn, Lippert and Paynton (2016) identified males and females have different communication strategies and behaviours. The results from the cross-tabulation indicating that more than the expected count of males disagreed that effective cross cultural communication can only take place when people start questioning their own biases, display a masculine communication style identified by Hahn *et al.* (2016) which tends to have problem solving or task accomplishment approach to communication, whereas more than the expected count of females that agreed with the statement, displays a feminine speech communication strategies of equity, support, conversational "maintenance work," responsiveness, a personal style, and tentativeness (Hahn *et al.*, 2016).

6.3.2.2 Creativity and innovation

a) Product and process innovation

With regard to product and process innovation, although the majority of respondents agreed that the design courses in the engineering curriculum nurture students' creative abilities, more than the expected count of engineers disagreed with this statement. Additionally, Sui (2012) states that the current engineering curricula does not prepare students to be creative and suggests that design courses that nurture students creative abilities, problem-solving skills and critical thinking should be offered to prepare them for this rapidly changing industry where traditional technical knowledge is no longer adequate. Turpin, Matthee and Kruger (2015) conclude open-ended problem solving requires not only the application of discipline-specific rules, but also the ability to think creatively in order to come up with novel solutions. To enhance creativity, creativity experts and practitioners believe that domain general creativity can be taught and enhanced through structured creativity development. Turpin *et al.* (2015) suggest innovative teaching approaches such as experiential learning, problem-based learning or game based learning should be used to nurture creativity.

6.3.3 Cross-functional process factors

6.3.3.1 Product design and development

a) Design teams

The results show that the younger age groups, 25 to 34, 35 to 44 and 45 to 54 agree that high quality design concepts are usually produced by a multidisciplinary design team. This is confirmed in the literature, Nelson, Yen, Wilson and Rosen (2009), who state that within an engineering team, engineers make use of the ideation components model when designing products, i.e. each designer is responsible for designing a different component or a larger part. They state that the design team must reach consensus on the unique theory to be employed or model of ideation to be used. Within this collaborative space; space, time, disciplines and cultures of the design team members has to be considered in order to be effective. The significant number of the older age groups, 55 to 64 and 65 to 74, disagreeing with this statement can be attributed to fact that computer-aided design (CAD) systems had evolved from standalone systems, operated from affordable personal desktop computers to computer-aided product development, referred to as cloud-based design (CBD). Wu, Rosen, Wang, and Schaefer (2015) note that the inherent characteristics of CBD systems are based on cloud computing, virtualization, multi-tenancy, ubiquitous access, software-as-a-service, pay-peruse business model, which potentially transform designing from individual efforts to collaborative design concepts.

b) Graduate design capabilities

Engineering design is a social and technical process in which products are designed by teams of people in single or multiple companies. The findings indicate that the majority of respondents agree that most engineering graduates lack design capabilities. This is corroborated by Todd, Sorenson, and Magleby (1993) who mentioned a number of weaknesses of engineering graduates that enter the industry. They (1993:1) found that "engineering graduates are technically arrogant, lack understanding of manufacturing processes, desire complicated and "high-tech" solutions, lack in design capability and creativity, lack in appreciation for considering alternatives, have a poor perception of the overall project engineering process; have a narrow view of engineering and related disciplines, have weak communication skills, and have little skill or experience working in teams". Lanzotti and Tarantino (2008) agreed and state that the problem with creating innovative designs within design teams is the lack design experience of entry level engineers.

6.3.3.2 Business practices for quality products.

a) Good business practices

The findings regarding good business practices and the production of a quality practices indicate that the majority of respondents agree that good engineering business practices improve the quality of the product. This is evident in the literature that a set of standards are usually applied to develop a safe product of high quality (Agusa & Hassan, 2011). For a product to be delivered or developed Agusa and Hassan (2011) says it has to meet all the client's requirements and specifications. The different measures to deliver quality products, include (a) implementing a service orientation culture within the organisation; (b) apply business processes such as TQM, lean principle, six sigma which focusses on customer satisfaction; (c) offer the customer different financing options; and (d) provide a product component upgrade. Moodliar, Genis, Anelich and Puren (2013) citing Kolarik (1999) who identified two fundamental elements that address the science of quality, i.e. the customer's experience of quality and the producer's creation of quality. The results further show that significant number engineers are of the opinion that good engineering business practices does not improve the quality of the product. This is justified by Moodliar *et al.* (2013) who state that the failure to understand the nature of the experience of quality will result in failure to systematically create quality. The creation of quality according the Moodliar *et al.* (2013) is achieved through good business processes such as the design, development, production, delivery, sales, customer service, use, and disposal or recycling processes.

Heires (2008) also mentions that in engineering practices the ISO standard is applied as a business management process. In engineering, the ISO 9000 series are the standards set for quality management and quality assurance, whereas the 9001 series is a methodology to set for improving and controlling the quality of a product or a service (Heires, 2008). The ISO 9001:2000 can specifically be applied in product realisation, customer requirements, and in the design and development of a product (Carmignani, 2009).

The results further show that significant numbers of engineers are of the opinion that good engineering business practices do not improve the quality of the product. Sivaram, Devadasan and Murugesh's (2013) criticism of ISO 9001 certification is because businesses experience a number of limiting factors to adequately obtain ISO certification, such as (a) internal bureaucracy and documentation, (b) very high implementation costs (cost of auditors, consultants, time, and resources) which are unaffordable for small- and medium-scaled enterprises, (d) ISO 9001 standard that is generic in nature, not industry-specific, and (d) the benefits of obtaining ISO 9001 certification are not clearly evident.

6.3.4 Technology factors

6.3.4.1 Engineering technology

a) Engineering software tools

The majority of respondents agree that engineering software tools match engineering requirements. This is confirm in the literature (Carrillo de Gea, Nicolás, Fernández Alemán, Toval, Ebert & Vizcaíno, 2011) who state that engineering software tools must be able to elicit, specify, analyse, commit, validate, and manage engineering requirements while considering user, technical, economic, and business-oriented needs and objectives. Carrillo de Gea *et al.* (2011) further state that these tools are fast evolving and the demands for more agile, flexible, advanced and worldwide collaborative software is increasing and therefore suggest that engineering software tools have to be evaluated for its suitability. Carrillo de Gea *et al.* (2011) mentioned the ISO/IEC TR 24766:2009 which is a type 2 technical report (TR) on a possible agreement on international standards focussing on the evaluation of computer-aided software engineering tools. Additionally a significant number of engineers also disagreed that engineering software tools manages engineering requirements. Their response can be ascribed to their experience in working with engineering software tools. It is therefore suggested that some enhancements needs to be made to engineering software tools in order to provide specific capabilities that are not yet sufficiently supported.

6.3.4.2 Performance management of technology competence.

a) User job specification

The majority of respondents agree that changes in technology require that the job specifications of the user be redesigned. Literature, (Davis *et al.*, 2014) state that the design of new technologies has a significant impact on the design of jobs and how work is organised. Bateman and Snell (2007, 2014) are also of the opinion that the changes in technology often require that the job specifications of the user to be redesigned to fit the demands of the technology and to maximise technology processes. The redesign of jobs and work processes was mentioned by Trist & Bamforth (1951) in the construction of the socio-technical theory, where they state that the adoption of new technology delivers more effective systems and contributes to improved work experiences for employees.

The results further indicate that although the majority of respondents agree that changes in technology require that the job specifications of the user be redesigned, more than the expected count of engineers disagreed with this statement. Bateman and Snell (2007) describe it as technologies that often fail to recognise the human aspect and social relationships of the task and hence fail to increase total productivity. Davis *et al.* (2014) investigating the social aspects of socio-technical systems, suggest that this aspect is often neglected. They readily acknowledge that engineering solutions to social problems may be necessary but are rarely sufficient and that industry lacks people with "expertise" in the social aspects of socio-technical systems.

6.3.4.3 Technology needs and demands.

a) Technology audits

The majority of the respondents agree that a technology audit establishes an organisation's technology needs. Clausing and Holmes (2010) state that technology innovation is one of the key factors for economic growth and investing in new innovative technology increases the organisation's competitive advantage. Adomavicius *et al.* (2013) and Clausing and Holmes (2010) state that before investing in new technology it is important to assess the organisation's technological assets and expand the vision to technologies beyond what the industry currently uses. A technology audit should be performed where the organisation identifies the key technologies it is dependent on.

However more than the expected count of respondents in the 45 to 54, 55 to 64 and engineers disagreed that a technology audit establishes an organisation's technology needs. A study by Shao and Lin (2016) states that a technology audit is not the only measure to assess technology needs. They see IT services as intangible in nature which is consumed at the moment it is produced and therefore cannot be inventoried for future usage. This making IT highly sensitive to demand fluctuations and rendering demand management as a top priority. Demand management is defined as an IT governance process that captures, evaluates, and prioritises all the demands placed on IT; from high-volume routine service requests to deploying changes across core applications. This is done (a) for better visibility and control over IT costs, risks, and resources, (b) to meet compliance requirements, and (c) to better align IT priorities and business objectives to increase the business value delivered by IT.

b) Value-add of new technology

The results show that the majority of respondents agree that the adoption of new technology for which an organisation is ill-prepared, adds little value to the organisation. Although the adoption of new technology brings improvements and affect the performance, Adomavicius *et al.* (2013) are of the opinion that organisations have to be prepared for the adoption of new technologies. If ill prepared, the endeavour can become expensive, adding little or no value to the organisation.

The results also indicate that age groups 35 to 44 (0.4), 55 to 64 (0.9) and the 75 and older as well as more than the expected count of males have the perception that the adoption of new technology for which an organisation is ill-prepared, may still add value to the organisation. Shao and Lin (2016) investigating the Malmquist productivity index (MPI) as a performance measure for new technology, identify two separate factors as potential contributors and/or inhibitors to measure productivity growth as a value add. The first factor is technological change that reflects innovation capability and the second one is efficiency change that relates to catch-up effort. They see technological change as the shift in the production frontier between two time periods while efficiency change captures the variation in the difference between the actual output measured and the maximum output indicated by the production frontier. Basically, they believe that technological change reveals the capacity of innovativeness and efficiency change signifies the capability of a production unit to draw near to its leading competitors. Therefore, by adopting new technology, managers and professionals has an opportunity to evaluate and prioritise decisions about expanding the demand for labour or potentially change the nature of the existing labour force. Adopting new technology, adds value to the organisation and consequently affects the labour force.

6.3.5 Environmental factors

6.3.5.1 Engineering standards and ethics.

a) Engineering standards

With regard to engineering standards, the results indicate that the majority of respondents agree that most engineers understand engineering standards. This is supported by Lynch and Kline (2000) who argue that it is important for engineers to understand engineering standards and procedures in order to reduce the effect of incremental changes and human error in engineering design and to anticipate and prevent potential threats to public safety that may arise during routine engineering works. Therefore, engineers should be able to learn how to identify features in their engineering work that can potentially contribute to problematic ethical outcomes. Engineers may face moral dilemmas when ethics are in conflict with management cost-benefit calculation.

However, a significant number of respondents in the 25 to 34 (0.5), 45 to 54 (0.9) and 65 to 74 (0.4) age groups and in the engineer group are of the opinion that most engineers do not understand engineering standards. This can be ascribed to universities not adhering to prescribed engineering standards and unregulated engineering professionals within the industry. Marjoram (2010) is of the opinion that universities play an important role in the training and development of engineers. They should provide world class engineering education, have engineering training capacity and capacity-building, provide continuous professional development for engineers and set engineering standards and professional accreditation. To achieve this, universities should (a) have diversity of schools or faculties of engineering with backgrounds in research and development and innovation, (b) be supported by government and foundation funding, and (c) have links to industry and private sector that can provide such support. South Africa being a developing economy has few such universities, whilst technologist and technicians are trained at universities of technology where the focus is on undergraduate training and teaching and less on research development and innovation.

Professional bodies that represent engineering professionals have to ensure that standards of professional competence and codes of conduct are adhered to by members. In 2015 (ECSA, 2016) there were 28 307 registered engineering professionals in South Africa with a vast majority unregulated. An important challenge for professional bodies is therefore to encourage standards for unregulated engineering professionals, facilitate that their work offering is of international standards and encourage them to acquire skills and experience outside the outside a regulatory framework.

6.3.5.2 Retention of engineering skills

a) Emigration

On emigration, the majority of respondents agree that the greatest threat to socio-economic development is the movement of highly-skilled workers from one country to another. This is supported by the literature, Ellis (2008), Gwaradzimba and Shumba (2010) who are of the opinion that labour market demands in developed countries have increased due to an ageing labour force and a rapid decline in birth rates. This condition encourages the movement of skilled professionals from developing countries to fill these gaps (Maharaj, 2010). Maharaj (2010:97) believe that "skilled immigrant entering a country comes with the sum of past investment and a stream of future revenue rooted in the competencies of that individual". This is supported by Gwaradzimba and Shumba (2010) who state that the country of origin suffers a net loss because it funds the education and training of the skilled professional, whereas the receiving country makes a net gain by obtaining qualified workers without having to bear the cost of training them.

Maharaj (2010) identifies pull and push factors as playing a major role in the movement of skilled workers to more developed countries and not necessarily whether their exit is a threat to the socioeconomic development of the country. This could be seen in the responses in a significant number of males in all engineering categories who disagreed that the greatest threat to socio-economic development is the movement of highly skilled workers from one country to another. Within South Africa, Gwaradzimba and Shumba (2010) identified crime, uncertainty about the future leadership, better business opportunities elsewhere, race discrimination, poor quality of education and poor quality of healthcare as push factors that affect the migration of skilled workers from South Africa to more developed countries.

6.3.5.3 Sustainable development in engineering

a) Immigration policies

The results show that more than a significant number of respondents 25 – 44, agree that South African immigration policies are eliminating the barriers to entry for people with scarce skills. This can be ascribed the huge influx of immigrants from neighbouring countries seeking better employment opportunities), creating an impression that South African immigration policies are lax. In 2013 it was estimated that there were more than 1.6 million non-South Africans living (StatsSA, 2013). Various data sources claim that there are actually up to six million immigrants in the country (SAIRR, 2013).

Additionally, the results show that the majority of respondents disagreed that South African immigration policies eliminate the barriers to entry for people with scarce skills. Rasool, Botha, and Bisschoff (2012) support this notion and state that the immigration policy which aims to influence the growing shortage of skills in the country is too restrictive and negatively impacts on the growth and expansion of the economy. They mention that changing permit conditions and/or status while in South Africa are restrictive. The Immigration Act (2002:2) indicates that to change permit conditions or work status can only happen under "exceptional circumstances" and that immigrants would, in most instances, need to return to their home countries to change the conditions or status of their permits (SAIRR, 2012).

b) Brain drain

The results confirmed that the majority of respondents disagreed that engineering professional emigrate because of the high cost of living in South Africa. This is confirmed in a study by Chappell and Glennie (2010) whom identified five common factors why skilled professionals emigrate as low wages, employment opportunities, professional development, professional and social networks and socio-economic and political conditions in their country of origin. Chappell and Glennie (2010) also cited safety concerns due to crime and violence as a major motivator for emigration.

The results further show that a significant number of respondents in the younger age groups, 18 to 24 and 25 to 34 agreed that the high cost of living in South Africa was one of the reasons why engineering professionals emigrate. This is corroborated by Labonté, Sanders, Mathole, Crush, Chikanda, Dambisya, Runnels, Packer, MacKenzie, Tomblin, Murphy and Bourgeault (2015) mentioning push factors that drive outward migrations as low remuneration, poor living and working conditions, lack of career development opportunities, high burden of HIV and MDR-TB, high cost of living and job and economic insecurity. The perceptions of the younger age groups can also be attributed to the fact that the younger generation bears the burden of shrinking opportunities, where a large number of young people's skills don't match the opportunities available to them. The system is thus seen as a closed economic space which creates the sense of exclusion from real opportunities. A lack of economic opportunities, results in a lack of income and an impoverished society.

6.4 Proposition for a conceptual framework for the CSF of the South African engineering industry

Engineering system (ES) theory developed due to a lack of existing theoretical knowledge to guide engineering professionals, engineering managers and policy makers responsible for the design and management of large-scale complex systems. Accordingly Bartolomei *et al.* (2012) identified a five domain system common to all engineering projects and systems, i.e. the environmental domain consists of system drivers that act or are acted upon by the system. The system drivers include the economic, political, social and technical influences that constrains, enable or change the characteristics of components in the system, the social domain consisting of the human factors and the relationships amongst them it includes a the person interacting with the technical components for some purpose, a collection of individuals interacting with the technical components and each other and where each individual contribution supports the goal of the group/team, interacting groups, whose contributions support the organisation's goal or interacting organisations, whose contribution supports the enterprise, the functional domain, includes the goals and purposes of the engineering system, as well as its functional architecture, the technical domain, the physical, non-human components of the system to include hardware, infrastructure, software and information and the process domain, the processes, sub-processes, tasks and units associated with an engineering system.

Other aspects included in ES frameworks include time, which indicates that engineering systems components can change over time, system boundaries that occur when components of the system no longer contribute to the goal of the system and remain inactive, in which case the system will self-regulate and path dependencies represent the consequences of human decisions, unexpected events and other system behaviours because of human decisions.

Further general investigation of the literature and a comparative BRICS literature study gave credence to the CSFs used in the proposed model. The proposed conceptual ES conceptual framework was deemed an applicable theoretical framework model because the study is investigating the engineering success factors most applicable to the South African engineering industry, all identified factors for the study fall within the five (5) domains i.e. social, functional, process, technical and environmental domains of an engineering system, engineering systems are large-scale complex system characterised by a high degree of technical involvedness, social complexity and intricate processes, and all elements are interrelated, where each element has an effect on the functioning of the whole, additionally each element is affected by at least one other element in the system. This proposed conceptual framework was then tested using various research methods and techniques to produce a useable framework for the South African engineering industry.

A CFA produces four (4) latent variables indexed training and development, cross-functional process, technology and environment and its corresponding observed or indicator variables. An SEM confirmed the model testing hypotheses that significant relationships exist between the latent variables and indicators and observed variables. It showed the directional relationship between the latent variables and an understanding of the patterns of correlations/covariance amongst the set of variables (De Beer, Pienaar and Rothmann, 2014). The conceptual framework, figure 6.1 is a representation of the SEM path model.

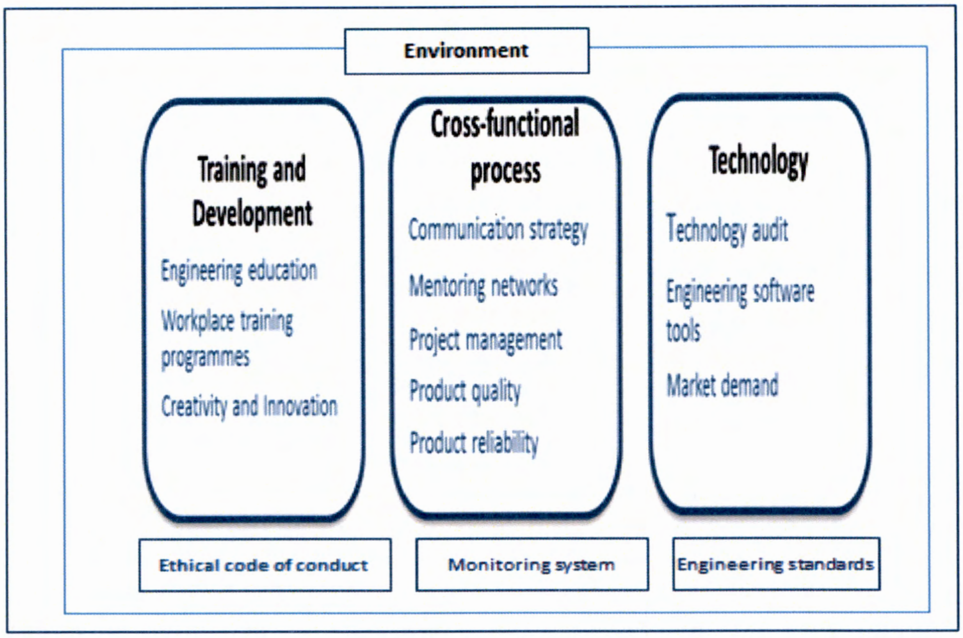


Figure 6.1 A conceptual framework for the South African engineering industry

6.4.1 Training and development

Training and development are social functions consisting of the human factors and the relationships amongst them. It includes a person, a group or team, or interacting groups who interact with the technical components for some purpose and whose contributions support organisations or interacting organisations goals. The social domain has been indexed training and development as the observed or indicator variables showed a strong correlation/variance with training and development activities.

6.4.1.1 Engineering education curriculum.

The question that arises is "does engineering education curriculum at higher education institutions in South Africa enables engineering students to deal with socio-economic challenges?" According to the World Higher Education Declaration (1998) an adequate higher education and research institution is required to provide a critical mass of skilled and educated people to ensure genuine endogenous and sustainable development to reduce the gap separating less develop countries from developed ones. Danilova *et al.* (2011) are of the opinion that engineering education has to ensure that engineering students are able to face the challenges of the 21st century and meet developing global requirements.

Hanrahan (2009:1) points out that engineering education at higher education institutions must embody the criteria for accredited engineering programmes defined by national accrediting bodies. South Africa's national accreditation body, ECSA, ensures that (a) engineering and engineering technology degrees and technician diplomas offered in South Africa are internationally benchmarked and mutually recognised, (b) evaluate qualifications that are neither accredited nor recognised by ECSA and (c) promotes the quality of engineering education programmes and policies and practices to increase the number of graduates to meet national needs (Act 46, 2000). Accreditation of engineering programmes is obtained when the programme meets all criteria being granted accreditation. Within the Bachelor of Science in Engineering (BSc(Eng))/ Bachelors of Engineering (BEng) degrees one of the accredited criteria is that graduates are required to demonstrate critical awareness of the impact of engineering activity on the social, industrial and physical environment (ECSA, 2004), thereby ensuring that the engineering education curriculum at South African HEIs enables engineering students to deal with socio-economic challenges.

6.4.1.2 Workplace training programmes.

The training for engineering graduates (BEng and BTech degrees) takes three to five years after obtaining the engineering degree. The aim is to gain relevant workplace experience and obtain the professional engineering registration if so chooses. Companies are competing for the same scarce resources and by investing in training as well as supporting the engineering graduate's career development will ensure that the organisation becomes the employer of choice. The employer must consequently ensure that the knowledge construct of the training programme aligns to vision, mission and strategies of the organisation as well as inform the engineering graduate about the organisational culture and the business operations. On the other hand, Patil *et al.* (2008) and Detsimas *et al.* (2016) observed that engineering graduates struggle to settle into workplace training programmes because of a skills gap between the engineering graduate's skills set and what the workplace requires. Although the training of engineers is mostly technical in nature, the knowledge construct of workplace training programmes with a well-developed mentoring programme can provide engineering graduates with responsibilities and develop their knowledge, skills and attitudes through direct work experience. According to Lo and Ramayah (2011) mentoring is a long-term process that should be developmental in nature. It should have a career development aspect where the mentor shows the mentee how to advance within the organisation as well as aiding the mentee on a personal level to build a positive self-image and become effective in a professional role. Effective engineering mentoring programmes require that (a) managers and engineers across the entire organisation are involved and (b) the organisation's systems and infrastructure supports the programme. The selection and correct matching of mentees to mentors are vital for its success. The sustainability of the programme depends on measuring, reviewing and reporting the successes, failures, opportunities and threats to the programme (O'Donald *et al.*, 2008).

6.4.1.3 Creativity and innovation.

The IEA Report (2013) describes engineering graduates' attributes and professional competencies that have a purposeful application of mathematical and natural sciences and a body of engineering knowledge, technology and techniques which seek to produce solutions whose effects are predicted to the greatest degree possible in often uncertain contexts. Creativity and innovation are seen as critical attributes and professional competency for engineering graduates.

Sui (2012) believes that engineers are increasingly required to have a broad understanding of their profession to enable them to identify the customers' needs, initiate design and business process strategies, and make decisions regarding new products. A study done by Todd *et al.* (1993) discuss a number of weaknesses of engineering graduates that enter the industry. They list the weaknesses as being technically arrogant, lack understanding of manufacturing processes, desire complicated and high-tech solutions, lack in design capability and creativity, lack appreciation for considering alternatives, have a poor perception of the overall project engineering process, have a narrow view of engineering and related disciplines, have weak communication skills and have little skill or experience working in teams. Sui (2012) further reiterates that the current engineering curricula do not prepare students to be creative and suggests that students should be offered design courses that nurture their creative abilities, critical thinking and prepare them for this fast changing industry where traditional technical knowledge is no longer adequate. This is supported by Lanzotti and Tarantino (2008) and May and Strong (2006) who are of the opinion that engineering design must be innovative and creative and believe that entry-level engineers in design teams usually lack innovation, creativity and design experience.

May and Strong (2006) explained innovation and creativity as (a) engineering design specifications, (b) design for manufacturing, (c) overall design process, (d) design for assembly, (e) creativity methods, (f) solid modelling, (g) team design projects, (h) open-ended problem solving, (g) CAD solid modelling, (h) interdisciplinary design projects and (i) written design reports as requirements for graduating and practicing engineers.

6.4.2 Cross-functional process

According to Bartolomei *et al.* (2012) the functional domain in the ES framework consists of the objectives that include all expressed and unexpressed needs of the customer in the system. All functions must relate to an objective, either directly or indirectly and must be measurable. This could include information flow, energy, material and spatial relations. A process domain includes processes, procedures, tasks and work units associated with an engineering system. The domain has been indexed cross-functional process as the indicator or observed variables contain both functions and processes. Functions include product quality and product reliability, communication strategy relate to an objective and are measurable. Mentoring networks are included under function as this can be defined as a spatial relation within an organisation. Project management is a business process. A correlations/covariance matrix indicates that relationships exist between communication strategy, product reliability and product reliability, project management and mentoring networks.

6.4.2.1 Communication strategy.

Effective communication is the ability to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions. A critical engineering attribute and competency is the ability to communicate effectively on complex engineering activities with the engineering community and with society at large. An effective communication strategy will prevent misunderstanding and ensures that the business produces a high quality end product. Additionally a continuous flow of information between business and customer is important as it involves the customer in every phase of the project (Bubshait *et al.* 2015). The customer's needs are therefore met because of (a) continuous support being offered, (b) offering a superior customer value, (c) adjusting the support according customer's needs, (d) coordinating support planning with the customer, (e) providing support at the customer location and (g) offering a fast response to customer's needs. A superior product is produced that will meet the customer's specification. Apart from the establishing good business-customer relations to respond effectively to customer needs, Sarker *et al.* (2012) state that it is important to establish a close, long-term relationship with the supplier to prevent the delivery of defective parts and improve delivery times. A healthy relationship with contractor-subcontractor relationship is also important. Contractor-sub-contractor relationships are formed on a project-by-project basis and are usually short-term. The delivery of a quality product is dependent on the performance of the contractor and sub-contractor.

6.4.2.2 Product quality.

Establishing good engineering business processes improves the quality of the product. By improving internal business process inefficiencies through product and service differentiation enables businesses to gain a competitive advantage. Good business processes include: implementing a service orientation culture within the organisation, apply business processes such as TQM, lean principle, six sigma which focus on customer satisfaction, offering the customer different financing options and providing a product component upgrade. Agusa and Hassan (2011) are of the opinion that standards are applied to develop a safe product of high quality. The adoption of ISO standards is therefore essential in quality assurance. For a product to be developed or delivered, Agusa and Hassan (2011) stated that it has to meet all the client's requirements and specifications.

6.4.2.3 Product reliability.

Producing a reliable product creates a satisfied customer base. Peter Drucker (1995) indicates that the quality of a product or a service is not what the supplier puts in, but what the customer gets out of it and is willing to pay for. Businesses that follow a high quality and product differentiation strategy have an advantage over its competitors. Porter (1986) comments that producing quality products ensures that the business can charge a higher price per unit thereby assuring a price advantage over its competitors. Chougale *et al.*

(2012) add that customer satisfaction and quality and reliability of a product are closely related. A customer can only describe the quality and reliability of the product or service based on the customer's own experience with that product or service (Chougule *et al.*, 2012). Womack and Daniel (2005) are of the opinion that customer satisfaction can be used as a product performance measurement and that one bad experience by a customer can be exaggerated to affect the quality related satisfaction of the product or service. Products and services that adhere to a set of standards has the following available, auditable documents that stipulates the product specifications and implementation procedures as well as corrections previously done, a continual flow of information to improve interaction and skills development, the production of a good quality, reliable product and service benchmarked against international standards, customised to the needs and wants of the customer, a regular quality control process as well as a description thereof and various operational models of various services that give a description of the end-result.

6.4.2.4 Mentoring networks.

The engineering industry needs high-level skilled professionals. A mentoring approach will enable the next generation of engineers to develop in an environment where weaknesses can be addressed early on. Since companies are competing for the same scarce resource, investing in the training and supporting the engineering graduate's career development will ensure that the organisation becomes the employer of choice. Effective engineering mentoring programmes involve managers and engineers across the entire organisation. The mentoring programme has to be supported by the organisation's systems and infrastructure. A well-constructed mentoring programme, supported by the entire organisation ensures the development of well-rounded engineering professionals.

Within the mentoring relationship the knowledge, skills and attitudes of the mentee are developed and aligned to the organisation's business objectives. O'Donnell *et al.* (2008) discern that mentoring is critical in the early career development phase of engineers.

Creating a mentoring network can bring minority groups (blacks and female engineers) together to create a greater sense of belonging. This will improve the recruitment and the retention of blacks and females in this profession (Watson and Froyd, 2007). Creating a nurturing environment where everybody feels valued and have a sense of belonging will assist in dealing with diversity and equality issues.

6.4.2.5 Project management.

Project management is an engineering activity that spans the engineering value chain. Engineering activities are integrated and the concept of project management enables the simultaneous thinking about engineering activities. Zhang and Gregory (2011) note that project management is particularly useful in long-life or complex engineering systems. Project management is thus the standard operation of delivering quality products and services within a limited time-frame in the engineering industry. Hall *et al.* (2009) indicate that main objectives of managing engineering project are: to meet or beat the engineering project budget costs, thus being profitable, to satisfy customer requirements, to tender for contracts, meet qualifying criteria and win contacts and to satisfy legal requirements such as health and safety regulations, environmental requirements, taxations.

Project management style leadership requires certain competencies to ensure the successful execution of the project. Nauman *et al.* (2010) point out that successful projects are led by people who possess technical and managerial knowledge and are able to motivate people in achieving the set goals. Team goals have to be clear to deliver a successful product. Project leaders must be supportive as well as achievement-orientated to achieve the project goals within a set time frame.

6.4.3 Technology

Technology is the physical, non-human component of the engineering system and includes hardware, infrastructure, software and information. The attributes and competencies of engineers as depicted in the IEA report (2013) state that engineers should be able to create, select and apply appropriate techniques, resources and modern techniques and IT tools, including prediction and modelling, to complex engineering problems, with an understanding of the limitations. The latent variable technology has a large direct effect on technology audits, engineering software tools and market demands. The CFA shows that the variable market demands had a strong negative loading of -0.519 indicating that if technology needs are not satisfied, the business owners will be unable to meet the demands in the market.

6.4.3.1 Technology audits.

Clausing and Holmes (2010) state that technology innovation is one of the key factors for economic growth and investing in new innovative technology increases the organisation's competitive advantage. Before investing and expanding technologies beyond what the industry currently uses, the organisation's technological assets of the organisation have to be assessed. The first step is to identify the key technology asset base which the organisation is dependent on and then perform a technology audit to establish the organisation's technology needs. The key technology asset base are technology assets, i.e. process, product and support systems, organisational assets which are the resources the organisation used to develop and set up its technology base, and external assets involving the relationships the organisation set up with suppliers, competitors and customers. Projects technology base can be assessed as it involves technology, organisational and external assets, how they are used and how well the daily operations are performed. Project management software packages assist with project scheduling, show a breakdown structure of the various activities, estimated times, start and finish times, slack and critical path. In this day and age computer software are frequently used in the development of products, processes and systems.

6.4.3.2 Engineering software tools.

Carrillo de Gea *et al.* (2011) believe that engineering software tools must be able to prompt, stipulate, analyse, commit, validate, and manage engineering requirements while considering user, technical, economic, and business-oriented needs and objectives. Since these tools are fast evolving the demand for more agile, flexible, advanced and worldwide collaborative software is increasing. Carrillo de Gea *et al.* (2011) are of the opinion that engineering software tools have to be evaluated for its suitability. They suggest that ISO/IEC TR 24766:2009 should be used to evaluate engineering software tools capabilities. The document is a type 2 technical report which shows future but not an immediate possibility agreement on an international standard. This report supplements the more general ISO/IEC 14102:2008 standard which focuses on evaluating computer-aided software engineering tools.

6.4.3.3 Market demands.

For business owners to improve the business's profitability, market share and competitiveness, they have to be innovative. Innovation is the ability of organisations to respond to consumers' demands and new competitors by developing and introducing new products and services to the market. Before introducing the new product/service, the business must assess the relevance of the product/service for the market, the competitive adeptness of the product/service and be realistic about what the market demands and the costs of meeting these demands. It must be apparent how the new product/service fits in the market, where the business has considerable influence and if the new product/service matches the organisation's core skills and resources.

New technology introduced to the market always has the potential for further development and innovation. Businesses that use new technology are known as technology leaders. They take considerable risks at huge costs with the aim of making a significant profit and be a market leader. On the other hand, technology followers improve on developed innovation in order to reduce costs and risks. Technology followers support a low-cost, differentiation strategy (Ray & Gehani, 2013). To choose to become a technology leader or follower, Adomavicius *et al.* (2013) suggest that organisations assess the strengths and weaknesses of their current technological base by identifying the current market needs, compare it with their current technology base, assess the functional specification of the future technology and decide whether to follow a low-cost, a differentiation strategy or develop new technology. Technology needs of an organisation have to be satisfied, to ensure that business owners meet the demands in the market.

6.4.4 Environment

Bartolomei *et al.* (2012) state that the environmental domain represents system drivers that act or are acted upon by the system. The system drivers include the economic, political, social and technical influences that constrain, enable or change the characteristics of components in the system. The IEA (2013) describes environmental attributes and competencies an engineer must possess as the ability to understand and evaluate the sustainability and impact of professional engineering work in the solution of complex engineering problems in societal and environmental context. Other environmental CSFs are ethics and standards, which involve the ability to apply ethical and responsible norms of engineering practice. Monitoring systems are used to evaluate the outcomes and impacts of complex systems

6.4.4.1 Ethical code of conduct.

The rules of conduct (Act 46 of 2000) define and explain the ethical framework for engineering professionals which includes competence, integrity, public interest, environment, the dignity of the profession and administrative issues related to the engineering profession. Accordingly engineers must be guided by an ethical code of conduct. Ethical behaviour and the application of engineering standards are closely related. This is confirmed in Lynch and Kline (2000) who observe that it is important for engineers to understand engineering standards and procedures. The effect of incremental changes and human error in engineering design can anticipate and prevent potential threats to public safety that may arise during routine engineering works. Engineers must learn how to identify features in their engineering work that can potentially contribute to problematic ethical outcomes. Another moral dilemma is when ethics are in conflict with management cost-benefit calculation.

The work of an engineer frequently directly affects public safety and health and can influence business and even politics, and the words *ethical* and *professional* are often synonymous with the engineering profession. In most countries the engineering profession is self-regulated, which means that it is governed by its own association of engineers. Obtaining professional engineering membership means that members are guided by the rules of conduct for registered persons. Most professional engineering associations provide their own ethical guidelines to help engineers avoid misconduct, negligence, incompetence, and corruption. A complaint against an engineer can lead to discipline, including a fine or losing the licence to practice. Another important aspect of ethical behaviour is how members from underrepresented groups are treated either by employers, peers or employees. Any form of discrimination against a person based on his race, gender, sexual orientation, and religious beliefs are not tolerated. Other unethical behaviours such as plagiarism, conflicts of interest, fraud and corruption are frowned upon. Another modern day phenomenon and a key component of ethical behaviour is the impact of technology on society. Technology brings major benefits as well as threats in its wake. Laws and ethical codes of conduct guiding the direction and impact of technological development can assist the engineer to become more socially responsible.

6.4.4.2 Engineering standards.

Registered engineering professionals must discharge their duties with integrity, fidelity and honesty according to acceptable engineering standards (Act 46, 2000). Standards are the tool of engineers through which a framework of acceptable engineering practice is established to arrive at a solution (Watermeyer, 2010). Within engineering, products, process and service performance standards are defined by the ISO international standards. Good quality, reliable products should be benchmarked against international standards, customised needs and wants of the customer. Adopting the ISO standards is therefore essential in quality assurance. Quality assurance standard practices also require that auditable documents are available that stipulate the product specifications and implementation procedures as well as corrections previously done.

6.4.4.3 Monitoring system.

Successful projects have a proper monitoring and feedback system to evaluate project performance (Steyn, 2005). This requires that deliverables on projects must be continually measured, appraised and reviewed. The actual progress of the project should be tracked and compared against the planned progress. If progress or costs change, immediate action should be taken to ensure the delivery of a successful project. Additionally, the project objectives have to be aligned to the corporate strategic objectives and project objectives should be adjusted if there is any deviation from the corporate strategy.

All project performance variables of the project which include the technical performance, the costs performance, the schedule performance, project planning and control, customer relationships, team relationships, communication and problem identification must be evaluated after project completion and recommendations should be then made for future projects. Engineering systems with a proper monitoring system to evaluate project performance will therefore improve product quality and reliability. This is supported by the results which show a positive correlation between monitoring systems, product quality and product reliability.

The fit statistics for the CFA and the SEM showed that the conceptual model for the needs of the South African engineering industry is sound. The entire industry consisting of vastly different sectors was sampled. The model can be evaluated within a sector to establish if the similar latent variables are produced, the strength of linear relationships between variables and the pattern of correlations/covariance.

6.5 Recommendation for implementation

To meet the needs of the South African engineering industry it is important that an implementation strategy be designed. The implementation strategy is developed based on the results of the SEM. The correlation structure between the latent variables, which are all less than 0.30, indicates that the latent constructs are all uncorrelated; however, correlations exist between the independent variables. The latent variable training and development, exogenous variables account for the highest percentage (35.5%) of the cross-functional process flow (18, 6%) the lowest.

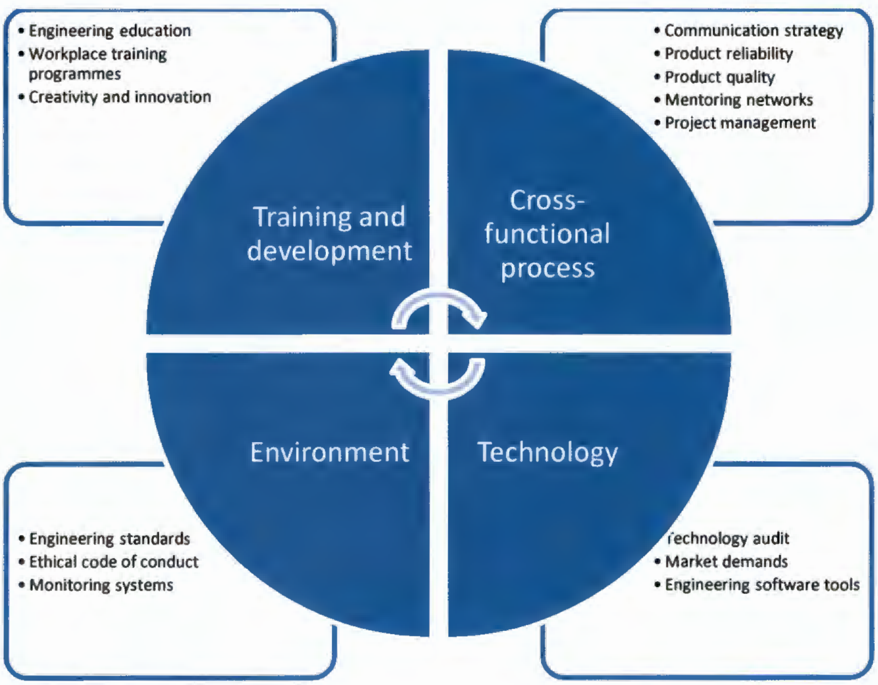


Figure 6.2 An implementation map for the needs of the South African engineering industry

The figure is used to show the central idea as the engineering industry/system. The latent constructs training and development, cross-functional process, technology and environment are all uncorrelated, meaning that the latent constructs are not dependent on one another and therefore attention can be given to a number of constructs simultaneously. Observed variables, or CSF, have a large direct effect on the latent constructs. Satisfactory results in each of these factors will ensure successful competitive performance for the system. Unobserved, exogenous variables affect each observed variable. There are exogenous or unobserved factors that affect each CSF. This may include time, system and path dependencies which are not defined here and need focussed research. Positive correlations were found between CSF of different constructs. This shows a relationship between the factors and not necessary a causal effect.

However, taken institutional theory into consideration that some CSF adopted by organisations or diffuse across organisations may not improve organisational efficiency or effectiveness. Furthermore the adoption and retention of the CSF are often more dependent on social pressures for conformity and legitimacy than on technical pressures for economic performance (Suddaby, 2013).

6.5 Revisiting the research questions

Research question 1: What are the factors and sub-factors for the needs of the South Africa engineering industry as identified in the literature?

Outcome: Firstly, A suggested conceptual framework, with CSF and sub-factors, was identified by investigating the ES framework as a theoretical framework and then identifying and cross referencing engineering success factors defined in IEA Report (2013). A review of the literature was done to substantiate the selection of the engineering success factors. Additionally the researcher performed a comparative analysis of the BRICS (Brazil, Russia, Indian, China and South Africa) consortium through a review of the literature to further elucidate and justify the selection of engineering success factors. BRICS is a consortium of developing economies with fairly comparable issues and challenges in engineering. A suggested conceptual model with factors and sub-factors was developed and tested

Research question 2: What are the significant factors and sub-factors impacting on the needs of the engineering industry in South Africa?

Outcome: Cross-tabulation and chi-square tests were performed to establish the impact of the independent variables age, gender and engineering categories on the CSF and sub-factors. Dependent variables where a significant difference in opinion between groups exists are depicted in the table below.

Table 6.1 CSF for the South African engineering industry

CSF for the South Africa engineering industry					
CSF aligned to ES framework	**Environmental-Social**	**Social**	**Functional - Process**	**Technical**	**Environmental**
CSF	**Education, Training and Development**	**Individual attributes**	**Engineering value-chain**	**Technology roadmap**	**Policy, legislation, market**
Sub-factors	Engineering Education Engineering education curriculum Financial support Experiential training Workplace training Workplace readiness Mentoring Workplace training programmes	Communication Cross-cultural communication Creativity and Innovation Product and process engineering	Product design and development Design teams Graduate design capabilities Business process management Good business practices for quality products	Technology needs and demands Technology audits Value-add of new technology Engineering technology Engineering software tools Performance management of technology competence User job specification	Engineering standards and ethics Engineering standards Retention of engineering skills Emigration Sustainable development in engineering Immigration policy Brain drain

Research question 3: What is the underlying structure for the proposed engineering systems framework of the South African engineering industry?

Outcome: Firstly, a factor analysis was performed to answer the following research question: "What are the underlying structure for the proposed engineering systems model for the South African engineering industry, i.e. do training and development/social-environmental, individual attributes/social of an engineer, engineering value chain/process-function, technical and environmental factors model the needs of the South African engineering industry as suggested in the engineering systems model". To perform a factor analysis, the following assumptions are made: the sample size should be 150 and more with a ratio of at least five cases for each of the variables, items to be considered suitable for factor analysis the correlation matrix should show at least some correlations of $r = .3$ or greater. The Bartlett's test of sphericity should be statistically significant at $p < .05$ and the Kaiser-Meyer-Olkin value should be .6 or above, it is assumed that the relationship between the variables is linear and the factor analysis can be sensitive to outliers, so as part of your initial data-screening process it should either be remove or recode to a less extreme value. The final step in the CFA is the development of a rotated component matrix. The underlying structure considered items with a primary factor loading of 0.4 and above with three (3) or more items loaded a component to be adequate.

The underlying structure for the needs of the South African engineering industry had 14 items with a primary factor loading of 0.4 and above, loaded on four (4) components. The first component seems to index cross-functional process flow and has five (5) items with strong loadings. The second component seems to index training and development has three (3) items with strong loadings. The third component seems to index the environment and has three (3) items with strong loadings and the fourth component seems to index technology has three (3) items with strong loadings.

Research question 4: What would a conceptual framework for the South African engineering industry look like?

Outcome: The SEM tested the hypothesis that directional relationships exist between: the latent variable cross-functional process flow and observed variables communication strategy, product reliability, product quality, transformation policy and project management, the latent variable training and development and the observed variables, creative and innovation, workplace training programmes and engineering education curricula, the latent variable environment, ethics, standards and evaluation and the observed variables engineering ethics, ethical code of conduct monitoring system and the latent variable technology and the observed variables technology audit, entrepreneurship and engineering technology. It then represented, estimated and tested a theoretical network of linear relationships between variables. This was then depicted as a path diagram for the needs of the South African engineering industry.

6.6 Recommendation for future research

Respondents represent different sectors within the engineering industry. The conceptual framework can be evaluated within a single engineering sector, i.e. civil, electrical and mechanical to establish whether the similar latent variables will be reproduced and the strength of the linear relationships between latent and observed variables.

A multinomial logistics regression is further suggested to predict the relationship of the nominal dependent variables, with the 14 independent variables on a continuous ratio.

An in-depth frequency distribution of demographic information, not analysed in this study, i.e. such as race, affiliation and practicing engineer should be performed, which may show different results.

A number of CSFs were identified through a thorough literature review, but not analysed. This could be the basis for future research.

6.7 Limitation of the study

Not all demographic information was collected. The race of the respondents was omitted. An analysis of this dependent variable could have produced significant results especially within South Africa where racial divisions are apparent and deeply systemic.

6.8 Conclusion

The ES framework was used as the theoretical framework for the study. A suggested conceptual framework for the needs of the South African engineering industry was developed through a literature review. A further literature review performed identified CSF associated with the suggested conceptual framework. An exploratory analysis was conducted to understand the variety of connections and relationships between independent and dependent variables for the needs of the South African engineering industry, by focusing on specific variables of interest to address the research questions. The CFA produced a number of latent constructs with associated observed variables CFA and SEM. The conceptual model framework was derived from the path model in the SEM. The research funding was then related to the literature. Recommendations were made to for the future needs of the South African engineering industry.

REFERENCES

Abimbola, O.W. (2016). Skilled labour in the South African construction industry: The nexus between certification, quality of work output and shortages: Original research. *South African Journal of Human Resources Management,* 14(1), 1 – 8.

Ackoff, R. (1981). On the use of models in corporate planning. *Strategic Management Journal,* 2, 353-359.

Adler, P.S. & Shenhar, A. (1993). Adapting your technological base: the organisational challenge. *Sloan Management Review*, 32, 25-37.

Adomavicius, G., Curley, S.P., Gupta, A., & Sanyal, P. 2013. User acceptance of complex electronic market mechanisms: Role of information feedback. *Journal of Operations Management*, 31 (6), 489-503.

Afida, A., Aini, H., Mohd M.M. & Muhd F.A.S.S. 2010. Nurturing creativity and innovative thinking through experiential learning. *Procedia Social and Behavioral Sciences*, 18, 247–254.

Andreasen, M.M. 1994. Modelling - The language of the designer, *Journal of Engineering Design*, 5(2), 103-115. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/09544829408907876#.Uv4WSvnoTEU.

Andrews, G. & J. D. Kemper. (2003). *Canadian Professional Engineering Practice and Ethics* (142–144). Saunders College Canada, Harcourt Brace & Company, Canada.

Agus, A. & Hassan, Z. (2008). The strategic supplier partnership in a supply chain management with quality and business performance. *International Journal of Business and Management Science*, 1(2), 129-145.

Aithal, P. S. (2016). Study on ABCD Analysis Technique for Business Models, Business Strategies, Operating Concepts & Business Systems. *International Journal in Management and Social Science*, 4(1).

Ariss, A., Cascio, W.F. & Paauwe, J. (2014). Talent Management: Current theories and future research directions, *Journal of World Business*, 49(2), 173-179.

Armstrong, J.R., & Wade, J. (2015). Development of Systems Engineering Expertise. *Procedia Computer Science*, 44, 689 – 698.

Atanasova, Y. & Senn, C. 2011. Global customer team design: Dimensions, determinants, and performance outcomes. *Industrial Marketing Management*, 40,278–289.

Atilola, O., Tomko, M. & Linsey, J.S. (2016). The effects of representation on idea generation and design fixation: A study comparing sketches and function trees. *Design Studies*, 42,110-136.

Bygrave, W. D. (1995). Mom-and-pops, high potential start-ups, and intrapreneurship: Are they part of the same entrepreneurship paradigm? In J. A. Katz & R. H. Brokhaus (Eds.), Advances in entrepreneurship, firm emergence and growth, 1−20. Greenwich, CT: JAI Press.

Banerjee, P.M. (2012). From information technology to bioinformatics: Evolution of technological capabilities in India. *Technological Forecasting & Social Change*, 79:665–675.

Baruah, B. & Ward, A. (2015). Metamorphosis of intrapreneurship as an effective organisational strategy. *International Entrepreneurship and Management Journal*, 11(4), 811-822.

Bartolomei, J.E., Hastings, D.E., De Neufville, R., Rhodes, D.H. (2012). *Engineering systems matrix: An organizing framework for modelling large-scale complex systems.* Massachusetts Institute of Technology, Cambridge, MA.

Bateman, T.S. & Snell, S.A. (2014). *Managing: Leading and collaborating in a competitive world.* McGraw-Hill Irwin, New York.

Bateman, T. Snell, C., & Komopaske, R. (2017). *Management: Leading & collaborating in a competitive world* (12th Ed). McGraw-Hill Irwin, New York.

Bayless, D.J. (2013) *Developing leadership skills in engineering students: Foundational approach through enhancement of self-awareness and interpersonal communication*. Paper presented at the Canadian Engineering Education Association Conference, Montreal, QC.

Becker, F.S (2010). Why don't young people want to become engineers? Rational reasons for disappointing decisions. *European Journal of Engineering Education,* 35(4), 349–366.

Bentler, P.M. & Bonnet, D.C. (1980). Significance Tests and Goodness of Fit in the Analysis of Covariance Structures, *Psychological Bulletin*, 88(3), 588-606.

Bresnahan, T. & Yin P-L. (2016). *Adoption of new information and communications technologies in the workplace today*. National Bureau of Economic Research, Cambridge, MA. (Working Paper 22346) Retrieved from: http://www.nber.org/papers/w22346.pdf

Bryman, A. (2006). Integrating quantitative and qualitative research: how is it done? *Qualitative Research*, 6(1), 97–113. Retrieved from http://www.socsci.uci.edu/~castellj/fieldstudies/webdocs/W-Readings/IntegratingQualandQuant.pdf

Bryman, A. (2008). Of methods and methodology: Qualitative research in organisations and management. *An International Journal*, 3(2), 159-168.

Bubshait. A.A., Siddiqui, M.K., & Al-Buali, A.M.A. (2015). Role of communication and coordination in project success: Case Study. *Journal of Performance in Constructed Facilities*, 29(4), 1-7.

Berger, C., Blauth, R., Bolster, C., Burchill, G., DuMouchel, W., Pouliot, F., Richter, R., Rubinoff, A., Shen, D., Timko, M. & Walden, D. (1993). Kano's methods for understanding customer-defined quality. *The Center for Quality Management Journal*, 2(4), 3-36. http://www.walden-family.com/public/cqm-journal/2-4-Whole-Issue.pdf

Bhaba, R., Sarker, A., Pius, J., Egbelu, T., Warren Liao, W. & Yu, J. (2012). Planning and design models for construction industry: A critical survey, *Automation in Construction,* 22, 23–134.

Bullen, C. V. & Rockart, J. F. (1981). *A primer on critical success factors*. Cambridge, MA: Center for Information Systems Research, MIT.

Burgelman, R.A., Maidique, M.A. & Wheelwright, S.C. (2000). *Strategic Management of Technology and Innovation.* McGraw-Hill Higher Education, New York.

Burmeister, S. (2012). *Infrastructure Sector Research Report 2012. Developing skills to meet Infrastructure demand.* AMROP LANDELAHNI, Melrose Estate, Johannesburg.

Burns, N., & Grove, S. K. (2009). *The practice of nursing research : appraisal, synthesis, and generation of evidence*. St. Louis, Mo: Saunders Elsevier.

Buse, K., Hill, C., & Benson, K. (2017). Establishing the research agenda for increasing the representation of women in engineering and computing. *Frontiers in Psychology*, 8, 598. Retrieved from http://doi.org/10.3389/fpsyg.2017.00598.

Byrne, A. & Barling, J. (2015). The Psychology and Management of Project Teams. In F. Chiocchio, E. Kelloway & B. Hobbs (Eds), *Business Management* (1,1-19) Oxford: Oxford University Press.

Careeer24 . (2016). The best engineering companies to work for in South Africa. Retrieved on the 11 April 2018 from https://career-advice/career-growth/ the-best-engineering-companies-to-work-for-in-south-africa-20160912

Carmignani, G. (2009). Supply chain and quality management: The definition of a standard to implement a process management system in a supply chain. *Business Process Management Journal*, 15(3), 395-407.

Case, J. M. (2006). *Issues facing engineering education in South Africa*. Proceedings of the African Regional Conference on Engineering Education, Pretoria.

Case, J. M. (2010). Experiential learning in entrepreneurship education: A prospective model for South African tertiary Institutions. *Education and Training*. 50 (4), 329-340.

Case, J., Marshall, D., & Grayson, D. (2013). Mind the gap: Science and engineering education at the secondary–tertiary interface. *South African Journal of Science*, 109(7/8), 1-5.

Chan, A.D.C. & Fishbein, J. (2009). A global engineer for the global community. *The Journal of Policy Education,* 1(2), 4-9.

Chan, J. (2015). China's innovation paradox. *Perspectives: Policy and Practice in Higher Education*, 19 (1), 23-27.

Chandra, Y., Styles, C. & Wilkinson, I. F. (2015). Opportunity portfolio: Moving beyond single opportunity explanations in international entrepreneurship research. *Asia Pacific Journal of Management*, 32(1), 199-228.

Chen, Y-C. (2013). Effect of Reverse Mentoring on Traditional Mentoring Functions. *Leadership Management in Engineering*, 13(3), 199-208.

Chetty, M., Bird, A. & Lawless, A. (2016). What has been done and still needs to be done to skill South Africans to deliver infrastructure projects. *Special Projects (DHET)*, 1-17.

Chougule, R., Khare, V.R. & Pattada, K. 2013. A fuzzy logic based approach for modelling quality and reliability related customer satisfaction in the automotive domain. *Expert Systems with Applications*, 40, 800–810.

Clausing, D. & Holmes, M. (2010). Technology Readiness. *Research Technology Management.* July-August, 52-59.

Clausing, D. & Holmes, M. (2010). Technology Readiness. *Research Technology Management*. July-August, 52-59.

Clinton, D. & Jones R. (2010). *Technical capacity-building and WFEO*. UNESCO Report.

Cochran, W. G. (1952). The chi-square test of goodness of fit. *The Annals of Mathematical Statistics*, 23(3), 315-344.

Coetzee, Z., Claassen, C., Bezuidenhout, H. & Kleynhans, E. 2015. Profiling Sectoral Risks of Foreign Direct Investment in Africa for the First Decade of the 21st Century. *Journal of Economic and Financial Sciences*, 9(1), 153-173.

Crasnow, S., Wylie, A., Bauchspies, W.K. & Potter, E. (2015). Feminist Perspectives on Science", *The Stanford Encyclopedia of Philosophy*, Summer 2015, https://plato.stanford.edu/archives/sum2015/entries/feminist-science/.

Creswell, J.W. (2014). *A concise introduction to mixed methods research*. Thousand Oaks, California: SAGE Publications, Inc.

CQM (Center for Quality Management). 2003. Kano's methods for understanding customer-defined quality. *The Center for Quality Management Journal*, 2(4), 3-36.

Danilova O.V. (2008). Social Business Responsibility: Theory, Methodology, Practice. Moskva: Krasnaya Zvezda, 140.

Davis, M.C., Challenger, R., Jayewardene, D.N.W. & Clegg, C.W. (2014). Advancing socio-technical systems thinking: A call for bravery. Applied Ergonomics, 45(2A), 171-180. Retrieved from http://scholar.google.co.za/citations?view_op=view_citation&hl=en&user=x9U_kRcAAAAJ&citation_for_view=x9U_kRcAAAAJ:YsMSGLbcyi4C

De Beer, L.T., Pienaar, J. & Rothmann Jr, S. (2014). Job burnout's relationship with sleep difficulties in the presence of control variables: a self-report study. *South African Journal of Psychology*. 44(4), 454-466.

De Almeida, N.M. Sousa, V., Dias, L.A. & Branco, F.A. (2015). Managing the technical risk of performance-based building structures. Journal of Civil Engineering and Management, 384-394.

De Beer, L., Rothmann, S. Jr. & Pienaar, J. (2012). A confirmatory investigation of a job demands-resources model using a categorical estimator. *Psychological Reports, 111,* 528–544. http://dx.doi.org/10.2466/01.03.10.PR0.111.5.528-544

De Carvalho, M., Patah, L.A. & De Souza Bido, D. (2015). Project management and its effects on project success: Cross-country and cross-industry comparisons. *International Journal of Project Management*, (33:7), 1509-1522.

De Gea, C., Nicolás, J., Alemán, J.L.F Toval, A., Ebert, C. & Vizcaín, A. (2011). Requirements Engineering Tools. IEEE Software Technology, July/August: 86-91.

DeLone, W.H. & McLean, E.R. (1992). Information System Success: The Quest for the Dependent Variables. *Information Systems Research*, (3: I), 60-95.

DeLone, W.H. & McLean E.R. (2003). The DeLone and McLean models of information success: A ten-year update. *Journal of Management and Information Systems*, 19 (4), 9-30.

De Medeiros, J.F., Ribeiro, J.L.D., & Cortimiglia, M.N. (2014). Success factors for environmentally sustainable product innovation: a systematic literature review. *Journal of Cleaner Production*, (65), 76-86.

De O'Melo, C., Cruzes, D.S., Kon, F. & Conradi, R. (In press). (2012). Interpretative case studies on agile team productivity and management. *Information and Software Technology*.

Deshmukh, A. (2017). A review on lean construction approach and its application in construction sector. *International Journal of Applied Research*, 3(8), 348-356.

Detsimas, N. Coffey, V., Sadiqi, Z. & Li, M. (2016). Workplace training and generic and technical skill development in the Australian construction industry, *Journal of Management Development*, 35(4), 486-504.

Dhliwayo, S. (2008). Experiential learning in entrepreneurship education: A prospective model for South African tertiary institutions. *Education + Training*, 50(4), 329-340. doi: 10.1108/00400910810880560.

DiFrancesca, D. Lee, C., & McIntyre, E. (2014). Where is the "E" in STEM for young children? Engineering design education in an elementary teacher preparation program. *Issues in Teacher Education*; 23(1), 49-64.

Dobbs, M.E. (2014). Guidelines for applying Porter's five forces framework: a set of industry analysis templates. *Competitiveness Review*, 24(1), 32-45, Retrieved from https://doi.org/10.1108/CR-06-2013-0059

Dries, N. (2013). The psychology of talent management: A review and research agenda. *Human Resource Management Review*, 23, 272-285.

Drucker, P.F. (1995). *People and performance: The best of Peter Drucker*. New York, NY: Routledge.

Drummond, G. & Ensor, J. (2005). *Introduction to marketing concepts*. New York. NY: Elsevier Butterworth-Heinemann.

Duderstadt, J.J. (2009). Engineering for a changing world. A roadmap to the future of American engineering practice. *Research, and Education. Engineering Education for the 21st Century: A Holistic Approach to Meet Complex Challenges*, 1-26.

Duderstadt, J.J. (2016). A flexner report for engineering: The future of engineering practice, research, and education [pdf format]. Retrieved from https://deepblue.lib.umich.edu/bitstream/handle/2027.42/120935/2016%20ASME%20Roe%20Lecture%20Duderstadt.pdf?sequence=4&isAllowed=y

Dugosh, K. L. & Paulus, P. B. (2005). Cognitive and social comparison processes in brainstorming. Journal of Experimental Social Psychology, 41, 313–320. doi:10.1016/j.jesp.2004.05.009.

Du Toit, R. & Roodt, J. (2008). *Engineering professionals: crucial key to development and growth in South Africa*. Cape Town: HSRC Press.

Du Toit, R. & Roodt, J. (2008). *Engineering in a developing country: The profession and education of engineering professionals in South Africa*. Cape Town: HSRC Press.

Dvir, D., Sadeh, A. & Malach-Pines, A. (2010). The fit between entrepreneurs' personalities and the profile of the ventures they manage and business success: An exploratory study. *Journal of High Technology Management Research*, 21, 43–51.

Ellis, S. (20080. *Migration in post-apartheid South Africa: Challenges and questions to policy-makers*. Lyon: Ferréol.

Edmondson, A.C. & Harvey, J-F. (In press). (2017). Cross-boundary teaming for innovation: Integrating research on teams and knowledge in organisations. *Human Resource Management Review*.

EESD (Engineering Education in Sustainable Development). (2004).*Declaration of Barcelona*. Retrieved from http://eesd08.tugraz.at/pics/declaration_of_barcelona_english.pdf.

Engineering Professions Act see South Africa

Emery, F. (1993). Characteristics of socio-technical systems. In: Trist, E. Murray, H, (eds). *The social engagement of social science vol II. The social technical perspective* (157-186). Philadelphia: University of Pennsylvania Press.

Engineering Council of South Africa (ECSA). 2010. *Strategic Plan 2010-2014*. Johannesburg: Engineering Council of South Africa.

Engineering Council of South Africa (ECSA). (2016). *2015/2016 Annual Report of ECSA*. Retrieved from https://www.ecsa.co.za/news/Annual%20Reports/Annual_Report_2015-2016.pdf

Erasmus, J. & Breier, M. (eds). (2009). *Skills shortages in South Africa: Case studies of key professions*. Cape Town: HSRC Press.

Facchini, G. & Lodigiani, E. (2014). Attracting Skilled Immigrants: An Overview of Recent Policy Developments in Advanced Countries. National Institute Economic Review, 229 (1), R3-R21.

Falade, F. (26-27 September 2006). *Engineering and globalisation in developing countries: Nigeria a case study.* In Proceedings of 3rd African Regional Conference on Engineering Education organized by University of Pretoria (5-11), South Africa.

Fan, T. Tao, F., Deng, S. & Li, S. (2015). Impact of RFID technology on supply chain decisions with inventory inaccuracies. *International Journal of Production Economics*, 159,117-125.

Faulkner, W. (2007). Nuts and Bolts and People: Gender-troubled engineering identities. *Social Studies of Science*, 37(3), 331-356.

Faulkner, W. (2009). Doing gender in engineering workplace cultures. II. Gender in/authenticity and the in/visibility paradox, *Engineering Studies*, 1(3), 169-189.

Farzaneh, G., Hassan, A., Gholamreza, P., Mirsalaldin, E., Parviz, A. & Alireza, H. (2010). Relationship between creativity, grade point average, achievement motivation, age and entrepreneurship among university students. Australian Journal of Basic and Applied Sciences, 4(10), 5372-5378.

Felder, R.M., Brent, R. & Prince, J.M. (2011). Engineering Instructional Development: Programs, best practices, and recommendations. *Journal of Engineering Education,* 100 (1), 89-122.

Fisher, G. (2011). *Improving throughput in the engineering bachelor's degree*. Unpublished Report commissioned by Engineering Council of South Africa (ECSA). Toronto: Glen Fisher Consulting. Accessed on the 30 January 2017 from https://www.oxford.co.za/download_files/higher-education/ECSA-Report-281011.pdf

Fleming, M., House, S., Shewakramani, V., Yu, L., Garbutt, J., McGee & Rubio, D.M. (2013). The mentoring competency assessment: Validation of a new instrument to evaluate skills of research mentors. *Journal of the Association of American Medical Colleges*, *88*(7), 1002–1008. http://doi.org/10.1097/ACM.0b013e318295e298

Fowler, F.J. (2013). *Survey research methods (5th Ed).* Thousand Oaks, California: SAGE Publications, Inc.

Fragoulis, I. Valkanos, E. & Florou, P. (2008). Trainees' perceptions of the quality and effectiveness of in-house education. *Training & Management Development Methods*, 22(4), A45.

Francis, M.M. (2009). Women in engineering: Identifying and analyzing gender socialization in the Faculty of Engineering at the University of Kwazulu-Natal (Master's thesis). Retrieved from http://uir.unisa.ac.za/bitstream/handle/10500/3133/?sequence=1

Fricke, I., Horak, E., Meyer, L. & van Lingen, N. (2008). Lessons from a Mathematics and Science Intervention Programme in Tshwane township schools. *South African Journal of Higher Education*, 22(1), 64-77.

Frize, M. (2011). Ethics for Bioengineers. *Synthesis Lectures on Biomedical Engineering*, *6*(3), 1-81. http://www.morganclaypool.com/doi/abs/10.2200/S00393ED1V01Y201111BME042

GDE (Gauteng Department of Education). (2010). Gauteng mathematics, science & technology education improvement strategy. Retrieved from http://www.nstf.org.za/ShowProperty?nodePath=/NSTF%20Repository/NSTF/files/Home/Newsletter/MSTStrategy.pdf.

Gehani, R. (2013). Innovative strategic leader transforming from a low-cost strategy to product differentiation strategy. *Journal of Technology Management and Innovation,* 8 (2), 144-155.

Gereffi, G., Wadhwa, V., Rissing, B.E.N. & Ong, R. (2008). Getting the numbers right: International engineering education in the United States, China, and India. *Journal of Engineering Education,* 97 (1), 13-25.

Gerybadze, A. (1998). Technological Competence Assessment within the Firm: Applications of Competence Theory to Managerial Practice. *Discussion paper on International Management and Innovation*. June. Stuttgart.

Ghosh, K. & Sahney, S. (2010). Organisational sociotechnical diagnosis of managerial retention in an IT organisation: SAP-LAP framework. *International Journal of Organisational Analysis*, 18(1), 151-166.

Gimeno-Sanz, A. (2016). Moving a step further from "integrative CALL". What's to come? *Computer Assisted Language Learning*, 29(6), 1102-1115.

Goel, P.S. & Poothia, A.K. (2010). India. In Engineering: Issues, challenges and 0pportunities for development (222-223). UNESCO Report: UNESCO. Retrieved from http://unesdoc.unesco.org/ulis/cgi-bin/ExtractPDF.pl?catno=212373&look=default&ll=1

Goel, A.K., Vat tam, S., Wiltgen, B. & Helms, M. 2012. Cognitive, collaborative, conceptual and creative - Four characteristics of the next generation of knowledge-based CAD systems: A study in biologically inspired design. *Computer-Aided Design*, 44(10), 879-900. http://dx.doi.org/10.1016/j.cad.2011.03.010

Grasso, D. & Burkins, M.B. (eds) (2010). Beyond technology: The holistic advantage. *Holistic Engineering Education,* 1-10.

Grunert K., Ellegard C. (1993). "The Concept of Key Success Factors: theory and method", in M. Baker (eds.), Perspectives on marketing management (245-274), Chichester: Wiley.

Gummesson, (2008). Extending the service-dominant logic: from customer centricity to balanced centricity. *Journal of the Academy of Marketing Science*, 36(1),15-17. http://link.springer.com/article/10.1007/s11747-007-0065-x

Gummesson, E. (2009). Customer centricity: Reality or a wild goose chase?. *European Business Review*, 20(4), 315 – 330.

Gummesson, E., Kuusela, H., & Närvänen, E. (2014). Reinventing marketing strategy by recasting supplier/customer roles, *Journal of Service Management*, 25(2), 228-240.

Gwaradzimba, E. & Shumba, A. (2010). The nature, extent and impact of the brain drain in Zimbabwe and South Africa. *Acta Academica*. 42(1), 209-241.

Hahn, G.J., Doganaksoy, N. & Hoerl, R. 2000. The evolution of Six Sigma. Retrieved from Quality Engineering, 12(2):317-26. http://waset.org/publications/8018

Hahn, L.K., Lippert, L. & Paynton, S.T. (2016). Survey of Communication. *Directory of Open Educational Resources*. Retrieved from http://en.wikibooks.org/wiki/Survey_of_Communication_Study

Hall, W.P., Nousala, S. & Kilpatrick, B. (2009). One company - two outcomes: Knowledge integration vs corporate disintegration in the absence of knowledge management. *VINE*. 39(3): 242-258. Doi: 10.1108/03055720911003996

Hall, J. & Sandelands, E. (2009). Addressing South Africa's engineering skills gaps. *Journal: Education and Training*. 51(3), 215-219.

Hameed, M.A., Counsell, S. & Swift, S. (2012). A conceptual model for the process of IT innovation adoption in organisations, *Journal of Engineering Technology Management*, 29,358-390.

Hanrahan, H. E., Beute, N., Fraser, D. M., Gosling, J., Lawless, A., & Jandrell, I. R. (2006). In C. Pistorius (Ed.). Engineering education in South Africa: In fragile good health, denial or crisis? *Engineering Education for Sustainable Development*, (pp 69-78). Pretoria: University of Pretoria.

Hanrahan, H. (2009). Toward consensus global standards for quality assurance of engineering programmes, in Patil, A.S. & Gray, P.J. (eds), *Engineering Education Quality Assurance: A Global Perspective* (pp. 51-71). Berlin: Springer.

Hanrahan, H.E., Beute, N., Fraser, D.M., Gosling, J., Lawless, A. & Jandrell, I.R. (2006). Engineering education in South Africa: In fragile good health, denial or crisis? Issues facing engineering education in South Africa,

Hansen, M.T. & Birkinshaw, J. (2007). The invitation value chain. *Harvard Business Review*, 85(6), 121-130.

Hazır, Ö. (2015). A review of analytical models, approaches and decision support tools in project monitoring and control. *International Journal of Project Management*, 33, 808-815.

Heires, M. 2008. The International Organisation for Standardization (ISO). *New Political Economy*, 13(3), 357-367.

Hobbs, L. (2013).Teaching 'out-of-field' as a boundary-crossing event: Factors shaping teacher identity. *International Journal of Science and Mathematics Education*, 11, 271- 279.

Hofstee, E. (2006). *Constructing a good dissertation: A practical guide to finishing a masters, MBA or PhD on schedule.* Sandton: Eppensteiner.

Hornby G. (2014) *Skills for Collaborating with Professionals and Parents*. In: Inclusive Special Education. New York, NY: Springer.

Horwitz, F.M. (2013). An analysis of skills development in a transitional economy: the case of the South African labour market. *The International Journal of Human Resource Management*, 24(12), 2435-2451.

Hsu J.S.C., Chang, J.Y.T., Klein, G. & Jiang, J.J. (2011). Exploring the impact of team mental models on information utilization and project performance in system development. *International Journal of Project Management,* 29, 1-12.

Hu, L. & Bentler, P. (1999). Cutoff criteria for fit indices in covariance structure analysis: conventional criteria versus new alternatives. *Structural Equation Modeling, 6*, 1-55.

Huang, K.F. 2011. Technology competencies in competitive environment. Journal of Business Research. *Journal of Business Research,* 64, 172–179.

Hudson, P. (2016). Forming the Mentor-Mentee Relationship, *Mentoring & Tutoring: Partnership in Learning,* 24(1), 30-43.

Hughes, T. (1983). *Networks of Power: Electrification in Western Society, 1880-1930.* Baltimore: Johns Hopkins University Press.

Ijagbemi, C.O., Kanakana, M.G. & Campbell, H.M. (2017). Interventions and pathways for South African women in engineering and the built environment professions. *African Journal of Science, Technology, Innovation and Development*, 1-10. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/20421338.2017.1355585

International Engineering Alliance (IEA). (2013). Graduate Attributes and Professional Competencies, Version 3 (Online). Retrieved from http://www.ieagreements.org/assets/Uploads/Documents/Policy/Graduate-Attributes-and-Professional-Competencies.pdf

International Organisation for Migration. (2003). Managing migration: Challenges and responses for people on the move. *In World Migration Report*, Geneva.

International Organisation for Standardization. (2015b). Quality management systems requirement. *In ISO 9001:2015 (E)*. Geneva, Switzerland.

Jajja, M.S.S., Kannan, V.R., Brah, S.A., & Hassan, S.Z. (2017). Linkages between firm innovation strategy, suppliers, product innovation, and business performance: Insights from resource dependence theory. *International Journal of Operations & Production Management*, 37 (8), 1054-1075.

Jawitz, J. & Case, J. (1998). Exploring the Reasons South African Students Give for Studying Engineering, *International Journal of Engineering Education, 14(4)*, 235-240.

Jeffrey, H., Sedgwick, J. & Robinson, C. (2013). Technology roadmaps: An evaluation of their success in the renewable energy sector. *Technological Forecasting and Social Change*, 80(5), 1015-1027.

Johns, R. (2010). *Likert items and scales*. Survey Question Bank: Methods fact sheets, 8-11. Retrieved from https://discover- likertfactsheet.

Joint Initiative on Priority Skills Acquisition (JIPSA). (2006). *Report March – December 2006*. Issued by the Office of the Deputy President of South Africa. December 2006.

Joint Initiative on Priority Skills Acquisition (JIPSA). (2008). *Report on activities in 2007*. Issued by the Office of the Deputy President of South Africa. April 2008.

Joint Initiative on Priority Skills Acquisition (JIPSA). (2011). Report on activities in 2010. Issued by the Office of the Deputy President of South Africa. April 2010. Retrieved from https://pmg.org.za docs 070326jipsa

Jones, R. C. (2006). Engineering Capacity Building in Developing Countries. *3rd African Regional Conference on Engineering Education*. Pretoria, September 2006. 1-4. University of Pretoria: School of Engineering.

Jöreskog, K. & Long, J.S. (1993), "Introduction," in Testing Structural Equation Models, Kenneth A. Bollen & J. Scott Long, Eds. Newbury Park, CA: Sage.

Kaewsri, N. & Tongthong, T. (2014). Favorable Female Attributes in Relation to Career challenges of women engineers in the Thai construction industry, *International Journal of Construction Education and Research*, 10, 222–236.

Kakuchi, S. (2014) Declaration on higher education for sustainability, *University World News*, 345. Retrieved from http://www.universityworldnews.com/article.php?story=20141128111121646.

Kärnä, S., Sorvala, V-M. & Junnonen, J-M. 2009. Classifying and clustering construction projects by customer satisfaction. *Facilities*, 27(9), 387 – 398.

Kashinaa, S.G., Chudnovskiyb, A.D., Aleksandrovac, N.S. Shamovd, I.V. & Borovayae, M.A. (2016). Management of Students' Vocational Training in Conditions of Social Partnership between the University and Industry. *IEJME — Mathematics Education,* 11(3), 447-456.

Kassim, H. & Ali, F. 2010. English communicative events and skills needed at the workplace: Feedback from the industry. *English for Specific Purposes* 29, 168–182.

Kastenhofer, K., Lansu, A., Van Dam-Mieras, R. & Sotoudeh, M. (2010).The contribution of university curricula to engineering education for sustainable development. *GAIA* 19(1), 44-51.

Kelley, D.J., Peters, L. & O'Connor, C.G. (2009). Intra-organisational networking for innovation-based corporate entrepreneurship. *Journal of Business Venturing,* 24, 221–235.

Kennedy, D.M., Sommer, S.A., & Nguyen, P.A. (2017). Optimizing multi-team system behaviours: Insights from modelling team communication. *European Journal of Operational Research*, 258(1), 264-278.

Kennedy, D.M., McCombb, S.A & Vozdolska, R.R. (2011). An investigation of project complexity's influence on team communication using Monte Carlo simulation. *Journal of Engineering Technology Management*, 28, 109–127.

Kipping, M. & Üsdiken, B. (2014) History in organisation and management theory: More than meets the eye, *The Academy of Management Annals*, 8(1), 535-588.

Kimita, K., Shimomura, Y. & Arai, T. (2009). Evaluation of customer satisfaction for PSS design. *Journal of Manufacturing Technology Management*, 20(5), 654 – 673.

Kissy, J., Dainty, A.R.J. & Tuuli, M.M. (2013). Examining the role of transformational leadership of portfolio managers in project performance. *International Journal of Project Management*, 31 (4), 485-497.

Kloot, B. & Rouvrais, S. (2016). The South African engineering education model with a European perspective: history, analogies, transformations and challenges. *European Journal of Engineering Education*, 1-16.

Kolarik, W.J. (1999). *Creating Quality: Process Design for Results*. Singapore: McGraw-Hill.

Kootsookos, A., Alam, A., Chowdhury, C. & Jollands, M. (2016). Offshore engineering education: Assuring quality through dual accreditation, 1st International Conference on energy and power, ICEP2016, 14-16 december 2016, RMIT University, Melbourne, Australia, *Energy Procedia*, (110), 537-542.

Kouzes, J.M. & Posner, B.Z. (2014). *Student Leadership Challenge: Five Practices for Becoming an Exemplary Leader*. San Francisco, California: A Wiley Brand.

Kraak, A. (2008). The education-economy relationship in South Africa, 2001–2005. Human Resources Development Review. Cape Town: HSRC.

Kraak, A. (2009). Sectors and skills: A need to policy alignment. Cape Town: HSRC Press.

Kraak, A. & Press, K., *eds*. (2008). Human resources development review: Education, employment and skills in South Africa. Cape Town: HSRC Press.

Kraisuth, D., & Panjakajornsak, V. (2017). Thai Engineer ASEAN Readiness: A Structural Equation Model Analysis. *Asia-Pacific Social Science Review*, 16(3), 96 -117.

Kratzer J., Leenders R. Th. A.J. & Van Engelen, J.M.L. (2010). The social network among engineering design teams and their creativity: A case study among teams in two product development programs. *International Journal of Project Management*: 28, 428–436.

Kruss, G., Wildschut, A., Janse van Rensburg, D., Visser, M., Haupt, G., & Roodt, J. (2014). *Learnerships and apprenticeships: key mechanisms for skills development and capability building in South Africa*. Cape Town: HSRC Press.

Labonté, R., Sanders, D., Mathole, T., Crush, J., Chikanda, A., Dambisya, Y., Runnels, V., Packer, C., MacKenzie, A., Tomblin Murphy, G. & Bourgeault, I.L. (2015). Health worker migration from South Africa: causes, consequences and policy responses *Human Resources for Health,* 13, 92. Retrieved from https://human-resources-health.biomedcentral.com/articles/10.1186/s12960-015-0093-4.

Laguador, J.M & Ramos Jr, L.R. (2014) Industry-Partners' preferences for graduates: Input on curriculum development. *Journal of Education and Literature*, 1(1), 1-8.

Lanzotti, A. & Tarantino, P. (2008). Engineering approach for total quality design and continuous innovation, *The TQM Journal*, 20(4), 324 – 337.

Lawless, A. (2005). *Numbers and needs in local government*. Halfway House: South Africa.

Lawless, A. (2008). Civil engineering – the critical profession for service delivery. *Civil Engineering*, 26-29.

Lawless, A. (2017). Numbers and Needs in Local Government – where are we now? *Civil Engineering*, 15-26.

Leahy, K. & Oster, G. (2012). The evolution of electronic systems Technology and its impact on methods of innovation. *Regent Global Business Review*, *5*(2), 8-15.

Leavitt, H.J. (1965). Applied organisation change in industry: Structural, technical, and human approaches; new perspectives in organisational research, in March, J.G (ed.) Handbook of Organisations (55-71), Chicago: Rand McNally.

Lee, E.S. (1966). A theory of migration. *Demography*, 3., 47–57.

Lee, L. & Faulkner, W. (2010). 'Turning good policies into good practice: why is it so difficult?' *International Journal of Gender, Science and Technology*, 2(1), 89-99.

Lee, C-c., , Lin, Y-h., L., Huang, H-C., Huang, W-w., & Teng, H-h. (2015). The effects of task interdependence, team cooperation, and team conflict on job performance. *Social Behavior and Personality*, 43(4), 529-536.

Lekhu, M.A. (2013). Assessing the teaching efficacy beliefs of science teachers in secondary schools in the Free State Province. (Unpublished Doctoral thesis). Central University of Technology, Free State.

Lewis, L.K. & Seibold, D.R. (1993). Innovation modification during intra-organisational adoption. *Academy of Management Review*, 18(2), 322-354.

Litzinger, T.A., Lattuca, L.R., Hadgraft, R.G. & Newsletter, W.C. 2011. Engineering education and the development of expertise. *Journal of Engineering Education*, 100 (1), 123-150.

Lo, M. C. & Ramayah, T. 2011. Mentoring and job satisfaction in Malaysian SMEs. *Journal of Management Development*, 30(4), 427-440.

Loyalka, P., Carnoy, M., Froumin, I., Dossani, R., Tilak J. B., Yang, P. 2014. Factors affecting the quality of engineering education in the four largest emerging economies. *High Educ*, 68, 977–1004.

Lynch, W.T & Kline, R. (2000). Engineering practice and engineering ethics. *Science, Technology & Human Values*, 25(2), 195-225.

Maalik, A., Ahmed, N., & Imran Nazir, I. (2015). *Impact of Work Life Balance, Career Development and Reward on Employee. Performance in Petroleum Sector of Pakistan.* Munich, GRIN Verlag, Retrieved from http://www.grin.com/en/e-book/305922/impact-of-work-life-balance-career-development-and-reward-on-employee.

Mafe, O.A.T. (2006). *Enhancing curriculum delivery in engineering through teachers' industrial work-experience*. 3rd African Regional Conference on Engineering Education, Pretoria.

Mahalingam, A. & Levitt, R.E. (2007). Institutional Theory as a Framework for Analyzing Conflicts on Global Projects. Journal of Construction Engineering and Management, 133(7), 517 – 528.

Maharaj, B. (2010). The African brain drain causes, costs, consequences. *Africa Insight*, 40(1).

Maheshwari, M., Kumar, U., & Kumar, V. (2012). Alignment between social and technical capability in software development teams: An empirical study. *Team Performance Management*, *18*(1/2),7-26. http://www.emeraldinsight.com/doi/pdfplus/10.1108/13527591211207680

Makki, B., Salleh, R., Memon, M. & Harun, H. (2015). The Relationship between Work Readiness Skills, Career Self-efficacy and Career Exploration among Engineering Graduates: A Proposed Framework. *Research Journal of Applied Sciences, Engineering and Technology*. 10, 1007-1011.

Male, S.A, Bush, M.B. & Murray, K. (2009). Think engineer, think male? *European Journal of Engineering Education,* 34(5), 455-464.

Malhotra, N., Krosnick, J.A. & Thomas, R.K. (2009). Optimal design of branching questions to measure bipolar constructs. *Public Opinion Quarterly*, 1–21.

Malik, A. & Blumenfeld, S. (2012). Six Sigma, quality management systems and the development of organisational learning capability: Evidence from four business process outsourcing organisations in India. *International Journal of Quality & Reliability Management*, 29(1), 71-91.

Manikandan, S. (2011). Frequency Distribution. *Journal of Pharmacology and Pharmacotherapeutics*, 2(1), 54-56.

March J.G. (1991). Explorations and exploitation in organisational learning. *Organisational Science*, 2(1), 71-87.

Martin, M. J. G., Jones, D., Benson, S., Murphy, L., Jamaluddin, A. K. M., Hoeksema, R. N. & Chhibber, R. (2014). Talent Evaluation Paradigms. *Society of Petroleum Engineers*, SPE Annual Technical Conference and Exhibition, 27-29 October. Amsterdam, Netherlands.

Martin, R., Maytham, B., Case, J. & Fraser, D. (2005). Engineering graduates' perceptions of how well they were prepared for work in industry. *European Journal of Engineering Education*, 30(2), 167-180.

Martin, M. W. & Schinzinger, R. (1996). Ethics in engineering (3rd ed.). New York: McGraw-Hill.

Martín-Rojas, R., García-Morales, V.J. & Bolívar-Ramos, M.T. (2013). Influence of technological support, skills and competencies, and learning on corporate entrepreneurship in European technology firms. *Technovation*, 33(12), 417-430.

Matoti, S.N. & Lekhu, M.A. (2008). Problems first-year university students bring to science classes and implications for teaching and learning. *Interim: Interdisciplinary Journal*, 7(2), 126-142. http://www.sabinet.co.za/abstracts/interim/interim_v7_n2_a8.html

Matlotleng P. Matlou, M.P. & Mutanga, S.S. (2010). The interlinkages between global migration flows and development issues: Past, present and future trends. *Africa Insight*, 40 (1), 78-95.

May, E. & Strong, D.S. (2006). Is Engineering Education Delivering what Industry Requires? 3rd Canadian Design Engineering Conference 2006 (pp. 204-212). Toronto.

Mayotova, V. (2011). Integration of educational and scientific–technological areas during the process of education of aerospace engineers. *Acta Astronautica*, 69, 737-743.

Mbanda, V. & Chitiga-Mabugu, M. (2017). Growth and employment impacts of public economic infrastructure investment in South Africa: A dynamic CGE analysis. *Journal of Economic and Financial Sciences*, 10(2), 235-252.

McLeod, I.A. (2010). The education of innovative engineers. *Engineering, Construction and Architectural Management*, 17 (1), 21-34.

McLeod, S. (2008). Likert Scale. *Simply Psychology*. Retrieved from http://www.simplypsychology.org/likert -scale.htm.

Mellado, D., Fernández-Medina, E. & Piattini, M. (2007). A common criteria based security requirements engineering process for the development of secure information systems. *Computer Standards & Interfaces*, 29,244-253. Retrieved from http://ac.els-cdn.com/S0920548906000511/1-s2.0-S0920548906000511-main.pdf?_tid=0f79e80c-1190-11e4-b67a-00000aacb361&acdnat=1406027296_5afb1bb640b37bc5b4ce627d5d53a104

Michael, R. S. (2013). Indiana University Tutorial (Online). Retrieved from http://www.indiana.edu/~educy520/sec5982/week_12/chi_sq_summary011020.pdf

Michael, R.S. (n.d.). Cross-tabulation and Chi Square (Online). Retrieved from http://www.indiana.edu/~educy520/sec6342/week_10/chi_sq_summary011020.pdf

Miller, H.J. (1999). Measuring space-time accessibility benefits within transportation networks: basic theory and computational procedures. *Geographical Analysis*, 31 (2), 187–212.

Mitchell,R. (1989). Master of innovation: How 3M keeps its new products coming. *Business Week*, April, 58-63.

Mnyandu, E. (2011). South Africa scores another goal after the World Cup in joining Brics. *Business Report*. Retrieved from http://www.iol.co.za/business/opinion/letters/south-africa-scores-another-goal-after-the-world-cup-in-joining-brics-1.1058517.

Mohamed, A.A., Radzuan, N.R.M., Kassim, H. & Ali, M.M.A. (2014). Conceptualizing English workplace communication needs of professional engineers: The challenges for English language tertiary educators. *Selangor Business Review,* 1(1), 1-9.

Moodliar, S Genis, E., Anelich, L. & Puren, A. (2013). The global need for Quality. *Medical Technology SA*, 27(2), 26-32.

Morelli, L., Bash, C., Trucco, M. & Patel, C. (October, 2012). *An engineering curriculum track for IT for sustainability,* Frontiers in Education Conference, Seattle, WA.

Morse, R & Krivian, A. (2017). How the US news calculated the best global university subject rankings. US News and World Report. Retrieved from https://www.usnews.com/edcation/best-global-universities/articles/subject-rankings-methodology

Mugo Fridah, W. (2002). *Sampling in research* (tutorial). Retrieved from http://trochim.human.cornell.edu/tutorial/mugo/tutorial.htm.

Mukora, J., Visser, M.M., Roodt, J., Arends, F., Molefe, M. & Letseka, M. (2008). *Impact assessment of learnerships and apprenticeships*. MERSETA Report. Retrieved from https://www.google.co.za/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&ved=0CCoQFjAA&url=http%3A%2F%2Fwww.hsrc.ac.za%2Fen%2Fresearch-outputs%2Fktree-doc%2F2562&ei=YyjlUsbmMtOBhAem44C4Aw&usg=AFQjCNHkEtnRoslrRaafTO44rf5gamEFRQ&sig2=DUQRYjxYYnlLOhp2j0FAjQ&bvm=bv.59930103,d.ZG4

Murphy, G.D. (2010). Testing a tri-partite contingent model of engineering cultures: A pilot study. *Reliability Engineering and System Safety,* 95, 1040-1049.

Mutereko, S. & Wedekind, V. (2015). Work integrated learning for engineering qualifications: a spanner in the works? *Journal of Education and Work*, 29(8), 902–921.

Nauman, S., Khan, A.M. & Ehsan, N. (2010). Patterns of empowerment and leadership style in project environment. *International Journal of Project Management,* 28, 638-649.

National Science Board. (2012). Science and Engineering Indicators 2012. Arlington VA: National Science Foundation (NSB 12-01).

Nel, W.P. (2014). Universities and decision-making: programme and qualification mix - four learning pathways. *Journal of the Southern African Institute of Mining and Metallurgy*, *114*(5), 01. Retrieved from http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S2225-62532014000500010&lng=en&tlng=e

Nelson, B.A, Yen, J., Wilson, J.O. & Rosen, D. (2009). Refined metrics for measuring ideation effectiveness. *Design Studies*, 30(6), 737-743. http://dx.doi.org/10.1016/j.destud.2009.07.002

Newberry, B., Miller, G., Johnson, D., Farber, D., Snieder, R., & Kroes, P. (2015). Grand challenge for engineers. *Issues in Science and Technology, 31*(2), 18-24. Retrieved from http://www.jstor.org.nwulib.nwu.ac.za/stable/43315073.

Ngai, E.W.T., Chau, D.C.K., Poon, J.K.L., Chan, A.Y.M., Chan, B.C.M. & Wu, W.W.S. (2012). Implementing an RFID-based manufacturing process management system: Lessons learned and success factors. *Journal of Engineering and Technology Management,* 29,112-130.

Nguyen, D.Q. (1998). The essential skills and attributes of an Engineer: A comparative study of academics, industry personnel and engineering students. *Global Journal of Engineering Education,* 2(1), 65-76.

Nguyen D.Q. & Shanks, G. (2009). A framework for understanding creativity in requirements engineering. *Information and Software Technology*, 51, 655–662.

Niazi, A.S. (2011). Training and Development Strategy and Its Role in Organisational Performance. *Journal of Public Administration and Governance*, 1(2), 42 – 57. Accessed on the 22 February 2016 from file:///C:/Users/a0051920/Downloads/862-3620-2-PB.pdf

Nicholas, J.M. & Steyn, H. (2017). Project Management for Engineering, Business and Technology, Fifth Edition. New York, NY: Routledge.

O'Donnell, H., Karallis, T., Sandelands, E., Cassin, J. & O'Neill, D. (2008). Case study: developing graduate engineers at Kent Engineers & Constructors. Education & Training, 50(5), 439-452.

Ojiako, U., Chipulu, M. Marshall, A., Ashleigh, M.J., & Williams, T. (2015). Project management learning: A comparative study between engineering students' experiences in South Africa and the United Kingdom. Project Management Journal, 46 (4), 47-62.

OECD (Organisation for Economic Co-Operation and Development). (2009). Policy responses to the economic crisis: Investing in Innovation for long-term growth. Retrieved from http://www.oecd.org/sti/42983414.pdf

Oosthuizen, P, & Nienaber, H. (2010). The status of talent management in the South African consulting civil engineering industry in 2008: a survey. *Journal of the South African Institution of Civil Engineering*, *52*(2), 41-47. Retrieved from http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S1021-20192010000200005&lng=en&tlng=en.

Pallant, J. (2005). SPSS Survival Manual: A step by step guide to data analysis using SPSS for Windows (Version 10) [Online]. Retrieved from https://www.mheducation.co.uk/openup/chapters/0335208908.pdf

Patel, S. (2017). *South Africa urgently requires engineers for development*. The Mail and Guardian. Retrieved from https://mg.co.za/article/2017-03-17-00-south-africa-urgently-requires-engineers-for-development.

Patel, H., Pettitt, M. Wilson, J. R. (2012). Factors of collaborative working: A framework for a collaboration model. *Applied Ergonomics,* 43(1e), 26.

Patil, A., Nair, C. & Codner, G. (2008). Global accreditation for the global engineering attributes: a way forward. (*In* Mann, L., Thompson, A. & Howard, P., *eds*. Proceedings of the 19th Annual Conference for the Australasian Association for Engineering Education: *To Industry and Beyond*. 7 - 10 December 2008 (pp. 1-8). Australia, Queensland, Yeppoon. Retrieved from http://aaee.com.au/conferences/papers/2008/aaee08_submission_T1B4.pdf

Peng, D.X., Heim, G.R., & Mallick, D.N. (2014). Collaborative product development: The effect of project complexity on the use of information technology tools and new product development practices. *Production and Operation Management*, 23(8), 1421-1438.
Perkins, J. (2013). *Review of Engineering Skills*. Retrieved from http://www.raeng.org.uk/publications/other/perkins-review-of-engineering-skills.

Perttula, M.K. (2006). *Idea generation in engineering design: Application of a memory search perspective and some experimental studies* (PhD thesis). Helsinki University of Technology, Espoo.

Phasha, T., Bipath, K. & Beckmann, J. (2016). Teachers' Experiences Regarding Continuous Professional Development and the Curriculum Assessment Policy Statement. *International Journal of Education Science*, 14(1, 2), 69-78.

Piazza, A. & Castellucci, F. (2014). Status in Organisation and Management Theory. *Journal of Management*, 40(1), 287-315.

Pichlak, M (2016). The innovation adoption process: A multidimensional approach. *Journal of Management & Organisation*, 22(4), 476-494.

Porter, M.E. (1985). *Competitive advantage*. New York, NY: Free Press.

Porter, M.E. (2008). The five competitive forces that shape strategy. *Harvard Business Review*, 88(1): 78 – 93.

Posner, B.Z. & Kouzes, J.M. (2011). The leadership challenge. *Journal of Education and Vocational Research*, 1(1), 1-3.

Pretorius, C.J. & Steyn, H. 2005. Knowledge management in project environments. *South African Journal of Business Management*, 36(3):41-50. Retrieved from http://reference.sabinet.co.za/webx/access/electronic_journals/busman/busman_v36_n3_a4.pdf

Pritchett, A.R. & Strong, A.C. (2016). Integrating Cognitive Engineering into Industry Design Teams. *Journal of Cognitive Engineering and Decision Making,* 10(2), 134-137.

Punch, K. F. (2009). *Introduction to research methods in education*. London: SAGE Publications, Inc.

Ramaswami, A., Huang J-C., & Dreher, G. (2013). Interaction of gender, mentoring, and power distance on career attainment: A cross-cultural comparison. *Human Relations,* 67(2), 153-173.

Ramnarain, U.D. (2014). Teachers' perceptions of inquiry-based learning in urban, suburban, township and rural high schools: The context-specificity of science curriculum implementation in South Africa. *Teaching and Teacher Education*, 38, 65 – 75.

Rasool, F. (2010). *The role of skills immigration in addressing skills shortages in South Africa*. (Unpublished doctoral thesis). North-West University, Potchefstroom.

Rasool, F., & Botha, C.J. (2011). The nature, extent and effect of skills shortages on skills migration in South Africa. *SA Journal of Human Resource Management,* 9(1), 287-299.

Rasool, F., Botha, C. & Bisschoff, C. (2012). The Effectiveness of South Africa's Immigration Policy for Addressing Skills Shortages. *Managing Global Transitions*, 10(4), 399-418.

Rauch, A., & Frese, M. (2007). Born to be an entrepreneur? Revisiting the personality approach to entrepreneurship. In J. R. Baum, M. Frese, & R. A. Baron (Eds.), *The psychology of entrepreneurship* (41−66). Mahwah, NJ: Erlbaum.

Raza, F.M., Ashi, M., Agusta, F., Jalal, A., & Hasan, S.H. (2016). An empirical study on employee empowerment in TQM practice in a Saudi Arabian firm: A case study of Saudi airlines. *International Journal of Computer Applications*, Volume 143(3), 11-17.

Rebollo, O., Mellado, D., Fernández-Medina, E. & Mouratidis, H. (2015). Empirical evaluation of a cloud computing information security governance framework. *Information and Software Technology*, 58, 44-57.

Research Advisors. (2014). Required sample size (Online). Retrieved from https://www.research-advisors.com/documents/SampleSize-web.xls

Reddy, V., Bhorat, H., Powell, M., Visser, M. and Arends, A., (2016) Skills Supply and Demand in South Africa, LMIP Publication, Human Sciences Research Council, Pretoria.

Rice, D. & Alfred, M. (2014). Personal and structural elements of support for African American female engineers. *Journal of STEM Education: Innovations and Research*, 15(2), 40-49.

Richardson, T.L. (2014). Faculty Perspectives on the Change Process of an Institution of Higher Education Undergoing Downward Expansion (Unpublished doctoral thesis). University of Minnesota, Minnesota, USA.

Rogers, G. (2006). Competing for Global Talent. *In International Institute for Labour Studies* (ix–x). Geneva.

Roodt, J. (2012). *National database sets and research on labour market demand*. In Labour Market Intelligence Partnership. Pretoria: HSRC Press.

Rubin, A. & Babbie, E.R. (2005). *Research methods for social work*. New York: Thomson Brooks/Cole.

Saavedra, L. Araújo, A.M. de Oliveira, J.M. & Stephens, C. (2014). Looking through glass walls: Women engineers in Portugal. *Women's Studies International Forum*, 45, 27-33.

Salas, E., Rico, R., & Passmore, J. (2017). A state-of-the-art psychological perspective on team working and collaborative organisational processes. Chichester, West Sussex: John Wiley and Sons.

SAPA. (September 2014). Pandor: Not enough engineers in SA. *Drum Digital*. Retrieved from htpps://m.fin24.com.

Sarkar, P. & Chakrabarti, A. (2014). Ideas generated in conceptual design and their effects on creativity. *Research in Engineering Design*, 25(3), 185-201.

Sarker, B.R., Egbelu, P.J., Liao, T.W. & Yu, J. (2012). Planning and design models for construction industry: A critical survey. *Automation in Construction*, 22, 123-134.

San Miguel, A.M. & Kim, M.M. (2014). Successful Latina Scientists and Engineers. *Journal of Career Development*. 42 (2), 133-148.

Saunders, M., Lewis, P. & Thornhill, A. (2009). *Research methods for business students* (5th ed.). Harlow, Pearson Education.

Scavarda do Carmo, L. & Dali'Acqua, C.A. (2010). Brazil. *In Engineering: Issues, Challenges and Opportunities for Development* (241-242). UNESCO report, UNESCO. Retrieved from http://unesdoc.unesco.org/Ulis/cgi-bin/ulis.pl?database=&lin=1&futf8=1&ll=s&gp=&look=default&sc1=1&sc2=1&nl=1&req=2&au=Scavarda%20do%20Carmo,%20Luiz

Schreiber, J.B. (2008). Descriptive Statistics. In: L. M. Given (ed.). *The SAGE Encyclopedia of Qualitative Research Methods* (210-213). Durban: SAGE Publications, Inc.

Schrimsher, R. H., Northrup, L. A. & Alverson, S. P. (2011). A survey of Samford University students regarding plagiarism and academic misconduct. *The International Journal for Educational Integrity*, 7(1), 3-17.

Schutte, C.S.L., Kennon, D. & Bam, W. (2016). The status and challenges of industrial engineering in South Africa. *South African Journal of Industrial Engineering*, 27(1), 1-19.

Sekaran, U. (2003). *Research methods for business: A skill building approaches* (4th ed.). California: Hermitage Publishing Services.

Shachaf, P. (2008). Cultural diversity and information and communication technology impacts on global virtual teams: An exploratory study. *Information & Management,* 45, 131-142.

Shah, J.J., Kulkarni, S.V. & Vargas-Hernandez, N. (2000). Evaluation of idea generation methods for conceptual design: Effectiveness metrics and design of experiments. *Journal of Mechanical Design*, 12(4), 377-384.

Shao, B.B.M. & Lin, W.T. (2016). Assessing output performance of information technology service industries: Productivity, innovation and catch-up. *International Journal of Production Economics,* 172, 43-53.

Siddiqui, K.A, Mirani, M.A. & Fahim, S.M. (2015). Model generation using structural equation modelling. *Journal of Scientific Research and Development* 2 (10), 112-116. Retrieved from https://ssrn.com/abstract=2671137

Singh, K., & Ahuja, I.S. (2015). An evaluation of transfusion of TQM-TPM implementation initiative in an Indian manufacturing industry. *Journal of Quality in Maintenance Engineering*, 21(2), 134-153.

Sitsev, V. (2010). Russia. Engineering: *In Issues, Challenges and Opportunities for Development* (234-235). UNESCO Report, UNESCO. Retrieved from http://unesdoc.unesco.org/Ulis/cgi-bin/ulis.pl?catno=212398&set=52E4152D_2_29&gp=0&lin=1&ll=1

Siu, K.W.M. (2012). Promoting creativity in engineering programmes: difficulties and opportunities. *Procedia - Social and Behavioral Sciences*. 46, 5290 – 5295.

Sivakumar, V. M., Devadasan, S.R. & Murugesh R., (2014) Theory and practice of knowledge managed ISO 9001:2000 supported quality system, *The TQM Journal*, 26(1), 30-49.

Sivakuram, N.M., Devadasan, S.R. & Murugesh, R. (2013). Conceptualisation for Implementing Total Productive Maintenance Through the ISO 9001:2008 Standard-Based Quality Management System. *South African Journal of Industrial Engineering,* 24(2), 33-46.

Skogstad, P.L.S. (2009). *A unified innovation process model for engineering designers and managers* (Doctoral thesis). Stanford University, California.

Slater, S.F., Mohr, J.K. & Sengupa, S. (2014). Radical Product Innovation Capability: Literature Review, Synthesis, and Illustrative Research Propositions. *Product and Innovation Management,* 31 (3): 552–566.

Slavova, K., Fosfuri, A., & De Castro, J.O. (2016). Learning by Hiring: The Effects of Scientists' Inbound Mobility on Research Performance in Academia. *Organisation Science*, 27(1), 72-89.

Small, M.H., Yasin, M.M. & Alavi, J. (2011). Assessing the implementation and effectiveness of process management initiatives at technologically consistent firms. *Business Process Management Journal*, 17(1):6 – 20. Retrieved from http://www.emeraldinsight.com/journals.htm?articleid=1896255&show=abstract

Smith, M.J. & Carayon, P. (2000). Balance theory of job design. In Karwowski, W. (ed.). *International encyclopedia of ergonomics and human factors* (pp. 1181-1184). London: Taylor & Francis.

South Africa. (2000). *Engineering Profession Act (EPA) Act no. 46 of 2000*. Retrieved from https://www.ecsa.co.za/regulation/RegulationDocs/EngProfAct46_2000.pdf

South Africa. (2002). *Immigration Act no.13 of 2002*. Pretoria: Government Printer

South African Institute of Race Relations. (2012). *South African Survey 2012*. Johannesburg: South African Institute of Race Relations.

South African Institute of Race Relations. (2013). *South African Survey 2013*. Johannesburg: South African Institute of Race Relations.

South Africa. Statistics South Africa (StatsSA). 2013. *Documented immigrants in South Africa, 2012*. Pretoria: Statistics South Africa.

South Africa. Statistics South Africa (StatsSA). (2014b). *Labour Market Dynamics in South Africa*. Pretoria: Statistics South Africa.

South Africa. The Higher Education Qualifications Framework (HEQF). (5 October 2007). Published by the Minister of Education. *Government Gazette, Volume 508, No 30353.*

Sonnenberg, M., van Zijderveld, V., & Brinks, M. (2014). The role of talent-perception incongruence in effective talent management. *Journal of World Business*, 49(2), 272-280. Retrieved from http://www.sciencedirect.com/science/article/pii/S1090951613000874.

Stark J. (2015). *Product Lifecycle Management*. 1, 1-29. In Project Lifecycle Management. Switzerland: Springer.

Stein C.M., Morris N.J., Nock N.L. (2012) Structural Equation Modeling. In: Elston R., Satagopan J., Sun S. (eds) Statistical Human Genetics. *Methods in Molecular Biology (Methods and Protocols*, 850, Humana Press.

Suddaby, R., Hardy, C, & Huy, Q. N. (2011). Introduction to special topic forum: Where are the new theories of organisation? *Academy of Management Review*, 36(2), 236-246.

Suddaby, R. (2013). Institutional Theory, in Kessler, E. (ed). *Encyclopedia of Management Theory*, 379–384, Thousand Oaks, CA, SAGE.

Suhr, D.D. (2006). The Basics of Structural Equation Modeling (Online). Retrieved from http://www.lexjansen.com/wuss/2006/tutorials/tut-suhr.pdf

Suhr, D. (2012). Exploratory factor analysis with the world values survey. In Proceedings of the SAS Global Forum 2012 Conference. Cary, NC: SAS Institute. Retrieved from http://support.sas.com/resources/papers/proceedings12/331-2012.pdf

Sundaresan, S. & Zhang, Z. (in press) (2012). Parallel teams for knowledge creation: Role of collaboration and incentives. *Decision Support Systems*.

Sunthonkanokpong, W. (2011). Future global visions of engineering education. *Procedia Engineering*, 8, 160–164. Retrieved from http://ac.els-cdn.com/S1877705811000439/1-s2.0-S1877705811000439-main.pdf?_tid=c330894e-8687-11e3-b8a7-00000aab0f6c&acdnat=1390740520_9c6a8278b28d982a2573492ce67b2d3d

Taha, Z., Hassan Alli, H. & Abdul-Rashid, S.H. (2013). The Characteristics of a New Product through User Knowledge in the Early Stages of a Design Process. *Advanced Materials Research*, 739, 678-683.

Tarhini, A., Ammar, H., Tarhini, T. & Masa'deh, R. (2015). Analysis of the Critical Success Factors for Enterprise Resource Planning Implementation from Stakeholders' Perspective: A Systematic Review. *International Business Research*, 8(4), 25-40.

Taylor, N. (2008). *The production of high level science, engineering and technology skills: Role of the Dinaledi Project*. Research Report. Retrieved from http://www.hsrc.ac.za/Research_Publication-20585.phtml

Taylor, M & Taylor, A. (2012). The technology life cycle: Conceptualization and managerial implications. *International Journal of Production Economics*. 140, 541–553.

Todd, R.H., Sorenson, C.D. & Magleby, S.P. (1993). Designing a senior capstone course to satisfy industrial customers. *Journal of Engineering Education*, 82(2), 92-100.

Trist, E.L. & Bamforth, K.W. (1951). Some social and psychological consequences of the longwall method of coal-getting. *Human Relations,* 4(1), 3-38.

Tsanwani, A. Harding, A., Engelbrecht, J. & Maree, K. (2014). Perceptions of teachers and learners about factors that facilitate learners' performance in mathematics in South Africa. *African Journal of Research in Mathematics, Science and Technology Education*, 18(1), 40-51.

Tuominen, M., Rajala, A. & Möller, K. (2004). How does adaptability drive firm innovativeness? *Journal of Business Research*, 57, 495-506.

Turpin, M., Matthee, M., & Kruger, A. (2015) The Teaching of Creativity in Information Systems Programmes at South African Higher Education Institutions. *African Journal of Research in Mathematics, Science and Technology Education*, 19(3), 278-288. Accessed on the 3 March 2017 from http://dx.doi.org/10.1080/10288457.2015.1104838

UNESCO (United Nations Education, Scientific and Cultural Organisation). (1998). *World Declaration on Higher Education in the Twenty-First Century: Vision and Action*. http://www.unesco.org/education/educprog/wche/declaration_eng.htm#world declaration

United Nations, Department of Economic and Social Affairs, Population Division. (2009). *International Migration. United Nations.*

United Nations Education, Scientific and Cultural Organisation (UNESCO). 2010. *Engineering: Issues, challenges and opportunities for development. UNESCO Report.*

Uriona-Maldonado, M., dos Santos, R.N.M., Varvakis, G. 2012. State of the art on the systems of innovation research: A bibliometric study up to 2009, *Scientometrics*, 91 (3), 977-996.

Utterback, J.M. (1994). *Mastering the dynamics of innovation*. Boston, MA: Harvard Business School Press.

Van Broekhuizen, H., Van den Berg, S. & Hofmeyr, H. (2016). *Higher education access and outcomes for the 2008 South African national matric cohort*. Discussion Paper No. 10358, Institute for the Study of Labor (IZA), Bonn, Germany. Retrieved from http://www.lmip.org.za/lmippublications

Vanhoucke, M. (2011). On the dynamic use of project performance and schedule risk information during project tracking. *Omega,* 39, 416-426.

Vainio, V.V. (2012). *Comparative research of PLM usage and architecture* (Master's thesis). Tampere University of Technology. Retrieved from https://wiki.tut.fi/pub/Fudge/WebHome/Ville_Vainio_-_Master_of_Science_Thesis_-_Final.pdf

Van Schalkwyk, T.D. 2013. *Introduction to learning factory concepts: A Stellenbosch University case study* [Abstract]. Presentation for SAIIE, Spier, Stellenbosch.

Van der Walt, F., Thasi, M.E., Chipunza, C., & Jonck, P. (2016). Skills shortages and job satisfaction - insights from the gold-mining sector of South Africa. *African Journal of Business and Economic Research*, 11(1), 143-183.

Vee, C. & Skitmore, M. (2003). Professional ethics in the construction industry. *Journal of Engineering, Construction and Architectural Management*, 10(2), 117-127.

Vetterli, C., Brenner, W. & Uebernickel, F. (2013) *A design thinking role model enables creativity in IT: Case of the financial industry.* In: 2013 International Conference on Information Resources Management, Natal, Brazil.

Vermeulen, L. (2007). Talent Management as strategic tool in retaining human capital. *Journal of Public Administration*, 42(5), 272 - 284.

Von Bertalanffy, L. (1968). An Outline of General System Theory. *British Journal of the Philosophy of Science*, 1, 134-164.

Watermeyer, R. 2010. Alternative models for infrastructure delivery. IMESA: 68-77. http://www.ioptions.co.za/Files/Doc/RBWnew/P7-2.pdf

Watkins, J.A. 2006. *Thesis/dissertation/research reports: A practical guide for students for the preparation of written presentation of academic research.* Pretoria: Tshwane University of Technology.

Watson, K. & Froyd, J. 2007. Diversifying the U.S. engineering workforce: A new model. *Journal of Engineering Education*, 19-32.

Wga, E.W.T., Chau, D.C.K, Poon, J.K.L, Chan, A.Y.M., Chan, B.C.M., & Wu, W.W.S. (2014). The role of radio frequency identification (RFID) technology in improving garment manufacturing. In Wong, W.K & Guo, Z.X. (Eds), *Fashion Supply Chain Management Using Radio Frequency Identification (RFID)*, 70-98. Cambridge, U K: Woodhead Publishing Limited.

Williams, C. (2007). Research Methods. *Journal of Business & Economic Research*, 5(3), 65-72.

Wilson, J. O., Rosen, D., Nelson, B. A., & Yen, J. (2010). The effects of biological examples in idea generation. *Design Studies*, 31, 169 -186.

Womack, J.P. & Jones, D.T. (2015). *Lean solutions: How companies and customers can create value and wealth together*. New York, NY: Free Press.

World Federation of Engineering Organisations. (n.d.). WFEO Model code of ethics. Retrieved from www.wfeo.net/wp.../WFEO_MODEL_CODE_OF_ETHICS_Final.pdf

Wong, K.Y. (2005). Critical success factors for implementing knowledge management in small and medium enterprises. *Industrial Management & Data Systems,* 105(3), 261-279.

Wong, J.M.W., Ng, T. & Chan, A.P.C. (2010). Strategic planning for the sustainable development of the construction industry in Hong Kong. *Habitat International*, 34(2), 256-253.

World Migration Report. (2003). *Managing migration – Challenges and responses for people on the move*. Geneva: International Organisation for Migration.

Wu, D. Rosen, D.W., Wang, L. & Schaefer, D. (2015). Cloud-based design and manufacturing: A new paradigm in digital manufacturing and design innovation. *Computer-Aided Design*, 59, 1-14.

Xuesheng, D.U. & Wenbiao, S.U.N. (2012). Science and technology research on the relationship between safety leadership and safety climate in coalmines. Department 2012 International Symposium on Safety. *Procedia Engineering, 45,214*-219.

Yackovlev, V. & Scavarda, L. (2010). *Regional perspectives on engineering: Americas and Caribbean*. UNESCO Report. UNESCO.

Yang, J. & Rui, M. (2009). Turning knowledge into new product creativity: An empirical study. *Industrial Management & Data Systems,* 109 (9):1197-1210. doi: 10.1108/02635570911002270.

Yang, J. Yu, G., Liu, M. & Rui, M. (2016). Improving learning alliance performance for manufacturers: Does knowledge sharing matter? *International Journal of Production Economics*, 171(2), 301-308.

York, J.G. & Venkataraman, S. (2010). The entrepreneur–environment nexus: Uncertainty, innovation, and allocation. *Journal of Business Venturing*, 25,449-463.

Yixin, Z. (2010). *Regional perspectives on engineering: China*. UNESCO Report. UNESCO

Yusoff, Y.M., Omar, M.Z. & Zaharim, A. 2013. Evaluation of graduates' performance using fuzzy approach. 6th International Forum on Engineering Education (IFEE2012). *Procedia – Social and Behavioural Sciences,* 120, 64-73.

Zaharim A, Md Yusoff Y, Omar M.Z., Mohamed A., Muhamad N. & Mustapha R. (April 14 – 16, 2010). Practical framework of employability skills for engineering graduate in Malaysia. IEEE EDUCON Education Engineering 2010. *The future of global learning engineering education*. Madrid, Spain, 921-927.

Zengele, T. (2013). *Have teacher unions taken over the South African education system? Redeployment in Progress*. WEI International Academic Conference Proceedings, Istanbul, Turkey.

Zhang, Y. (2011). New trends of English teaching in outstanding engineers' education. *Procedia Engineering*, 15, 4291-4294.

Zhang, Y. & Gregory, M. (2011). Managing global network operations along the engineering value chain. *International Journal of Operations & Production Management*, 31(7), 736 – 764. http://www.emeraldinsight.com/journals.htm?issn=0144-3577&volume=31&issue=7

Zhang, Y., Gregory, M., & Neely, A. (2016). Global engineering services: Shedding light on network capabilities. *Journal of Operations Management*, 42-43, 80-94.

Zou, W., Kumaraswamy, M., Chung, J. & Wong, J. (2014). Identifying the critical success factors for relationship management in PPP projects. *International Journal of Project Management*, 32(2), 265-274.

ANNEXURE A

Engineering sector critical success factor survey

1. Introduction: Engineering sector critical sucess factors survey

My name is Yolanda Davids and I am registered at North-west University at the School of Business Management and Administration. I am undertaking a doctoral study, under the supervision of Professor P.D. Gerber, that aims to identify the critical success factors needed for supporting and advancing the South African engineering sector.

I will use quantitative tools to analyse the data that I obtain from this survey, including descriptive statistics, cross - tabulations, chi-square test of significance, factor analysis and structural equation modelling. The outcomes of this study, will be used to develop an analytical framework that describes the factors needed for supporting and advancing the engineering sector in the country.

Please be assured that your participation in this study will be anonymous and the information presented here will be treated with confidentiality. Should you require any additional information, please do not hesitate to contact me: ydavids013@gmail.com.

The first set of questions are demographic profile questions. The second set of questions affords you the opportunity to select an answer, from the following options: Strongly Disagree, Disagree, Agree, Strongly Agree and Unable to Provide a Response. I kindly request that you complete the survey, which will take a maximum of 15 minutes, by 15 December 2014.

Engineering critical success factor survey

2. Demographic Information

1. What is your age?

- ◯ 18 to 24
- ◯ 25 to 34
- ◯ 35 to 44
- ◯ 45 to 54
- ◯ 55 to 64
- ◯ 65 to 74
- ◯ 75 or older

1

2. What is your gender?

◯ Female

◯ Male

3. What is your nationality

[ ]

4. In which engineering discipline are you qualified in?

[ ]

Other (please specify)

[ ]

5. What engineering category do you fall under?

[ ]

Other (please specify)

[ ]

6. Do you belong to any other professional body or Voluntary Organisation?

◯ Yes

◯ No

If Yes (please specify)

[ ]

7. Are you registered with any other professional engineering body(ies) outside South Africa?

◯ Yes

◯ No

If Yes (please specify)

[ ]

8. Are you a practicing engineer/engineering technologist/technician in South Africa?

◯ Yes

◯ No

If NO (please specify the country you are currently practicing in?)

[ ]

2

9. About how long have you been in your current position?

Years

Months

Engineering sector critical success factor survey

3. Lickert scale

10. Evaluate the following statements and select an answer, from the following options: Strongly Disagree, Disagree, Agree, Strongly Agree and Unable to Provide a Response?

	Strongly Disagree	Disagree	Agree	Strongly Agree	Unable to provide a response
Training/development strategies in the engineering industry take into consideration international skills requirements.	○	○	○	○	○
The learning of science concepts are influenced by availability of adequate teaching resources.	○	○	○	○	○
Project management is the standard operation for delivering engineering products.	○	○	○	○	○
New ideas are formed due to creativity, not experience.	○	○	○	○	○
Most leaders adapt their leadership style to the situation that arises.	○	○	○	○	○
Most academic staff at higher education institutions provides expert teaching in each sub-discipline of engineering.	○	○	○	○	○
Most engineering graduates lack design capability.	○	○	○	○	○

3

	Strongly Disagree	Disagree	Agree	Strongly Agree	Unable to provide a response
An engineer must possess a measure of technological expertise.	○	○	○	○	○
The greatest threat to socio-economic development is the movement of highly skilled workers from one country to another.	○	○	○	○	○
Producing a reliable product creates a satisfied customer base.	○	○	○	○	○
Engineering graduates possess the necessary skills the workplace requires.	○	○	○	○	○
Changes in technology require that the job specifications of the user be redesigned.	○	○	○	○	○
Engineering solutions have a positive effect on the consumption of natural resource.	○	○	○	○	○
The electronic media is a vital communication tool in the engineering industry.	○	○	○	○	○
The knowledge construct of workplace training programmes teaches the engineering graduate about the business operations.	○	○	○	○	○
Design courses in the engineering curriculum nurture students' creative abilities.	○	○	○	○	○
The acquisition of new technology affects the human resources requirements of the organisation.	○	○	○	○	○
South African immigration policies eliminate the barriers to entry for people with scarce skills.	○	○	○	○	○

4

	Strongly Disagree	Disagree	Agree	Strongly Agree	Unable to provide a response
Adapting available technology is more cost-effective than developing new technology.	○	○	○	○	○
The engineering education curriculum at higher education institutions enables engineering students to deal with socio-economic challenges.	○	○	○	○	○
Most engineering organisations reward new ideas.	○	○	○	○	○
Female engineers require a nurturing workplace environment.	○	○	○	○	○
Engineering is crucial in creating a sustainable economy.	○	○	○	○	○
Most engineers are guided by an ethical code of conduct.	○	○	○	○	○
Engineering professional emigrate because of the high cost of living in South Africa.	○	○	○	○	○
The engineering industry applies set standards to develop a safe, high quality product.	○	○	○	○	○
Leaners poor performance in Mathematics and Science is due to a shortage of qualified teachers.	○	○	○	○	○
Engineering graduates are provided with adequate workplace training.	○	○	○	○	○

	Strongly Disagree	Disagree	Agree	Strongly Agree	Unable to provide a response
The hierarchical gap between the mentor and the engineering graduate are more important than the experience gap.	○	○	○	○	○
High quality designs concepts are usually produced by multi-disciplinary design teams.	○	○	○	○	○
New business owners prefer to invest in high novelty (new) business ventures.	○	○	○	○	○
Effective cross cultural communication can only take place when people start questioning their own biases.	○	○	○	○	○
A mentoring network creates a greater sense of belonging.	○	○	○	○	○
Most engineers understand engineering standards.	○	○	○	○	○
The adoption of new technology affects existing human resources competencies.	○	○	○	○	○
High level strategic goals usually take priority over individual goals.	○	○	○	○	○
A technology audit establishes an organisation's technology needs.	○	○	○	○	○
Good engineering business practices improve the quality of the product.	○	○	○	○	○
Sufficient financial support is provided to most engineering students.	○	○	○	○	○

	Strongly Disagree	Disagree	Agree	Strongly Agree	Unable to provide a response
Customer satisfaction improves when there is a continuous flow of information.	○	○	○	○	○
Innovative solutions are found when team members share information.	○	○	○	○	○
Most engineering projects have a proper monitoring system to evaluate project performance.	○	○	○	○	○
Incorrectly designed team activities affect the productivity within a team.	○	○	○	○	○
Most successful engineering projects are led by people with a high technical knowledge.	○	○	○	○	○
Most technology leading organisations tend to make small incremental improvements to its technology from time to time.	○	○	○	○	○
Engineering software tools manage engineering requirements.	○	○	○	○	○
Most engineering business owners aim to meet the demands in the market.	○	○	○	○	○
Losing skilled professionals increases the expenditure on education to compensate for the loss of skills.	○	○	○	○	○
The adoption of new technology for which an organisation is ill-prepared, adds little value to the organisation.	○	○	○	○	○

	Strongly Disagree	Disagree	Agree	Strongly Agree	Unable to provide a response
Talent management is the training and development of staff members.	○	○	○	○	○

8

ANNEXURE B

Table 7.1 Descriptive statistics per item

Q	Item	Sub-Factors	CSF	Agree		Disagree		Unable to provide a response		N	Mean	SD	Min	Max
				f	%	f	%	f	%					
2	The learning of science concepts are influenced by availability of adequate teaching resources.	Mathematics and Science Education	S-E	544	90.4	43	7.1	15	2.5	602	2.96	.940	1	5
27	Leaners poor performance in Mathematics and Science is due to a shortage of qualified teachers.	Mathematics and Science Education	S-E	424	70.8	120	20.0	55	9.2	599	3.36	1.035	1	5
6	Most academic staff at higher education institutions provides expert teaching in each sub-discipline of engineering	Engineering Education	S-E	388	64.6	170	28.3	43	7.2	601	2.96	.885	1	5
20	The engineering education curriculum at higher education institutions enabl es engineering students to deal with socio-economic challenges.	Engineering Education	S-E	192	32.0	335	55.8	73	12.2	600	2.62	1.127	1	5
39	Sufficient financial support is provided to most engineering students.	Engineering Education	S-E	177	29.6	321	53.8	99	16.6	597	2.77	1.202	1	5
28	Engineering graduates are provided with adequate workplace training.	Experiential Training	S-E	260	43.6	313	52.5	23	3.9	596	2.50	.880	1	5
11	Engineering graduates possess the necessary skills the workplace requires.	Mentoring	S-E	247	41.3	334	55.9	17	2.8	598	2.50	.873	1	5
15	The knowledge construct of workplace training programmes teaches the	Mentoring	S-E	428	71.7	133	22.3	36	6.0	597	3.06	.874	1	5

Q	Item	Sub-Factors	CSF	Agree		Disagree		Unable to provide a response		N	Mean	SD	Min	Max
				f	%	f	%	f	%					
	engineering graduate about the business													
29	The hierarchical gap between the mentor and the engineering graduate are more important than the experience gap.	Mentoring	S-E	122	20.5	417	70.1	56	9.4	595	2.36	1.112	1	5
1	Training/development strategies in the engineering industry take into consideration international skills requirements.	Talent management	S-E	367	61.0	191	31.7	44	7.3	602	2.96	.940	1	5
50	Talent management is the training and development of staff members.	Talent management	S-E	469	79.0	92	15.5	33	5.6	594	3.19	.824	1	5
14	The electronic media is a vital communication tool in the engineering industry.	Communication	S	554	92.8	19	3.2	24	4.0	597	3.64	.629	1	5
32	Effective cross cultural communication can only take place when people start questioning their own biases.	Communication	S	454	76.0	91	15.2	52	8.7	597	3.24	.865	1	5
36	High level strategic goals usually take priority over individual goals.	Multi-disciplinary teams	S	485	81.4	82	13.8	29	4.9	596	3.19	.784	1	5
43	Incorrectly designed team activities affect the productivity within a team.	Multi-disciplinary teams	S	544	91.6	26	4.4	24	4.0	594	3.41	.687	1	5
5	Most leaders adapt their leadership style to the situation that arises.	Leadership	S	383	63.7	205	34.1	13	2.2	601	2.84	.845	1	5
44	Most successful engineering projects are led by people with a high technical knowledge.	Leadership	S	425	71.3	144	24.2	27	4.5	596	3.15	.890	1	5

Q	Item	Sub-Factors	CSF	Agree		Disagree		Unable to provide a response		N	Mean	SD	Min	Max
				f	%	f	%	f	%					
16	Design courses in the engineering curriculum nurture students' creative abilities.	Creativity and Innovation	S	417	69.6	143	23.9	39	6.5	599	3.05	.867	1	5
41	Innovative solutions are found when team members share information.	Creativity and Innovation	S	565	94.6	13	2.2	19	3.2	597	3.57	.610	1	5
31	New business owners prefer to invest in high novelty (new) business ventures.	Entrepreneurship	S	206	34.4	255	42.6	137	22.9	598	3.06	1.249	1	5
47	Most engineering business owners aim to meet the demands in the market.	Entrepreneurship	S	527	89.3	40	6.8	23	3.9	590	3.26	.672	1	5
4	New ideas are formed due to creativity, not experience	Idea generation	F-P	282	47.3	296	49.7	18	3.0	596	2.66	.920	1	5
21	Most engineering organisations reward new ideas.	Idea generation	F-P	284	47.5	277	46.3	37	6.2	598	2.64	.954	1	5
7	Most engineering graduates lack design capability.	Product design and development	F-P	423	70.1	163	27.0	17	2.8	603	3.06	.868	1	5
30	High quality designs concepts are usually produced by multi-disciplinary design teams.	Product design and development	F-P	466	78.1	112	18.8	19	3.2	597	3.18	.821	1	5
26	The engineering industry applies set standards to develop a safe, high quality product.	Business process Management	F-P	514	85.7	67	11.2	19	3.2	600	3.22	.707	1	5
38	Good engineering business practices improve the quality of the product.	Business process Management	F-P	560	94.0	19	3.2	17	2.9	596	3.52	.636	1	5
3	Project management is the standard operation for delivering engineering products	Project Management	F-P	474	79.0	116	19.3	10	1.7	600	3.15	.796	1	5

Q	Item	Sub-Factors	CSF	Agree		Disagree		Unable to provide a response		N	Mean	SD	Min	Max
				f	%	f	%	f	%					
42	Most engineering projects have a proper monitoring system to evaluate project performance.	Project Management		308	51.8	268	45.0	19	3.2	595	2.62	.858	1	5
10	Producing a reliable product creates a satisfied customer base.	Customer Orientation	F-P	553	92.2	28	4.7	19	3.2	600	3.55	.662	1	5
40	Customer satisfaction improves when there is a continuous flow of information.	Customer Orientation	F-P	547	91.9	24	4.0	24	4.0	595	3.48	.647	1	5
37	A technology audit establishes an organisation's technology needs.	Technology needs and wants	T	417	70.0	129	21.6	50	8.4	596	3.10	.871	1	5
49	The adoption of new technology for which an organisation is ill-prepared, adds little value to the organisation.	Technology needs and wants	T	497	83.7	66	11.1	31	5.2	594	3.18	.695	1	5
45	Most technology leading organisations tend to make small incremental improvements to its technology from time to time.	Technology Innovation	T	466	78.5	70	11.8	58	9.8	594	3.24	.815	1	5
19	Adapting available technology is more cost-effective than developing new technology.	Technology Innovation	T	373	62.5	185	31.0	39	6.5	597	2.97	.917	1	5
35	The adoption of new technology affects existing human resources competencies.	Technology Competence	T	499	83.7	70	11.7	27	4.5	596	2.97	.917	1	5
8	An engineer must possess a measure of technological expertise.	Engineering Technology	T	577	95.8	10	1.7	15	2.5	602	3.64	.577	1	5

Q	Item	Sub-Factors	CSF	Agree		Disagree		Unable to provide a response		N	Mean	SD	Min	Max
				f	%	f	%	f	%					
46	Engineering software tools manage engineering requirements.	Engineering Technology	T	331	55.5	227	38.1	38	6.4	596	2.82	.921	1	5
17	The acquisition of new technology affects the human resources requirements of the organisation.	Performance Management of Engineering Competence	T	513	85.8	70	11.7	15	2.5	598	3.22	.689	1	5
12	Changes in technology require that the job specifications of the user be redesigned.	Performance Management of Engineering Competence	T	437	73.2	130	21.8	30	5.0	597	3.08	.807	1	5
22	Female engineers require a nurturing workplace environment.	Transformation in engineering	E	316	52.9	230	38.5	51	8.5	597	2.84	.995	1	5
33	A mentoring network creates a greater sense of belonging.	Transformation in engineering	E	553	92.6	20	3.4	24	4.0	597	3.42	.662	1	5
24	Most engineers are guided by an ethical code of conduct.	Engineering ethics	E	511	85.7	67	11.2	18	3.0	596	3.30	.746	1	5
34	Most engineers understand engineering standards.	Engineering ethics	E	428	71.3	162	27.0	10	1.7	600	2.85	.725	1	5
9	The greatest threat to socio-economic development is the movement of highly skilled workers from one country to another.	Engineering technology policy	E	401	66.6	176	29.2	25	4.2	602	3.09	.994	1	5
48	Losing skilled professionals increases the expenditure on education to compensate for the loss of skills.	Engineering technology policy	E	453	76.0	103	17.3	40	6.7	596	3.36	.905	1	5
18	South African immigration policies eliminate the barriers to entry for people with scarce skills.	Retention of engineering skills	E	156	26.0	304	50.7	140	23.3	600	2.85	1.417	1	5

Q	Item	Sub-Factors	CSF	Agree		Disagree		Unable to provide a response		N	Mean	SD	Min	Max
				f	%	f	%	f	%					
25	Engineering professional emigrate because of the high cost of living in South Africa.	Retention of engineering skills	E	74	12.4	490	82.2	32	5.4	596	1.99	1.033	1	5
13	Engineering solutions have a positive effect on the consumption of natural resource.	Engineering for sustainable development	E	501	83.9	70	11.7	26	4.4	597	3.29	.769	1	5
23	Engineering is crucial in creating a sustainable economy.	Engineering for sustainable development	E	541	91.1	7	1.2	46	7.7	594	3.87	.566	1	5

Table 7.2 Chi-Square Tests: Engineering education curriculum and age groups

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	46.000[a]	12	.000
Likelihood Ratio	48.578	12	.000
Linear-by-Linear Association	14.064	1	.000
N of Valid Cases	597		

a. 5 cells (23.8%) have expected count less than 5. The minimum expected count is .24.

Table 7.3 Chi-Square Tests: Engineering education curriculum and engineering category

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	30.803[a]	4	.000
Likelihood Ratio	29.090	4	.000
Linear-by-Linear Association	25.779	1	.000
N of Valid Cases	585		

cells (11.1%) have expected count less than 5. The minimum expected count is 4.43.

Table 7.4 Chi-Square Tests: financial support and age

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	21.382[a]	12	.045
Likelihood Ratio	22.108	12	.036
Linear-by-Linear Association	1.383	1	.240
N of Valid Cases	594		

6 cells (28.6%) have expected count less than 5. The minimum expected count is .33.

Table 7.5 Chi-Square Tests: Financial support and gender

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	9.064[a]	2	.011
Likelihood Ratio	8.738	2	.013
Linear-by-Linear Association	5.360	1	.021
N of Valid Cases	584		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 9.30.

Table 7.6 Chi-Square Tests: age and workplace training

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	26.631[a]	12	.009
Likelihood Ratio	21.118	12	.049
Linear-by-Linear Association	4.757	1	.029
N of Valid Cases	593		

a. 10 cells (47.6%) have expected count less than 5. The minimum expected count is .08.

Table 7.7 Chi-Square Tests: age and workplace readiness

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	22.439[a]	12	.033
Likelihood Ratio	25.051	12	.015
Linear-by-Linear Association	3.669	1	.055
N of Valid Cases	595		

a. 10 cells (47.6%) have expected count less than 5. The minimum expected count is .06.

Table 7.8 Chi-Square Tests: gender and workplace readiness

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	8.384[a]	2	.015
Likelihood Ratio	8.224	2	.016
Linear-by-Linear Association	8.007	1	.005
N of Valid Cases	585		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 1.63.

Table 7.9 Chi-Square Tests: engineering category and workplace training programmes

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	22.017[a]	4	.000
Likelihood Ratio	31.982	4	.000
Linear-by-Linear Association	17.006	1	.000
N of Valid Cases	582		

a. 1 cells (11.1%) have expected count less than 5. The minimum expected count is 2.29.

Table 7.10 Chi-Square Tests: gender and cross cultural communication

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	7.237[a]	2	.027
Likelihood Ratio	12.025	2	.002
Linear-by-Linear Association	3.165	1	.075
N of Valid Cases	584		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 4.80.

Table 7.11 Chi-Square Tests: engineering category and product and process information

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	20.107[a]	4	.000
Likelihood Ratio	21.884	4	.000
Linear-by-Linear Association	17.132	1	.000
N of Valid Cases	584		

a. 1 cells (11.1%) have expected count less than 5. The minimum expected count is 2.41.

Table 7.12 Chi-Square Tests: age and design teams

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	23.115[a]	12	.027
Likelihood Ratio	23.477	12	.024
Linear-by-Linear Association	17.769	1	.000
N of Valid Cases	594		

a. 9 cells (42.9%) have expected count less than 5. The minimum expected count is .06.

Table 7.13 Chi-Square Tests: engineering categories and graduate design capabilities

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	10.129[a]	4	.038

Likelihood Ratio	9.413	4	.052
Linear-by-Linear Association	4.634	1	.031
N of Valid Cases	588		

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 1.13.

Table 7.14 Chi-Square Tests: engineering categories and quality products

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	11.410[a]	4	.022
Likelihood Ratio	12.977	4	.011
Linear-by-Linear Association	1.984	1	.159
N of Valid Cases	581		

4 cells (44.4%) have expected count less than 5. The minimum expected count is 1.05.

Table 7.15 Chi-Square Tests: engineering categories and engineering software tools

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	17.307[a]	4	.002
Likelihood Ratio	18.264	4	.001
Linear-by-Linear Association	16.138	1	.000
N of Valid Cases	581		

a. 1 cells (11.1%) have expected count less than 5. The minimum expected count is 2.17.

Table 7.16 Chi-Square Tests: engineering categories and user job specification

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	9.704[a]	4	.046
Likelihood Ratio	11.705	4	.020
Linear-by-Linear Association	7.824	1	.005
N of Valid Cases	582		

a. 1 cells (11.1%) have expected count less than 5. The minimum expected count is 1.78.

Table 7.17 Chi-Square Tests: age and technology audits

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	21.481[a]	12	.044
Likelihood Ratio	22.046	12	.037
Linear-by-Linear Association	1.735	1	.188
N of Valid Cases	593		

a. 5 cells (23.8%) have expected count less than 5. The minimum expected count is .17.

Table 7.18 Chi-Square Tests: engineering categories and technology audits

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	14.829[a]	4	.005
Likelihood Ratio	16.120	4	.003
Linear-by-Linear Association	14.312	1	.000
N of Valid Cases	581		

a. 1 cells (11.1%) have expected count less than 5. The minimum expected count is 3.10.

Table 7.19 Chi-Square Tests: age and value-add of new technology

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	22.836[a]	12	.029
Likelihood Ratio	16.934	12	.152
Linear-by-Linear Association	.108	1	.742
N of Valid Cases	591		

a. 6 cells (28.6%) have expected count less than 5. The minimum expected count is .10.

Table 7.20 Chi-Square Tests: gender and value-add of new technology

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	7.419[a]	2	.024
Likelihood Ratio	11.252	2	.004
Linear-by-Linear Association	5.843	1	.016
N of Valid Cases	581		

1 cells (16.7%) have expected count less than 5. The minimum expected count is 2.93.

Table 7.21 Chi-Square age and engineering standards

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	26.826[a]	12	.008
Likelihood Ratio	16.114	12	.186

Linear-by-Linear Association	.264	1	.607
N of Valid Cases	597		

Table 7.22 Chi-Square Tests: engineering categories and engineering standards

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	12.791[a]	4	.012
Likelihood Ratio	9.011	4	.061
Linear-by-Linear Association	.386	1	.534
N of Valid Cases	585		

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is .63.

Table 7.23 Chi-Square Tests: gender and emigration

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	8.972[a]	2	.011
Likelihood Ratio	11.827	2	.003
Linear-by-Linear Association	6.885	1	.009
N of Valid Cases	589		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 2.42.

Table 7.24 Chi-Square Tests: engineering category and emigration

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	15.922[a]	4	.003
Likelihood Ratio	16.974	4	.002
Linear-by-Linear Association	14.906	1	.000
N of Valid Cases	587		

1 cells (11.1%) have expected count less than 5. The minimum expected count is 1.55.

Table 7.25 Chi-Square age and immigration policies

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	22.625[a]	12	.031
Likelihood Ratio	23.586	12	.023
Linear-by-Linear Association	9.442	1	.002
N of Valid Cases	597		

Table 7.26 Chi-Square Tests: engineering category and immigration policies

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	11.785[a]	4	.019
Likelihood Ratio	11.224	4	.024
Linear-by-Linear Association	5.921	1	.015
N of Valid Cases	585		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 8.79.

Table 7.27 Chi-Square Tests: age and brain drain

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	32.240[a]	12	.001
Likelihood Ratio	23.640	12	.023
Linear-by-Linear Association	2.363	1	.124
N of Valid Cases	593		

a. 6 cells (28.6%) have expected count less than 5. The minimum expected count is .11.

Table 7.28 Communalities

	Initial	Extraction
Project management is the standard operation for delivering engineering products.	1.000	.298
Producing a reliable product creates a satisfied customer base.	1.000	.441
The knowledge construct of workplace training programmes teaches the engineering graduate about the business operations.	1.000	.520
Design courses in the engineering curriculum nurture students' creative abilities.	1.000	.505
The engineering education curriculum at higher education institutions enables engineering students to deal with socio-economic challenges.	1.000	.516
Most engineers are guided by an ethical code of conduct.	1.000	.576
The engineering industry applies set standards to develop a safe, high quality product.	1.000	.646
A mentoring network creates a greater sense of belonging.	1.000	.373
A technology audit establishes an organisation's technology needs.	1.000	.580
Good engineering business practices improve the quality of the product.	1.000	.450
Customer satisfaction improves when there is a continuous flow of information.	1.000	.554
Most engineering projects have a proper monitoring system to evaluate project performance.	1.000	.445
Engineering software tools manage engineering requirements.	1.000	.359
Most engineering business owners aim to meet the demands in the market.	1.000	.613

Extraction Method: Principal Component Analysis.

Table 7.29 Intraclass Correlation Coefficient

	Intraclass	95% Confidence Interval		F Test with True Value 0			
	Correlation[b]	Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.164[a]	.144	.188	3.951	571	7994	.000
Average Measures	.747[c]	.715	.776	3.951	571	7994	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type C intraclass correlation coefficients using a consistency definition. The between-measure variance is excluded from the denominator variance.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 7.30 Variances of exogenous variable shows a 95% confidence intervals

95% Conf. Interval	
0.879044	1.1341
0.437949	0.573578
0.343889	0.448784
0.31128	0.416825
0.308279	0.419925
0.727884	0.993052
0.608411	0.876326
0.7732069	1.045519
0.585877	0.785687
0.384377	0.57007
0.91696	1.231838
0.712596	0.956729
1.046486	1.362039
0.469671	0.600212
0.1144	0.303694
0.244831	0.515899
0.159887	0.3526
0.150988	0.374671

Table 7.31 Covariances between latent constructs with 95% Confidence intervals

[95% Conf. Interval]	
0.051122	0.147378
0.061427	0.149987
0.1221	0.247253
0.095245	0.203677
0.140819	0.279131
0.140612	0.25741