Title

The effectiveness of the organization’s system design management process and the applicability and benefits of concurrent engineering

by

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DISSERTATION

Submitted in partial fulfillment of the requirements for the degree

MASTER OF PHILOSPHY

in

ENGINEERING MANAGEMENT

in the

FACULTY OF ENGINEERING AND THE BUILT - ENVIRONMENT

at the

UNIVERSITY OF JOHANNESBURG

SUPERVISOR: Prof J.H.C. Pretorius

DECLARATION

I, Nelisiwe Nhlapo, hereby declare that this minor dissertation is my own original work and has not been submitted before for any academic purposes. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions. It is being submitted in partial fulfilment of the degree of Master of Philosophy in Engineering Management in the Faculty of Engineering and The Built Environment to the University of Johannesburg, Johannesburg.

I further state that I know what plagiarism is and everything done is of my own work except where others has been referred to and clearly referenced.

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It has not been submitted before for any degree or examination to any other University.

19 July 2020
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Signature Date

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ACKNOWLEDGMENTS

First and foremost, I would like to thank God almighty for providing me the strength, knowledge, ability, opportunity and privilege to undertake this research study as well as the perseverance to see the study to completeness.

I wish to express my very great appreciation to my supervisor Prof J.H.C. Pretorius for availing himself as well as the valuable and insightful guidance he has provided in finalizing the document.

I wish to also acknowledge my Organization for allowing me to conduct the study, as well as my colleagues for participating in the research survey.

I also take pride in acknowledging my parents whose guidance, loving and nurturing upbringing has enabled the achievements of my life today. Had it not been for their unflinching insistence and support, my dreams of excelling in education would have remained mere dreams.

My acknowledgement would be incomplete without thanking my biggest source of strength my dearest husband; Sibusiso Nhlapo. My love, thank you for your unwavering support throughout this period. For always believing in me and pushing me outside of my comfort zone. I wouldn't have come this far and even finished this paper if it was not for your unwavering and selfless love and support you've given me at all times, I truly am grateful. To my dearest boys, mommy loves you. Thank you for giving me reason to keep pushing.

EXECUTIVE SUMMARY

There are various and numerous SEM practices that have been established and published in literature. Thereby, the difficulty in designing engineering solutions does not just arise from simply the technical complexity but also in the managerial complexity necessary to manage the interactions between the different engineering disciplines.

The main objective of this minor research dissertation was to understand the non-performance of the organization's SEM model and whether concurrent engineering can be considered as an alternative to the organization's current SEM model. In order to understand the non-performance, three (3) questions together with their hypothesis and null hypothesis were posed. The first question was to see how the current SEM model compares with industry best practice. A review of the organization's SEM model together supporting documentation such as engineering policy, instruction manuals and procedures revealed that the organization's SEM model compares very well with best practice.

The second question was to see if the SEM model actually gets implemented during projects and was a form of research survey. The results revealed that the SEM model does get implemented during projects. The third question established the effectiveness of the organizations SEM model by looking at project performance. The results revealed that the organization's SEM model is not effective.

Having established the none-performance of the organization's SEM model, the 4th question investigated whether concurrent could be most suitable and provide greater benefits to the organization. The results to the 4th question revealed that concurrent engineering is the most befitting SEM model for the organization.

The make-up, engineering or re-engineering of the actual concurrent engineering process to be adopted and retrofitted as the organizations SEM model is recommended as topic to be explored in separate research study.

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LIST OF ABBREVIATIONS

B2B	Back2Basics
BKCASE	Body of Knowledge and Curriculum to Advance Systems Engineering
C&I	Control & Instrumentation
CE	Concurrent Engineering
CoE	Centre of Excellence
CPI	Cost Performance Index
ECM	Engineering Change Management
ECR	Engineering Change Request
EDWL	Engineering Design Work Lead
EMAP	Engineering Management Plan
EMF	Engineering Management Framework
GUTSE	grand unified theory of systems engineering
HPUM	High Performance Utility Model
IEEE	Institute of Electronics Engineers
INCOSE	International Council on Systems Engineering
LPS	Low Pressure Services
MDR	Multi-Disciplinary Review
NCOSE	National Council on Systems Engineering
NPD	New Product Development
PLC	Project Life Cycle
PLCM	Project Life Cycle Model
PMBOK	Project Management Body of Knowledge
ROC	Required Operational Capability
S/CCCC	Site/Central Change Control Committee
SE	Systems Engineering
SEBoK	Systems Engineering Body of Knowledge
SEM	System Engineering Management
SEMBASE	Systems Engineering Management Base Theory

SEMP	Systems Engineering Management Plan
SEP	Systems Engineering Process
SPI	Schedule Performance Index
SRD	Stakeholder Requirements Definition
WBS	Work breakdown Structure

CHAPTER 1: PROBLEM DEFINITION

1.1 INTRODUCTION

Systems Engineering (SE) is concerned with concepts, principles, practices and methods for developing systems design solutions. There are varies SE processes that have been established and published in literature. The variance of the SE processes is typically as a result of the different technical complexity and environmental conditions in which organizations and projects operate and function.

Thereby the difficulty in designing engineering solutions does not just arise from simply the technical complexity but also in the design development practices.

This section of the research introduces the problem definition of this minor dissertation in respect of the effectiveness of the organization's SE development model in appropriately addressing the challenges faced by the organization. Background information is provided which serves as a motivation for the minor dissertation in establishing whether the current SE development model provides benefit to the organization.

1.2 ENGINEERING WITHIN THE ORGANIZATION

The Organization is an asset-intensive business and Engineering is a vital component of the organization's Business Service Functions as depicted in figure 1. Engineering is also represented at Group Executive level within the organization, which again re-iterates the significance of engineering for achieving organizational strategic objectives and success.

The primary role of Engineering within the organization is to establish, improve and sustain the technical integrity of the organization's assets. To this end, Engineering has developed and adopted the Engineering Management Framework (EMF), which in essence is a set of tools (processes and procedures) for carrying out engineering work within the organization. One such is the project design and development process during asset creation and modification, i.e. Engineering Change Management (ECM), for effective and efficient engineering design work delivery.

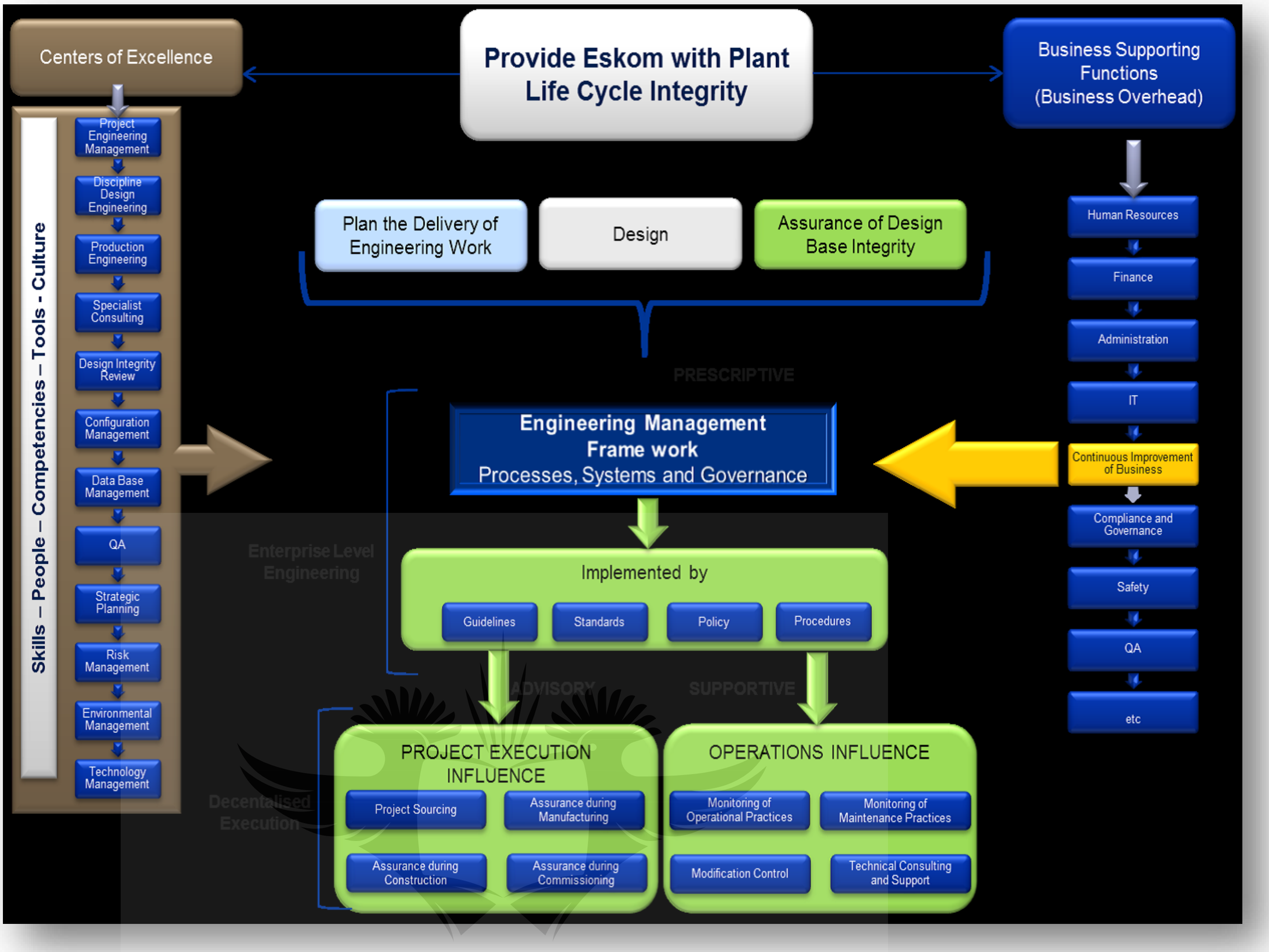


Figure 1: Depicting Executive Role of Engineering within Organization [1]

1.2.1 PLCM AND ECM IN CONTEXT

1.2.1.1 PROJECT LIFE CYCLE MODEL (PLCM)

The creation or modification of an asset or project is controlled via the Project Life Cycle Model (PLCM). The function of the project life cycle model is to ensure sufficient governance of projects through a comprehensive and consistent method of project management and control to ensure project success. This approach to project governance helps ensure the business does not take on additional risk or commit additional resources without first analysing the risk of the project and its impact on the business. It also ensures the decision to proceed with the project is made by the correct governance structures with the correct delegation of authority to do so.

As depicted in figure 2, all engineering phases from initial planning, design creation, technical assurance, to operating and overall decommissioning, are combined and modeled within the Project Life Cycle Model (PLCM) for the overall Project Life Cycle (PLC).

The resulting model provides a detailed engineering stream throughout the entire process and identifies the interfaces between Engineering and the various services functions of the organizations, specifically project engineering and commercial. It is evident from this integrated model that engineering is the central element throughout the entire process within the PLCM of PLC.

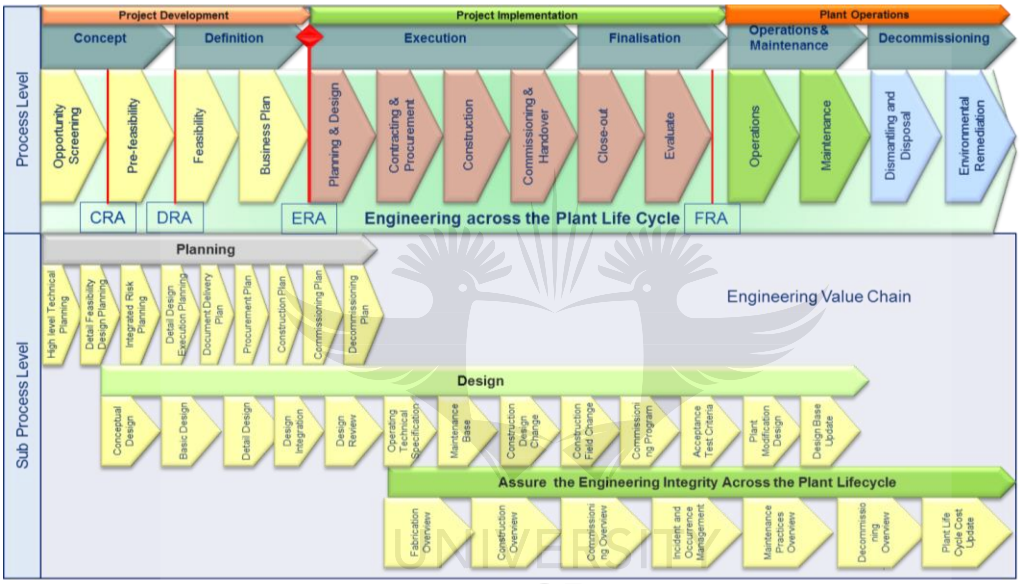


Figure 2: Engineering phases within the Organization's PLCM [1]

1.2.1.2 *ENGINEERING CHANGE MANAGEMENT (ECM)*

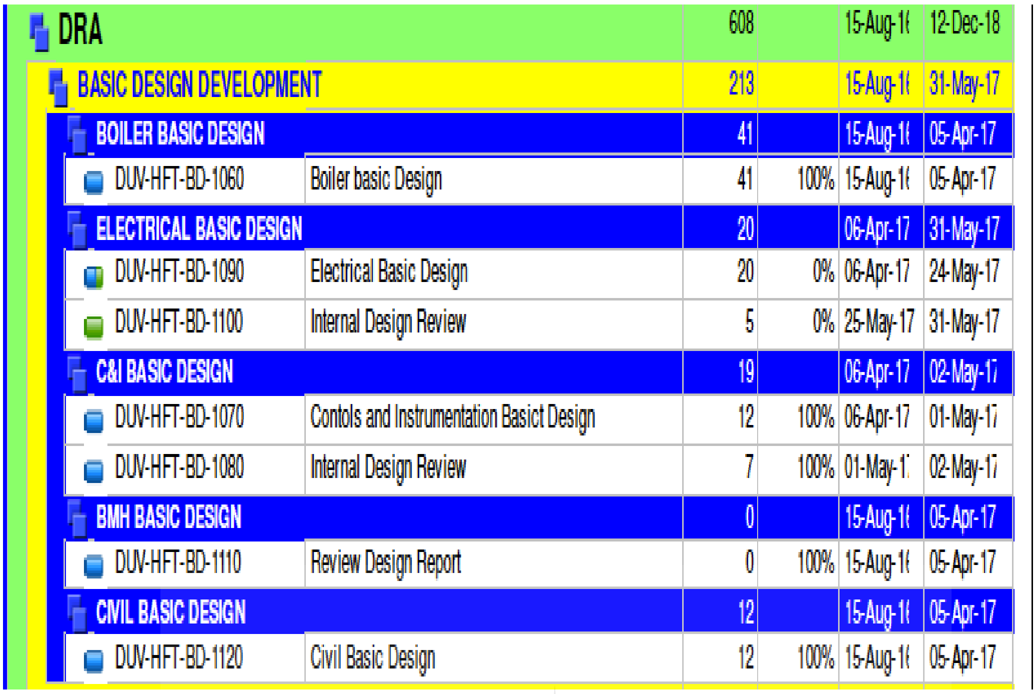
The Engineering Change Management (ECM) process is governance and quality control engineering design and management process for all engineering design work undertaken within the organization during asset modification or small asset upgrade projects. The ECM process is undertaken to ensure that all Engineering Changes (i.e. asset modification or upgrade projects) are correctly prepared, motivated, reviewed, approved, controlled and recorded. Therefore the ECM process is a systems design and development management process with the primary objective of ensuring effective management of all engineering project design deliverables.

During asset modification or upgrade, the ECM process describes several design review phases that have to be achieved prior to the project proceeding to the next phase. The process covers all phases of the Project Life Cycle Model (PLCM) from the stakeholder requirements definition right through to hand-over review. The process is initiated by the client through the Required Operational Capability (ROC); engineering and all other relevant stakeholders then develop the Stakeholder Requirements Definition (SRD), followed by the Concept Design, Basic Design and Technical Specification.

Further, End-of-phase design reviews are performed through the Multi-Disciplinary Review (MDR) and Site/Central Change Control Committee (S/CCCC). The detail design, execution, commissioning and capability performance phases are the responsibility of the Contractor with Engineering assuming the technical assurance role.

1.2.2 REVIEW OF ECM PROCESS PERFORMANCE AND EFFECTIVENESS

Depicted in figure 3 is a project schedule for one of the typical ECM projects undertaken within the organization; the grant chart is then plotted in figure 4. The design and development process involves multiple engineering disciplines, and typically, the design of one discipline is a predecessor of one or more disciplines. As a result then, those disciplines typically cannot commence their designs until the predecessors have completed their design(s).



DRA		608		15-Aug-1	12-Dec-18
BASIC DESIGN DEVELOPMENT		213		15-Aug-1	31-May-17
BOILER BASIC DESIGN		41		15-Aug-1	05-Apr-17
DUV-HFT-BD-1060	Boiler basic Design	41	100%	15-Aug-1	05-Apr-17
ELECTRICAL BASIC DESIGN		20		06-Apr-17	31-May-17
DUV-HFT-BD-1090	Electrical Basic Design	20	0%	06-Apr-17	24-May-17
DUV-HFT-BD-1100	Internal Design Review	5	0%	25-May-17	31-May-17
C&I BASIC DESIGN		19		06-Apr-17	02-May-17
DUV-HFT-BD-1070	Contols and Instrumentation Basict Design	12	100%	06-Apr-17	01-May-17
DUV-HFT-BD-1080	Internal Design Review	7	100%	01-May-1	02-May-17
BMH BASIC DESIGN		0		15-Aug-1	05-Apr-17
DUV-HFT-BD-1110	Review Design Report	0	100%	15-Aug-1	05-Apr-17
CIVIL BASIC DESIGN		12		15-Aug-1	05-Apr-17
DUV-HFT-BD-1120	Civil Basic Design	12	100%	15-Aug-1	05-Apr-17

Figure 3: Typical Planning Schedule for Typical Project Within Organization

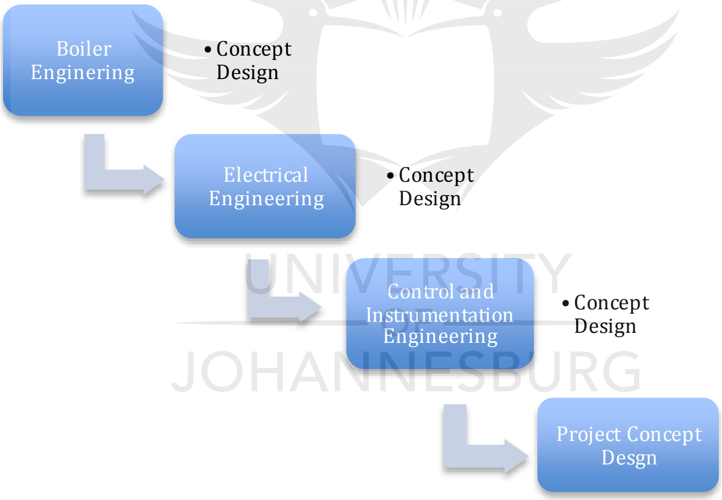


Figure 4: Showing the Design Execution Process

Thus, the ECM design and development management process follows the traditional sequential systems engineering development approach during asset creation, modification or upgrade. According to literature [5] the sequential design process has been known and is considered inefficient as it typically leads to greater development time, greater cost and lower overall design quality, and thereby lowering the overall benefit of the generated design to the organization.

The perceived lack of performance of the ECM process can further be substantiated by the number of re-baselined project schedules depicted in figure 5 below.

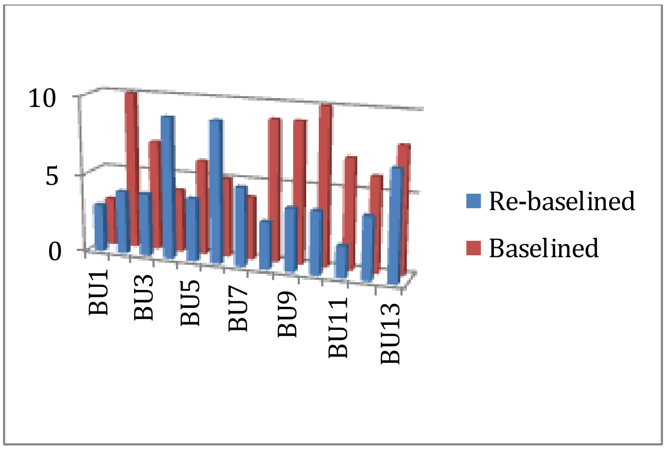


Figure 5: Depicting number of re-baselined projects for thirteen of the organization's business units

The above figure depicts project performance of thirteen of the organization's business units for the financial year 2017/2018 carried under the ECM process. Considering that re-baselining simply implies that the engineering project deliverables i.e. engineering baselines have been revised for a later date and thereby impacting the project performance, it is clear from the figure that a number of the projects have been failing particularly in respect to time and can thus substantiate the position that the organization's ECM design and development management process does not provide benefits to the organization and should be reviewed.

It is easy to consider re-baselining as a technical issue in nature rather than process related; however the ECM process, as a design and development management process should guard against all project risks.

It would be imperative to understand the dynamics that inform none performances of the ECM process given that the above review suggests that the current design and development process does not provide organizational benefits and that there is a need for a more efficient and cost effective systems engineering design and development process if the organization is to remain competitive; particularly for projects that result in substantial loss of production.

For such projects it should be possible to follow or adopt a systems engineering design and development process that focuses primarily on time but without compromising on project quality and budget.

1.3 LITERATURE BACKGROUND

1.3.1 *PROJECT SUCCESS AND SYSTEMS ENGINEERING*

According to the PMBOK Guide [2] project management is the application of knowledge, skills, tools, and techniques to project activities in order to meet or exceed the stakeholder's needs and expectations from a project. It further goes on to define the competing demand factors (scope, time, cost and quality; stakeholder with differing needs and expectations; identified needs and expectations) that need to be balanced in meeting or exceeding stakeholder expectations. Research work has equated measures of project success with keeping up with project plan in terms of budget, time schedule and satisfaction of a given level of quality [3]. It is against this background that many organizations constantly invest in Systems Engineering (SE) processes that will improve on project delivery on time, cost and quality.

Organizations competing in international markets today consider New Product Development (NPD) or system engineering (SE) processes (NPD and SE will be used interchangeably within this paper and both refer to systems engineering design and development processes) as an important factor for keeping their competitive advantage [4]. Also both researchers and managers are constantly searching for methods and practices that will allow them to improve their organizations and the management of their NPD processes as well as boost their effectiveness or success. Thus then, SE processes are of organizational interest rather than a specific function within the organization

.

1.3.2 *SYSTEMS ENGINEERING DEVELOPMENT METHODS*

As shown above, the organization's project systems engineering design and development process (i.e. ECM) is a multi-disciplinary engineering activity requiring contributions from more than just one engineering discipline - whether it is an upgrade or improvement of an existing asset or the development of a new asset. The ECM process follows the traditional project systems engineering design and development process - also referred to as sequential systems design, wherein functional activities are performed in stages from concept development right through to product or project delivery. The sequential operation of these functional stages have been understood to result in long development times and many quality problems due to the lack of communication and understanding of the different product design, manufacturing and above all customer requirements [5].

Organizations globally have re-organized their SE processes and have moved away from the above described sequential approach - which is fundamentally characterized by the minimal interaction amongst departments or project team members involved with activities being carried out sequentially, and have adopted a SE process that compresses the project development lead-time by enabling any upstream and downstream phases of the project life cycle model to be considered when taking decisions at the project concept phase [6]. This approach is known as Concurrent Engineering (CE) and is described as '*the systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support'* [7].

1.3.3 CONCURRENT ENGINEERING

The application of CE has gradually become the norm for developing projects [8]. A number of studies have illustrated that CE has helped organizations better their performance in the form of lower cost, shorter design development lead-time and greater quality; and as explained earlier these are factors for sustainable competitiveness.

Whilst the business benefits of CE are well understood, a survey of UK industry concluded that although its implementation within certain sectors such as power generation, petro-chemical and aerospace claimed to be at a higher level, other sectors such as automobile and machinery reported relatively low levels [9]. Even recent research [10] has shown that the use and application of CE does not necessarily prove efficient but depends on the organizational context within which it is used. Also, the degree to which companies have implemented concurrent engineering and the amount of success varies greatly.

The above demonstrates the lack of unanimity in the subject of the effectiveness of concurrent engineering. This suggests that the subject matter to be considered is not only whether concurrent engineering is a means of improving systems design and development; but rather to understand under what organizational conditions does concurrent engineering prove effective. Therefore a detailed analysis of the organization must be performed before the decision can be taken for implementing CE. It is thus the objective of this research to understand these empirical contradictions on the subject and also establish the organizational circumstances for which the application of concurrent engineering is likely to prove effective as systems design and development process.

1.4 RESEARCH PROBLEM

It is evident that the organization's sequential design and development process is inefficient in that it is likely to lead to greater development time, greater cost, lower design quality, all which lower the overall profit generated by the design; and inevitable, the organizations competitive advantage. It is imperative that an alternative is considered.

Literature review provides evidence that the integrated design approach in the form of concurrent engineering is the most effective for achieving sustainable competitiveness. The contrary is also equally true; that the concurrent engineering process does not always lead to positive results.

Thus the difficulty in designing complex engineering projects does not just arise from simply the technical complexity but also in the design process practices. Also that transforming design processes from a sequential engineering to concurrent engineering practices does not necessary lead to success but depends on the context of practice; that is on the prevailing competitive and technological circumstances of the organization.

Thus then the first problem to be considered is whether the current organizational design and development process provides any benefits to the organization. The second problem to be considered is whether the concurrent process can be considered as the alternative tool for improving organizational performance in the design process

.

1.5 RESEARCH OBJECTIVES AND RESARCH QUESTIONS

The main objective underpinning this minor dissertation is to investigate the success and benefits of the organizations current design and development process and establish if the organization can be more effective by leveraging concurrent engineering practices to its system engineering design and development process during asset creation i.e. ECM projects. To this end, there are four imperative questions to be answered to achieve the research objectives:

1.5.1 RESEARCH QUESTION 1

Does the organization's current SE design and development process compare with SE best practices?

Preliminary investigation of policy and procedural documentation suggests that there is a SEM model within the organization and given the perceived ineffectiveness of the model in addressing the organization's challenges, the null and alternate hypothesis statements are formulated as follows:

- **$1H_o$:** The organization's current SE design and development process model does not compare with SE best practices.
- **$1H_a$:** The organization's current SE design and development process model does compare with SE best practices

Following analysis and outcome of the above hypothesis statement, question 2 had to be formulated to further address the research objectives.

1.5.2 RESEARCH QUESTION 2

Does the organization's current SE design and development process get implemented during ECM projects?

Again, given the perceived ineffectiveness of the SE model in addressing the organization's challenges, the null and alternate hypothesis statements are formulated as follows:

$2H_o$: The organization's current SE design and development process does not get implemented during ECM project.

2H$_a$: The organization's current SE design and development process does get implemented during ECM project.

The answer to the above questions together with question 3 below will address the first objective of the minor dissertation.

1.5.3 RESEARCH QUESTION 3

Does the organization's current SE design and development process provide project benefits and success with respect to time, budget and quality?

Given the perceived ineffectiveness of the SE model in addressing the organization's challenges, the null and alternate hypothesis statements for the above question are formulated as follows:

3H$_o$: The organization's current SE design and development process does not provide project benefit with respect to time, cost and quality.

3H$_a$: The organization's current SE design and development process does provide project benefit with respect to time, cost and quality.

1.5.4 RESEARCH QUESTION 4

Can concurrent engineering bring organizational benefits and success in respect of time, budget and quality?

In order to address the fourth question of the mini dissertation, it is necessary to formulate a hypothesis statement based on existing literature in respect of the effectiveness of concurrent engineering with regards to the nature of technological uncertainty and importance of project performance in respect to time within the organization.

4.1H$_o$: The organization is characterized by high degree of technological uncertainty.

4.1H$_a$: The organization is characterized by high degree of technological certainty.

4.2H_o: The organization is not characterized by high degree of technological uncertainty.

4.2H_a: The organization is not characterized by high degree of technological certainty.

The analysis of the hypothesis statement to question 4 will address the second objective of the mini dissertation.

1.6 RESEARCH LIMITATIONS AND EXCLUSIONS

The organization's standard PLCM is comprised of four phases and each phase has a phase that is applicable to the pre-defined organizational governance and divisional management structures authorized to allocate additional resources, approve additional financial investment and take on additional risk for the projects.

The minor research dissertation is limited to the technical scope of the PLCM for the entire PLC. Other functions such as the project management, commercial and financial aspect of the project which is concerned with the project cost estimate of the four phases of the project life cycle model will be excluded from the research dissertation.

The research dissertation is further limited to engineering work undertaken for small modifications projects or small upgrades, typically undertaken under the ECM process. Capital projects follow a different process and are not covered in this minor research dissertation.

1.7 RESEARCH METHODOLOGY

Given that the research is investigative in nature with hypothesis formulation, the quantitative, survey-type research approach with self-administered questionnaire has been adopted for the mini research project. The quantitative approach is befitting of the research problem as it is of the statistical paradigm and offers the ability to test the research hypothesis empirically and report the result in a scientific manner.

Also the structured questionnaire surveys are concerned with hypothesis formulation and variables can be observed and reported without manipulation. It further generates quantitative data from which quantitative analysis can be conducted with the aim to combine relevance to the research problem. The structured survey questionnaire will enable coverage of wider research participants and therefore increased sample of the research population. The questionnaire will be administered to ensure confidentiality of all respondents as the results will be analyzed and turn the research findings into quantitative results. Lastly, and importantly, the quantitative research method meets the criteria for selecting the appropriate method for the study proposed.

Furthermore the survey results will be subjected to statistical analysis and tested for statistical significance using the chi-squared method or fisher's exact test in order to conclusively confirm whether the organization's developmental model provides benefit to the organization and whether concurrent engineering would prove more effective and beneficial.

1.8 RESEARCH OVERVIEW

The structure of this paper is as follows: Chapter 2 is the theoretical background to the study of systems engineering and aims to establish the evolution of systems engineering as we understand it today. Chapter 3 is a literature review of concurrent engineering. Literature overview on the measures of project success is covered comprehensively in chapter 4. Chapter 5 presents the SE practices within the organization and a gap analysis exercise is conducted in comparison to the SEMBASE practices. Chapter 6 describes the methodology followed in solving the research problem, followed by statistical data analyses of the research survey results in Chapter 7. The findings are analyzed and discussed in Chapter 8. The paper is then concluded in Chapter 9 followed with reference material in Chapter 10.

1.9 CONCLUSION

This chapter has shown that concurrent engineering has on one end been shown to provide time, cost and quality benefits to organizations as a systems development process for projects. The other end is also equally true that concurrent systems engineering does not provide any time, cost or quality benefits. This suggests that the positive effectiveness of concurrent engineering in terms of development cost, time and quality depends on the particular environment of the organization. The objective of this paper is investigate if such a relationship does indeed exist and make proposition if the concurrent engineering process can add value to the organization’s systems development process in the engineering effort of asset creation.

CHAPTER 2: LITERATURE REVIEW ON SYSTEMS ENGINEERING

2.1 INTRODUCTION

In order to give context to the subject matter of the minor research dissertation, it is necessary to get an understanding of systems engineering. This section of the research provides comprehensive background to the evolution that lead to the systems engineering as we understand it in the modern day.

2.2 EVOLUTION OF SYSTEMS ENGINEERING

2.2.1 Systems Engineering: Pre-NCOSE/INCOSE

Systems engineering has been faced with contrasting and contradictory positions on its nature right from the days of its inception. It is not surprising then that the call for the development of a grand unified theory of systems engineering (GUTSE) dates to very early literature study into the nature of systems engineering by Hill and Warfield in 1972 [12]; who in summary concluded that the development of a broadly accepted theory of systems engineering is much needed. The call was informed by the different interpretation of the definition and description of systems engineering from the early literature studies; one such example is Chapanis in 1960 who, after accepting that it was difficult to find a universally accepted definition of systems engineering, resorted to define the systems engineer as the man who is generally responsible for the over-all planning, design, testing and production of the day's automatic and semi-automatic systems [13]. This was contrasted by Hall in 1962 who defined systems engineering as a function rather than what a group does [71].

In his study into the nature of systems engineering Jenkins [14] in 1969 expanded the concluding comment by Chapanis and defined twelve roles (i.e. the list of activities performed by a person with the title systems engineer) tabulated in table 1 below:

Table 1: The Twelve Activities Performed by System Engineer [14]

	Activity Description
1	He tries to distinguish the wood from the trees – what's it all about?
2	He stimulates discussion about objectives – obtains agreement about objectives.
3	He communicates the finally agreed objectives to all concerned so that their co-operation can be relied upon.
4	He always takes an overall view of the project and sees that techniques are used sensibly.
5	By his overall approach, he ties together the various specializations needed for model building.
6	He decides carefully when an activity stops.
7	He asks for more work to be done in areas, which are sensitive to cost.
8	He challenges the assumptions on which the optimization is based.
9	He sees that the project is planned to a schedule, that priorities are decided, tasks allocated, and above all that the project is finished on time.
10	He takes great pains to explain carefully what the systems project has achieved, and presents a well-argued and well-documented case for implementation.
11	He ensures that the users of the operational system are properly briefed and well trained.
12	He makes a thorough retrospective analysis of systems performance.

Jenkins identified that seven of the roles performed by systems engineer (activities performed by a person with a title systems engineer) overlap the role performed by project manager (activities performed by a person with the title of project manager). As represented in figure 6 below, a study by the Japan Aerospace Exploration Agency (JAXA) showed an overlap of activities between system engineering and project management during the system development process [20].

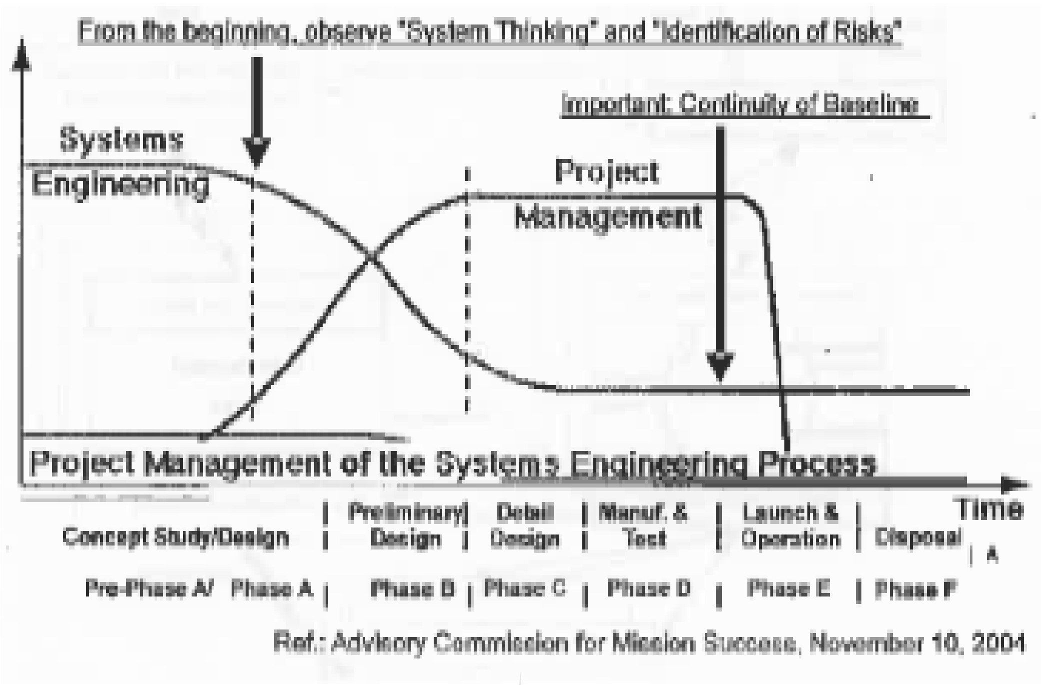


Figure 6: Overlapping Activities of Systems engineering and Project Management [20]

It has further been suggested by Emes [21] and Hari [22] in their contributions into the subject that an overlap of activities exist between systems engineering and other engineering disciplines - including that of the new product development process. Also argued is that activities, including the knowledge requirements for performing those activities, performed by systems engineering personnel in one organization are different to those performed by systems engineers in other organizations. Consequently, defining a body of systems engineering based on the role of systems engineer is very difficult and that a change in approach is required.

2.2.2 SYSTEMS ENGINEERING: POST NCOSE/INCOSE

The heed to the call of GUTSE continued to be met with conflicting and contradictory interpretation of the nature of systems right into the NCOSE/INCOSE (National Council on Systems Engineering and International Council on Systems Engineering) era. When we consider that in the 1994 symposium of the NCOSE in which presenter after presenter had a different definition of the nature of systems [15]; it is clear that systems engineers have had difficulties defining systems engineering and explaining what they do, not only to other people, but also amongst themselves. The experience of the 1994 symposium triggered a research program intended to give an understanding into the nature of systems engineering and its overlap with project management.

The twelve roles of the individual with the title systems engineer by Jenkins in 1969 were further adopted, developed and documented by Sheard [17] in 1996 into the following activities:

Table 2: Activities of Systems engineering [17]

	Activity Description
Requirements Owner (RO) Role.	Requirements Owner and requirements manager, allocator, and maintainer and specifications writer or owner and developer of functional architecture and developer of system and subsystem requirements from customer needs.
System Designer (SD) Role.	System Designer and owner of “system” Product and chief engineer and system architect and developer of design architecture/specialty engineer (some, such as human-computer interface designers) “keepers of the holy vision” (Boehm, 1994).
System Analyst (SA) Role.	System Analyst/performance modeler/keeper of technical budgets system modeler and simulator/risk modeler/specialty engineer (some, such as electromagnetic compatibility analysts).
Validation and Verification (VV) Role.	Validation and Verification engineer/test planner/owner of system test program/system selloff engineer. VV engineers plan and implement the system
Logistics and Operations (LO) Role.	Logistics, Operations, maintenance, and disposal engineer/developer of users’ manuals and operator training materials.
Glue (G) Role.	Owner of “Glue” among subsystems/system integrator/owner of internal interfaces/seeker of issues that fall “in the cracks”/risk identifier/“technical conscience of the program”.
Customer Interface (CI) Role.	Customer Interface/customer advocate/customer surrogate/customer contact.
Technical Manager (TM) Role.	Technical Manager/planner, scheduler, and tracker of technical tasks/ owner of risk management plan/product manager/product engineer.
Information Manager (IM) Role.	Information Manager (including configuration management, data management, and metrics).
Process Engineer (PE)	Process engineer/business process reengineer/business analyst/owner of the systems engineering process.

Role.	
Coordinator (CO) Role.	Coordinator of the disciplines/tiger team head/head of integrated product teams (IPTs)/system issue resolver .
“Classified Ads Systems Engineering” (CA) Role.	This role was added to the first eleven in response to frustration encountered when scanning the classified ads, looking for the INCOSE-type of systems engineering jobs.

The above makes a distinction between a set of activities known as systems engineering and the role of the systems engineer. Sheard’s roles addresses the original systems engineering approach to conceiving and planning the solution system in that it relates to the interpersonal relationships between the individual disciplines implementing the solution system. The focus on the set of activities known as systems engineering is a return to Hall’s definition of systems engineering as a function.

Other research into the nature of systems engineering included a literature review of text-books published between 1959 and 2009 as well as a review of proceedings of the international symposia of the INCOSE since 1991 and determined that there still exist a multichotomy into the nature of systems engineering. Also a study [24] in 2011 had shown that the search for a universally accepted view of the nature of systems engineering had actually evolved into six camps of systems engineering by the early 21st century namely; Life cycle, Process, Problem, Discipline, Systems thinking and non-systems thinking, and the Enabler and that all needed to be reconciled.

According to literature review thus far, the issue with recognizing systems engineering as a discipline is its overlapping nature with management and that of defining the role and activities of systems engineer. The premise of the next subsection of the chapter will be focused on addressing and putting context to these two issues.

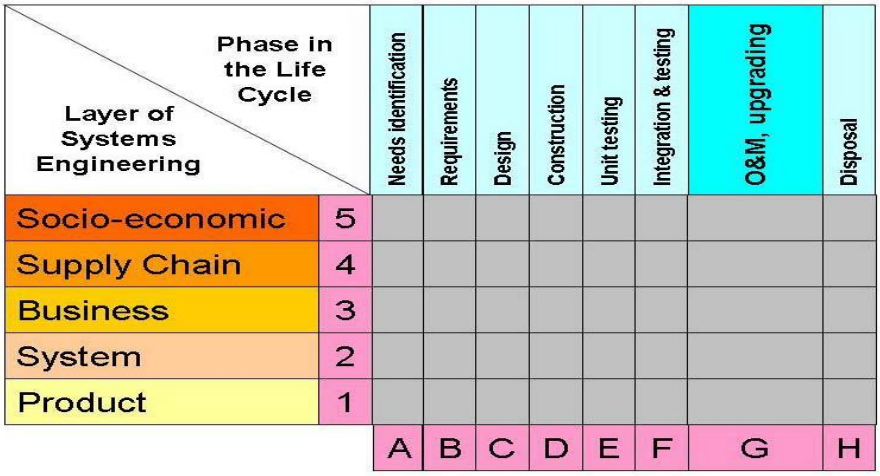
2.3 SYSTEMS ENGINEERING PARADIGM SHIFT

By the beginning of the 21st century the heed to the call for GUTSE still had no answer. The state of affairs of the time represented a discipline under development very much similar to the chemistry discipline before the development of the periodic table, and that of the electrical engineering discipline before of Ohm's Law. The discussion of the literature review has thus far shown that defining a body of knowledge based on the role of systems engineer proved difficult. Hill and Warfield's call for a grand unified theory on systems engineering were again echoed in 2006 by Friedman [25] who also called for the need for the development of grand unified theory on systems engineering.

2.3.1 HKM SYSTEM ENGINEERING FRAMEWORK

The paradigm shift to understanding systems engineering started with Hitchens [26] proposal of a vertical, five-layer nestling framework model to systems engineering. The nestling layers in ascending numerical order are the Product Level, Project or Systems Level, Business Systems Engineering, Industrial Systems Engineering and Socioeconomic. In the same article, Hitchens stated that the nestling is formed as many products make a project, many projects make a business, many businesses make an industry and many industries make a socio-economic system. The paper also acknowledges that the statement is rather only an estimate due to the fact that a socioeconomic system has more than just an industry and that a business is more than just projects; also that the organization can re-organize the work in a number of ways resulting sub-layers [26].

The model was further extended by Kasser and Massie [18] - also referred to as Hitchins-Kasser-Massie (HKM), to include the phases of the project life cycle; though the phases were not actually defined by the authors but were proposed in conference papers and books. Kasser, eventually defined them in 2007 [27], see figure7, as the horizontal dimension of the framework also nested, but in time.



Phase in the Life Cycle / Layer of Systems Engineering		Needs identification	Requirements	Design	Construction	Unit testing	Integration & testing	O&M, upgrading	Disposal
Socio-economic	5								
Supply Chain	4								
Business	3								
System	2								
Product	1								
		A	B	C	D	E	F	G	H

Figure 7: HKM Systems Engineering Framework [18]

Thus then the initial acquisition of a system could be linearly across the system development life cycle starting in the area 2B right through to delivery and operations and maintenance. But importantly, the activities that take place in 2G, are very much the same as those taking place in requirements analysis (2B), design (2C), construction (2D), testing (2E) and integration (2F) of the configurations of the various systems upgrade. The framework gives a 2-dimensional matrix of 40 areas of activities. This means that a systems engineer performing design would be working in area 2C, while another systems engineer performing test and integration on the same or even different system would be in area 2F. This explains that systems engineering can be performed throughout the systems development life cycle model.

The Hitchins-Kasser-Massie Framework (HKMF) model provides a map for locating the phases within the project life cycle for which the services of systems engineering are performed or employed. The model was further extended to include a 3rd dimension by defining four levels of technological uncertainty (risk) namely low risk, medium risk, high risk and super-high risk. Therefore, though the employment of systems engineering maybe called upon in different areas of the HKM framework, the nature of the problems confronted by systems engineer in one area would be different to those in the next area. This as the challenges will depend on the level of technological uncertainty of a specific system. This is further supported by Shenhar and Bonen [73] who observed that adopting the wrong system and management style can bring about many and varied difficulties during the process of system creation.

As a result, the HKM model framework has shown the reason that systems engineers have not been able to agree on roles and activities that make-up systems engineering in that systems engineers work in different systems engineering layers and in different phases of each layer.

Figure 6 of JAXA can be extended to show the relationship between the activities known as systems engineering, project management and engineering during the systems development process.

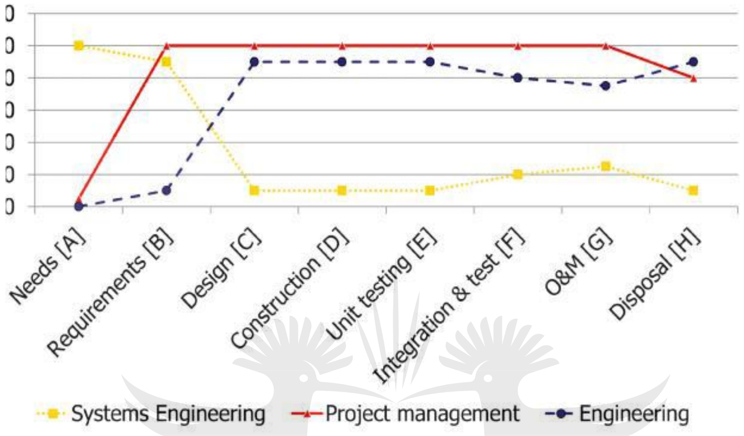


Figure 8: Overlapping activities of systems engineering, project management and engineering during SDP [20]

From figure 8 above, it can be seen that the phases in providing a whole complete solution to a problem can be considered as a set of activities performed by various people in various discipline and at various times. Each person's role will be different because the mixture of activities depends on the organizational situation and is different. Also, some of the activities are systems engineering and some are not systems engineering.

The above framework therefore answers the question for the seemingly overlapping functions of systems engineering and project management, the next subsection of the chapter will be concerned with the set of activities known as system engineering i.e. will be concerned with the activity-based approach as opposed to the role-based approach to systems engineering.

2.3.2 SYSTEMS ENGINEERING ACTIVITY APPROACH

It was previously mentioned that there is a need for a paradigm shift to the approach in understanding the nature of systems engineering. As part of the heed for the call for defining a body of knowledge for systems engineering is the paradigm change proposed by Kasser and Palmer [28]. As elaborated below, the paradigm shift is by making a distinction between the set of activities known as systems engineering and the role of the systems engineer. In addition to the HKMF, distinctions between two systems engineering school of thoughts are made as part of the shift in paradigms:

- Systems engineering – the role (SETR) being what systems engineers do in the workplace.
- Systems engineering – the activity (SETA) that can be performed by anyone.

Thus then SETA is the set of activities known as systems engineering and SETR is the role of the systems engineer. A further criterion is used to determine whether or not the activity belongs within the systems engineering activity SETA through the following distinction:

- If the activity deals with parts and their interaction as a whole, then it is an activity within the set of activities known as SETA.
- If the activity deals with a part in isolation, then the activity is not an activity within the activities to be known as SETA but is part of another set of activities i.e. software engineering etc.

Thus then SETA (the activity paradigm) is an alternative system’s engineering to SETR (the role paradigm) and is a return to Hall’s [29] definition of systems engineering “as a function rather then what a group does”. It is then necessary to identify the activities performed in each of the system lifecycle using the activity-based criterion.

As determined by Hitchins in 2007, systems engineering began as SETA and evolved into SETR with SETR being performed in all columns of the HKMF model, and SETA is primarily performed in columns A and B; which are activities in figuring out the problem and determining and specifying the optimal solution. Activities performed in C, D and E are non-SETA activities performed by engineers, designers and commissioning personnel, however SETA still occurs.

SETA occurs again during systems testing and commissioning phases of the systems development life cycle. Systems engineering is thus the activity-based (SETA) approach to the system development life cycle and consists of the Systems Engineering Domain and the Component Engineering Domain.

SETA activities within the activity-based approach to systems engineering produces no tangible items but instead produce things such as documents (specification, reports, plans etc.) during the system development life cycle model. The non-SETA activities i.e. SETR including engineering produces the actual system solution.

When we consider that Mathematics is an enabling discipline providing the set of tools and techniques for attending to problems, systems engineering provides the tools and techniques which is the set of activities that deal with parts of a system and their interactions as a whole and are used to identify the underlying problems and realize the optimal solutions during the systems development process.

2.4 SYSTESMS ENGINEERING BODY OF KNOWLEDGE (SEBOK)

The most recent responds to the call for the development of systems engineering body of knowledge is the broadly accepted Systems Engineering Body of knowledge (SEBoK) which informs the systems engineering practice and is intended for many and varied users including practicing systems engineers, engineering managers, project managers, curriculum developers and engineers from other disciplines.

SEBoK is the product of a three-year effort starting in 2009 by the Body of Knowledge and Curriculum to Advance Systems Engineering (BKCASE^{TM}) project made up of 70 authors from different companies around the world [30]. The project was funded primarily by the U.S. Department of Defense and led by the university partnership between the Stevens Institute of Technology and the U.S. Naval postgraduate School (NPS). The partnership and project was further with the support professional societies, especially the International Council on Systems Engineering (INCOSE) and the Institute of Electronics Engineers (IEEE) and other universities.

There are areas where the body of knowledge fell short in meeting the needs of the practicing community and these were identified in the very early versions 0.25, 0.5 and 0.75 of the SEBoK by the systems engineering community and included authors of the SEBoK and reviewers [31,32]. The official version 1.0 was released in September 2012 and incorporated the feedback from the authors and reviewers of the earlier version.

On the scope of systems engineering, SEBoK is clear that systems engineering scope does not encompass the entire engineering systems domain. The relationship between systems engineering, system implementation, and project/systems management is depicted in the Venn diagram in figure 9. From the diagram it is clear that activities that include analyzing alternative production methods, testing, and operations, are part of systems engineering planning and analysis functions. Whereas, while activities such as production line equipment ordering and installation are still important systems engineering environment, they are considered outside the scope boundary of systems engineering.

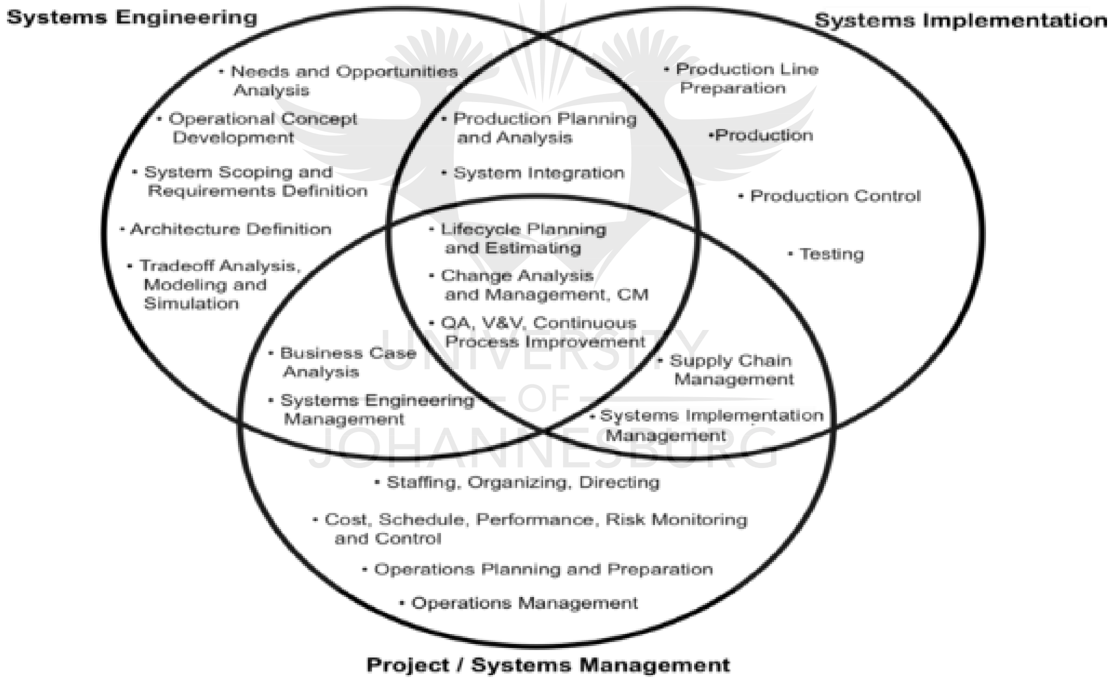


Figure 9: Venn Diagram for Scope of System Engineering [30]

2.5 SYSTEMS ENGINEERING MANAGEMENT BASE THEORY MODEL (SEMBASE)

In consolidating the literature review it is clear that systems engineering is concerned with the engineering of systems and the management of the process. Therefore the subject of systems engineering spans two fields - the field of design engineering and management sciences [74]. Thus the scope of systems engineering consist of the Systems Engineering Process (SEP) and Systems Engineering Management (SEM).

2.5.1 SYSTEMS ENGINEERING PROCESS

Schmidt [75] described SEP as a generic systems problem solving process applied sequentially top-down one level at a time - with additional detail and definition with each level of development. Its purpose is to fundamentally provide a structured but flexible process that transforms requirements into specifications, architectures, and configuration baselines [76]. There are a number of SEP that have been established in literature and the primary SEP's have been covered in system engineering standards; the primary being ISO/IEC 26702/IEEE Std 1220, EIA Std 632 and ISO/IEC 15288/IEEE Std 152888. The fundamental systems engineering process include requirements analysis, functional analysis, synthesis and systems analysis and control. There are also the requirements, design and validation loops; this is depicted in figure 10 below.

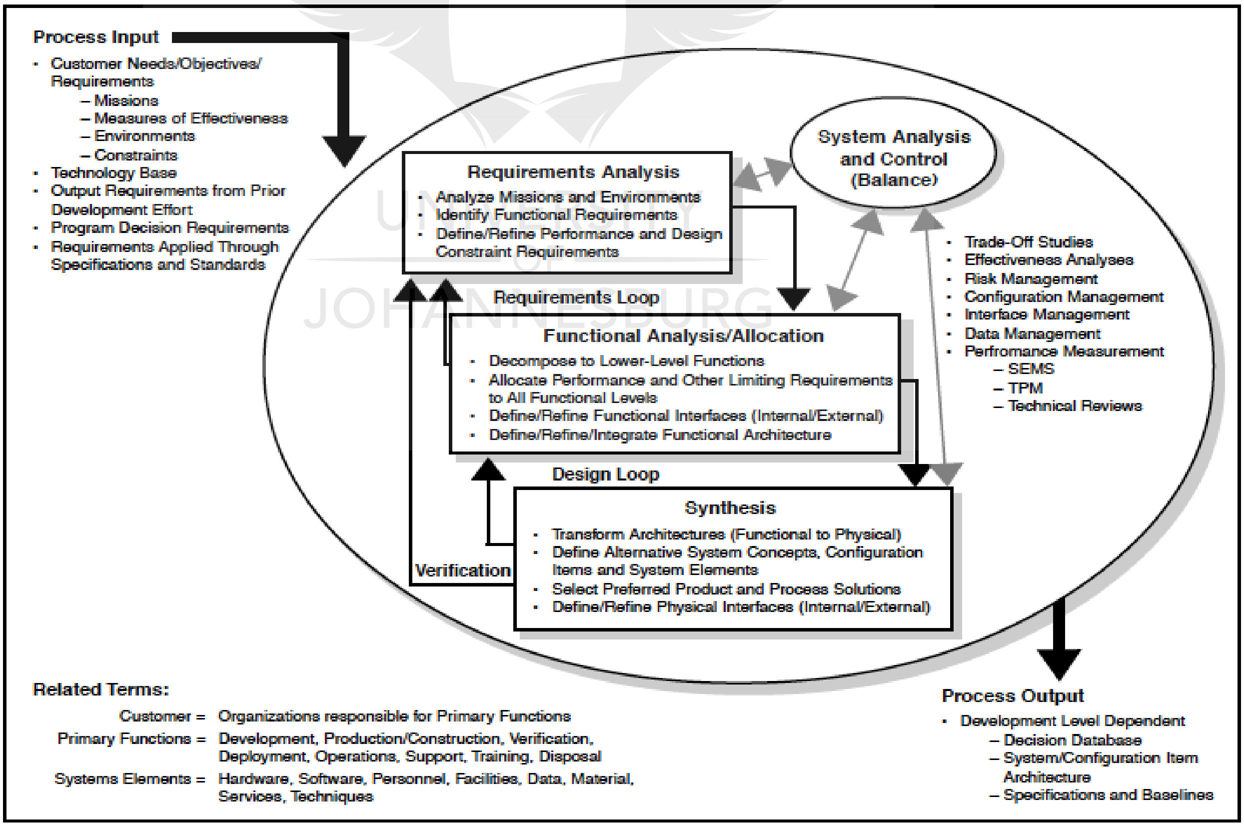


Figure 10: Depicting the Systems Engineering Process [76]

2.5.2 SYSTEMS ENGINEERING MANAGEMENT

Sage [77] stated that a successful system generally results from a successful SEP and that an appropriate SEP is generally the result of a successful SEM. Thus, in order to successfully implement the Systems Engineering Process, an effective and efficient support mechanism in the form of SEM must be in place to facilitate the process. Three major activities necessary to achieve proper management of a development effort are performed in systems engineering management [76] and [78]:

1. Development phasing: controls the system design process and defines baselines for coordinating the subsystems, disciplines and specialties design efforts.
2. Systems engineering process: defines a structure for solving design problems as well as tracking the flow of requirements through the design effort.
3. Life cycle integration: involves customers and direct stakeholders in the design process and ensures viability of the developed system for a sustainable life cycle.

There are two major functional roles to the phasing development activity; it controls the design effort through developing design baselines that govern each level of development. It interfaces with the project or acquisition management by providing key events of the design process. As already explained the engineering process provides a structured but flexible process that transforms requirements into specifications, architectures and configuration baselines. Life cycle integration is the concurrent consideration of all life cycle functional needs into the design and engineering process thereby ensuring that the design solution is viable throughout the life cycle of the system [76].

The above systems engineering management description, and other current material [79], [80], [81] and [82] are restricted to the primary objects used and produced in the various activities including among other baselines, plans, schedules, integrated teams, etc.; but the main actors of the process, i.e. the stakeholders, specialty engineers and discipline experts, etc. and the underlying structures are not addressed explicitly. Therefore the interaction rather than the intersection between the three SEM activities, including the actors and their relationships must be into account.

2.5.3 SYSTEMS ENGINEERING MANAGEMENT BASE THEORY MODEL

The Systems Engineering Management Base Theory (SEMBASE) model shown in figure 11 is an elaborated depiction of systems engineering management and views the interaction between life cycle integration and the SEP as an integrated model.

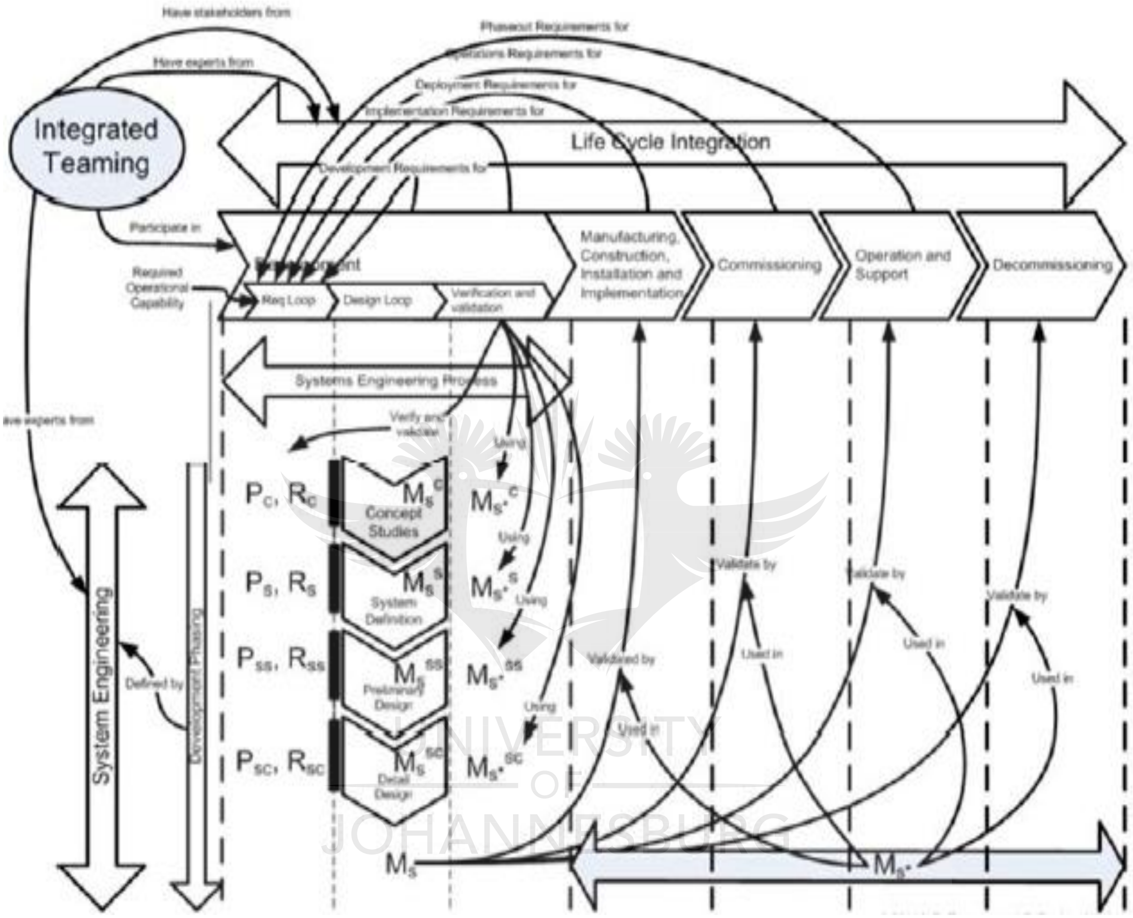


Figure 11: SEMBASE Model [78]

The model is based on the description of system engineering management by [76], [79], [80], [81]] and from the experience of [78]. It is a further development of a depiction of the systems hierarchy level and the system engineering process by de Waal [83] with the following difference; what de Waal has called systems engineering process, is named system engineering and is further simplified as requirements and design loops.

2.6 CONCLUSION

This chapter provided a comprehensive review of systems engineering and covered literature between 1962 and 2013 on the subject. The chapter has t shown that systems engineering has been dealt with conflicting and contradictory opinions on its nature dating right from early literature; which resulted in the call for a grand unified theory of systems engineering (GUTSE) in 1972. The responds to this challenge saw the evolution of systems engineering through the formation of the National Council on Systems Engineering (NCOSE), International Council on Systems Engineering (INCOSE) and the respective symposia which informed six different camps on the perspective of systems engineering.

The solution to the problem is to reconcile the different camps by distinguishing between two systems engineering paradigms; systems engineering the role (SETR), which is concerned with what systems engineers do, and systems engineering the activity (SETA), which is the set of activity during the systems development process. Systems engineering is thus the set of activities that concern the integration within the system development process.

CHAPTER 3: LITERATURE REVIEW ON CONCURENT ENGINEERING

3.1 INTRODUCTION

A common method used to reduce overall project delivery time is to overlap sequential activities. Also in chapter 1 of this minor research dissertation it is shown that concurrent engineering does not always produce positive results and that the success somewhat depends on the technological advances within the organization. This chapter provides the literature review of concurrent engineering and provides the theoretical framework. Also the objective is finding insight into the contrary nature of concurrent engineering described in chapter 1 of this minor research dissertation.

3.2 EMPIRICAL CONTRADICTINS TO CONCURENT ENGINEERING

By the beginning of the 21st century concurrent engineering or integrated product development had been positioned as the norm for developing and introducing new products to the market place by Ainscough and Yazdani [45]. Moreover, in the same year, Tennant and Roberts [46] had concluded concurrent engineering as a tool for enhancing an organization's competitive advantage. As demonstrated by a number of studies from 1991 [47] right through to 2004 [48], the organizational benefits include shorter product developmental times, lower cost, greater product quality and major knowledge creation.

However, while the organizational benefits are clear and understood, there are studies that are of the position that concurrent engineering development time is less efficient with respect to resources, resulting in large incremental cost than sequential methods of product development [49]. What has also been shown is that the degree to which organizations have implemented concurrent engineering and the amount of success achieved has been shown to vary [50]. In fact, a recent survey [45] demonstrated that the implementation of concurrent engineering proved highly successful with certain sectors (i.e. petro-chemical and power generation), while relatively low with other sector (i.e. automobile and machinery). This was supported by an earlier study [51], and the reasons were poor management of the change process as oppose to the lack of keenness to manage change. Another study [52] went as far as making the general statement ‘70% of all companies who embark upon a business process re-engineering program will fail’.

The above suggest then that in spite of the many research efforts, the study into the matter of the success of concurrent engineering had been plagued with empirical contradictions with no consensus. Though the studies proved fruitless, it paved the way to what would ultimately be the position on the success of concurrent engineering.

It started with Yassine [49] who concluded that concurrent engineering is a clear option but should only be used when reducing development time is of higher priority than cost. In the same study it was proposed that partial overlapping which is likely to result in reduced developmental time, although to lesser extent, but with smaller increase in development cost. A more recent paper [53] provided a clearer perspective to concurrent engineering by showing and concluded that the use of concurrent engineering does not always lead to positive results and that the success depends on the context in which concurrent engineering is applied; that is, on the prevailing competitiveness and technological circumstances surrounding the organization. Thus then the matter to be considered is therefore not whether concurrent engineering is a mechanism for improving the introduction of new products but, rather, under what circumstances such improvement can be achieved [53].

3.3 THEORETICAL FRAMEWORK TO CONCURRENT ENGINEERING

3.3.1 DEFINITION OF CONCURRENT ENGINEERING

The widest accepted definition of Concurrent Engineering (CE) is one given by the American Institute for Defense Analysis (AIDA) and later supported by Carter and Baker as “a systematic approach to the integrated, concurrent design of products and related processes, including manufacturing and support” [54]. The approach is about the organizations ability to carry out the design and development process as a series of overlapping activities. It is understood as an integrated problem solving process where all activities necessary for the introduction of a new product are considered simultaneously in order that all factors and questions “downstream” of product development process are incorporated into the “upstream” phase of the systems development process.

3.3.2 SEQUENTIAL SYSTEMS ENGINEERING

The sequential approach for system or product development process follows a structured process with defined series of phases through which the future product is defined, designed, transferred to the manufacturing plant and rolled out to the market. Each of the phases and associated activities starts only once the predecessor has been completely finished which results in a total lack of integration and co-ordination between different functional areas and other contributors involved in the process.

Each function within the phase carries out work in isolation with very little or no reference to the needs of subsequent phases. This then translates into continuous retracing of steps in each of the different phases of the project to correct the mistakes made; thereby resulting in very long development times and additional costs for the design process. Also many other quality problems arise as a result of the lack of communication and understanding between product design, production and consumer needs. The process is understood to decrease companies’ competitiveness and as a result have resorted to processes for developing new product, which, unlike the sequential approach, is based on an integrated approach to product development in which everyone involved works in parallel and proper links are established amongst the activities of the different departments.

3.3.3 CONCURRENT ENGINEERING

In order to achieve the desired time saving goals, concurrent engineering advocates for overlapped work activities instead of the series of activities in the sequential product development process [55]; a typical project schedule between concurrent and sequential approach is presented in figure 12. The overlapping should however be done in a systematic manner in order to reduce the cost and risks as the extent to which activities can be overlapped depends on their relationship [49].

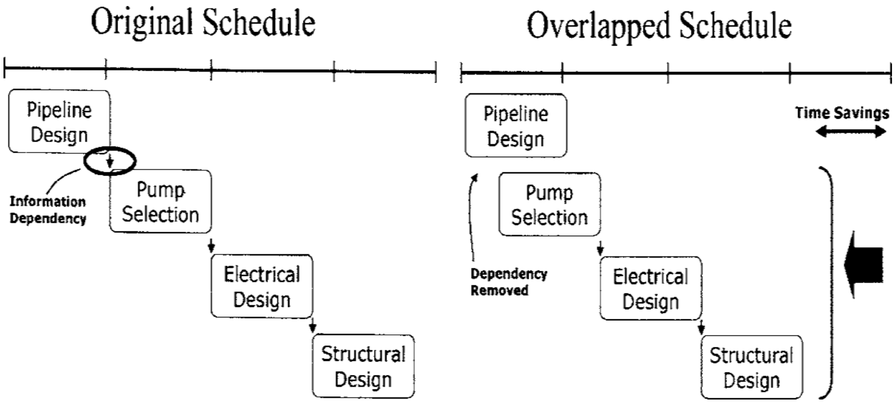


Figure 12: Showing typical project scheduling for sequential and concurrent approach [55]

Prasad [55] defines and describes four types of overlapping relationships: dependent activities, semi-independent activities, independent activities and interdependent activities as shown in figure 13 below.

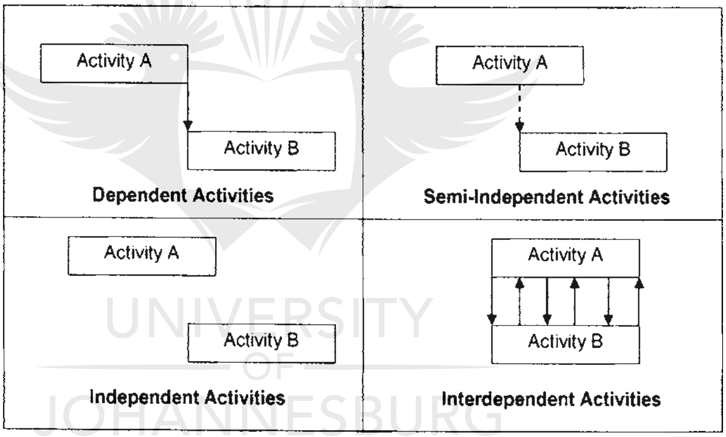


Figure 13: Showing the four relationships for overlapping [56]

The condition for dependent activities is when one activity requires information from a second activity before the first activity can be started. Semi-independent activities are characterized by one activity requiring only partial information from other activities before it can begin. Independent activities on the other hand require no information from one activity before either of the other activities can begin. Interdependent activities require a two-way information exchange between the activities before both can be completed and as a result must be conducted in parallel.

There is thus a level of risk to the four overlapping relationships with the dependent activities carrying the highest risk when they are overlapped. As a result then, overlapping of activities should be done in a systematic manner that allows for increased information exchange if it is to produce positive results.

Concurrent engineering literature [56, 57] describes this information exchange between an upstream task and a downstream task in terms of the natural rate of information evolution in each task and the sensitivity of the downstream task to changes in upstream information. In simple terms, the development of information and knowledge in a design task can evolve quickly or slowly.

An example of the concept of design task evolution is the selection of a pump for a pump station depicted in figure 14. Initially, several pump types, with a range of manufacturers and models, may be under consideration by the engineer. In a sequential operation, the electrical engineer waits for the process engineer to conclude on the capacity requirements of the pump. Further the structural engineer waits for the electrical engineer to select the final pump i and then uses the final pump dimensions and weight to design the pad for the pump.

When tasks are overlapped, however, the electrical and structural engineer may design the pump and pad based on a range of possible pumps respectively. As the capacity requirements by the process engineer evolves, the final pump selection also evolves so that the information provided to the electrical and structural engineer may change, which could require additional work on the part of the electrical and structural engineer. The amount of additional work required is a measure of the sensitivity of the downstream task to changes in upstream information and evolution rate at which the upstream work activity develops to completion.

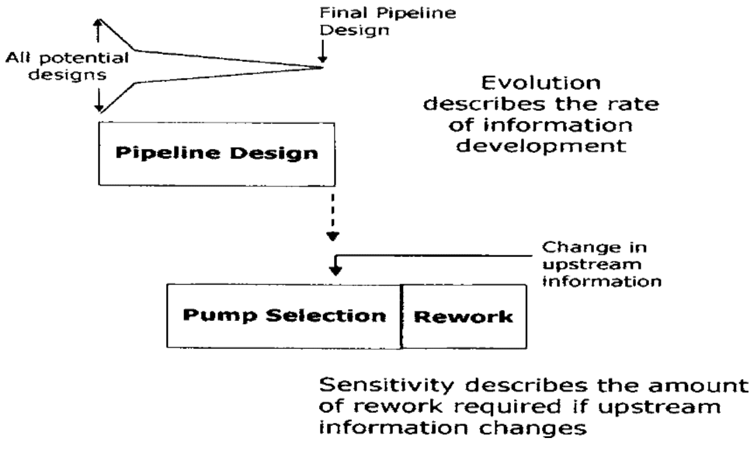


Figure 14: Illustrating Sensitivity and Evolution Characteristic of Design Activities [57]

Therefore overlapping depends not only on the dependency of activities but also on information exchange between upstream and downstream activities as well as evolution progress. Krishnan's [57] model-based framework to manage the overlapping of coupled activities by introducing the concept of information evolution (i.e. useful information generated by upstream for the downstream activity) and downstream sensitivity to describe their interaction. Thus depending on the nature of information evolution and sensitivity, overlapping should take one of the four forms presented in figure15 below.

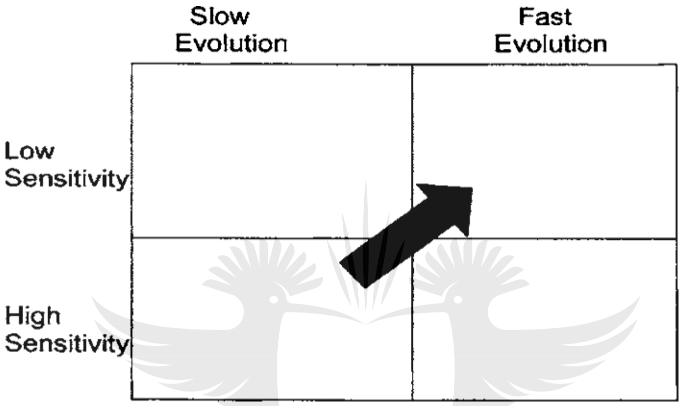


Figure 15: The four information exchange characteristics of evolution and sensitivity [57]

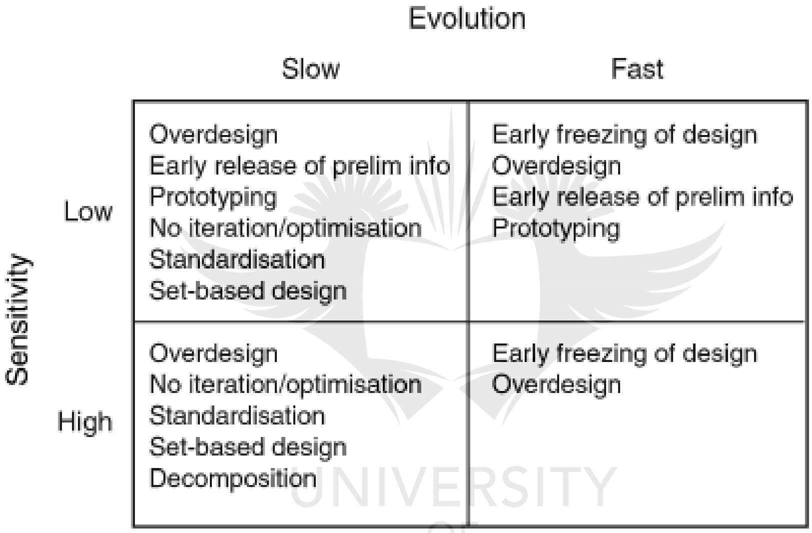
With the above background, Krishnan [58] defined the appropriated overlapping strategies as iterative, preemptive, distributive and divisive.

The distributive strategy represents best situation for overlapping and is when the evolution is fast and sensitivity is low. In this situation there is both exchange of preliminary design information and early finalization of the upstream design information and sensitivity of downstream tasks

If there is slow evolution and low sensitivity then overlapping through the exchange of preliminary design information is recommended referred to as iterative overlapping.

Highly sensitive activities with fast evolution are best overlapped by early finalization of upstream information referred to as preemptive overlapping. Highly sensitive activities with slow evolution are the least likely to benefit from overlapping and should be decomposed to sub activities, if possible referred to as divisive overlapping.

Bogus [59] further developed Krishnan's management of overlapped activities for the design environment. Bogus, in the context of design, identified that by removing or reducing information dependencies between activities that lead to the highly sequential nature of design schedule that the opportunity for overlapping activities increases. The same paper then identified strategies for speeding up the evolution of upstream activity so that downstream activities can begin, as well as those for reducing the sensitivity of downstream activities to changes in upstream information as shown in figure 16 below.



	Evolution	
Sensitivity	Slow	Fast
Low	Overdesign Early release of prelim info Prototyping No iteration/optimisation Standardisation Set-based design	Early freezing of design Overdesign Early release of prelim info Prototyping
High	Overdesign No iteration/optimisation Standardisation Set-based design Decomposition	Early freezing of design Overdesign

Figure 16: Basic Overlapping Strategies Framework for Design Environment [58]

There are more strategies for slow evolving activities than there are for fast evolving activities. This makes logic since slow evolving activities use the least potential of being overlapped. Bogus' framework was further improved by Lin [59] by incorporating the downstream progress evolution and so determined the optimal overlap amount. In their investigation, they found that the downstream progress increase overtime when the upstream evolution is fast or linear and that it is indefinite when the upstream evolution is slow.

3.4 CIRCUMSTANCES FOR CONCURRENT ENGINEERING

It is clear that concurrent engineering is not be considered as reliable methodology for all situations and that the right scenario should be determined before recommending and embarking on the method. A study in 2009 [60] seek to understand and clarify the organizational circumstances for which concurrent engineering development approach would most likely prove effective by considering and concluding on the following hypothesis:

Hypothesis1. The positive effect of CE on NPD time reduction depends on the type of innovation (incremental versus radical) carried out.

Hypothesis2. The positive effect of CE on NPD cost reduction depends on the type of innovation (incremental versus radical) carried out.

Hypothesis3. The positive effect of CE on new product superiority depends on the type of innovation (incremental versus radical) carried out.

In the first hypothesis the study concluded that first proposed hypothesis can be supported, that is to say that the concurrent engineering positive impact on development time reduction depends on the type of innovation being carried out within the organization. The paper further elaborates that concurrent engineering reduction in development time is true for organizations with moderate to low levels of uncertainty and complexity; and that the converse is true for organizations with very radical environment.

On the second hypothesis the study observed and concluded that proposed hypothesis is supported for organizations with high uncertainty. Thus the concurrent engineering positive impact of reduction in design and development cost depends on the type of organizational environment with respect to uncertainty and level of innovation.

Also on the third hypothesis, the results from the research study showed that the positive impact of concurrent engineering for obtaining superior quality depends on the type of innovation being carried out by the organization. The results showed significant impact for obtaining superior design and development quality but for organization with incremental innovation, and showed no link for organizations of involved in radical innovation. Therefore as was the case for the first hypothesis, concurrent engineering leads to superior quality for organization with low to no uncertainty.

3.5 ANALYSIS OF CONCURRENT ENGINEERING RESEARCH

Concurrent engineering has seen radically drastic decline in interest since the beginning of the 21st century. This observation is shown in figure 17 below which documents the number of journal articles from 2000 [88]. As identified with the referenced literature in this chapter, journal articles on concurrent engineering started appearing in the late 1980's right through to the 21st century where it gained significant interest.

By the 21st century literature on the subject of concurrent engineering revolved around the evolution and sensitivity model. From the analysis deduced from the review it is observed that concurrent engineering implementation related journal articles surveyed are about 47.5%; and journal articles surveyed on concurrent engineering uses and or values formed about 21.3% and finally concurrent engineering extension and perspective and related journal articles formed 31.3% of the journal articles surveyed.

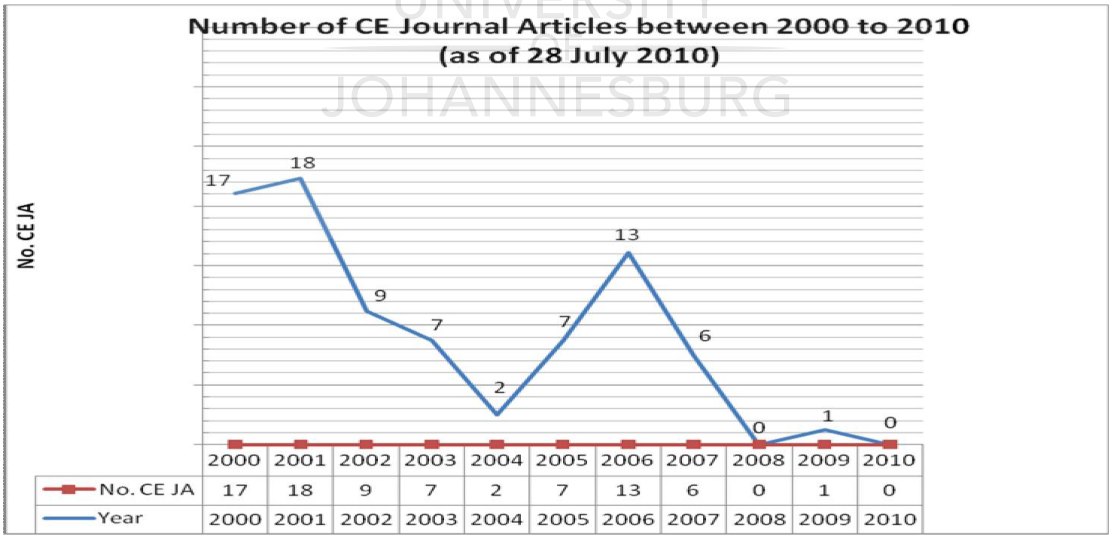


Figure 17: Depicting Number of CE Journal Articles between 2000 to 2010 [88]

Therefore there has not been significant research into the subject of concurrent engineering and the findings from [60] will form the culmination of research into the subject and also the basis of this research paper.

3.6 CONCLUSION

The Chapter established that the sequential design process is considered inefficient since it leads to greater development time, greater cost and poor overall design quality and that many organizations have employed the concurrent engineering design to improve their competitiveness. The chapter also showed how concurrent engineering design does not always lead to positive results. In an effort to understand the phenomena, the system design process is understood as being made out of design activities with four interrelations among the activities; dependent, independent, semi-independent and interdependent. The degree of dependency between two activities informs the amount of information exchange between the two activities. There is thus a degree of risk to performing concurrent engineering for dependent activities. This is further described by the rate of evolution of design information of upstream activity to the sensitivity rate of downstream activity.

The above theory has allowed for hypothesis formulation to concurrent engineering and concluded that concurrent engineering produces organizational benefits in terms of time and quality for incremental innovation. And that concurrent engineering produces positive organizational impact with respect to cost for organizations with radical innovation. Therefore the positive impact of concurrent engineering depends on the type level of technological advancement.

CHAPTER 4: PROJECT SUCCESS MEASURES

4.1 INTRODUCTION

Though Project Management is not the primary subject of this minor research dissertation, it was shown in chapter one that concurrent engineering is advocated on the basis that it provides benefits to projects with respect to time, cost and quality. These are the Project Management Triangles and as a result it is necessary to cover the subject on project success, which is a topic within Project Management. Thus then this chapter of the research paper is concerned with gaining an understanding of project success so that concurrent engineering can be evaluated in the correct context.

4.2 PROJECT AND SIGNIFICANCE OF PROJECT PLANNING

According to the PMBOK® Guide [33] a project is defined as a temporary endeavor undertaken to create a unique product or service. A project can thus be seen as a special task that has never been done before. It then becomes impossible to know exactly of all activities (including their duration as well as cost factors) necessary for project completion; and as a result, it is easy to conclude of project planning as an unnecessary activity having no helpful contribution to successful project execution. A number of authors have written on the subject of project planning with different proposals.

Andersen [34] has the view that traditional methods be replaced with the milestone approach. Where milestone describes what needs to be done and not the way it should be done. Milestone approach therefore encourages result-oriented thinking over the activity-oriented thinking associated with traditional methods. Bart [35] on the other hand finds traditional methods as detrimental to project success. To him traditional approaches are far too formal and kill creativity and flexibility – which play a crucial role in successful execution of projects. Bart proposes that the formal control be reduced and kept at a minimum.

However, research studies have found that 55% of problems in projects take place during specification and requirement analysis stage and that 43% will be found only once the testing stage has been completed [36,37]. Furthermore, Dvir [38] in his recent study of project development found that project initiation phase (this is where major decisions are made including projects objective and execution planning) has the most influence on project success. Work by [39,40] also determined the initiation phase to stand out significantly to project success relative to other stages of project life cycle.

There is thus no dispute of the significant contribution the project planning activity has towards project successful execution – especially the initial phase of complete and accurate capturing of end-user requirements. There is thus a need to distinguish three levels of planning; customer level, technical level and project management level.

4.3 PROJECT MEASURES OF SUCCESS

A common view of project success is that of completion of some predetermined goal on time, within the budget cost and with a given level of quality [41]. This view is however considered partial as there are a number of other projects which were executed within the above mentioned constraints but deemed complete failures as they failed to be of benefits to the customer or organization. There are further other projects (example, the one million square meter shopping complex in Kuala Lumpur by Malaysian-Japanese Consortium), which was a contractual failure as it was completed with a 4-month extension period, and R 46M over budget [42]. The overall perception of the same project by users and other stakeholders was a complete success as it proved very popular with both tenants and shoppers.

Furthermore a great number of projects have been found to have been executed as planned (i.e. on budget, on time and with a given level of quality) but considered complete failures on basis that they produced no benefits to the organization [42]. The three measures alone are realized as partial in defining a project as a success or failure. As pointed out by Freeman and Beale [43], project success has a different meaning from one person to another. It is biased towards an individual’s own subjective judgment. Hence the need for a holistic criterion for defining project success that takes into accounts the different views and interest of all stakeholders.

With a substantial amount of work into the subject matter, Montel and Pantel have concluded on three measures of defining project success: customer satisfaction with delivered project, value of the project and lastly, implementation process.

Also from the 13 measures of success that have been adopted from past research work, Shenhar [44] showed these could be grouped into four dimensions: measuring design goals benefits to customer, commercial success and the future potential of the project. L'povetsky et al further ranked these in order of their importance and found meeting design goals and benefit to customer as the most important to all stakeholders.

4.4 FINDINGS AND OBSERVATIONS

4.4.1 PROJECT PLANNING

The amount of effort invested in the planning phase of the project was considered along the three dimensions taken from previous research work of Shenhar [44]. A principal component analysis on each set of items was carried out to determine its internal consistency. Furthermore a single factor was found to account for most sample variance, and as such the use of the average score for subsequent correlation analysis is justified.

For the development of functional requirements there were 93 participants with full responds to listed items with a variance of 51%. Development of technical specification saw 76 participants with a variance of 61%. Lastly for the implementation of project management processes and procedures saw 49 observes with 60% variance.

4.4.2 PROJECT SUCCESS MEASURES

Project success measurement criteria as applied and validated from previous research by Shenhar [44] are: Meeting planning goals, end-user benefits and contractor benefits.

For meeting project planned goals there were 81 participants with valid responses for given items with a variance of 61%. As a consequence for correlation analysis the average of the response to the 5 items is used. End-user benefits saw 60 participants with a variance of 66%, again, the average responses was used. Lastly for the contractor benefits, 87 participants took part will valid responses to all the nine items and produced a 50% variance. Again, for correlation purposes the average responses to the nine items was used.

4.5 DISCUSSION

The objective here is to find and interpret any correlative relationship between the three measures of project planning as well as those for the three measures of project success. Without much effort in being statistically correct, there are a number of interesting outcomes coming from the results in the table.

It is not surprising to find a high correlative relationship between the quality in developing functional specification and the definition of technical specification; since one establishes the other. There is however no correlative relationship between the quality of functional and technical specification and the implementation of the project planning processes and procedures. This is understandable since the two are not mutually exclusive. There is also no correlative relationship between the three dimensions for project success and the implementation of project planning procedures and processes.

There is a significantly high correlative relationship between end-user benefits and the quality of capturing and developing of functional and technical specifications. On the other hand, there exist a not so significant positive correlative relationship between the two planning variables and meeting planning goals and achieving contractor benefits.

As a final note; is the significant inter-correlated relationship of the three measures of success. This has the implications that projects to be perceived as successful to all stakeholders must be successful in these three measures – otherwise it is defined as partially successful.

4.6 CONCLUSION

The premise of this section of the research paper was to identify the main project stakeholders and to define factors that would completely define project success. The aims were to find a relationship between project planning and project success. Considering the literature study and results of our data analysis the following conclusions are made:

The constraints of managing and delivering a project within specified time, cost and scope constraints should not be seen as project success factors but rather be seen as a project controls tool for ensuring that the three levels of project planning are realized. Project success factors should take into account the biased opinion of main stakeholders involved in a project. The project manager, contractor and end-user are the main project stakeholders and meeting planned goals, meeting end-user benefits and contractor benefits are factors for defining a project as a success or failure. Furthermore requirements definition is significantly correlated to customer benefits and as such, a great deal of effort should be given in defining the requirements definition.

CHAPTER 5: THE ORGANIZATIONS SYSTEMS ENGINEERING PROCESS

5.1 INTRODUCTION

The primary objective of the paper is to document whether concurrent engineering can be adopted within the organizations for the Engineering Change Management (ECM) process. Before we can proceed with proposing any systems engineering model for the organization, it is imperative that the paper documents what is currently employed and identify any gaps making use of literature and so address the objective of the paper. This chapter presents the systems engineering process employed within the organization for the engineering activities carried out during asset modification in accordance with the internal engineering change management procedure.

5.2 CORPORATE GOVERNANCE STRUCTURE

5.2.1 THE EXECUTIVE MANAGEMENT COMMITTEE

The organization has brought together its operational functional elements into a structure and has clarified the main mandate and role of each entity. As a result, the executive management then consists of Line functions, Service functions and Strategic functions as depicted in figure 18 below. The Line functions are primarily responsible for operations of the business and creating value, while the Service function services the operations by providing expertise services on day-to-day basis to ensure safeguard of the organizations assets, and the strategic functions to develop the enterprise.

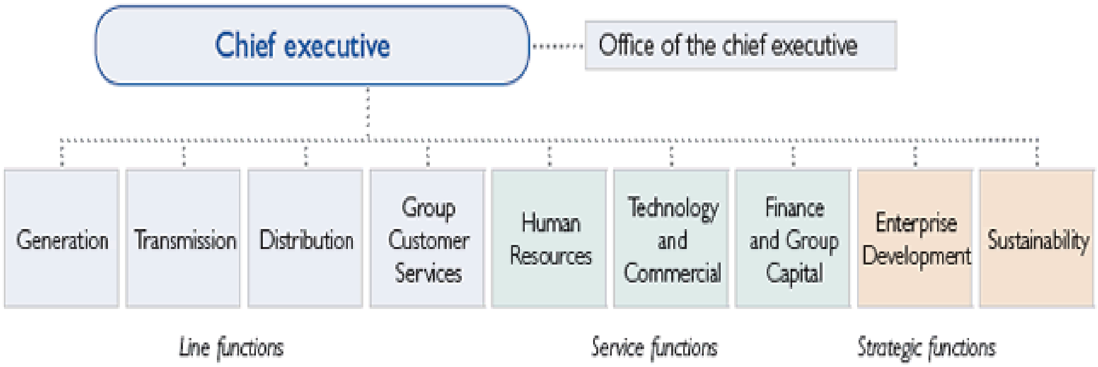


Figure 18: Organization's Executive Structure [1]

5.2.2 TECHNOLOGY AND COMMERCIAL

The Group Technology and Commercial division is newly established as part of the newly established executive management structure of 2012. The division's core responsibilities are the oversight, monitoring, and execution of the engineering and procurement activities within the organization.

The technology division has been specifically mandated with the optimum performance of plant assets, and to infuse the organizations capacity expansion program with excellence in design and project engineering. As a result, the division has been entrusted with helping restore the organizations engineering capability to a high standard with respect to design, operating and maintenance and project engineering service.

5.3 BACK2BASICS PROGRAMME & ORGANIZATIONS HIGH PERFOMANCE UTILITY MODEL.

The Back2Basics (B2B) programme was established in 2010 to improve overall performance across the organization by simplifying and optimizing processes and systems. The programme included services tools, project tools, engineering tools, and operations, maintenance and outage management initiatives. In the process the organization also introduced the Integrated High Performance Utility Model (HPUM) for the identification of core capabilities and processes that spans across the entire value chain, including the service and strategic functions.

Following the successful implementation of Back2Basics programme in the Service

Tool streams (i.e. release 1), which is a standardized SAP application system in 2011, the Back2Basics programme was extended to other business units including Group Technology. The programme continued to develop standardized and optimized processes, focusing on the project and engineering tools in the form of Process Control Manuals in 2012.

A key part of this new way of working was to create new, standardized processes and procedures for all divisions within the Engineering Business. The project created a completely new business model for Engineering within the organization. It also supports the organization's business objectives of becoming a high performing organization.

5.4 ORGANIZATIONS HIGH PERFOMANCE UTILITY MODEL (EHPUM): DELIVER PROJECTS AND PERFOM ENGINEERING

The HPUM (High Performance Utility Model) is a 6 level hierarchy decomposition of business capabilities and their processes across the strategic, services and line functions of the business. The model provides the organization with leading process practices for an energy utility such as Eskom. Deliver Projects and Perform Engineering are business capabilities functions within the services function of the EHPUM and defines the suit of standardized processes for managing projects and performing design work respectively across the organization.

5.4.1 PROJECT DELIVERY

Project Delivery is a business capability function within the HPUM and requires that all work activities defined as a project be governed and managed in accordance with business policies, procedures, processes and standards developed to ensure effective project management within the organization.

5.4.1.1 ORGANIZATIONS STANDARD PLCM REFERENCE MODEL & SUBSET MODELS

A project life cycle is a series of sequential phases which a project passes through from the initiation of the project to the close-out of the project. The function of a project life cycle model is to ensure sufficient governance of the project through a comprehensive and consistent method of management and control to ensure its success. This approach to project governance helps ensure the business does not take on additional risk or commit additional resources without first analysing the risk of the project and its impact on the business. It also ensures the decision to proceed with the project is made by the correct governance structures with the correct delegation of authority to do so.

The organizations Standard Project Life Cycle Reference Model is depicted in figure 19 and is comprised of six project phases organized to ensure effective governance of the project's planning, resource allocation and management of risk.

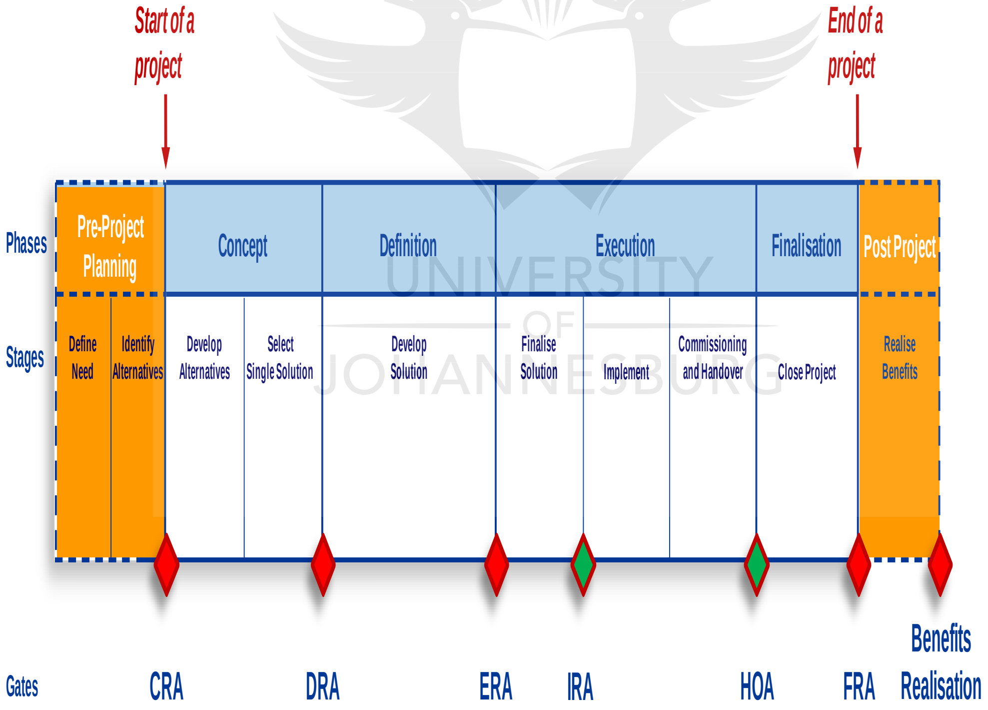


Figure 19: Organization's Standard Project Life Cycle Reference Model [1]

The organizations Standard Project Life Cycle Model [PLCM] is used to govern the work of the project, the management, approval and project investment process. It is the policy of the organization that all projects undertaken by the organizations

Divisions and the organizations Holdings Limited companies will be required to conform to the organizations standard project life cycle governance framework, to govern the management of the project and the approvals authorising the project investment decision to proceed to the next phase of the life cycle. And that all projects will pass through defined decision control gates for technical, investment and implementation decisions, at each phase of the project life cycle.

The PLCM Reference Model provides an overarching generic project life cycle that will be generally applicable to almost all projects. Due to the nature of the projects carried out within the organization and the different types of projects in terms of approach and technology, a life cycle model specific to the project type will be applicable. For an example projects carried out within the Generation Division on generation power plant involve very different systems and technologies compared with projects carried out within the Transmission Division on transmission plant. Thus there is a requirement for a Generation PLCM subset specific to Generation projects and a Wires PLCM subset specific to most Transmission and Distribution projects.

Each PLCM subset developed for a specific project type is aligned to the organizations Standard PLCM Reference Model. Each PLCM subset has the same phases, stages and stage gates and work packages as the reference model. In addition to the standard work packages, each project-type-specific PLCM subset will have additional work packages that are applicable to the explicit requirements of a specific type of project.

1. Renewables PLCM
2. Generation PLCM
3. Wires PLCM
4. Group Information technology PLCM
5. New Build Coal & Gas PLCM
6. Research and Innovation PLCM
7. Business PLCM
8. Nuclear New Build PLCM

The PLCM Reference Model is comprised of 76 PLCM work packages. The PLCM subset models will include additional PLCM work packages that are applicable to the specific project type. Further, the PLCM defines only the key deliverables that are required to be produced to ensure a successful project and PCM’s (Process Control

Manuals) define how it will be delivered. An example of this is depicted in figure 20 below.

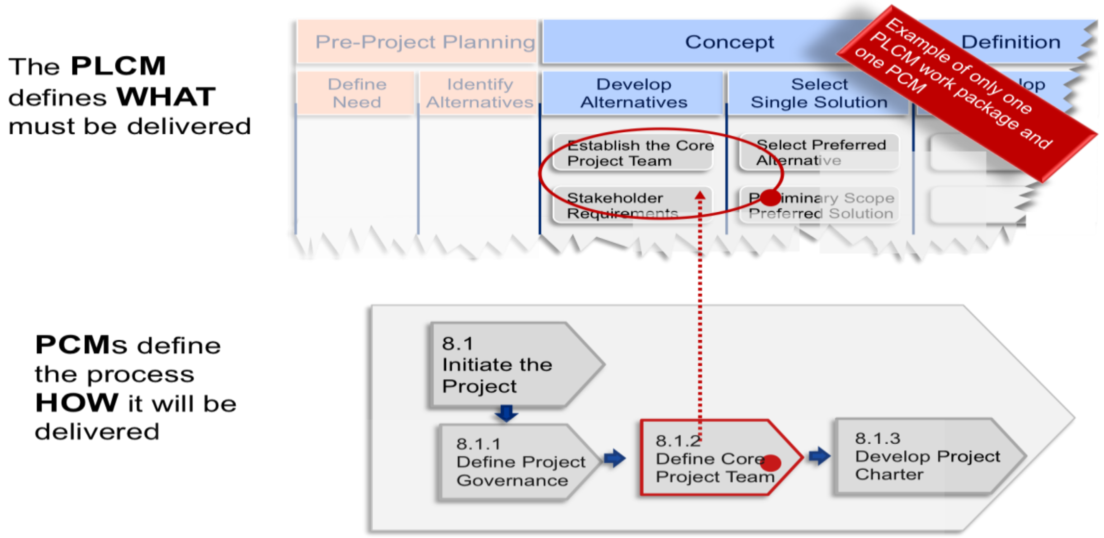


Figure 20: Depicting Work Packages and Process Control Manuals Within the PLCM [1]

5.5 PERFORM ENGINEERING

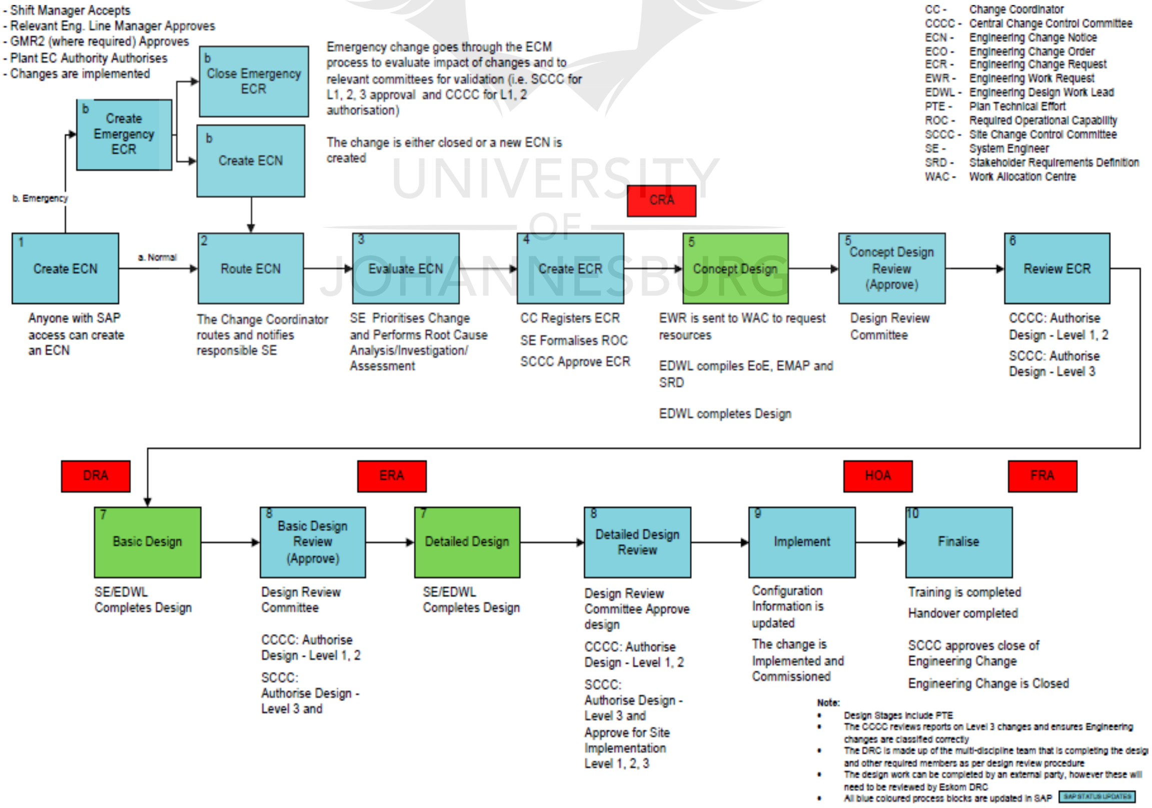
Perform Engineering is a business capability function within the HPUM and requires that all work activities defined as engineering design be governed and managed in accordance with business policies, procedures, processes and standards developed to ensure effective delivery of engineering design work within the organization.

5.5.1 ENGINEERING CHANGE MANAGEMENT (ECM)

The Engineering Change Management (ECM) process is a governance and quality control engineering design management process for all engineering work undertaken within the organization during asset modification or small upgrade projects. The ECM process is undertaken to ensure that all Engineering Changes (i.e. asset modification or upgrade projects) are correctly prepared, motivated, reviewed, approved, controlled and recorded. Therefore the ECM process is a systems design and development management process with the primary objective of ensuring effective management of all engineering project design deliverables.

This subsection aims to provide a brief explanation of the ECM process by identifying and describing all activities associated with the ECM process. The explanation will be further demonstrated with a practical example. The complete ECM process is depicted in figure 21. The process can be considered as consisting of three (3) phases namely, the originating and processing phase, implementation phase and the close-out phase.

The originating and processing phase is initiated by the Client at a particular power station through the creation of an ECN (Engineering Change Notice); typically an operating, system engineer or maintenance personnel. The ECN can be for a number of reasons including operating deficiencies. The ECN is then reviewed and evaluated by the plant or systems engineer for validity. If the change is deemed valid, the system engineer then compiles the Engineering Change Request (ECR) package which includes the required operational capability (ROC) which will serve as the document for which all project design engineering deliverables will be validated against. The ECR package is then reviewed by the SCCC (Site Change Control Committee). Once accepted, an ECR (Engineering Change Request) is then made to the relevant and respective CoE (Centre of Excellence) design authorities.



CC -	Change Coordinator
CCCC -	Central Change Control Committee
ECN -	Engineering Change Notice
ECO -	Engineering Change Order
ECR -	Engineering Change Request
EWR -	Engineering Work Request
EDWL -	Engineering Design Work Lead
PTE -	Plan Technical Effort
ROC -	Required Operational Capability
SCCC -	Site Change Control Committee
SE -	System Engineer
SRD -	Stakeholder Requirements Definition
WAC -	Work Allocation Centre

Note:
- Design Stages include PTE
- The CCCC reviews reports on Level 3 changes and ensures Engineering changes are classified correctly
- The DRC is made up of the multi-discipline team that is completing the desig
and other required members as per design review procedure
- The design work can be completed by an external party, however these will need to be reviewed by Eskom DRC
- All blue coloured process blocks are updated in SAP

Figure 21: Engineering Change Management Process Overview [1]

The implementation phase of the ECM process will start by assigning an Engineering Design Work Lead (EDWL) and LDE's by the Work Allocation Center within Systems Integration discipline. The EDWL is the coordinating manager of the engineering design work deliverables and will first get the team to document the Engineering Management Plan (EMAP) for the project as per the Plan Technical Management Process Control Manual (PCM).

It is in this document where the engineering design effort costs are estimated for the applicable design phases. Prior to the start of engineering design work, the EMAP is first approved by the leading discipline's Middle Manager and authorized by the CCCC Chairperson.

The project then begins with the documentation of the Stakeholder Requirements Definition (SRD) document. This is in consultation with the client to properly interpret and document the project requirements. The development of the EMAP and SRD is done with the concurrently participation of all engineering disciplines making up the project design team.

The SRD is baselined through a design review process which is a multi-disciplinary review and includes participation of the Client and all other relevant and disciplines.

The concept design then begins once the SRD has been reviewed, accepted and signed-off. The concept design development follows sequentially wherein the leading engineering disciplines is required to first complete their conceptual design before any of the preceding disciplines can commence. This is depicted in the primavera schedule of the Duvha Deep Dirty Water Drains depicted in figure 22 where the Chemical Discipline is first required to complete their concept design before the Low Pressure Services, Civil, Electrical and C&I engineering disciplines could commence their designs.

The concept design is further reviewed by the design team through a multi-disciplinary review effort before it is presented to the CCCC (Central Change Control Committee) for approval. The quality of the review will be greatly improved with the proposed concurrent design process as the entire team will be well aware of the requirements and the gaps due to their interaction during the design.

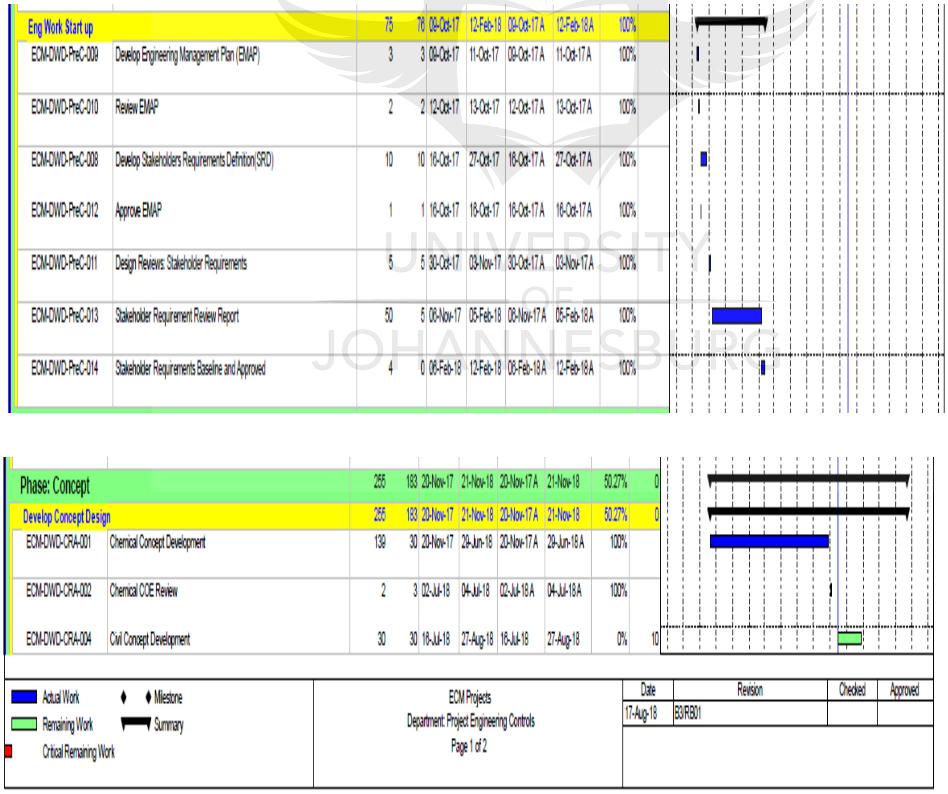
It has been theoretically demonstrated that concurrent engineering would provide great benefits to the concept design stage when compared to the sequential process.

The team then prepares the EMAP for the basic design and is submitted for approval

The basic design engineering design process also follows a sequential method where the Chemical discipline is again expected to complete their basic design before the LPS, Civil, Electrical and C&I disciplines can commence their designs. This is illustrated in the primavera project schedule shown in figure 23 below. As substantiated by the literature review, there is an opportunity to streamline and improve design management process.

As with the concept design, the basic design is reviewed and accepted by the design team through the multi-disciplinary review as governed by the in-house design review procedure. The basic design is then baselined following approval by the CCCC.

The engineering effort during the execution phase is the development of requirements and specification of the baselined basic design. During this phase all project engineering disciplines prepare the technical specification document concurrently.



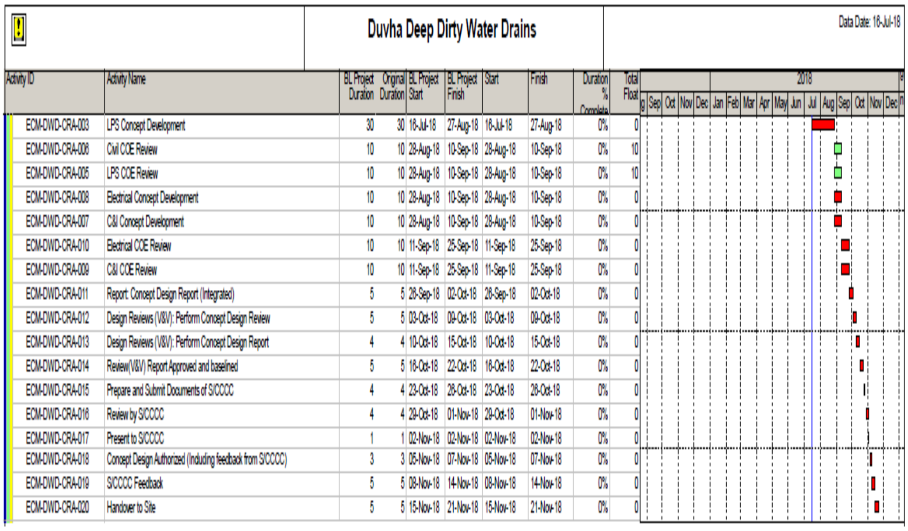
Eng Work Start up		75	78	09-Oct-17	12-Feb-18	09-Oct-17 A	12-Feb-18 A	100%	
ECM-DWD-PreC-009	Develop Engineering Management Plan (EMAP)	3	3	09-Oct-17	11-Oct-17	09-Oct-17 A	11-Oct-17 A	100%	
ECM-DWD-PreC-010	Review EMAP	2	2	12-Oct-17	13-Oct-17	12-Oct-17 A	13-Oct-17 A	100%	
ECM-DWD-PreC-008	Develop Stakeholders Requirements Definition(SRD)	10	10	16-Oct-17	27-Oct-17	16-Oct-17 A	27-Oct-17 A	100%	
ECM-DWD-PreC-012	Approve EMAP	1	1	16-Oct-17	16-Oct-17	16-Oct-17 A	16-Oct-17 A	100%	
ECM-DWD-PreC-011	Design Reviews: Stakeholder Requirements	5	5	30-Oct-17	03-Nov-17	30-Oct-17 A	03-Nov-17 A	100%	
ECM-DWD-PreC-013	Stakeholder Requirement Review Report	50	5	06-Nov-17	05-Feb-18	06-Nov-17 A	05-Feb-18 A	100%	
ECM-DWD-PreC-014	Stakeholder Requirements Baseline and Approved	4	0	06-Feb-18	12-Feb-18	06-Feb-18 A	12-Feb-18 A	100%	
Phase: Concept		255	183	20-Nov-17	21-Nov-18	20-Nov-17 A	21-Nov-18	50.27%	0
Develop Concept Design		255	183	20-Nov-17	21-Nov-18	20-Nov-17 A	21-Nov-18	50.27%	0
ECM-DWD-CRA-001	Chemical Concept Development	139	30	20-Nov-17	29-Jun-18	20-Nov-17 A	29-Jun-18 A	100%	
ECM-DWD-CRA-002	Chemical COE Review	2	3	02-Jul-18	04-Jul-18	02-Jul-18 A	04-Jul-18 A	100%	
ECM-DWD-CRA-004	Civil Concept Development	30	30	16-Jul-18	27-Aug-18	16-Jul-18	27-Aug-18	0%	10

🟦 Actual Work
🟩 Remaining Work
🟥 Critical Remaining Work
♦ ♦ Milestone
▬ Summary

ECM Projects
Department: Project Engineering Controls
Page 1 of 2

Date	Revision	Checked	Approved
17-Aug-18	B3/RB01		

Figure 22: Primavera Schedule of the Duvha Dirty Water Drains



Duvha Deep Dirty Water Drains

Activity ID	Activity Name	BL Project Duration	Original Duration	BL Project Start	BL Project Finish	Start	Finish	Duration % Complete	Total Float
ECM-DWD-CRA-003	LPS Concept Development	30	30	16-Jul-18	27-Aug-18	16-Jul-18	27-Aug-18	0%	0
ECM-DWD-CRA-006	Civil COE Review	10	10	28-Aug-18	10-Sep-18	28-Aug-18	10-Sep-18	0%	10
ECM-DWD-CRA-005	LPS COE Review	10	10	28-Aug-18	10-Sep-18	28-Aug-18	10-Sep-18	0%	10
ECM-DWD-CRA-008	Electrical Concept Development	10	10	28-Aug-18	10-Sep-18	28-Aug-18	10-Sep-18	0%	0
ECM-DWD-CRA-007	C&I Concept Development	10	10	28-Aug-18	10-Sep-18	28-Aug-18	10-Sep-18	0%	0
ECM-DWD-CRA-010	Electrical COE Review	10	10	11-Sep-18	25-Sep-18	11-Sep-18	25-Sep-18	0%	0
ECM-DWD-CRA-009	C&I COE Review	10	10	11-Sep-18	25-Sep-18	11-Sep-18	25-Sep-18	0%	0
ECM-DWD-CRA-011	Report: Concept Design Report (Integrated)	5	5	26-Sep-18	02-Oct-18	26-Sep-18	02-Oct-18	0%	0
ECM-DWD-CRA-012	Design Reviews (V&V): Perform Concept Design Review	5	5	03-Oct-18	09-Oct-18	03-Oct-18	09-Oct-18	0%	0
ECM-DWD-CRA-013	Design Reviews (V&V): Perform Concept Design Report	4	4	10-Oct-18	15-Oct-18	10-Oct-18	15-Oct-18	0%	0
ECM-DWD-CRA-014	Review(V&V) Report Approved and baselined	5	5	16-Oct-18	22-Oct-18	16-Oct-18	22-Oct-18	0%	0
ECM-DWD-CRA-015	Prepare and Submit Documents of S/CCCC	4	4	23-Oct-18	26-Oct-18	23-Oct-18	26-Oct-18	0%	0
ECM-DWD-CRA-016	Review by S/CCCC	4	4	29-Oct-18	01-Nov-18	29-Oct-18	01-Nov-18	0%	0
ECM-DWD-CRA-017	Present to S/CCCC	1	1	02-Nov-18	02-Nov-18	02-Nov-18	02-Nov-18	0%	0
ECM-DWD-CRA-018	Concept Design Authorized (Including feedback from S/CCCC)	3	3	05-Nov-18	07-Nov-18	05-Nov-18	07-Nov-18	0%	0
ECM-DWD-CRA-019	S/CCCC Feedback	5	5	08-Nov-18	14-Nov-18	08-Nov-18	14-Nov-18	0%	0
ECM-DWD-CRA-020	Handover to Site	5	5	15-Nov-18	21-Nov-18	15-Nov-18	21-Nov-18	0%	0

Figure 23: Primavera Schedule for Basic Design for Duvha Dirty Water Drains

As depicted in figure 23 above, This engineering design management process follows the sequential route which, according to the literature review leads to extended project delivery times and numerous quality issues This issue is also experienced in the organization, where projects take long to complete due to all design phases having to run sequentially even on small, repeatable projects. By the time the project is actually complete the execution budget that was allocated to the projects has been diverted to other projects and also the station has made other amends to fix the problem outside the process due to immense pressure experienced as the plant continues to deteriorate.

The proposal would be to streamline the design development process by systematically overlapping the design activities. The type of overlapping relationship between the design activities would depend on the evolution and sensitivity of the predecessor and proceeding design activities respectively. Thus the interdependent relationship would allow all disciplines to commence with their design activities all at the same time but will overlap the completion of the supporting disciplines. This proposal would promote the interaction of the design team and would provide great benefits including the team being aware of the design requirements as well as a substantial amount of saving in development time. According to literature this proposal can only be considered if the organization provides the necessary environment for concurrent engineering i.e. incremental innovation. This will be established later in the paper as part of the survey questionnaire.

5.6 ORGANIZATIONS SYSTEM ENGINEERING PROCESS

The management and integration of all design and engineering work activities and as a result, the functionality of the final design solution, is the accountability and responsibility of the Plant and Engineering Design Work Lead. This is achieved by multidisciplinary teams employing a combination of process control manuals from the Engineering Business Capability function. The design systems process translates stakeholder's requirements into a design solution(s). Multi-disciplinary design activities are performed to establish a process design, physical design, life cycle support systems design, integration and consolidation of the design.

The Engineering Design Business Capability provides a systematic approach to establishing a single set of requirements, from the user and other stakeholder requirements, right through to defining and specifying the system that will satisfy these requirements. It provides for a process for completing Engineering Design activities across the Engineering Business Function during Power Generation Asset Creation within the organization. It is made out of four process flows namely; Define Requirements, Design System, Functional Architecture and Perform Design Analysis as can be seen in figure 24 below.

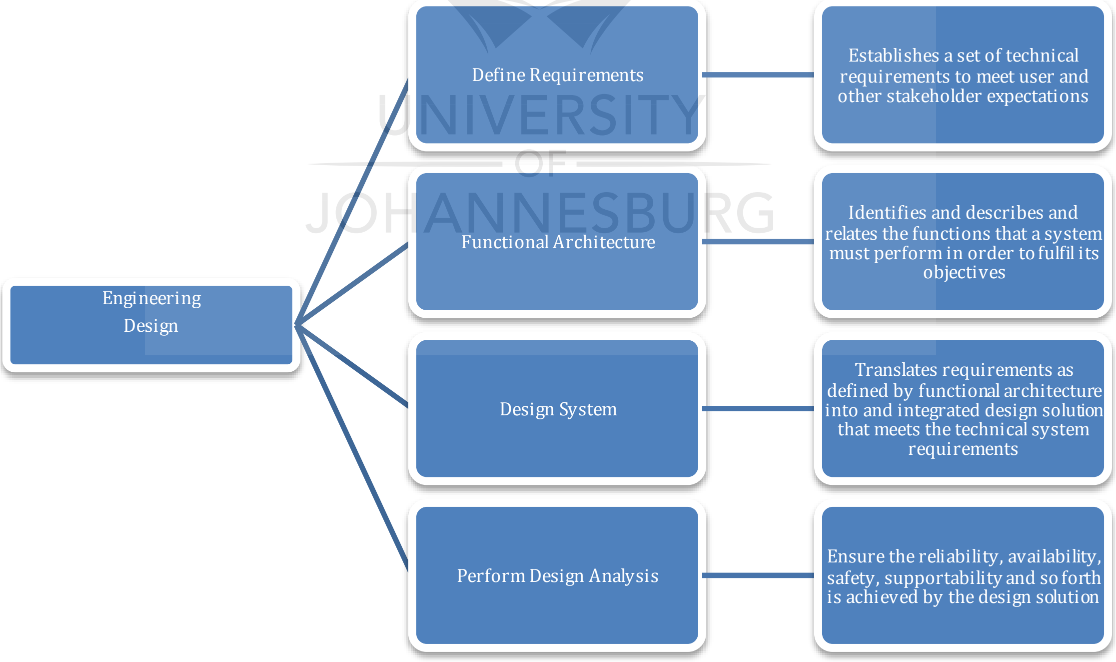


Figure 24: Engineering Design Business Capability

The process can be tailored to suit any specific project and is applied recursively during the Concept, Basic and Functional Specification design phases; providing increasing detail during each phase and therefore minimizing inherent risk in the project.

5.7 CONCLUSION

The current chapter presented the organizational governance structure and explained that engineering plays a significant role in enabling the organization to achieve its business objectives. This is seen by the fact that engineering is represented in the chief executive office within the generation group of the executive and therefore pivotal part in carrying the mandate given by the board.

Following the Back2Basics programme, the HPUM (High Performance Utility Model) was formed wherein processes and procedures was developed by the different operational functional so that work is carried out in standardized manner by the respective operational functions. As a result, all engineering work carried out within the organization is governed by standardized processes and procedures.

It is established that for all generation engineering projects for assets creation, engineering design is generally divided into the concept, basic and detail design stages and are aligned with the organization standard project life cycle phases of initiation, development and execution phases.

The chapter also established that the organization employs Systems Engineering (i.e. (SEP) System Engineering Processes and (SEM) Systems Engineering Management), during the system the design and development process. The SEP is constituted of four processes namely requirements definition, functional architecture, design system (design synthesis) and design analysis. The SEM on the other hand is a plan for the system engineering effort and is documented in the SEMP (Systems Engineering Management Plan). The two processes are carried out throughout the phases of the project life cycle of the system design and development process.

CHAPTER 6: RESEARCH AND DESIGN METHODOLOGY

6.1 INTRODUCTION

The foregoing chapters of this minor research dissertation were primarily concerned with the Research Methodology and fundamentally addressed amongst others; the reason for undertaking the research, defining the research problem and the gathering of evidence to answer questions of the mini research dissertation. This chapter of the dissertation covers the Research Design and is concerned with developing the research techniques for relating the available data and gathered literature research information and deduces a solution to the research objectives, research questions and research hypothesis. Furthermore, the chapter presents the statistical methods and techniques that were used to analyzing the gathered data and thereby obtaining valid, objective and accurate answers to the research problem and as a result ensuring the integrity of the results.

6.2 BACKGROUND TO RESEARCH DESIGN AND METHODOLOY

Research design according to Welman [61], is best described as the overall plan according to which the respondents of a proposed study are selected and the means for which data is collected or generated. The main function of a research design according to Mouton [62] is to enable the researcher to anticipate what appropriate research decisions are likely to maximize the validity of the eventual results. Evaluating the above definitions and for the purposes of this dissertation, research design is the functional overall plan in which research methods and procedures are linked to acquire a reliable and valid body of data for empirically grounded analyses, conclusions and theory formulation.

Although there are other distinctions to research methods, they are all commonly classified into quantitative and qualitative methods. The distinction between the research methods is given in figure 25 below and elaborated in the two sub-sections.

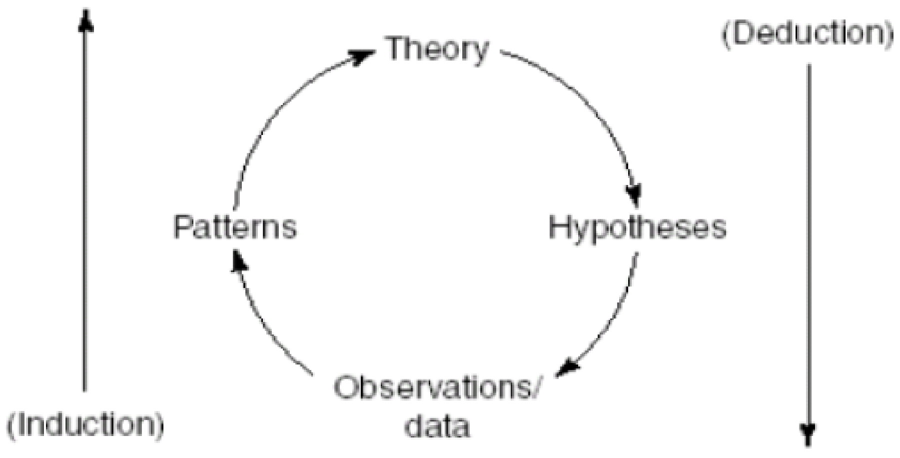


Figure 25: Showing Direction of Reasoning for Qualitative (Clockwise direction) and Quantitative (Ant-clockwise direction) [63]

6.2.1 QUALITATIVE RESEARCH APPROACH

The qualitative research method approach is associated with the interpretive paradigm where the forms of investigation are based on the significance of the experiential realm. Therefore qualitative research provides the avenues that can lead to the discovery of new phenomena. As a result of its underlying paradigms, the qualitative method is subjective and involves a small number of participants in the research process and results in an in-depth gathering of information [63].

From the above description one can deduce the limited aspects of qualitative methods and one major limitation is its inability to use large samples representative of the targeted population. The other limitation of qualitative methods is that it requires a considerable amount of time and financial resources for the research data collection as well as the analysis and interpretation of the research findings [63]. Furthermore the fact that qualitative research is subjective, reports are not presented in statistical methods but of a more descriptive nature.

6.2.2 QUANTITATIVE RESEARCH APPROACH

The quantitative research method on the other hand adopts a deductive theory approach to the research process. It commences with theories followed by research questions and hypothesis on the particular subject and further gathers data from a real-world setting and performs statistical analysis to support or reject the stated research hypothesis. Therefore the overall objective with the quantitative research approach is to test and verify a theory rather than to develop one. The method allows for the abstraction of data from the participants and as a result the research process is objective and findings can be generalized to represent the entire population under the study.

Quantitative research holds that the research must be limited to what one can observe and measure objectively and exist independent of the feelings and opinions of the participants. The main strength to quantitative research is in its precision and control achieved through sampling and design techniques that give precise and reliable quantitative measurements of data collection. A further strength to this approach is that experimentation can lead to statements about causation since the systematic manipulation of one variable can be shown to have a direct causal effect on another when the other variable have been eliminated or controlled.

6.3 RESEARCH DESIGN APPROACH

In order to address the research objectives, research questions and research hypothesis, the principle of triangulation will be used. The first node of the triangulation is a comparison of the organizations development practices to best systems engineering best practices based on literature and contemporary standards.

The second node of triangulation involves the qualitative investigation into the following:

- The application of systems engineering best practices within the organization practices of systems engineering.
- The project performance in respect to schedule, cost and quality.
- The nature of the technological environment within the organization.
- The areas of project performance improvement within the organization (schedule, cost and quality)

The quantitative, survey-type research approach with self-administered questionnaire (see Appendix A) has been adopted as the primary data collection for this research project. The quantitative approach is befitting of our research problem as it is of the statistical paradigm and offers the ability to test the research hypothesis empirically and report the result in a scientific manner. Also the structured questionnaire surveys are concerned with hypothesis formulation and variables can be observed and reported without manipulation. It further generates quantitative data from which quantitative analysis can be conducted with the aim to combine relevance to our research hypothesis.

The structured survey questionnaire was designed on the basis of literature review, the research objectives, research problems, research questions and the research hypothesis; and will enable coverage of wider research participants and therefore increased sample of the research population. Furthermore, the structured question allows all participants to respond to the same questions making it simpler to interpret statistically.

The primary data was supplemented by secondary data collection which entailed consulting existing documentation governing the design development practices within the organization.

6.4 THE RESEARCH STUDY POPULATION AND SAMPLING

According to Bryman and Bell [64] the population represents the universe of units from which the sample is selected. And as a result, the population for this research is ECM projects between the 2014 and 2017 financial year and consists of; Plant and Project EDWL's who are responsible for the systems engineering of projects, LDE's who are responsible for technical integrity of projects, the client Generation who is the end-user of design's and the ECM Projects manager who is responsible for the management and scheduling of all ECM projects.

The sampling frame is a list of 50 participants consisting of LDE's, EDWL's and Client representatives who have participated in the deployment of the organization's SEM process during the organization's asset creation projects between 2014 and 2017.

6.5 DATA COLLECTION

6.5.1 PRIMARY AND SECONDARY METHODS

The research data collection follows the triangular method and made up of the primary and secondary data. The primary data collection method is achieved through the survey method of correlational research design. In the correlational methods of design, a single group of the population is analyzed and each instrument is measured using different variables. The relationship between variables is then analyzed statistically. As determined by Field [66], correlational research provides the researcher a natural view of the research questions that are being investigated due to the fact that researchers have no influence what happens during data collection and the variance of measures of variables is thus unbiased.

The primary data collection method is supplemented through the secondary data collection methods; which form the literature review collected from the different sources.

6.5.2 RESPONDS RATE

None responses to survey are a very common problem to survey type research approach. As realized by Welman [61] no-responses would not matter if the researcher could ascertain with certainty that non-respondents are very similar to respondents on all relevant variables in that they would have to answer the survey similarly if they had taken part. He further states that non-responses occur because participants refused to be involved in the research for various reasons.

Given that low response rate limit the generalization of the results from the survey, the following steps will be taken to maximize the responds rate:

- Keep the questionnaires sufficiently short and attractive;
- Minimize cost and effort to the respondents;
- Follow-up phone calls and emails to the respondents

6.6 RESEARCH QUESTIONS AND HYPOTHESIS

6.6.1 ORGANIZATION'S SEM COMPARISON TO SEMBASE

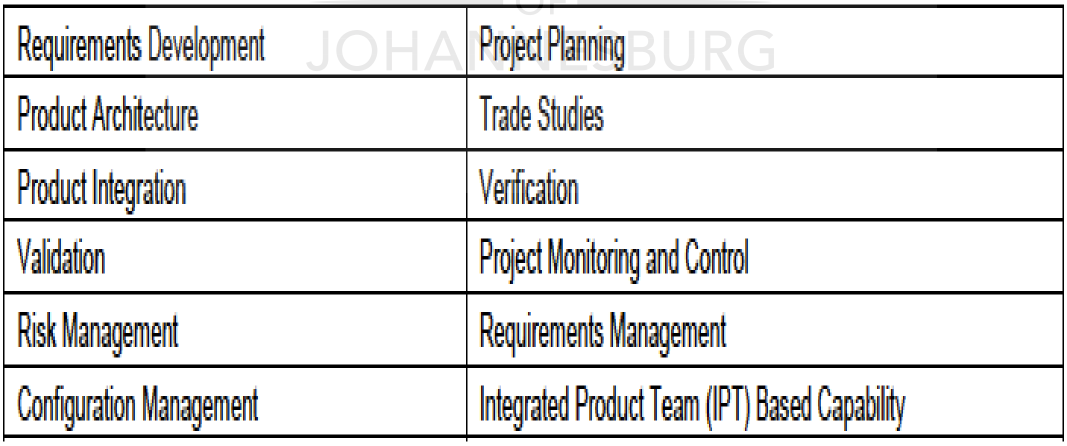
Literature review has revealed that a successful system is generally the result of a successful SEP and that an appropriate SEP is generally the result of a successful SEM. This section focuses on doing a comparison of the organization's SEM against the formal theoretical model SEMBASE with particular emphases on the three major activities namely SEP, development phasing and life cycle integration.

The organization's SEM model is based on the secondary sources of information comprising of the engineering management policy document as well as process control manuals. SEMBASE is based on Blanchard's acquisition process.

6.6.2 QUANTITATIVE COMPARISON

The second part is to obtain a quantitative evidence of organization's SE practices to best practices. The Capability Maturity Model Integration (CMMI) for Systems Engineering (SE) model work products is chosen as representative of effective SE practices [84, 85, 86]. The work products are a result of 42 CMMI standard practices that were collected in the 12 process groups shown in table 10 below.

Table 3: CMMI Process Groups [84]



Requirements Development	Project Planning
Product Architecture	Trade Studies
Product Integration	Verification
Validation	Project Monitoring and Control
Risk Management	Requirements Management
Configuration Management	Integrated Product Team (IPT) Based Capability

A structured survey questionnaire asking about the presence and characteristic of the work products was compiled. The questions were structured in the form of an assertion, wherein the respondents were asked to identify their level of agreement with the assertion by choosing one of the following: strongly agree, disagree, agree or strongly disagree.

6.6.3 ORGANIZATION'S SEM PERFORMANCE

Literature review has revealed that successful systems or projects are in terms of meeting schedule, budget and satisfying the requirements. As a result the 3rd node is to measure the impact of organization's SEM on project performance.

6.6.4 ORGANIZATION'S TECHNOLOGY ENVIRONMENT

The quantitative research methodology is chosen as research instrument for this research because it is generally easier to analyze statistically and simplifies the ability to turn the collected data into quantitative results that can be used for decision-making. Our literature review has shown linkage between the use and adoption of concurrent engineering in the design process and the different types of innovation in the organization. The supported trend throughout our literature review on the subject is that concurrent engineering adoption into the design process achieves time reduction and higher product quality for organizations carrying incremental innovation. Whereas for organizations carrying out radical innovation there is no positive results of time reduction and higher product quality for adopting concurrent engineering into their design process. For the cost factor; positive cost reduction is shown for organizations with radical environment and significant cost reduction is observed for organizations practicing incremental innovation.

It is clear then that concurrent engineering is not necessarily the ticket for success; but that companies and organizations should analyze their environment and prioritize their objectives in order to select the most appropriate design process for their environment.

A Likert scale survey questionnaire is used as the main instrument to gather quantitative data for this research study. The questionnaire used was designed on the basis of the existing literature and the conclusions obtained from a previous case study. In both the design and the administration of the questionnaire the techniques highlighted by Frohlich [67] to improve the response ratio and the rules put forward by Synodinos [68] were taken into consideration. The questionnaire is designed around a range of formulated statements as a means to explore respondents' perception.

The formulated statements on the structured questionnaire were based on the procedures recommended by Saunders [69]. The main steps that were followed when formulating the questionnaire included a careful review of the literature on the topic, a review of similar questionnaires that were used in prior surveys and insights gained from an examination of the latest information gathered through the academic journals and books on the subject. All these culminated in the formulation of 64 attitudinal statements that represent the main variables of the study.

6.7 RELIABILITY AND VALIDITY

6.7.1 RELIABILITY

Reliability is concerned with the findings of the research and relates to the credibility of the findings. Reliability of data signifies the degree to which an instrument consistently measures whatever it is measuring [70]. Thus, data reliability represents a condition in which the same results will be achieved whenever the same technique is repeated to do the same study after a given time [63].

There is also the issue of generalization when one looks at reliability. The requirements for generalization relate to the reliability of the scores obtained, in that generalization implies consistency of the ranking of the scores that are assigned to individual objects, irrespective of the timing of the measuring instrument, in which form it was used, and by whom it was administered or scored (Welman et al., 2005:145). Thus, reliability refers to the extent to which the scores that were obtained may be generalized to different measuring occasions, measurement forms and measurement administrators. The scores assigned to individuals should therefore be consistent, irrespective of the time of measurement, the test used, and the person administering the test scored [Welman]. Thus, reliability refers to the extent to which the scores that were obtained may be generalized to different measuring occasions, measurement forms and measurement administrators. The scores assigned to individuals should therefore be consistent, irrespective of the time of measurement, the test used, and the person administering the test.

6.7.2 *VALIDITY*

Data validity represents a research mechanism that ensures that the process implemented to collect data has indeed collected the intended data successfully. Data validity represents the extent to which the research findings accurately demonstrate what is really happening in a given situation [Welman] Stated differently, data validity refers to whether or not an indicator (or set of indicators) that is devised to measure a concept really measures that defined concept [64]. The instrument that is used to measure variables must measure that which the instrument is supposed to measure; and this is referred to as construct validity. The construct validity of a measuring instrument refers to the extent to which the instrument measures the intended construct rather than an irrelevant construct or measurement errors. Thus, data validity refers to the extent to which an empirical measure adequately reflects the real meaning of the subject under investigation [63]. Data validity can be undermined by research errors such as poor samples, faulty research procedures and inaccurate or misleading measurements on the instrument.

6.8 DATA ANALYSIS

The survey data was captured and analyzed using survey monkey. The package was considered because of its statistical capabilities. The statistical capabilities offered by the software tool include Data Editor (for entering, modifying and viewing data), Descriptive Statistics (such cross-tabulations, correlational analysis on both bivariate and multivariate analysis). Further the tool has integrative graphic capabilities and allows changing or adding chart elements and variables dynamically.

For the purpose of data analysis, respondents are asked to rank their responses to questions in a Likert scale format as already explained in previous section. Data analysis is done mainly through descriptive statistics and correlational analysis using bivariate and multivariate methods.

6.9 HYPOTHESIS TESTING

The questions to the research dissertation are answered using inferential statistics and specifically the chi square goodness-of-fit test. The method is befitting of the mini research dissertation given the variables under study is categorical and the sample method follows simple random sampling. The data in the sample is examined in order to see whether the distribution of respondents is consistent with the hypothesized distribution of the population or not.

The following process will be followed for computing the test [87]:

- Make null hypothesis (H_o) statement.
- Compute the probability (P-value) using the observed and expected frequencies utilizing equation 1 referenced below.
- If P<5%, then H_o is rejected and if P> 5% then H_o cannot be rejected.

$$\chi^2 = \sum_{i=1}^{k} (O_i - E_i)^2 / E_i$$

Equation 1: Formulae for computing chi square [87]

Where O_i is the observed number of cases in category *i*, and E_i is the expected number of cases in category *i*.

This chi square statistic is obtained by calculating the difference between the observed number of cases and the expected number of cases in each category. This difference is squared and divided by the expected number of cases in that category. These values are then added for all the categories, and the total is referred to as the chi squared value.

6.10 ETHICAL CONSIDERATION

The questionnaire was constructed in such a way that it did not transgress against any ethical requirements. As an example, individual respondents could not be identified during the data collection and data analysis, as the survey was anonymous. Through the questionnaire instructions, the participants were assured that the study involved an anonymous survey, where their names were not to appear on the questionnaires.

Participants were also assured that the answers they gave would be treated as strictly confidential and that they could not be identified in person based on the answers they gave. Participants were also reminded of the significance of their participation in the study, as it was very important to get their input to complete the project.

6.11 CONCLUSION

This chapter has discussed the research design and methodology undertaken in the research paper. Issues surrounding both quantitative and qualitative research methods were briefly detailed. Based on the attributes of this research paper, the quantitative research method was selected as the most appropriate for this study. The design of the structured questionnaire as a research instrument was based on a Likert scale rating method. Finally, the chapter has discussed the sampling methods, data collection and data analysis, providing the rationale for the choice of each method. Statistical issues relating to sampling, data validity and data reliability have also been reported upon in this chapter.

CHAPTER 7: RESULTS AND ANALYSIS

7.1 INTRODUCTION

The questionnaire serves as the primary data that will used to ascertain whether to accept or reject the formulated research hypothesis. Secondary data which include available documentation (policy, procedures and manuals) is used as the other source of information for accepting or rejecting the formulated research hypothesis. This section presents the results obtained from the survey questionnaire that was distributed to research sample population as well as results of how well the organization's developmental model compares to SE best practices

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7.2 COMPARISON OF THE ORGANIZATION'S SEM TO SEMBASE

As already revealed through literature review of this minor research dissertation, a successful system is generally the result of a successful SEP; and also that an appropriate SEP is generally the result of a successful SEM. This section focuses on comparative results of the organization's SEM practices against the formal theoretical model of SEMBASE with particular emphases on the three major activities namely SEP, development phasing and life cycle integration.

The organization's SEM model is based on the secondary sources of information comprising of the engineering management and governance document as well as engineering process control manuals. SEMBASE is based on Blanchard's acquisition process.

The SEP and SEM set of activities of the organization and those of SEMBASE are compared respectively in table 11 and table 12 below. The columns and rows of the tables represent the organizations SEP and SEMBASE SEP activities respectively. Further, a correlation of activities between the two models is indicated by "x" whereas the indication "-" represents no correlation between activities of the two models of SEP.

Table 4: Comparison of Organization's SEP to SEMBASE

Systems Engineering Process			Organization's SEP			
			Define Requirements	Develop Functional Architecture	System Design	Design Analysis
			1	2	3	4
SEMBASE	1	Requirements Analysis	x	-	-	-
	2	Requirements Validation	x	-	-	-
	3	Functional Analysis	-	x	-	-
	4	Functional Verification	-	x	-	-
	5	Synthesis	-	-	x	-
	6	Design Verification	-	-	x	-
	7	Systems Analysis	-	-	-	x

As depicted in table 4 above, the organizations SEP process consist of four phases whereas SEMBASE consist of seven phases. There is correlation to four phases between SEMBASE and organization's SEP model. SEMBASE considers Requirements Validation, Functional Verification and Design Verification as design phases whereas the organization's SEP process considers them as activities within phases.

Table 5: Comparison of Organization's SEM to SEMBASE

Life Cycle Phases			Organization's SEM			
			Concept Phase	Definition Phase	Execution Phase	Finalization Phase
			1	2	3	4
SEMBASE	1	Concept Study	x	-	-	-
	2	System Definition	-	x	-	-
	3	Preliminary Design	-	x	-	-
	4	Detail Design	-	-	x	-

	5	Manufacturing, Construction, Installation and Implementation	-	-	x	-
	6	Commissioning				
	7	Operation and Support				
	8	Decommissioning				

As depicted in table 5 above, SEMBASE SEM model consist of 8 phases whereas the organization's SEM consists of only 4 phases. The first four phases of SEMBASE (i.e. Concept study, Systems Definition, Preliminary Design and Detail Design) are considered as the development phases while the organization's SEM model considers the first three phases (Concept, Definition and Execution) as development phases. SEMBASE SEM model considers Commissioning and Decommissioning as process phases whereas the organization's SEM model considers these as activities within the Finalization phase.

Further, the SEMBASE model emphasizes the integration of stakeholders in the design process early in the development process. The organization's SEM model also stresses the importance of incorporating stakeholder early in the development process.

7.3 IMPLEMENTATION OF ORGANIZATION'S DEVELOPMENT MODEL

As evident in the evaluated engineering design documentation and engineering policy documents, including the discussion from the previous sub-section, the organization has a systems engineering management model that compares very well to systems engineering best practice. However the model can be rendered useless unless it is put into practice. It is necessary to perform a qualitative investigation into the application of SE to evaluate the systems engineering management processes practiced within the organization.

The mini research study utilized v1.3 of the CMMI and selected nine SE capabilities relating to management and technical groups as the basis of the study to evaluate the organization's application of system engineering management best practices. . The process groups are given table below.

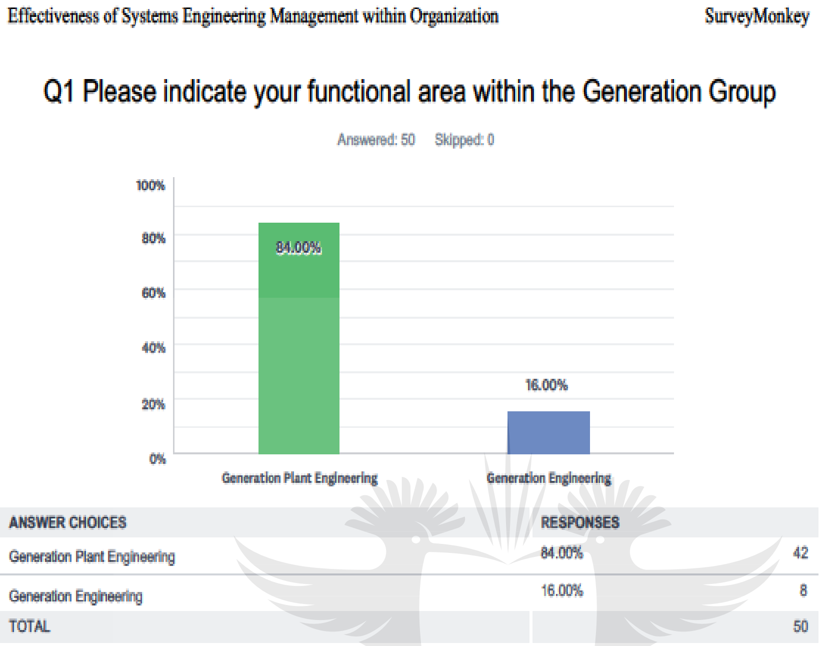
Table 6: Systems Engineering process groups for evaluating application of systems engineering in organization

Process Group	**Type**
Requirements Management	Technical
Requirements Development	Technical
Verification	Technical
Systems Architecture	Technical
Validation	Technical
Risk Management	Management
Configuration Management	Management
Project Planning	Management
Project Controls and Management	Management

The survey questions were crafted to gather and assess information about the presence and the qualities of the SE work products in the projects that the participants have been deployed in. The questions were structure in the form of an assertion, utilizing a Likert scale of four: Strongly Disagree, Disagree, Agree and Strongly Agree. Given that the collected data is ordinal, nonparametric statistical methods will be used analyze them in the next chapter of the mini research dissertation.

7.3.1 DEMOGRAPHICS

The first three questions of the questionnaire were intended to gather the demographics of the respondents. The results to the respondents' demographics are depicted in figures 26-28 below. It can be seen that 84% of respondents are from Generation Plant Engineering and 16% from Generation Engineering. Furthermore that most of the respondents are LDE's who are responsible for carrying the design activities. It can also be seen that the respondents have a great deal of experience in carrying out design work for ECM's with approximately only 10% having performed or participated in less than 5 ECM projects.



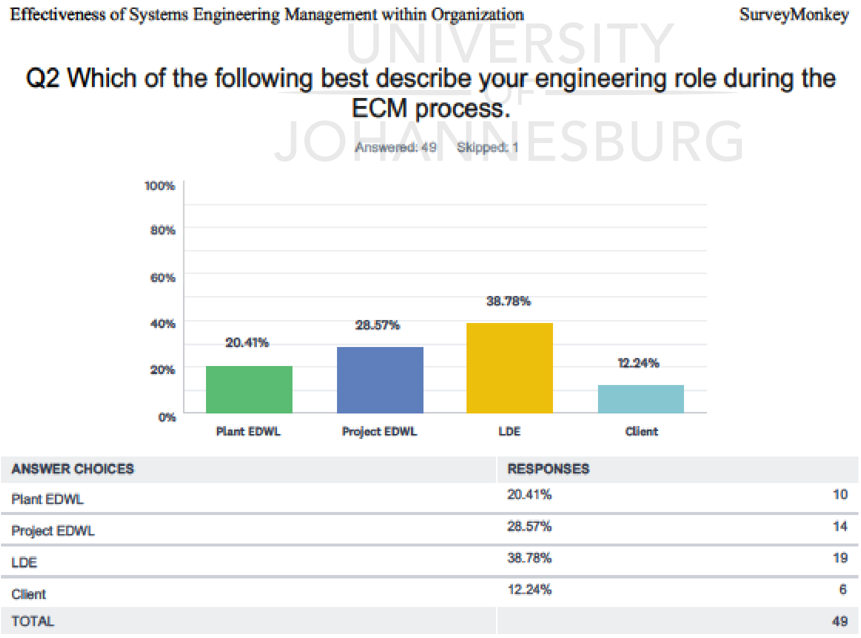
Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q1 Please indicate your functional area within the Generation Group

Answered: 50 Skipped: 0

ANSWER CHOICES	RESPONSES	
Generation Plant Engineering	84.00%	42
Generation Engineering	16.00%	8
TOTAL		50

Figure 26: Depicting the Functional Demographics of Respondents



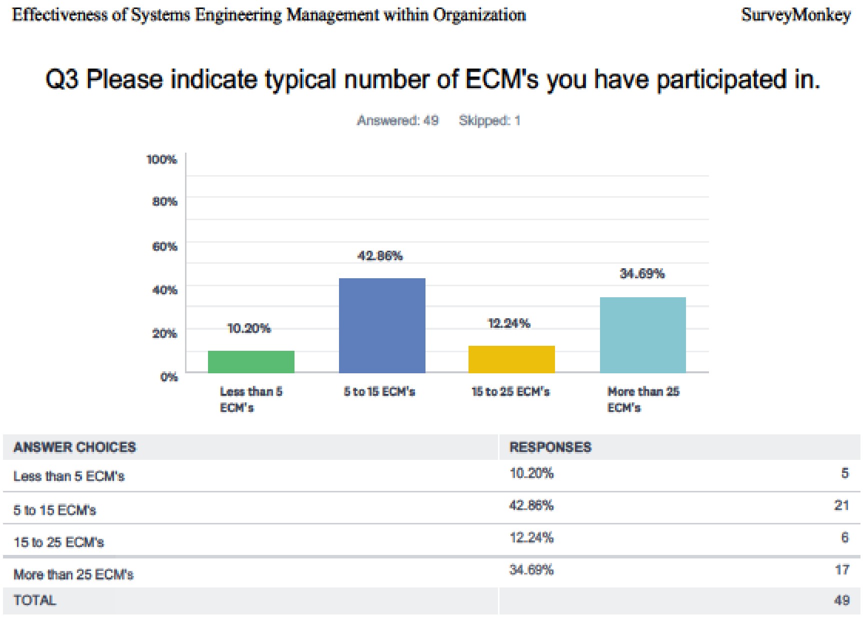
Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q2 Which of the following best describe your engineering role during the ECM process.

Answered: 49 Skipped: 1

ANSWER CHOICES	RESPONSES	
Plant EDWL	20.41%	10
Project EDWL	28.57%	14
LDE	38.78%	19
Client	12.24%	6
TOTAL		49

Figure 27: Depicting the Roles of Respondents


Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q3 Please indicate typical number of ECM's you have participated in.

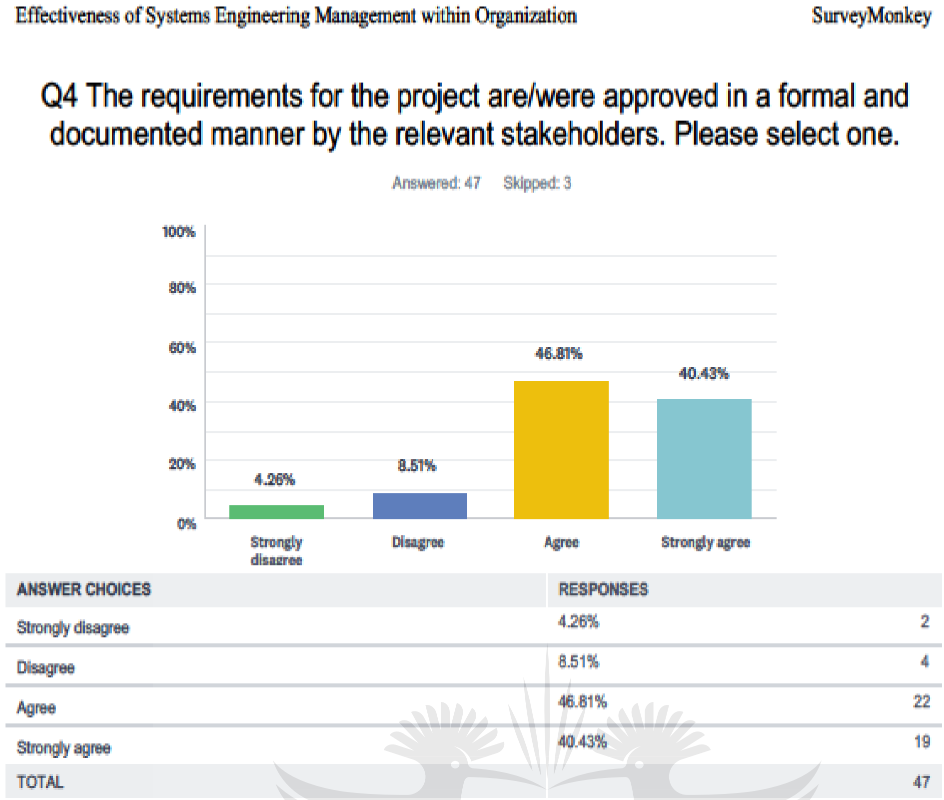
Answered: 49 Skipped: 1

ANSWER CHOICES	RESPONSES	
Less than 5 ECM's	10.20%	5
5 to 15 ECM's	42.86%	21
15 to 25 ECM's	12.24%	6
More than 25 ECM's	34.69%	17
TOTAL		49

Figure 28: Depicting the level of Experience with ECM Projects of the Respondents

7.3.2 REQUIREMENTS MANAGEMENT

The results of the organization's systems engineering management activities related to the Requirements Management process group is shown in the figure 29-31 below. Generally the respondents agree to have employed the requirements management with a convincing 87.24%, 80.85% and 82.92% of the respondents agreeing to have employed the Requirements Management process group of systems engineering activities of questions Q4, 5 and 6 respectively. This make up for an average of 83.67% of respondents agree to employing the requirements management set of systems engineering management activities. This amounts to capability maturity level of 4.



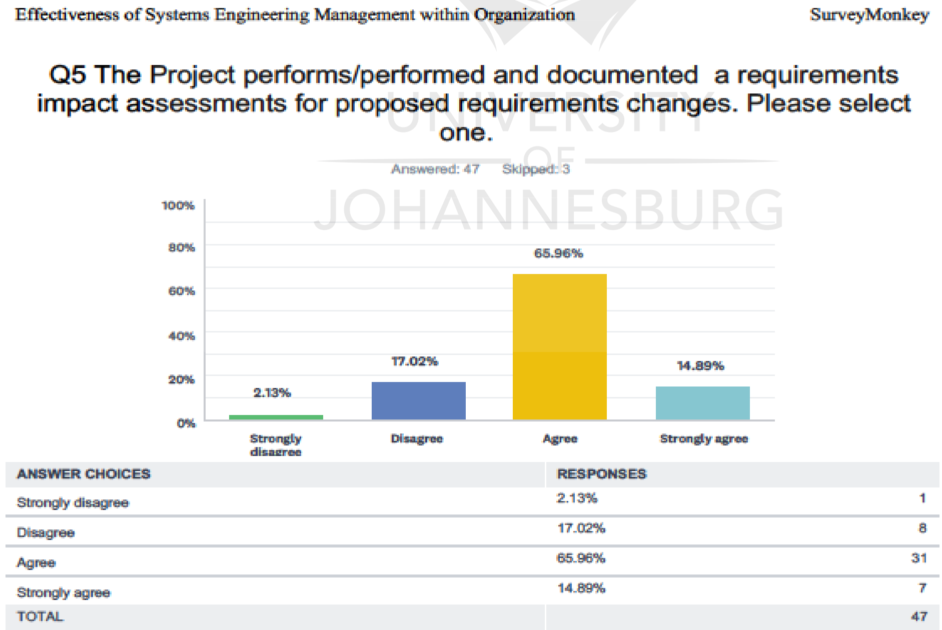
Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q4 The requirements for the project are/were approved in a formal and documented manner by the relevant stakeholders. Please select one.

Answered: 47 Skipped: 3

ANSWER CHOICES	RESPONSES	
Strongly disagree	4.26%	2
Disagree	8.51%	4
Agree	46.81%	22
Strongly agree	40.43%	19
TOTAL		47

Figure 29: Depicting Respondents Assertion of SE Activity Related to Requirements Management



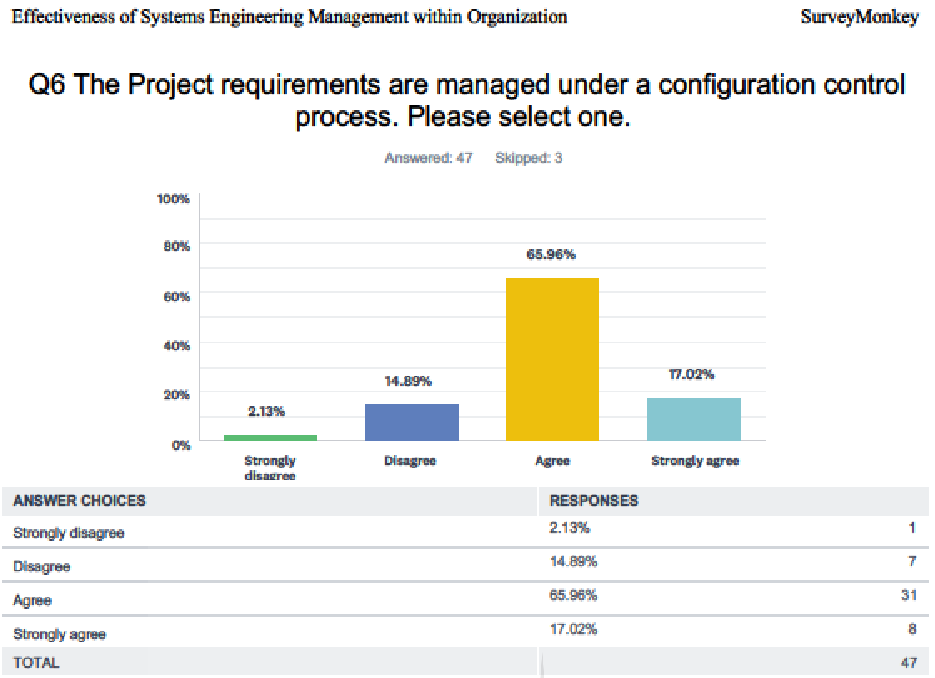
Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q5 The Project performs/performed and documented a requirements impact assessments for proposed requirements changes. Please select one.

Answered: 47 Skipped: 3

ANSWER CHOICES	RESPONSES	
Strongly disagree	2.13%	1
Disagree	17.02%	8
Agree	65.96%	31
Strongly agree	14.89%	7
TOTAL		47

Figure 30: Depicting Respondents Assertion of SE Activity Related to Requirements Management



Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q6 The Project requirements are managed under a configuration control process. Please select one.

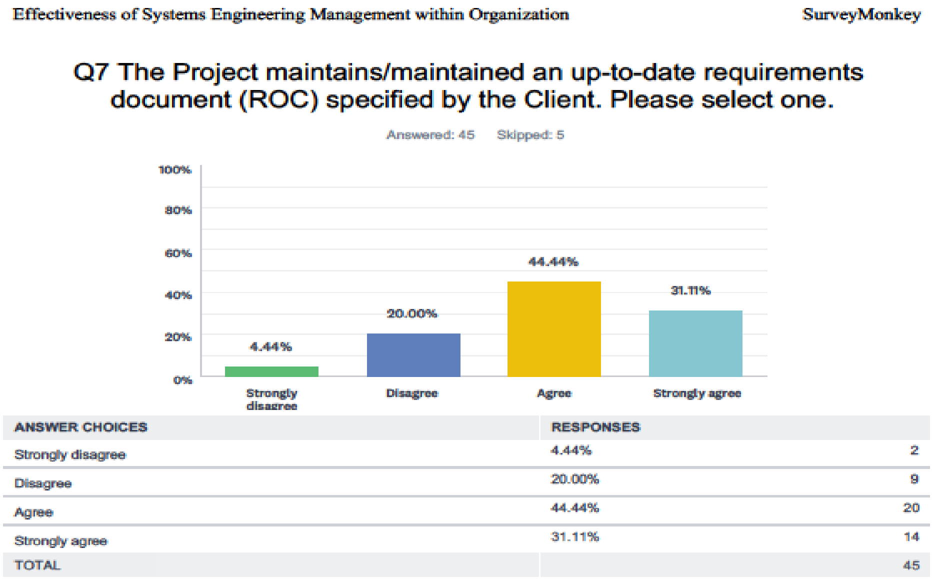
Answered: 47 Skipped: 3

ANSWER CHOICES	RESPONSES	
Strongly disagree	2.13%	1
Disagree	14.89%	7
Agree	65.96%	31
Strongly agree	17.02%	8
TOTAL		47

Figure 31: Depicting Respondents Assertion of SE Activity Related to Requirements Management

7.3.3 REQUIREMENTS DEVELOPMENT

The results of the organization's systems engineering management activities related to the Requirements Development process group is shown in the figure 32-33 below. Generally the respondents agree to have employed the requirements development systems engineering management activities with a convincing 75.55% and 88.89% of the respondents agreeing to have employed the Requirements Development process group of systems engineering activities of questions Q7 and 8 respectively. This make up for an average of 82.22% of respondents agree to employing the requirements development set of systems engineering management activities. This amounts to capability maturity level of 4.



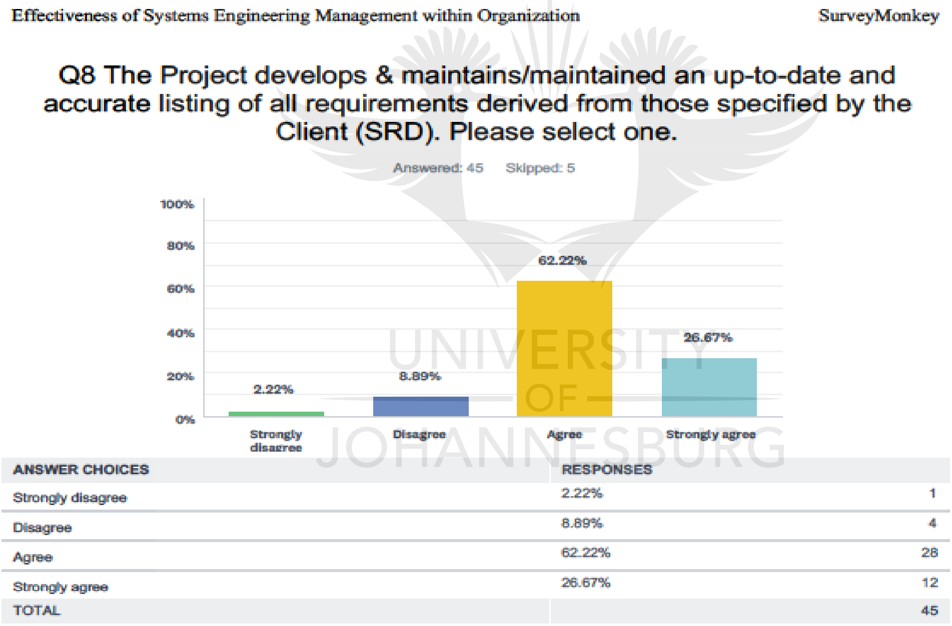
Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q7 The Project maintains/maintained an up-to-date requirements document (ROC) specified by the Client. Please select one.

Answered: 45 Skipped: 5

ANSWER CHOICES	RESPONSES	
Strongly disagree	4.44%	2
Disagree	20.00%	9
Agree	44.44%	20
Strongly agree	31.11%	14
TOTAL		45

Figure 32: Depicting Respondents Assertion of SE Activity Related to Requirements Development



Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q8 The Project develops & maintains/maintained an up-to-date and accurate listing of all requirements derived from those specified by the Client (SRD). Please select one.

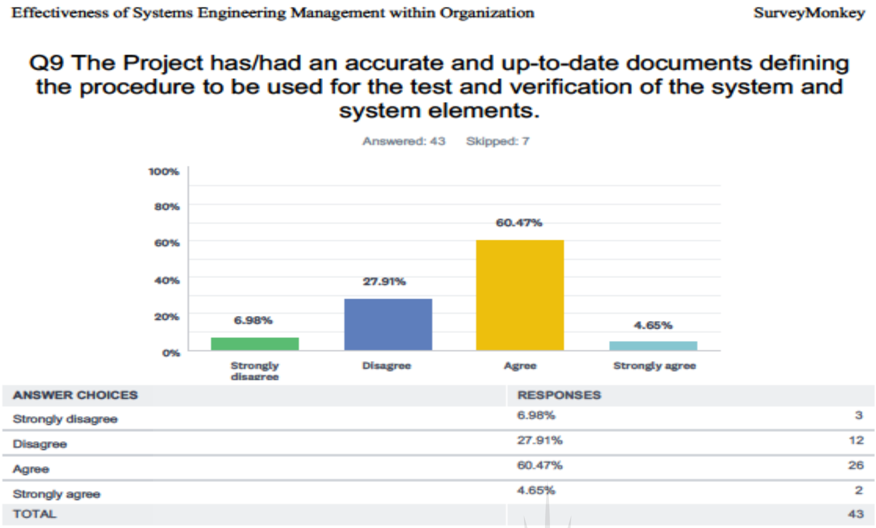
Answered: 45 Skipped: 5

ANSWER CHOICES	RESPONSES	
Strongly disagree	2.22%	1
Disagree	8.89%	4
Agree	62.22%	28
Strongly agree	26.67%	12
TOTAL		45

Figure 33; Depicting Respondents Assertion of SE Activity Related to Requirements Development

7.3.4 VERIFICATION

The results of the organization’s systems engineering management activities related to the Verification process group is shown in the figure 34-35 below. Generally the respondents agree to have employed the verification systems engineering management activities with 65.12% and 92.02% of the respondents agreeing to have employed the Verification process group of systems engineering activities of questions Q9 and 10 respectively. This make up for an average of 79.07% of respondents agree to employing the requirements development set of systems engineering management activities. This amounts to capability maturity level of 3.

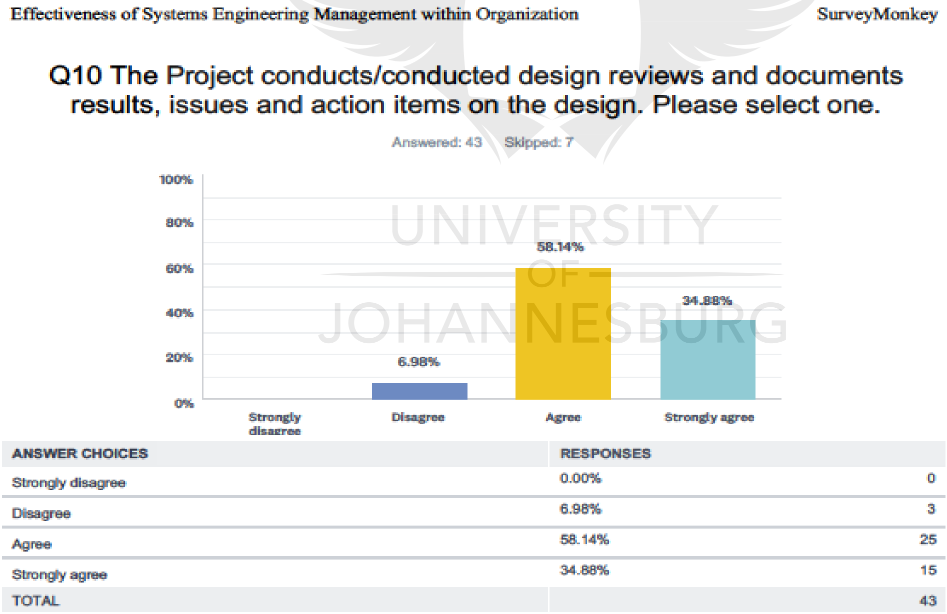

Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q9 The Project has/had an accurate and up-to-date documents defining the procedure to be used for the test and verification of the system and system elements.

Answered: 43 Skipped: 7

ANSWER CHOICES	RESPONSES	
Strongly disagree	6.98%	3
Disagree	27.91%	12
Agree	60.47%	26
Strongly agree	4.65%	2
TOTAL		43

Figure 34: Depicting Respondents Assertion of SE Activity Related to Verification


Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q10 The Project conducts/conducted design reviews and documents results, issues and action items on the design. Please select one.

Answered: 43 Skipped: 7

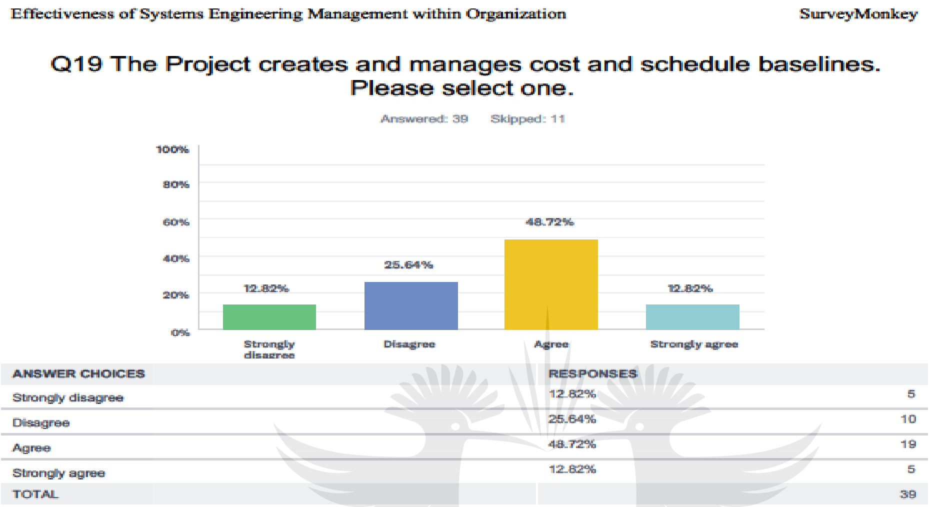
ANSWER CHOICES	RESPONSES	
Strongly disagree	0.00%	0
Disagree	6.98%	3
Agree	58.14%	25
Strongly agree	34.88%	15
TOTAL		43

Figure 35; Depicting Respondents Assertion of SE Activity Related to Verification

7.3.5 PROJECT CONTROLS AND MANAGEMENT

The results of the organization's systems engineering management activities related to the Project Controls and Management process group is shown in the figures 36-38 below. In the case of project controls and management process group 61.54%, 41.03% and 25.04% of respondents agreed to have utilized the systems engineering management activity of Q19, 20 and 21 respectively. And correspondingly 38%.46, 58.97% and 74.35% of respondents disagreed to have utilized the systems engineering management activity of Q19, 20 and 21.

This makes for 42.5% of respondents in agreement and 57.5% in disagreement. This amounts to capability maturity level of 2.



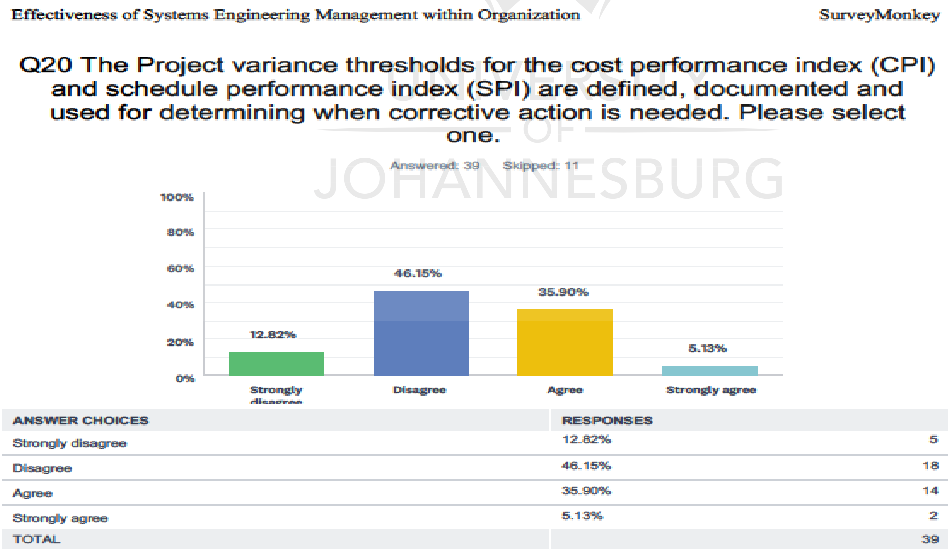
Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q19 The Project creates and manages cost and schedule baselines. Please select one.

Answered: 39 Skipped: 11

ANSWER CHOICES	RESPONSES	
Strongly disagree	12.82%	5
Disagree	25.64%	10
Agree	48.72%	19
Strongly agree	12.82%	5
TOTAL		39

Figure 36: Depicting Respondents Assertion of SE Activity Related to Project Controls and Management



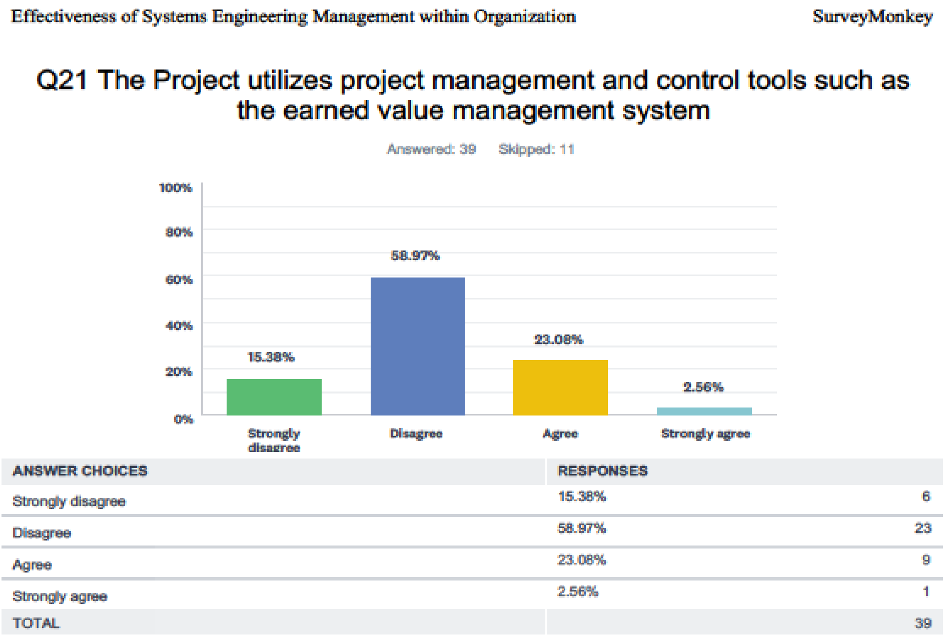
Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q20 The Project variance thresholds for the cost performance index (CPI) and schedule performance index (SPI) are defined, documented and used for determining when corrective action is needed. Please select one.

Answered: 39 Skipped: 11

ANSWER CHOICES	RESPONSES	
Strongly disagree	12.82%	5
Disagree	46.15%	18
Agree	35.90%	14
Strongly agree	5.13%	2
TOTAL		39

Figure 37: Depicting Respondents Assertion of SE Activity Related to Project Controls and Management


Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q21 The Project utilizes project management and control tools such as the earned value management system

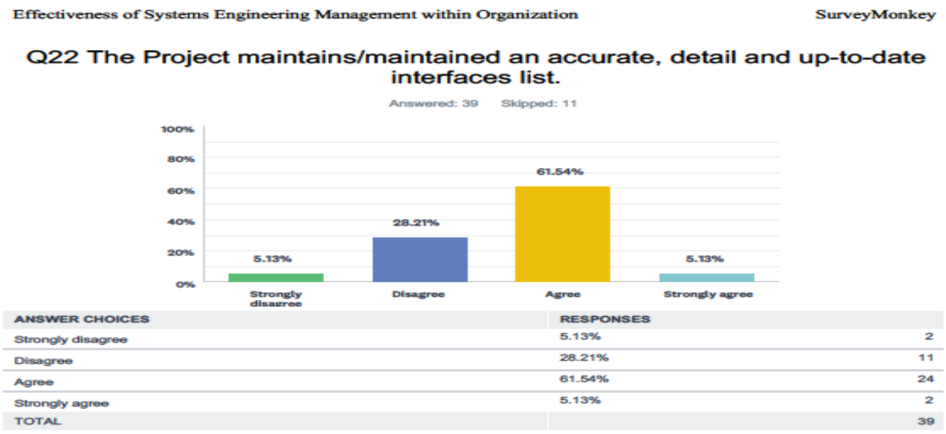
Answered: 39 Skipped: 11

ANSWER CHOICES	RESPONSES	
Strongly disagree	15.38%	6
Disagree	58.97%	23
Agree	23.08%	9
Strongly agree	2.56%	1
TOTAL		39

Figure 38: Depicting Respondents Assertion of SE Activity Related to Project Controls and Management

7.3.6 SYSTEMS ARCHITECTURE

The results of the organization's systems engineering activities related to the Systems Architecture process group is shown in the figure 39-41 below. Generally the respondents agree to have employed the Systems Architecture systems engineering process activities with 66.67%, 94.87% and 70.45% of the respondents agreeing to have employed the Systems Architecture process group of systems engineering activities of questions Q22, 23 and 24 respectively. This make up for an average of 77.33% of respondents agree to employ the Systems Architecture set of systems engineering process activities. This amounts to capability maturity level of 3.

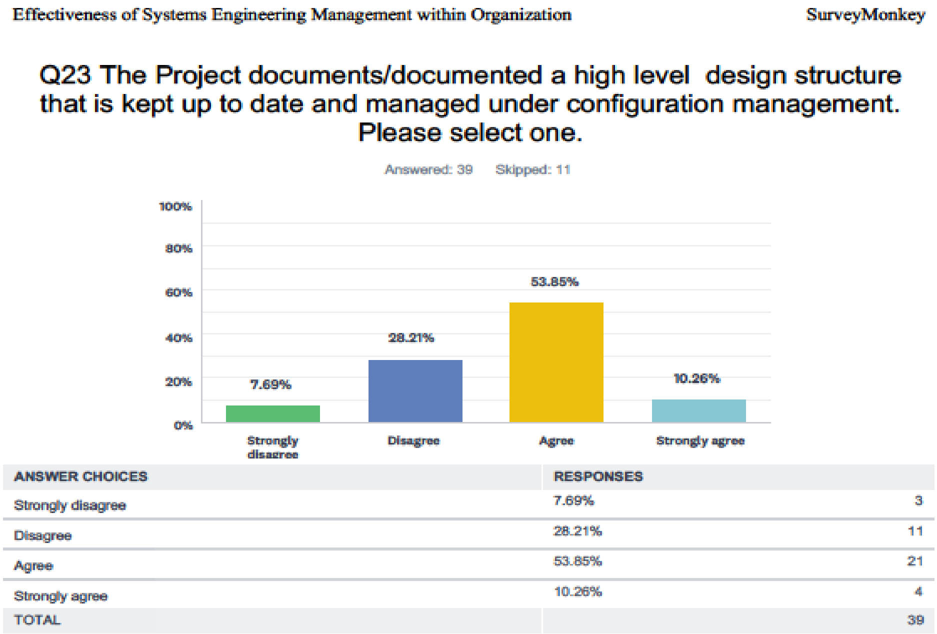

Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q22 The Project maintains/maintained an accurate, detail and up-to-date interfaces list.

Answered: 39 Skipped: 11

ANSWER CHOICES	RESPONSES	
Strongly disagree	5.13%	2
Disagree	28.21%	11
Agree	61.54%	24
Strongly agree	5.13%	2
TOTAL		39

Figure 39: Depicting Respondents Assertion of SE Activity Related to Systems Architecture



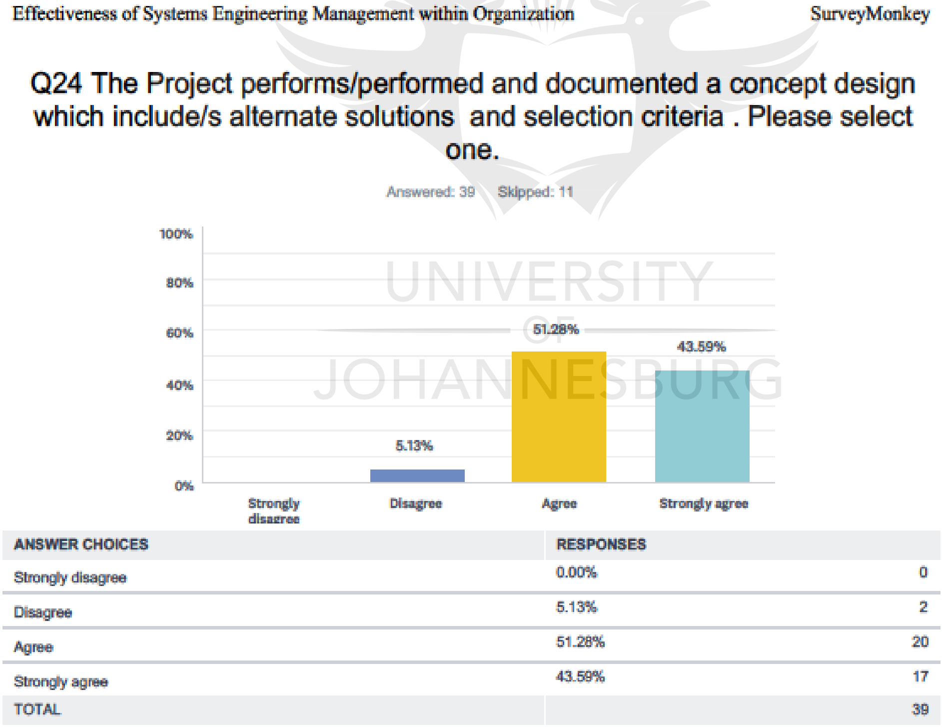
Effectiveness of Systems Engineering Management within Organization — SurveyMonkey

Q23 The Project documents/documented a high level design structure that is kept up to date and managed under configuration management. Please select one.

Answered: 39 Skipped: 11

ANSWER CHOICES	RESPONSES	
Strongly disagree	7.69%	3
Disagree	28.21%	11
Agree	53.85%	21
Strongly agree	10.26%	4
TOTAL		39

Figure 40: Depicting Respondents Assertion of SE Activity Related to Systems Architecture



Effectiveness of Systems Engineering Management within Organization — SurveyMonkey

Q24 The Project performs/performed and documented a concept design which include/s alternate solutions and selection criteria . Please select one.

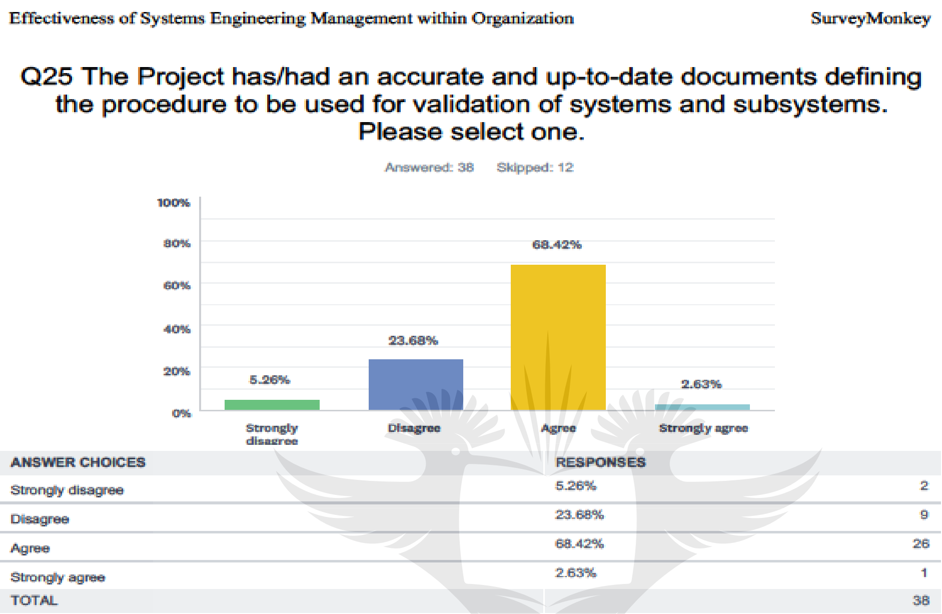
Answered: 39 Skipped: 11

ANSWER CHOICES	RESPONSES	
Strongly disagree	0.00%	0
Disagree	5.13%	2
Agree	51.28%	20
Strongly agree	43.59%	17
TOTAL		39

Figure 41; Depicting Respondents Assertion of SE Activity Related to Systems Architecture

7.3.7 VALIDATION

The results of the organization’s systems engineering activities related to the Validation process group is shown in the figure 42-43 below. Generally the respondents agree to have employed the Validation systems engineering process activities with 71.05% and 89.23% of the respondents agreeing to have employed the Validation process group of systems engineering activities of questions Q25 and 26 respectively. This make up for an average of 80.14% of respondents agree to employ the Validation set of systems engineering process activities. This amounts to capability maturity level of 4.

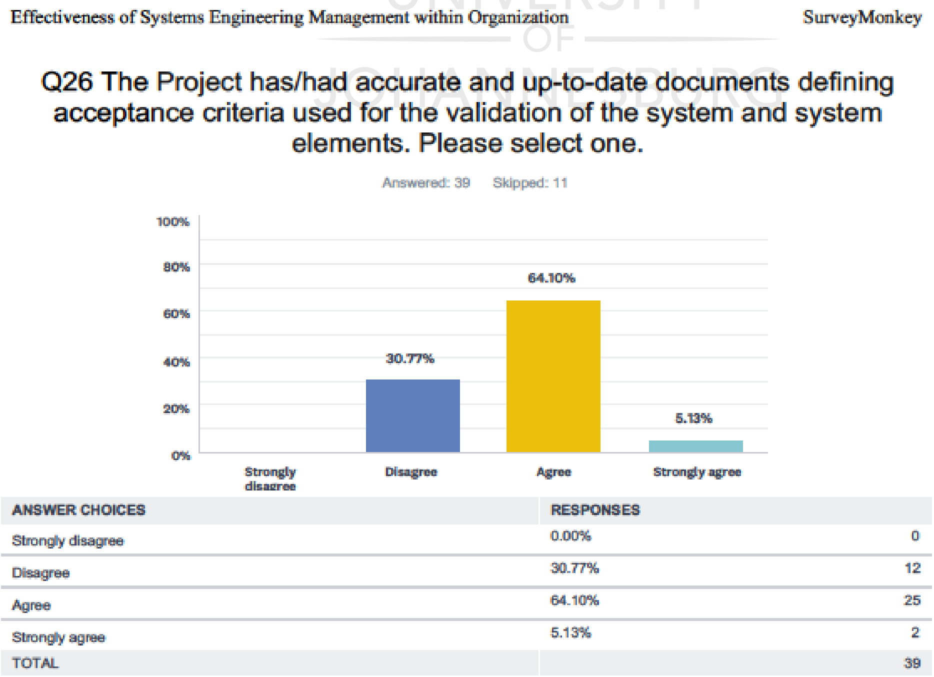

Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q25 The Project has/had an accurate and up-to-date documents defining the procedure to be used for validation of systems and subsystems. Please select one.

Answered: 38 Skipped: 12

ANSWER CHOICES	RESPONSES	
Strongly disagree	5.26%	2
Disagree	23.68%	9
Agree	68.42%	26
Strongly agree	2.63%	1
TOTAL		38

Figure 42: Depicting Respondents Assertion of SE Activity Related to Validation


Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q26 The Project has/had accurate and up-to-date documents defining acceptance criteria used for the validation of the system and system elements. Please select one.

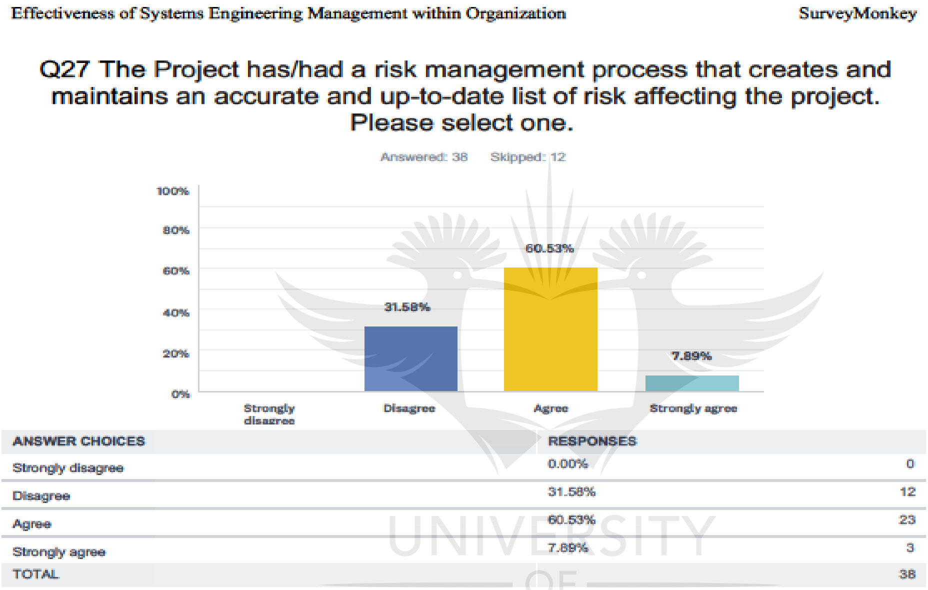
Answered: 39 Skipped: 11

ANSWER CHOICES	RESPONSES	
Strongly disagree	0.00%	0
Disagree	30.77%	12
Agree	64.10%	25
Strongly agree	5.13%	2
TOTAL		39

Figure 43: Depicting Respondents Assertion of SE Activity Related to Validation

7.3.8 RISK MANAGEMENT

The results of the organization's systems engineering activities related to the Validation process group is shown in the figure 44-45 below. Generally the respondents agree to have employed the Validation systems engineering process activities with 71.05% and 89.23% of the respondents agreeing to have employed the Validation process group of systems engineering activities of questions Q25 and 26 respectively. This make up for an average of 80.14% of respondents agree to employ the Validation set of systems engineering process activities. This amounts to capability maturity level of 4.



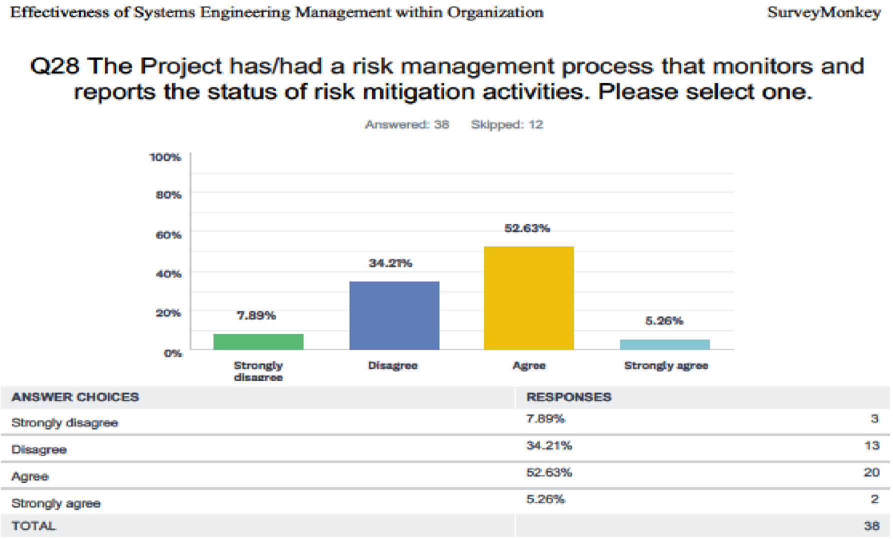
Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q27 The Project has/had a risk management process that creates and maintains an accurate and up-to-date list of risk affecting the project. Please select one.

Answered: 38 Skipped: 12

ANSWER CHOICES	RESPONSES	
Strongly disagree	0.00%	0
Disagree	31.58%	12
Agree	60.53%	23
Strongly agree	7.89%	3
TOTAL		38

Figure 44: Depicting Respondents Assertion of SE Activity Related to Risk Management



Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q28 The Project has/had a risk management process that monitors and reports the status of risk mitigation activities. Please select one.

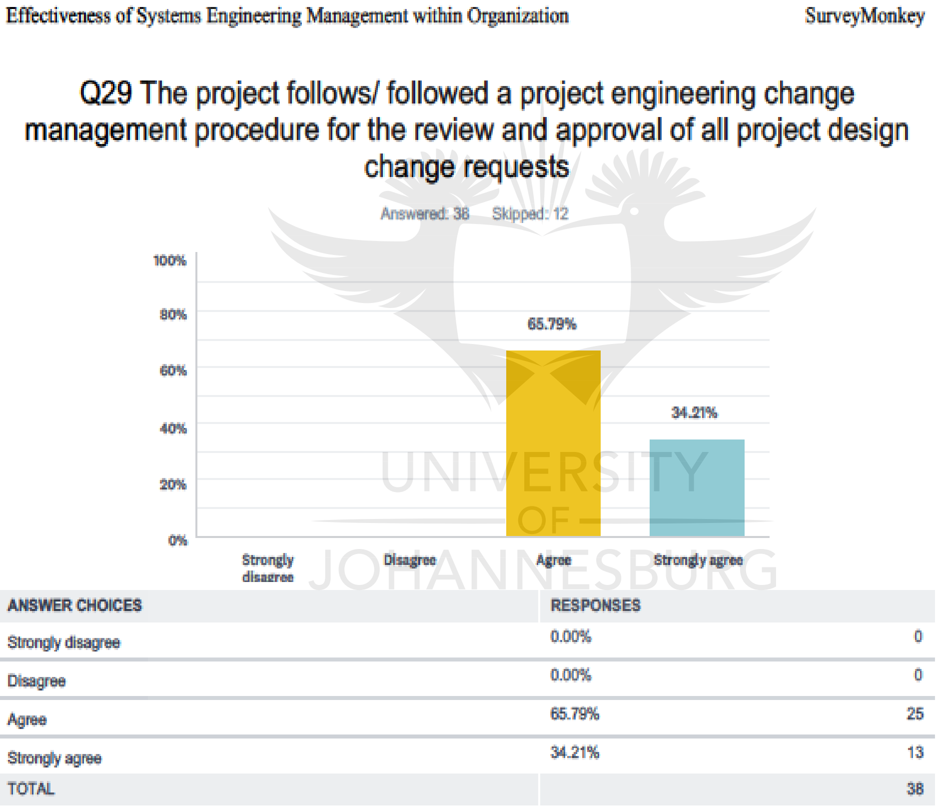
Answered: 38 Skipped: 12

ANSWER CHOICES	RESPONSES	
Strongly disagree	7.89%	3
Disagree	34.21%	13
Agree	52.63%	20
Strongly agree	5.26%	2
TOTAL		38

Figure 45: Depicting Respondents Assertion of SE Activity Related to Risk Management

7.3.9 CONFIGURATION MANAGEMENT

The results of the organization’s systems engineering activities related to the Configuration Management process group is shown in the figure 46-48 below. Generally the respondents agree to have employed the Configuration Management systems engineering management activities with 100%, 92.15 and 97.38% of the respondents agreeing to have employed the Configuration Management process group of systems engineering activities of questions Q29, 30 and 31 respectively. This make up for an average of 96.5% of respondents agree to employ the Configuration Management set of systems engineering management activities. This amounts to capability maturity level of 5.



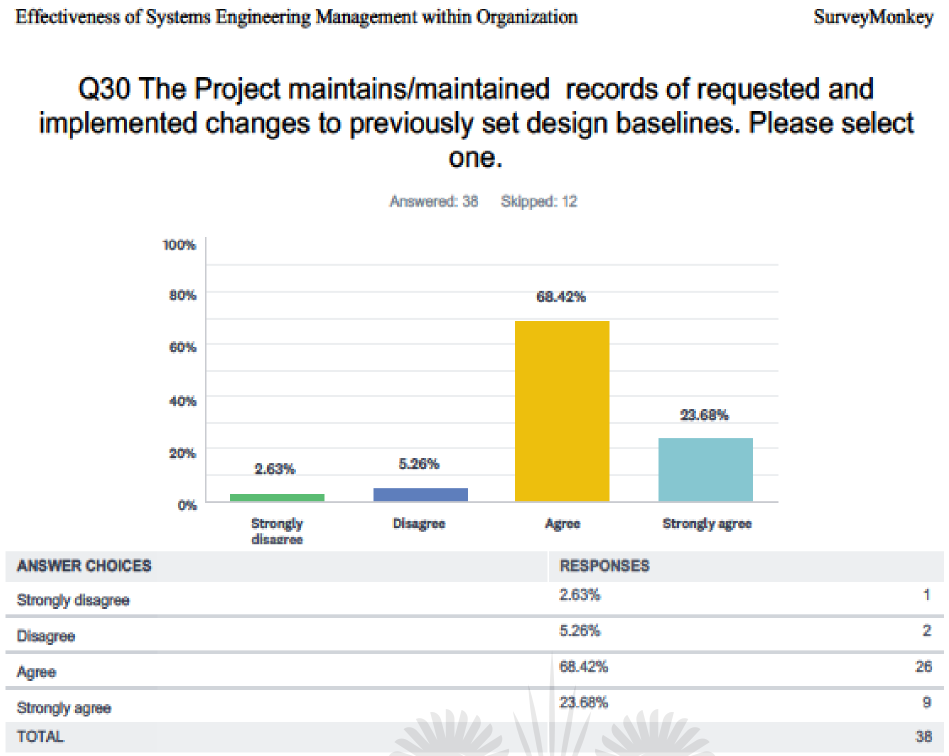
Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q29 The project follows/ followed a project engineering change management procedure for the review and approval of all project design change requests

Answered: 38 Skipped: 12

ANSWER CHOICES	RESPONSES	
Strongly disagree	0.00%	0
Disagree	0.00%	0
Agree	65.79%	25
Strongly agree	34.21%	13
TOTAL		38

Figure 46: Depicting Respondents Assertion of SE Activity Related to Configuration Management



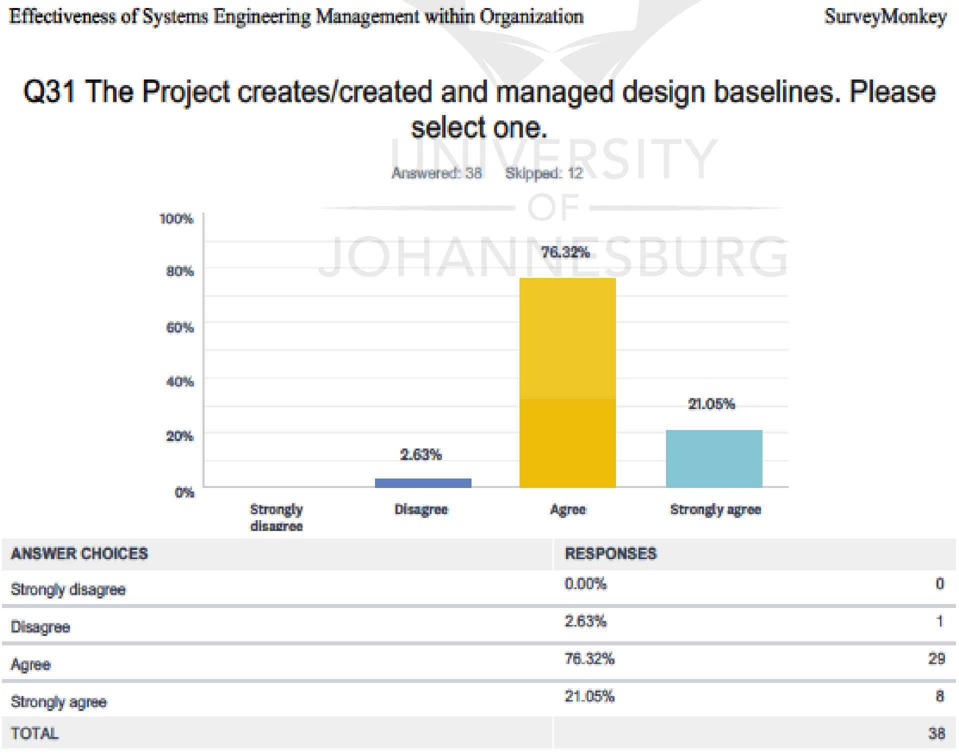
Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q30 The Project maintains/maintained records of requested and implemented changes to previously set design baselines. Please select one.

Answered: 38 Skipped: 12

ANSWER CHOICES	RESPONSES	
Strongly disagree	2.63%	1
Disagree	5.26%	2
Agree	68.42%	26
Strongly agree	23.68%	9
TOTAL		38

Figure 47: Depicting Respondents Assertion of SE Activity Related to Configuration Management



Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q31 The Project creates/created and managed design baselines. Please select one.

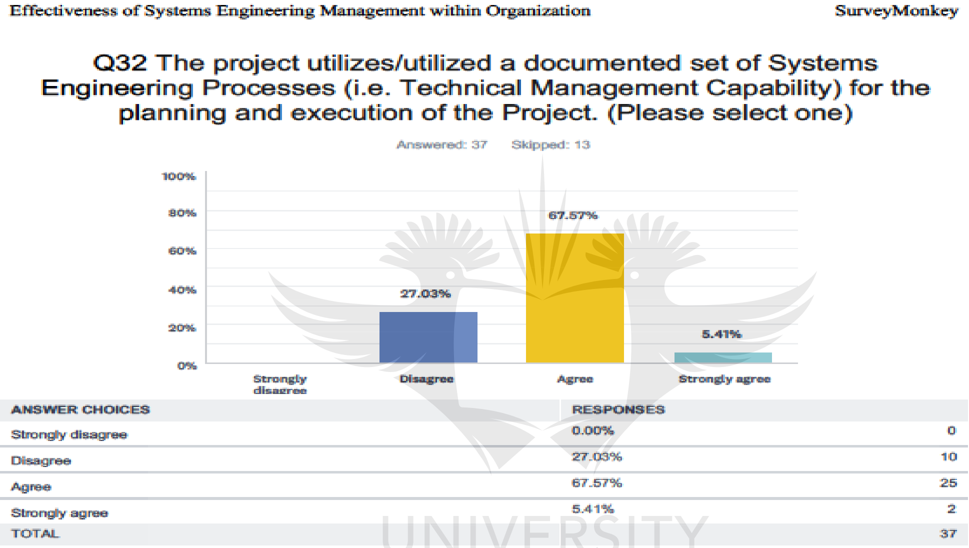
Answered: 38 Skipped: 12

ANSWER CHOICES	RESPONSES	
Strongly disagree	0.00%	0
Disagree	2.63%	1
Agree	76.32%	29
Strongly agree	21.05%	8
TOTAL		38

Figure 48: Depicting Respondents Assertion of SE Activity Related to Configuration Management

7.3.10 PROJECT PLANNING

The results of the organization's systems engineering activities related to the Project Planning process group is shown in the figure 49-51 below. Generally the respondents agree to have employed the Project Planning systems engineering management activities with 72.98%, 71.16% and 94.21% of the respondents agreeing to have employed the Project Planning process group of systems engineering activities of questions 32, 33 and 34 respectively. This make up for an average of 80% of respondents agree to employ the Project Planning set of systems engineering management activities. This amounts to capability maturity level of 4.



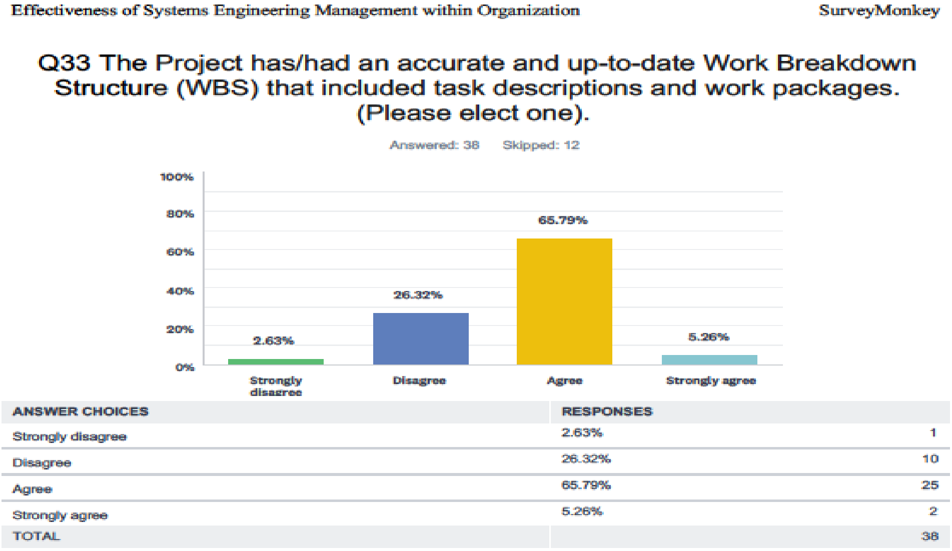
Effectiveness of Systems Engineering Management within Organization — SurveyMonkey

Q32 The project utilizes/utilized a documented set of Systems Engineering Processes (i.e. Technical Management Capability) for the planning and execution of the Project. (Please select one)

Answered: 37 Skipped: 13

ANSWER CHOICES	RESPONSES	
Strongly disagree	0.00%	0
Disagree	27.03%	10
Agree	67.57%	25
Strongly agree	5.41%	2
TOTAL		37

Figure 49: Depicting Respondents Assertion of SE Activity Related to Project Planning



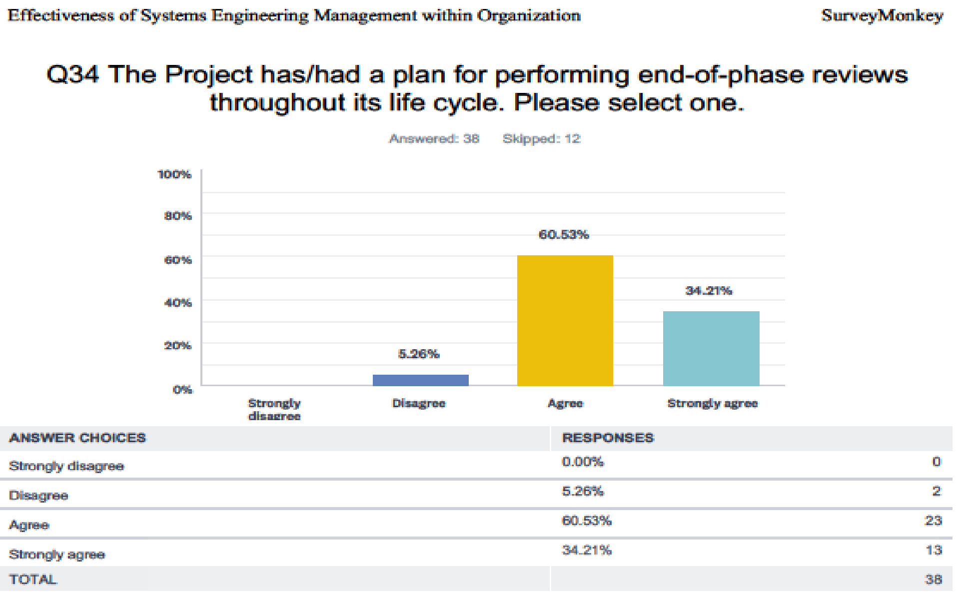
Effectiveness of Systems Engineering Management within Organization — SurveyMonkey

Q33 The Project has/had an accurate and up-to-date Work Breakdown Structure (WBS) that included task descriptions and work packages. (Please elect one).

Answered: 38 Skipped: 12

ANSWER CHOICES	RESPONSES	
Strongly disagree	2.63%	1
Disagree	26.32%	10
Agree	65.79%	25
Strongly agree	5.26%	2
TOTAL		38

Figure 50: Depicting Respondents Assertion of SE Activity Related to Project Planning



Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q34 The Project has/had a plan for performing end-of-phase reviews throughout its life cycle. Please select one.

Answered: 38 Skipped: 12

ANSWER CHOICES	RESPONSES	
Strongly disagree	0.00%	0
Disagree	5.26%	2
Agree	60.53%	23
Strongly agree	34.21%	13
TOTAL		38

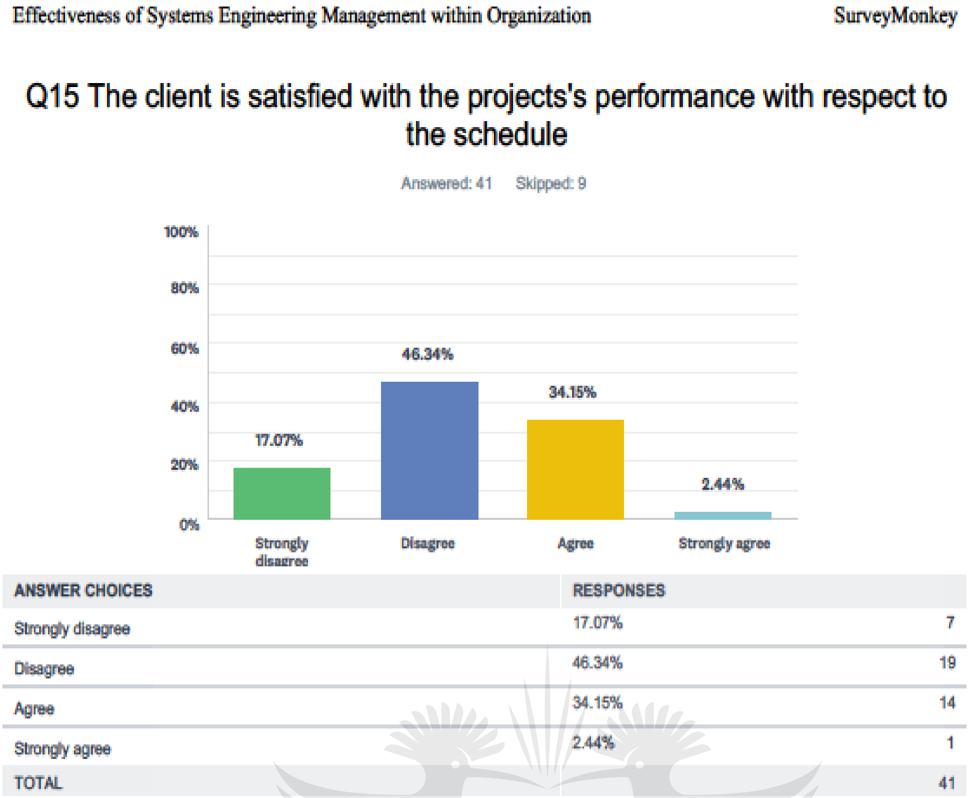
Figure 51: Depicting Respondents Assertion of SE Activity Related to Project Planning

7.4 PROJECT PERFOMANCE

The literature review of the mini research paper has confirmed the measure of project success as having met project schedule, budget and technical requirements. Based on the results of the first two questions of the mini research paper, the immediate thought is that the implementation of the Organization's SEM model produces benefit to the organization in respect of project performance of meeting project schedule, cost and technical requirements.

The respondents were asked to assert on a Likert of scale of 4 their level of agreement. The results are presented in figure below.

The results pertaining to project performance with respect to meeting schedule is depicted in figure 52 wherein respondents who strongly dis-agree account for 17% and 46.3% of those who disagree. This accounts for 63% respondents who are in disagreement that projects performed well in meeting project performance in respect of schedule. Whereas a total of 36.59% of respondents agree that the projects performed with meeting the project performance with respect to schedule. It can thus be concluded that the organization's SEM model does not produce benefits to the organization in project performance in respect to meeting project schedule.



Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q15 The client is satisfied with the projects's performance with respect to the schedule

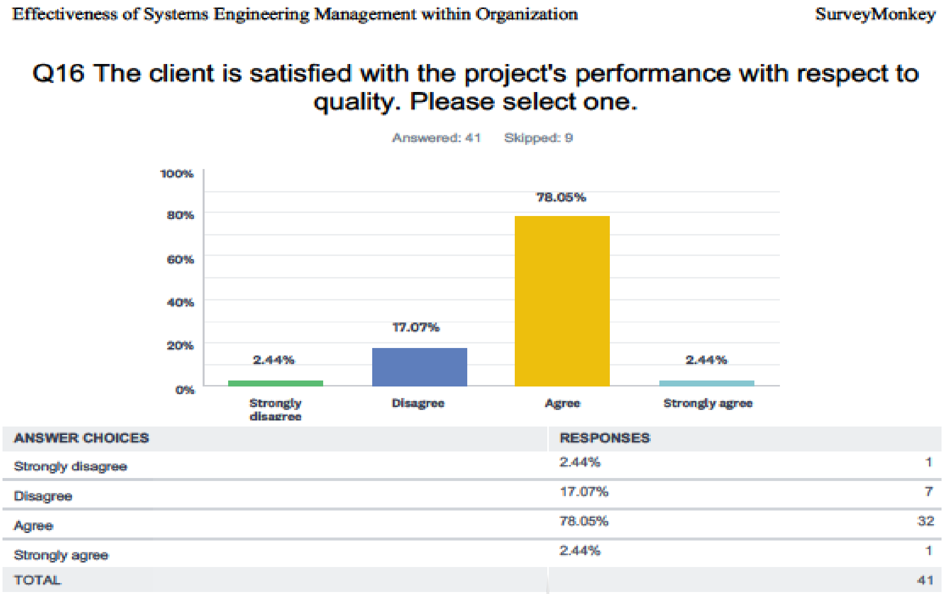
Answered: 41 Skipped: 9

ANSWER CHOICES	RESPONSES	
Strongly disagree	17.07%	7
Disagree	46.34%	19
Agree	34.15%	14
Strongly agree	2.44%	1
TOTAL		41

Figure 52: Depicting Respondents Assertion of Project Performance in Respect of Schedule

The results pertaining to project performance with respect to meeting quality is depicted in figure 53 wherein respondents who strongly dis-agree account for 2.44% and 17.07% of those who disagree. This accounts for 19.51% respondents who are in disagreement that projects performed well in meeting project performance in respect of quality. Whereas a total of 80.49% of respondents agree that the projects performed with meeting the project performance with respect to quality. It can thus be concluded that the organization's SEM model does produce benefits to the organization in project performance in respect to meeting project quality.

The results pertaining to project performance with respect to meeting technical requirements is depicted in figure 54 wherein respondents who strongly dis-agree account for 2.44% and 14.63% of those who disagree. This accounts for 17.07% of respondents who are in disagreement that projects performed well in meeting project technical requirements. Whereas a total of 82.93% of respondents agree that the projects performed with meeting the project performance with respect to technical requirements. It can thus be concluded that the organization's SEM model does produce benefits to the organization in project performance in respect to meeting project technical requirements.



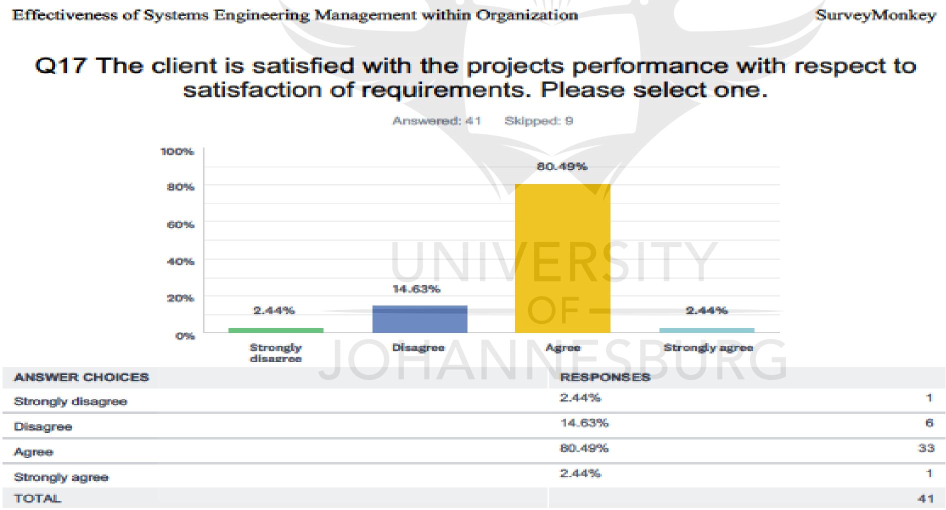
Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q16 The client is satisfied with the project's performance with respect to quality. Please select one.

Answered: 41 Skipped: 9

ANSWER CHOICES	RESPONSES	
Strongly disagree	2.44%	1
Disagree	17.07%	7
Agree	78.05%	32
Strongly agree	2.44%	1
TOTAL		41

Figure 53: Depicting Respondents Assertion of Project Performance in Respect to Quality



Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q17 The client is satisfied with the projects performance with respect to satisfaction of requirements. Please select one.

Answered: 41 Skipped: 9

ANSWER CHOICES	RESPONSES	
Strongly disagree	2.44%	1
Disagree	14.63%	6
Agree	80.49%	33
Strongly agree	2.44%	1
TOTAL		41

Figure 54: Depicting Respondents Assertion of Project Performance in Respect of Satisfying Project Requirements

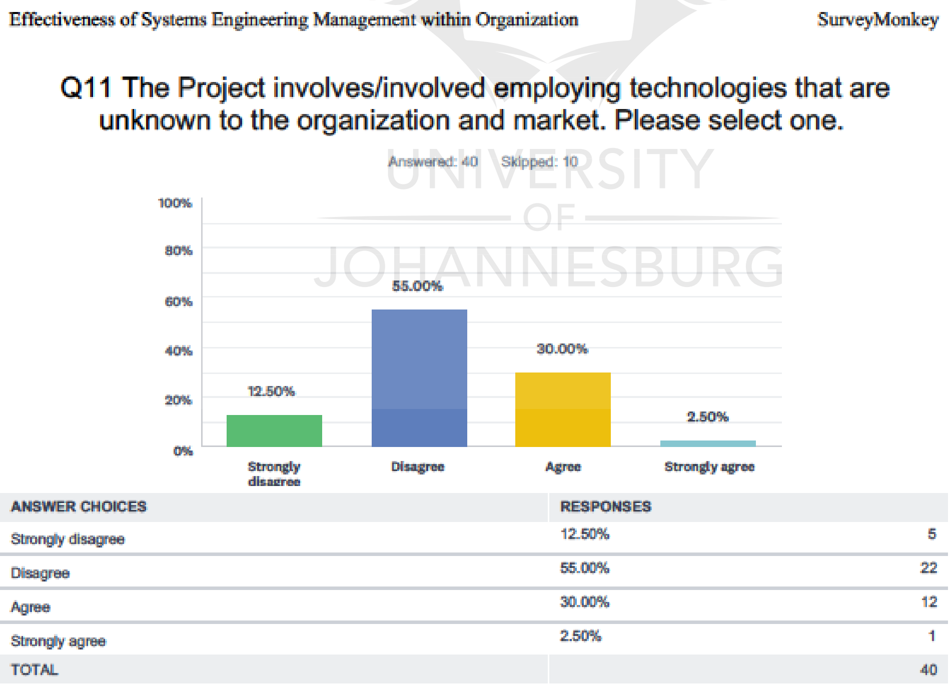
7.5 TYPE OF INNOVATION

What has been established as part of the literature review is that the difficulty in designing complex engineering projects does not just arise from simply the technical complexity but also in the design process practices. Also that transforming design processes from one to another does not necessary lead to success but depends on the context of practice; that is on the prevailing competitive and technological circumstances of the organization.

The results to the nature of technological advancement employed within the organization are depicted in figure 55-58 below. A total of 67.5% of respondents disagree that the organization employs technologies that are not known to the organization or the general market. This result is further confirmed in figure 57 wherein 80% of respondent disagree that the organization is characterized by technological uncertainties.

Further, figure 56 shows that a total of 84.62 of respondents agree that the organization does employ technologies that are known to the organization and the market at large. The result is further correlated in figure 58 wherein 82.5% of respondents agree that the organization is faced with a high degree of technological certainty.

It can thus be concluded that the organization's design environment is characterized by a high degree of technological certainties and can be considered as incremental.



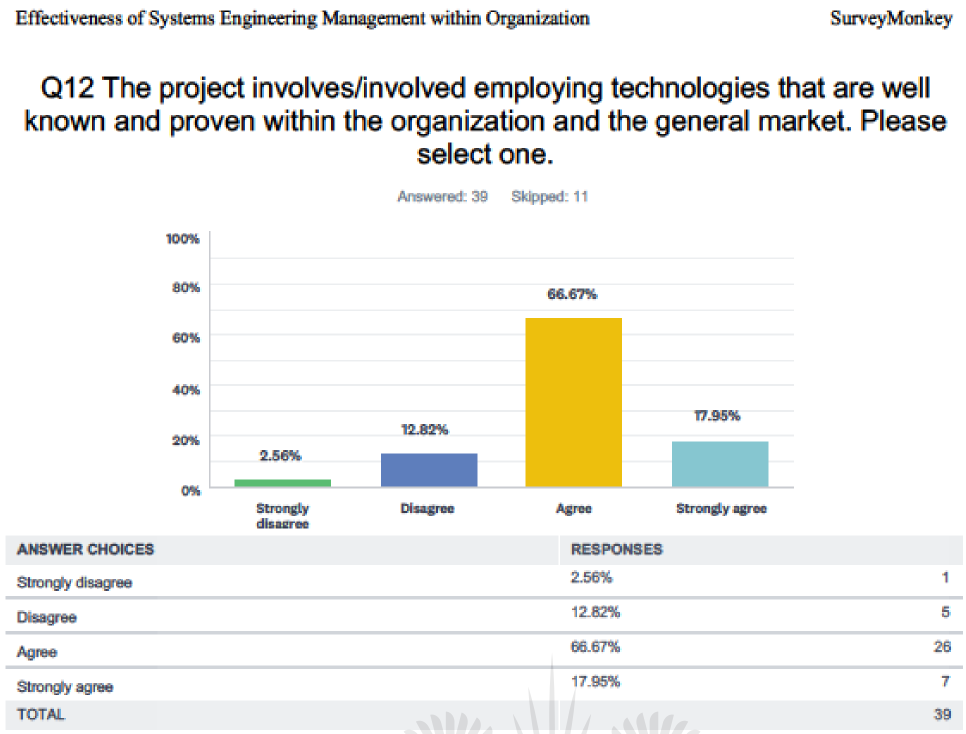
Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q11 The Project involves/involved employing technologies that are unknown to the organization and market. Please select one.

Answered: 40 Skipped: 10

ANSWER CHOICES	RESPONSES	
Strongly disagree	12.50%	5
Disagree	55.00%	22
Agree	30.00%	12
Strongly agree	2.50%	1
TOTAL		40

Figure 55: Depicting Respondents Assertion to Degree of Technological Uncertainty within the Organization

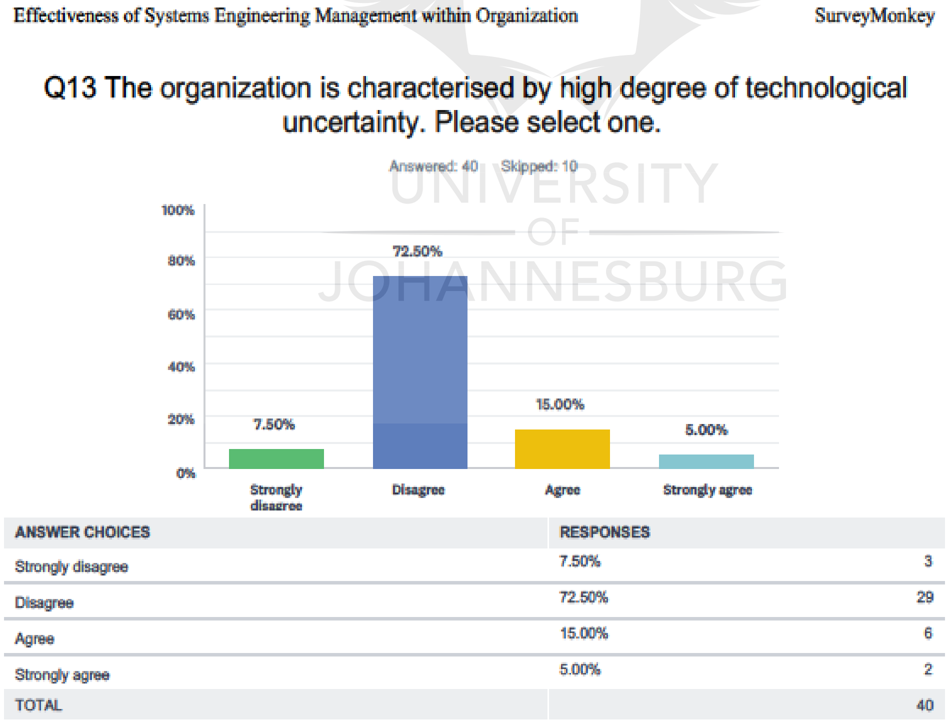

Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q12 The project involves/involved employing technologies that are well known and proven within the organization and the general market. Please select one.

Answered: 39 Skipped: 11

ANSWER CHOICES	RESPONSES	
Strongly disagree	2.56%	1
Disagree	12.82%	5
Agree	66.67%	26
Strongly agree	17.95%	7
TOTAL		39

Figure 56: Depicting Respondents Assertion to Degree of Technological Certainty within the Organization

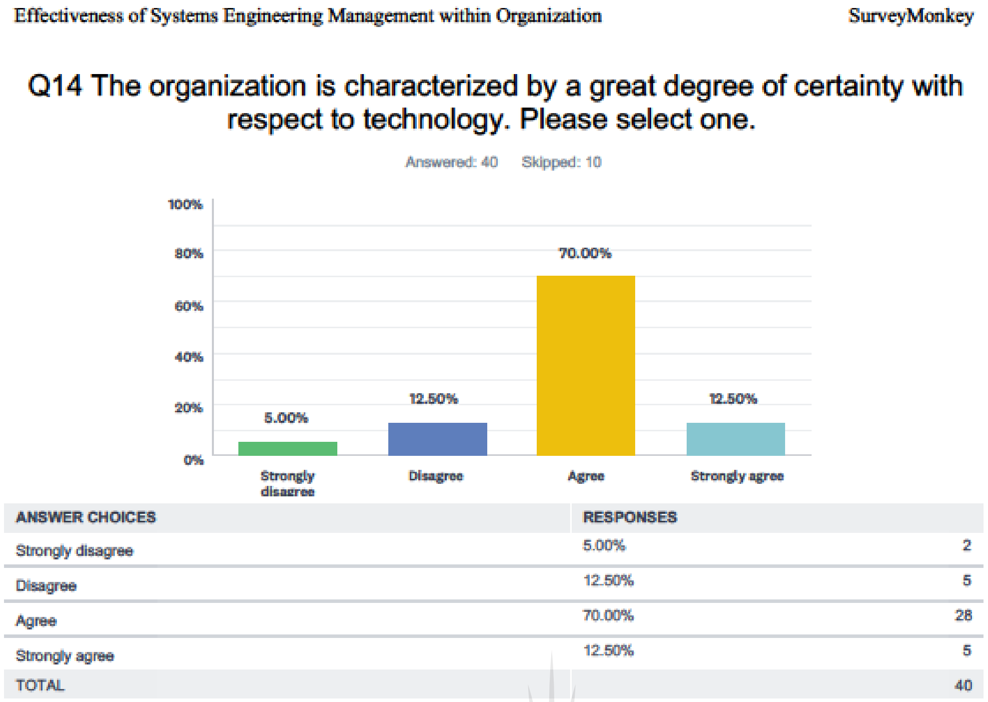

Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q13 The organization is characterised by high degree of technological uncertainty. Please select one.

Answered: 40 Skipped: 10

ANSWER CHOICES	RESPONSES	
Strongly disagree	7.50%	3
Disagree	72.50%	29
Agree	15.00%	6
Strongly agree	5.00%	2
TOTAL		40

Figure 57: Depicting Respondents Assertion to Degree of Technological Uncertainty within the Organization



Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q14 The organization is characterized by a great degree of certainty with respect to technology. Please select one.

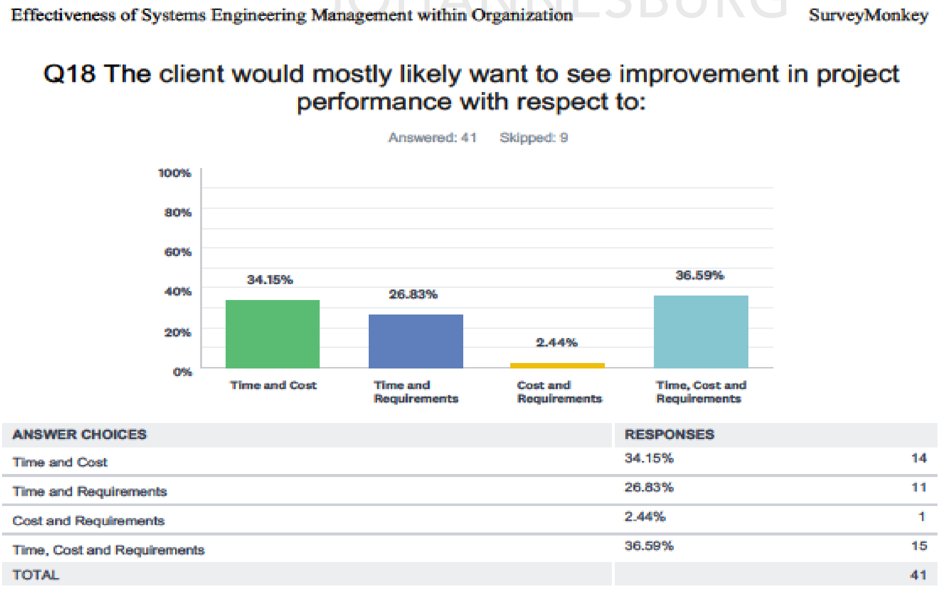
Answered: 40 Skipped: 10

ANSWER CHOICES	RESPONSES	
Strongly disagree	5.00%	2
Disagree	12.50%	5
Agree	70.00%	28
Strongly agree	12.50%	5
TOTAL		40

Figure 58: Depicting Respondents Assertion to Degree of Technological Certainty within the Organization

7.6 IMPROVEMENTS TO PROJECT PERFOMANCE

The objective is to understand what areas of project performance improvements are required within the organization. In the below figure it can be interpolated that project performance in respect to time is of significance to the organization.



Effectiveness of Systems Engineering Management within Organization SurveyMonkey

Q18 The client would mostly likely want to see improvement in project performance with respect to:

Answered: 41 Skipped: 9

ANSWER CHOICES	RESPONSES	
Time and Cost	34.15%	14
Time and Requirements	26.83%	11
Cost and Requirements	2.44%	1
Time, Cost and Requirements	36.59%	15
TOTAL		41

Figure 59: Depicting Respondents Assertion to Areas that Require Improvement to Project Performance

7.7 CONCLUSION

The results have shown the organization's systems engineering management model compares with systems engineering best practices. Furthermore the results to the systems engineering management capability maturity of the organization's SEM model have shown that the process is being implemented during the ECM projects with an average capability maturity of 4.

It was also determined that even the organization's SEM model is being implemented; the model does not produce benefits to the organization project performance in respect to schedule. Further it was determined that area of meeting schedule performance is the areas that require improvement. Lastly the results also showed that the organization is characterized by high level technological certainty.

CHAPTER 8: HYPOTHESIS TESTING

8.1 INTRODUCTION

This section of the mini dissertation is concerned with answering questions of the research paper by accepting or rejecting the proposed hypothesis based on the findings of the results presented in Chapter 7. Further the results obtained in Chapter 7 are tested for Statistical Significance by using the chi-square test and fisher's exact test to validate the research results.

8.2 COMPARISON OF ORGANIZATION'S SEM MODEL TO SEMBASE

Sections 7.1 of the results chapter of this research paper have demonstrated that there exists sufficient documentation to show that the organization's SEM model for design development is comparable to Blanchard's development process. SEMBASE which is based Blanchard's development process is therefore comparable with the organization's design development process. This allows us to answer the first question of the mini research paper:

Q1: "How does the Organization's SEM model compare to SEM best practice models?"

With the null and alternate hypothesis statement as follows:

- **$1H_o$**: The Organization's SEM model compares with systems engineering management best practices.
- **$1H_a$**: The Organization's SEM model does not compare with systems engineering management best practices.

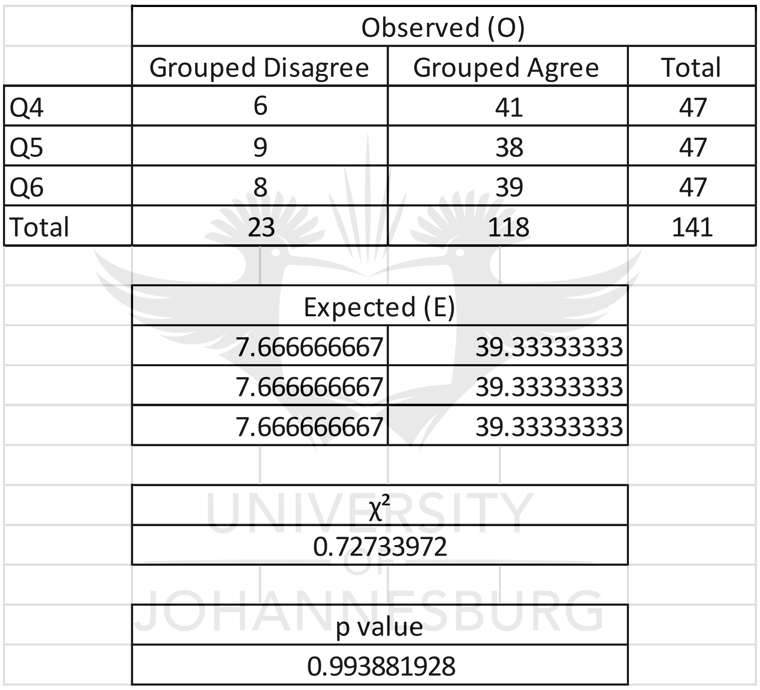
Therefore based on the results and discussion of section 7.1, the alternate hypothesis is rejected and the null hypothesis is accepted.

Therefore the organization's development model compares with SE best practices.

8.3 IMPLEMENTATION OF ORGANIZATON’S SEM MODEL

As part of addressing the research objectives and to answer the second question of the research dissertation of whether the development model gets implemented during ECM projects, quantitative methods in the form of questionnaire was completed. The questionnaire was designed to solicit the information regarding the extent to which the organization’s development model gets implemented during ECM projects.

8.3.1 REQUIREMENTS MANAGEMENT



	Observed (O)		
	Grouped Disagree	Grouped Agree	Total
Q4	6	41	47
Q5	9	38	47
Q6	8	39	47
Total	23	118	141

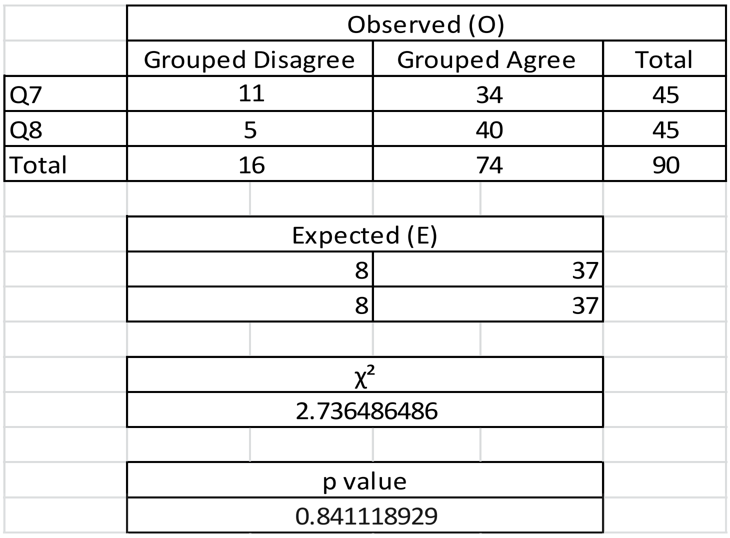
Expected (E)	
7.666666667	39.33333333
7.666666667	39.33333333
7.666666667	39.33333333

χ^2
0.72733972

p value
0.993881928

The p value is greater than 0.05 and thereby confirms that elements of the requirements management product group does get implemented during the ECM projects.

8.3.2 REQUIREMENTS DEVELOPMENT



	Observed (O)		
	Grouped Disagree	Grouped Agree	Total
Q7	11	34	45
Q8	5	40	45
Total	16	74	90

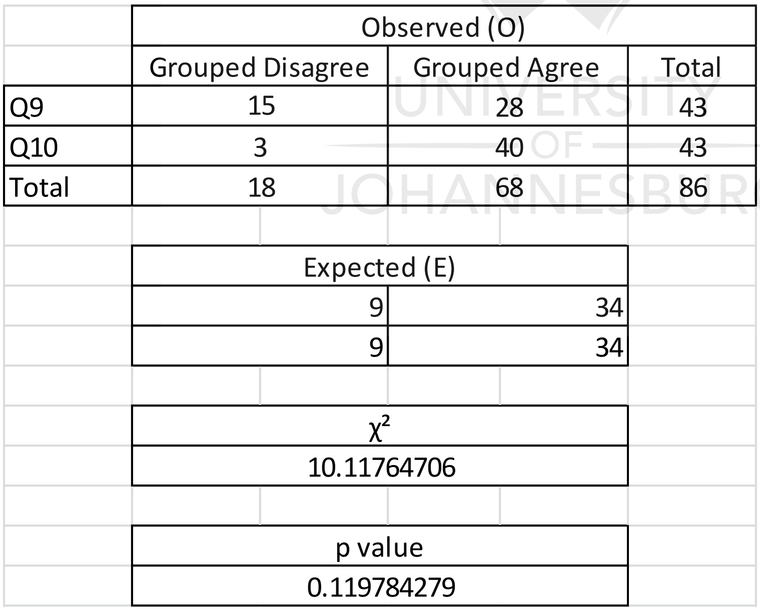
Expected (E)	
8	37
8	37

χ^2
2.736486486

p value
0.841118929

The p value is greater than 0.05 and thereby confirms that elements of the requirements development product group does get implemented during the ECM projects

8.3.3 VERIFICATION



	Observed (O)		
	Grouped Disagree	Grouped Agree	Total
Q9	15	28	43
Q10	3	40	43
Total	18	68	86

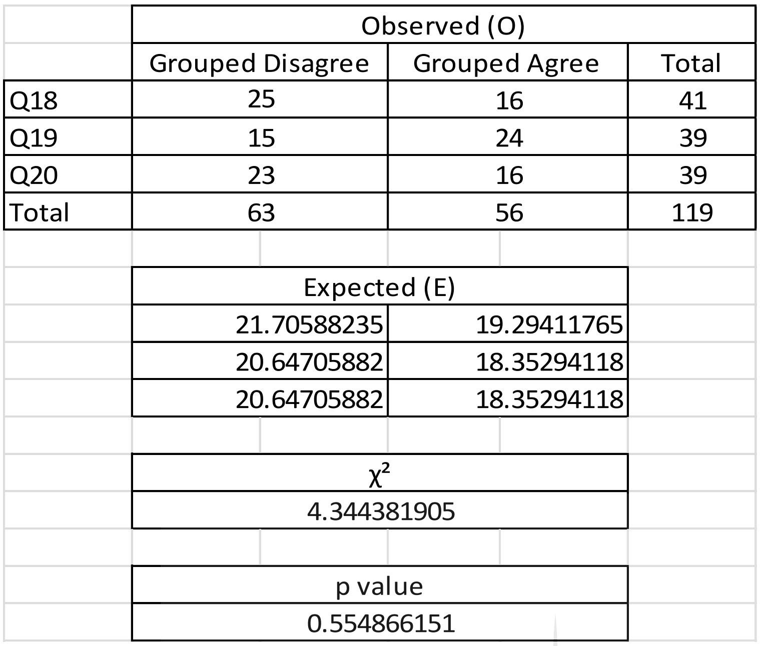
Expected (E)	
9	34
9	34

χ^2
10.11764706

p value
0.119784279

The p value is greater than 0.05 and thereby confirms that elements of the verification product group does get implemented during the ECM projects

8.3.4 PROJECT CONTROLS AND MANAGEMENT



	Observed (O)		
	Grouped Disagree	Grouped Agree	Total
Q18	25	16	41
Q19	15	24	39
Q20	23	16	39
Total	63	56	119

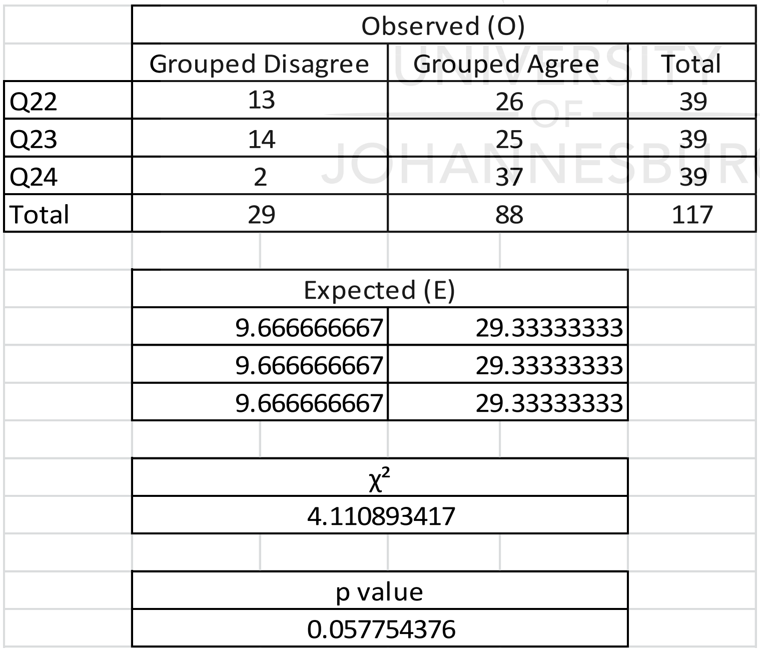
Expected (E)	
21.70588235	19.29411765
20.64705882	18.35294118
20.64705882	18.35294118

χ²
4.344381905

p value
0.554866151

The p value is greater than 0.05 and thereby confirms that elements of project controls and management product group does get implemented during the ECM projects

8.3.5 SYSTEMS ARCHITECTURE



	Observed (O)		
	Grouped Disagree	Grouped Agree	Total
Q22	13	26	39
Q23	14	25	39
Q24	2	37	39
Total	29	88	117

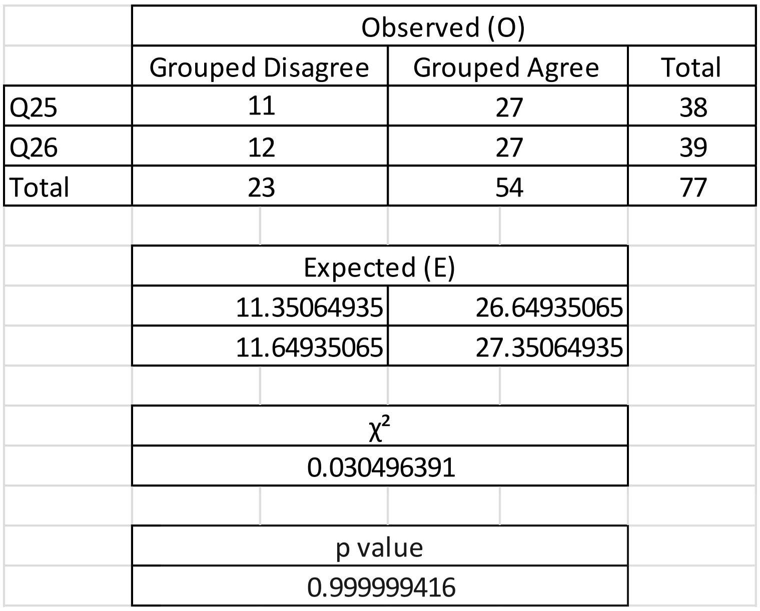
Expected (E)	
9.666666667	29.33333333
9.666666667	29.33333333
9.666666667	29.33333333

χ²
4.110893417

p value
0.057754376

The p value is greater than 0.05 and thereby confirms that elements of the systems architecture product group does get implemented during the ECM projects

8.3.6 VALIDATION



	Observed (O)		
	Grouped Disagree	Grouped Agree	Total
Q25	11	27	38
Q26	12	27	39
Total	23	54	77

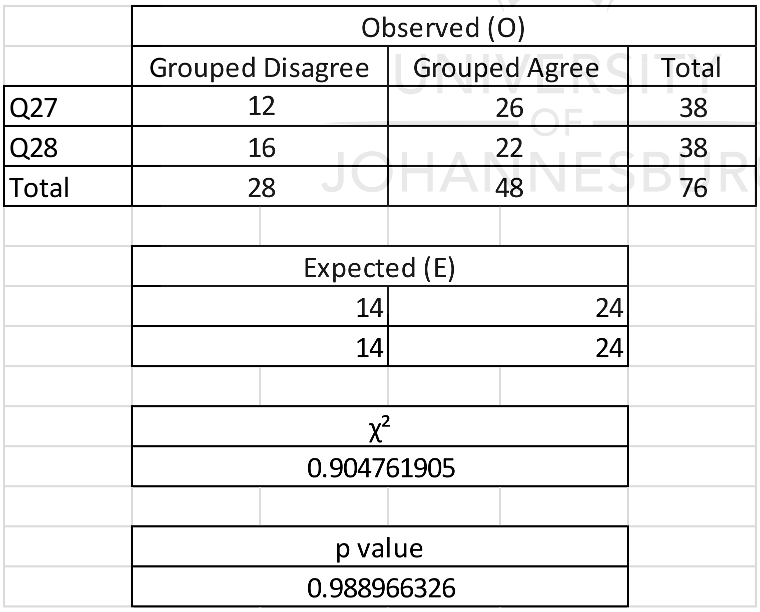
Expected (E)	
11.35064935	26.64935065
11.64935065	27.35064935

χ²
0.030496391

p value
0.999999416

The p value is greater than 0.05 and thereby confirms that elements of the validation product group does get implemented during the ECM projects

8.3.7 RISK MANAGEMENT



	Observed (O)		
	Grouped Disagree	Grouped Agree	Total
Q27	12	26	38
Q28	16	22	38
Total	28	48	76

Expected (E)	
14	24
14	24

χ²
0.904761905

p value
0.988966326

The p value is greater than 0.05 and thereby confirms that elements of risk management product group does get implemented during the ECM projects.

8.3.8 CONFIGURATION MANAGEMENT

	Observed (O)		
	Grouped Disagree	Grouped Agree	Total
Q29	0	38	38
Q30	3	35	38
Q31	1	37	38
Total	4	110	114

Expected (E)	
1.333333333	36.66666667
1.333333333	36.66666667
1.333333333	36.66666667

χ^2
3.540909091

p value
0.726966785

Fishers p value
0.995779996

The p value is greater than 0.05 and thereby confirms that elements of configuration management product group does get implemented during the ECM projects

8.3.9 8.2.9 PROJECT PLANNING

	Observed (O)		
	Grouped Disagree	Grouped Agree	Total
Q32	10	27	37
Q33	11	27	38
Q34	2	36	38
Total	23	90	113

Expected (E)	
7.530973451	29.46902655
7.734513274	30.26548673
7.734513274	30.26548673

χ^2
2.74734059

p value
0.231902069

The p value is greater than 0.05 and thereby confirms that elements of the project planning product group does get implemented during the ECM projects.

8.4 PROJECT PERFOMANCE

8.4.1 SCHEDULE

	Observed (O)		
	Grouped Disagree	Grouped Agree	Total
Q15	26	15	41
Q16	8	33	41
Q17	9	34	43
Total	43	82	125

Expected (E)	
14.104	26.896
14.104	26.896
14.792	28.208

χ^2
15.29522156

p value
0.001580977

The p value is less than 0.05 and thereby confirms that the organizations development model does not provide benefits to the organization during ECM projects.

8.5 TYPE OF INNOVATION

8.5.1 RADICAL INNOVATION

	Observed (O)		
	Grouped Disagree	Grouped Agree	Total
Q11	28	13	41
Q13	32	10	42
Total	60	23	83

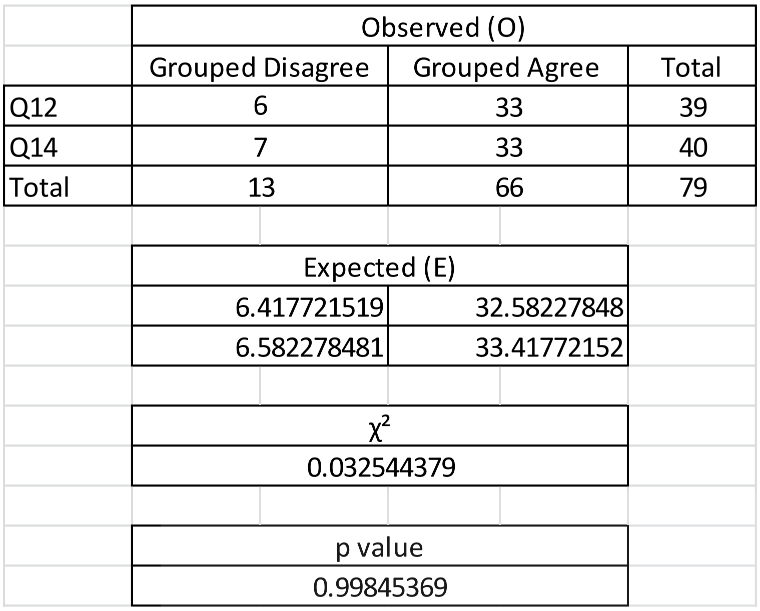
Expected (E)	
29.63855422	11.36144578
30.36144578	11.63855422

χ^2
0.326899965

p value
0.95489242

The p value is greater than 0.05 and thereby confirms that the organization is not characterized by high degree of technological uncertainty.

8.5.2 INCREMENTAL INNOVATION



	Observed (O)		
	Grouped Disagree	Grouped Agree	Total
Q12	6	33	39
Q14	7	33	40
Total	13	66	79

Expected (E)	
6.417721519	32.58227848
6.582278481	33.41772152

χ^2
0.032544379

p value
0.99845369

The p value is greater than 0.05 and thereby confirms that the organization is characterized by high degree of technological certainty.

CHAPTER 9: DISCUSSIONS

9.1 INTRODUCTION

Chapter 1 of this mini research dissertation has shown that the organization's current systems engineering and development process does not provide benefits to the organization as a great number of the ECM projects are not developed within the specified and agreed time. The chapter further proposed research questions that have to be answered in order to pinpoint where the problem might be.

9.2 ORGANIZATION'S SEM COMPARISON TO SEM BEST PRACTICES

The results of section 8.1 have shown that the organization's systems engineering management practices compares very well with systems engineering management best practices. Therefore the hull hypothesis to the first question of the minor desertion is rejected with the conclusion that the organization's current SEM model has the SEM model best practice as bases. This is expected given the substantial amount of documentation that exists that discusses the organization's SEM model. Furthermore these documentations also forms part of the management policy which every employee is expected to follow and comply with. There are also well-defined methodologies used during the development process that bring about baselines and project development milestones. This amount of governance guidelines had to be informed by some form of best practice and thus not surprising that the results have shown to be the case.

9.3 SYSTEMS ENGINEERING MANAGEMENT CAPABILITY MATURITY

Given that the organization's SEM model compares very well with industry best practices as confirmed in question 1 of the minor dissertation, the next step was to determine whether the organization's SEM model is being implemented during project. The second question of the mini research dissertation was to establish if the problem could be in the implementation of systems engineering process during ECM process by assessing the systems engineering maturity levels within the organization. The results regarding the systems engineering management maturity levels as measured in the sample population of the organization's Generation and Plant employees have shown that the SEM model is being implemented during the ECM process. Therefore the null hypothesis to the second question of the minor dissertation is rejected.

9.4 BENEFITS OF ORGANIZATION'S SEM MODEL

The results obtained within section 8.1 and 8.2 of the research dissertation have shown that the organizations systems engineering development process compares very well with systems engineering best practices and also that the organization's systems engineering practices are well practiced or implemented within the ECM projects.

Having obtained positive results to the first two questions of the mini dissertation, Question 3 is intended to establish if there are indeed problems in delivering ECM projects and thus the development process. Section 8.3 has shown that the systems engineering development process does not provide benefits to the organization despite the fact that the process compares very well with best practices and also that organizations maturity level are advanced. Thus the null hypothesis to the 3rd question of the minor dissertation is accepted.

Based on the fact the organization's SEM model compares does not bring about benefits to the organization despite the fact that the model compares very well with SEM best practices and that the model gets implemented during projects suggests that the adopted development process is not benefiting of the organization's environment.

9.5 CONCURRENT ENGINEERING AS SEM MODEL

The literature review within the mini research paper have shown that concurrent engineering (CE) is not necessary a recipe for success. If the objectives are to reduce development time in the context of high uncertainty and complexity, then CE is not advisable. However if the objective is to reduce development time in the context of low uncertainty and complexity, the CE is advisable. The results indicate that the area of improvement within the ECM design development process is the reduction in development time and further that the organization operates in environment characterized with low uncertainty and complexity. Thus, as with the findings of the research paper literature review, the aim is in reduction in development time and carries out incremental innovation and therefore should adopt CE. Based on the above information the first of the hypothesis propose in this minor research dissertation can be supported, i.e. concurrent engineering can be more effective for the organization.

Therefore the research findings have shown that the problem is in nature rather than technical i.e. related to the development process rather implementation.

CHAPTER 10: CONCLUSION

10.1 TYPE OF INNOVATION EMPLOYED

The results to question 3 have shown that the ECM projects do not provide benefit to organization and specifically with respect to time and cost. Therefore, having confirmed that there are problems and that the problems is not in the actual process nor in the implementation, the next thing to do was determine if the problem is not type of systems development process for the type of environment that the organization operates in. This then brought about question 4 and 5 of the research dissertation.

The results to question 4 have shown that the organization is characterized by environment with low uncertainty and complexity.

10.2 INTRODUCTION

This section of the minor dissertation serves as conclusion to the minor research paper and further provides recommendations for further development in separate research paper.

10.3 CONCLUSION

The objective of the minor research dissertation was to investigate if there were any benefits and success to the organizations ECM projects with the current SEM model and whether Concurrent Engineering can prove to be more benefiting as an SEM model to the organization. Preliminary records of organization’s projects performance revealed that the current SEM model does not provide benefits to the organization.

This then brought about four (4) research questions together their respective hypothesis and null hypothesis to understand where the problem was and whether concurrent engineering can still prove as a better option for the organization.

The first question was to establish how well the organization's SEM model compares with general industry best practices to SEM. The results showed that the organization's SEM model compares very well with industry best practices. It was thus clear that the problem with the none-performance of ECM projects was not with the SEM model itself.

The second question was to establish whether the organization's SEM model does get implemented during ECM projects. The results showed that the SEM model does get implemented during ECM projects. This then led to the third question wherein it established that the current SEM model does not provide benefit to the organization.

The minor research dissertation then proceeded to establish the conditions for successful concurrent engineering SEM model and whether the organization does offer such conditions. The results showed that the organization does satisfy the conditions for the successful implementation of concurrent engineering.

Thus the problem with the none-performance of the ECM projects is that the current SEM model is not suited for the type of innovation practices within the organization and that concurrent engineering would prove to be much beneficial.

10.4 RECOMMENDATIONS

The following are recommended to further develop the study:

- The research questionnaire should be extended to a larger population of the engineering fraternity within the organization in order to establish a better understanding of the nature and magnitude of the problem to the none performance of the ECM projects.
- A SEM model which has incorporated concurrent engineering principles should be developed.
- The newly developed concurrent engineering models should then first be piloted with one of the projects to determine its effectiveness before being rolled out in the organization.

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APPENDIX A: QUESTIONARE

RETHINK. REINVENT.

UNIVERSITY
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Dear Colleagues,

You are kindly requested to participate in the research survey in a study to determine the effectiveness of the organizations Systems Engineering process in the deployment of projects.

The first section of the survey study seeks to measure and ascertain the current systems engineering process capability and maturity levels. The second section of the study establishes the effectiveness of the organizations systems engineering by gathering quantitative evidence of project performances. The last section establishes the type of innovation employed within the organization.

Please provide your most earnest answer based on your experience during the acquisition process. The questionnaire is estimated to take at least 10 minutes.

Requirements Management

1. The requirements for the project are/were approved in a formal and documented manner by relevant stakeholders. (Please select one)
2. This project performs and documents requirements impact assessments for proposed requirements changes (Please select one)
3. The project requirements are managed under a configuration control process.

Requirements Development

1. This project maintains an up-to-date requirements document (ROC) specified by the client (Please select one)
2. The project develops and maintains/maintained an up-to-date and accurate listing of all requirements derived from those specified by the client (SRD) (Please select one)

Verification

1. This project has accurate and up-to-date documents defining the procedures to be used for the test and verification of systems and system elements. (Please select one)

2. This project conducts/conducted design reviews and documents results, issues, action items, risks, and risk mitigations (Please select one)

Type of innovation

1. The project involves/involved employing a technology that was unknown to the organization and market.
2. The project involves/involved employing a technology that was well known and proven within the organization and the general market.
3. The organization is characterized by high degree of technological uncertainty
4. The organization is characterized by a great degree of certainty with respect to technology

Project Performance

1. The Client is satisfied with the project's performance with respect to the schedule
2. The client is satisfied with project's performance with respect to quality
3. The client is satisfied with respect to the projects performance with respect to satisfaction of requirements
4. The client would mostly likely want to see improvement in project performance with respect to
    a. Time & cost
    b. Time and requirements
    c. Cost and requirements
    d. Time, cost and requirements

Project Controls management

1. This project creates and manages cost and schedule baselines. (Please select one)
2. The project variance thresholds for the Cost Performance Index (CPI) and Schedule Performance Index (SPI) are defined, documented, and used to determine when corrective action is needed. (Please select one)
3. The Project utilizes project management and control tools such as the earned value management system

System Architecture

1. This project maintains/maintained an accurate and up-to-date descriptions (e.g. interface control documents, models, etc.) defining interfaces in detail. (Please select one)
2. The project documents/documented a high level design structure that is kept up to date and managed under configuration management (Please select one)
3. The project performs/performed and documented a concept design which includes alternate solutions and selection criteria

Validation

1. This project has accurate and up-to-date documents defining the procedures used for the validation of systems and system elements. (Please select one)
2. This project has accurate and up-to-date documents defining acceptance criteria used for the validation of systems and system elements. (Please select one)

Risk Management

1. This project has a risk Management process that creates and maintains an accurate and up-to-date list of risks affecting the project (e.g., risks to cost, risks to schedule, risks to performance) (Please select one)
2. This project has a Risk Management process that creates and maintains up-to-date documentation of risk mitigation plans and contingency plans for selected risks (Please select one)
3. This project has a Risk Management process that monitors and reports the status of risk mitigation activities and resources. ((Please select one)

Configuration Management

1. The project follows/ followed a project engineering change management procedure for the review and approval of all project design change requests
2. This project maintains records of requested and implemented changes to previously set design baselines. (Please select one)
3. This project creates and manages configuration baselines (e.g., functional, allocated, product). (Please select one)

Project Planning

1. The project utilizes/utilized a documented set of Systems Engineering Processes (i.e Technical Management Capability) for the planning and execution of the Project. (Please select one).
2. The Project has/had an accurate and up-to-date Work Breakdown Structure (WBS) that included task description and work package descriptions. (Please select one)
3. The project has/had a plan for the performing end-of phase reviews throughout its life cycle.

Conclusion

Is there anything else that you would like to tell us about your project or this survey?

(Please describe here)