TOWARDS A SUSTAINABLE FRAMEWORK FOR APPLICATION OF THE SYSTEMS ENGINEERING APPROACH (SEA) IN NON-TRADITIONAL IMPLEMENTATION AREAS

A Model Tailored

For

SMEs in the South African Manufacturing Sector

by

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A Research Report

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MOTIVATION

The quality of a man's life is in direct proportion to excellence, regardless of their chosen field of endeavour -

Vince Lombardi

DEDICATION

This research report is dedicated to my late Father - ***Jackson*** who to this day I failed to understand but whom the genes of all this effort can be traced to. I can only broadly describe him as a simple but sophisticated ordinary man who lived in a rather simple and limited world but whose vision and decisions, calculated or otherwise resided beyond the less complex world of his era.

DECLARATION

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I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Science in Engineering to the University of the Witwatersrand, Johannesburg. It has not been submitted before any degree or examination to any other University. Due acknowledgement must always be made of the use of any material contained in or derived from this research report.

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ABSTRACT

This research is centred on designing a framework for application of systems engineering in non-conventional application areas. It uses the manufacturing – *small and medium enterprises* (SMEs) as a framing case. The *system engineering approach* (SEA) application and the value it brings is greatly appreciated in the traditional application areas like defence and aerospace industries, however, the SEA application in other industries particularly manufacturing has been very low. This has led to the mind-set that the formal systems engineering approach application is more practical and viable in high technology systems. The research focused on exposing the structural elements of the SEA combining the two systems engineering extremes (*soft* and *hard systems*) and proposing a framework tailored to the sophistication levels of the targeted manufacturing SMEs. The aim of the study was to illustrate that the SEA can be applied in other non-conventional applications areas.

The Delphi study was used as the front-end primary research instrument to get input to build the conceptual framework. This involved a pilot study and a two round Delphi iteration exercise. Sixteen (16) expert's participated in round 1 while twelve (12) participated in round 2. This represents a response rate of 20% in the first round and 80% in the second round. An acceptable convergence of opinion of over 67% was achieved on most of the proposed SEA process activities targeted for the manufacturing SMEs. The tools required to validate the conceptual framework and frame the final implementation framework were then extracted. The study then proposed a conceptual implementation framework targeting the low to medium technology manufacturing SMEs.

A *sustainable* hybrid SE framework is proposed in Chapter 7 which acknowledges the limitations and the constraints in the manufacturing SMEs in particular. This study adds to the body of knowledge of systems engineering by showing that a methodical approach can be followed in structuring a hybrid SEA for specific applications. The report concludes by recommending validating the proposed framework in pilot case study companies to provide useful comments and applicability levels within the targeted SMEs context.

ACKNOWLEDGEMENTS

... If I have seen a little further than others it is only by standing on the shoulders of giants –

Isaac Newton wrote in a Letter to Robert Hooke, in **1676**

This is my second effort in structuring models that are useful in the manufacturing context of *low to medium* technology production systems. First it was on institutionalising reliability in manufacturing plants using critical elements of the *reliability centred maintenance* (RCM) approach and now it is on structuring problem-solving of unstructured complex phenomena in similar contexts. To this day throughout my career I have been described as being unnecessarily inquisitive, persistent and reading too much into scenarios and theory as I always sought **-** *first* to understand and then intervene confidently. From this background my strong interest in *the systems approach* is not surprising as this approach seeks first to understand before intervention.

In submitting this work I am greatly indebted to my advisor Bernadette Sunjka for guiding me closely but allowing me the freedom to follow my own course and amplify my thinking without congesting the report. She was always there for me when I needed her and would respond timeously when I needed her beyond the scheduled times. I appreciate.

This study would have not been possible without the *Delphi Exercise experts* who participated in this study. The author is exceedingly humbled by the fact that several high calibre experts spared their precious time to participate. Special mention goes to:

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My gratitude to all who participated and contributed in this study will remain a debt I can never repay.

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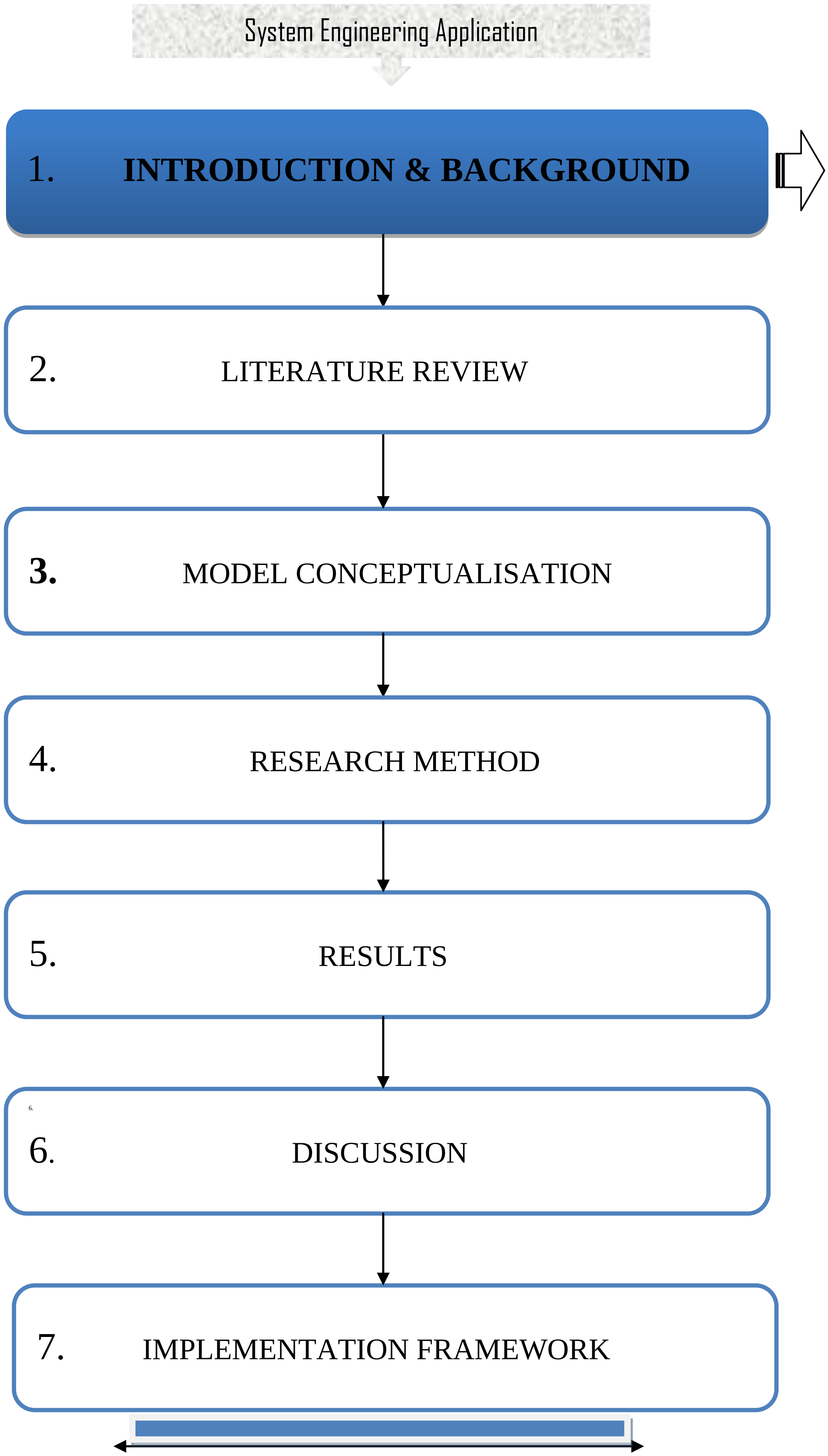
LIST OF ACRONYMS

ACE	Association of Costing Engineers
Arch	Architecture
CAS	Complex Adaptive Systems
CxS	Complex Systems
DoD	Department of Defence (US- DoD)
DoD	Department of Defence (US- DoD)
ECSA	Engineering Council of South Africa
EWS	Enterprise Wide Systems
EIA	Electronic Industries Association
GST	General Systems Theory
HAZOPs	Hazard and Operability Studies
HS	Hard Systems
HSA	Hard Systems Approach
HSM	Hard Systems Methodology
IEEE	Institute of Electrical and Electronic Engineers
INCOSE	International Council of Systems Engineers
LE	Large Enterprises
LMT	Low to Medium Technology
MIL-STD	Military Standard (US – MIL STD)
NASA	National Aeronautics and Space Administration (US – NASA))
OR	Operations Research
PMP	Project Management Plan
PMBOK	Project Management Body of Knowledge
RAND	Research and Development Cooperation

List of Acronyms... *Continued*

RCM	Reliability Cantered Maintenance
RFP	Request for Proposal
SA	Systems Analysis
SE	Systems Engineering
SEA	Systems Engineering Approach
SME	Small and Medium Enterprise
SS	Soft Systems
SEMP	Systems Engineering Management Plan
SI&V	Systems Integration and Verification
SoS	System of Systems
SSA	Soft Systems Approach
SSM	Soft Systems Methodology
TPM	Total Productive Maintenance
TQM	Total Quality Management
URD	User Requirements Definition


System Engineering Application
1. INTRODUCTION & BACKGROUND
2. LITERATURE REVIEW
3. MODEL CONCEPTUALISATION
4. RESEARCH METHOD
5. RESULTS
6. DISCUSSION
7. IMPLEMENTATION FRAMEWORK

Chapter 1 - Introduction & Background

Small and Medium Enterprises (SMEs) have significant presence in South Africa. They make 91% of the formal business entities, contributing to between 51 and 57 % of GDP, providing almost 60% of employment, (Kongolo, 2010). Despite this importance, a study by experts from the Centre for Global Development (2008) on the business environment in sub-Saharan Africa revealed several challenges and constraints faced by SME's in Southern Africa. These included among the top concerns, *electricity outages, out-dated technology, access to capital, management and technical skills deficiencies, socio-political threats* impacting on macroeconomics, *anti-competitive practices, limited access to international markets, supply chain challenges, burdensome regulations, crime* and *unethical business practices* in particular *corruption*. (Abor and Quartey, 2010) in their article on the *challenges faced by SME's in Ghana and South Africa* agree.

Several white papers and programs have been put in place by the government to address these problems, but there is very limited evidence or literature on the effectiveness of these programs. Two notable flaws of the approaches used include; 1) institutionalising the proposed interventions in isolation and, 2) imposing a *large business problem solving models* on SME's (Garwe & Olawale, 2010; Kunene, 2008; Falkena et al, 2009). In the developing world (South Africa included) the prescription of most of these interventions focused solely on the accountability framework to attract capital injection and introductory strategies around launching a business, (Kauffman et al, 2004). The assumption being that by solving the financing issues the rest of the problems will naturally disappear. "…few *studies have strived to investigate the impact of the assistance programs on SME's, particularly manufacturing assistance programs",* (Hashim et al, 2006:60).

The above high-level problems and constraints have resulted in slow growth and lower performance of these companies especially on the traditional metrics of profit, sales, market penetration, overall equipment effectiveness, plant reliability, productivity, lead time, innovativeness, (Ging and Lee, 2007; Kongolo, 2010; Garwe & Olawale, 2010). The study proposes the *system engineering approach* as a rescue framework to provide a sustainable way to address the challenges of the medium-technology SME's in manufacturing sector.

1.1 Problem Statement

Systems engineering is not a new concept. It is widely appreciated that a lot of work has been done by academics on the subject and related work in the past four decades. Several authorities e.g. (Chase, 1974; Woods, 1993; Lake J et al, 1993 as quoted by Martin, 1997:236; Hitchins, 2007) have referenced the concept back to at least the years of World War II. However practical application of this methodology has been limited to the design and analysis of *high-tech systems* such as defence weaponry systems, aerospace systems and nuclear power plant projects. This has led to the mind-set that the formal systems engineering approach application is more practical and viable in high-technology systems.

The challenge with systems engineering is that it is not well understood by many as it has not reached maturity levels of many traditional engineering disciplines like electrical engineering or civil engineering which have clearly laid down guidelines which can be applied universally, (Hitchins, 2007). This is complicated by the fact that even experts still differ in some areas in as much as they agree on the value of systems engineering as a discipline, (Sage and Armstrong, 2000). Referring to the same subject, (Adamsen, 2000:7) concurs "…although effort is being expended to change things, in many circles, there remains little consensus on nomenclature, metrics or the systems engineering process itself". By uncovering the underlying structure of the systems approach and specifying the appropriate mix of the two extremes of systems engineering ('hard' and 'soft' systems) and in-light of the *unstructured* problems faced by SMEs the research attempts to prescribe a sustainable solution specific to the SMEs environment.

1.2 Objectives

The primary objective of this study was to develop a Systems Engineering Approach model (SEA model) that will be used in less conventional application areas such as in SMEs.

Secondary Objectives;

I. Study the systems engineering literature and uncover the underlying structure or key elements of the approach common across industries.

II. Develop a hybrid (*soft* and *hard*) systems engineering framework applicable to the *medium-technology* manufacturing SME's.

III. Validate the developed model via the Delphi process by bringing together existing but fragmented expert knowledge in an interactive process and re-engineering the developed model as necessary.

IV. Make recommendations by developing a roadmap of institutionalizing the developed SEA in *low to medium technology* (LMT) manufacturing SMEs.

1.3 Research Question

Central Research Question:

Can a hybrid systems engineering approach (*elements of both 'hard' and 'soft' systems****) be framed to solve specific problems in non-conventional applications such as SMEs?***

1.4 Significance of Study

Preliminary work on this study has shown that SMEs' in general have a significant role to play in a developing economy like South Africa, contributing to between 51 and 57% of GDP, providing almost 60% of employment (Kongolo, 2010). However, their growth and success is constrained by many challenges, which span from human issues, technological limitations to financial issues. This leads to the hypothesis that these *complex issues* are due to a lack of an integrated approach to problem solving that considers the whole and its *emergent properties*.

A literature review has shown that the systems engineering approach is a useful methodology to approach *complex problems,* gain deeper understanding and find optimum solutions. *S*uccess cases over the past two decades include those in high-technology sectors such as the defence weaponry systems, aerospace projects and large information technology companies and in climate changes cases (Checkland, 1999; Blanchard & Fabrycky, 2006; Hitchins, 2007). Hence, this research is motivated by the fact that the application of SEA approach has been limited to high-tech operations in as much as there is agreement among authorities that the primary objective of this methodology is to create a '*whole' solution* to complex problems. The reviewed literature could not establish any research, which has applied the SEA specific to the medium-technology manufacturing SMEs in a developing country. This research is therefore an attempt to close this gap.

1.5 Study Strategy

The purpose of this study was to develop a *Systems Engineering Approach* (SEA) model tailored to the needs of non-conventional application areas such as in LMT manufacturing SMEs. The work began with an in-depth study of the subject area – *systems engineering* in order to:

- Synthesise and outline the key elements of SEA and expose the inconsistencies in understanding the subject
- Identify the relationships between ideas and actual elements of the subject area that are being used in practise
- Distinguish what has been accomplished, from what needs to be done and expose what evidence is lacking

Literature on SMEs is then explored in order to:

- ✓ Understand what is an SMEs in the case study's context - the Republic of South Africa
- ✓ Place the research into context by understanding the structure and the problem space of challenges and issues / problems in manufacturing SMEs.

Elements of the initial SEA framework were then outlined. These were tested and refined via the Delphi process involving subject area experts from all over the world. Input from the experts was then evaluated and used to incorporate or subtract elements from the proposed SEA approach tailored for SMEs.

1.6 Assumptions and Limitations

Limitations: This study is confined to developing a specific *systems engineering approach* framework for low – medium technology *SMEs* in the *manufacturing sector* in South Africa. This is because it would be difficult to develop a generic model within the time period available for the study. An industry wide generic model even targeting only SMEs would be problematic in primarily for three reasons:

a. The researcher has little to no experience in other industries
b. It will also be a time consuming activity for Delphi panelists to reach consensus on this
c. It will be difficult for the researcher to access information in other industries

Also due to time period available for the study, the model testing phase in the real-world will not be covered in this scope.

Assumptions:

- It was assumed that SE is relevant and of value to any industry and it is possible to uncover patterns or common theoretical themes from experts to help structure and contextualise the core elements of the SE domain. This is based on the evidence found in literature that, there exits some common elements that allows experts to agree on the value of SE as a domain, (Sage and Armstrong, 2000; Adamsen, 2000:7). This emergent design which allowed ideas to evolve as the research progressed is also a key element in qualitative – exploratory research.
- It was also assumed that the Delphi exercise questionnaire as a research instrument will comprehensively cover and answer the research questions. For a new domain like SE, experts are spread all over the world and the Delphi process as a technique by design provided the platform to tap knowledge regardless of geographical location. To validate the questionnaire a pilot study preceded the actual launch.
- It was assumed that the responses to the Delphi exercise questionnaires will be done independently and truthfully. Confidentiality and anonymity of the participants was respected as by design of the Delphi technique and the participants were also volunteers, who could be withdrawn.

In this study, an SME is defined *as a manufacturing firm with an annual turnover equal or less that R51million and has permanent employees equal or less than 200* (Government Gazette of the Republic of South Africa, 2003).

1.7 Outline Structure of Project

The figure below summaries the key chapters of the study;

CHAPTER 1 (Introduction and Background)	This chapter contextualises the study and introduces the project by defining the problem and raising research questions.
CHAPTER 2 (Literature Review)	This chapter explores the necessary avenues to frame the study with reference to a blend of theory and case study examples.
CHAPTER 3 (Model Conceptualisation)	This chapter develops the analytical framework and the success evaluation criteria for the targeted manufacturing SMEs
CHAPTER 4 (Research Method)	This chapter describes the approach to taken in the research and the roadmap to achieving the objectives set in chapter 1.
CHAPTER 5 (Results)	This chapter presents & categories the findings from Delphi exercise using different formats (tables, graphs, charts, and point form outline)
CHAPTER 6 (Discussion)	This chapter analyses the results in relation to the contest - *the LMT manufacturing SME* reflecting on the literature reviewed
CHAPTER 7 (Implementation Framework)	This part develops and presents the SEA implementation framework based on the findings and arguments from chapters 2, 5 & 6

Chapter 2 - Literature Review

"The world that we have made as a result of the level of thinking we have done thus far creates problems that we cannot solve at the same level as they were created"

Sir A. Einstein '

2.1 Introduction

This chapter gives an insight of what has been done and what still needs to be done in the subject area of systems engineering with a particular focus on the practical application of the soft and hard systems approaches. The chapter is divided into five parts;

- Part A: Overview of the subject – *Systems Engineering*
- Part B: The core of the study (1) - a high-level analysis of the *Soft Systems Methodology*
- Part C: The core of the study (2) - a high-level analysis of the *Hard Systems Methodology*
- Part D: Reviewing application of the methodologies to propose a hybrid approach
- Part E: Contextualising the study with reference to the *real-world* - SMEs

The emphasis of the literature review is on practical application of the *systems engineering approach* but will also deal with some methodological flaws that constrain adoption and some theories related to the subject will also be explored. The goal being two fold;

i. **Identification of central issues**: concentrating on synthesising the key elements of the systems approach and developing a line of argument.
ii. **Integration**: of the different views and the many methodological frameworks emanating from systems engineering as a discipline and incorporating other complementing tools/ methods.

The work reviewed includes work that has been done in that past 50 years when systems engineering slowly emerged as a discipline, after great pioneers of the subject, Peter Checkland and Russell Ackoff made significant contributions in structuring what others called and may still call common sense. Academic papers reviewed where limited to between 1968 and 2011 as this was the period when most work was done resulting in the formation of the International Council of Systems Engineers (INCOSE) in 1990 in Seattle, USA. "Initially the council was known as the National Council on Systems Engineering (NCOSE). It became known as INCOSE in July 1995", Martin (2000:237). The study <u>will not</u> dwell much on the systems concepts, the systems thinking dimensions, systems models (systems of systems alike), systems architecting or the details of the systems engineering process to avoid digressing, but will follow a path that will attempt to answer the research question as outlined on the next page; figure 2:1 Literature Review Roadmap.

Research Question

Can a hybrid (*elements of both 'hard' and 'soft'****) systems engineering approach be framed to solve specific problems in SMEs?***

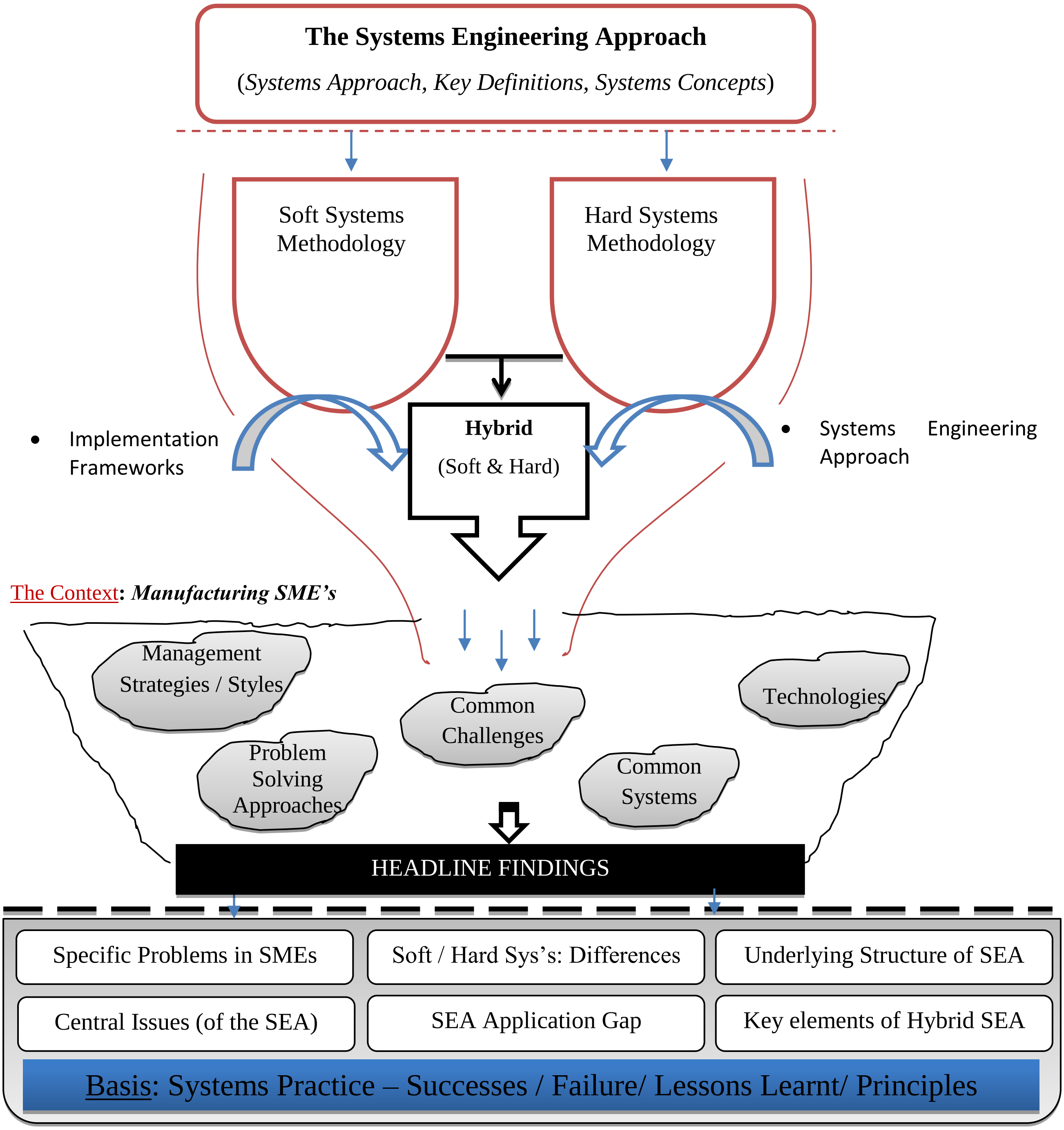


Figure 2:1 Literature Review Roadmap

Part A – Overview of the Subject – <u>Systems Engineering</u>

2.2 Historical Cycles of Change (Systems Thinking)

Prior to world war-two the world was dominated by the thinking that to better understand a problem one has to reduce, decompose or disassemble to simple indivisible parts to get a clearer explanation regardless of size and complexity (Checkland 1999; Armstrong & Sage, 2000; Blanchard &Fabrycky, 2006; Hitchins, 2007). This approach had its advantages which included better description and knowing how things work by focusing on structure and separate analysis of parts. Rene' Descartes the pioneer of the European Industrial revolution is quoted by Hitchins, (2007 p.4) to have believed that, it was possible to understand and explain the smaller parts, then the whole could also be explained by bringing together the various parts explanations. This approach brought about industrial revolution and advanced mechanisation, (Blanchard & Fabrycky, 2006; Hitchins, 2007). Ackoff, (1981) as quoted by Hitchins, (2007) referred to this era as the machine age and to date three decade later this has become the common name for this development phase. Checkland, (1981) referred to this approach as being reductionist. In simple terms, a way to analytically think about the problem area by limiting the scope to focus on getting explanation and better understanding of the individual parts of a system separately

The *machine age – reductionists* approach however encountered several problems;

a) Failure to cope with complexity - … *human-made or technical systems became so complex that even the designers failed to totally understand them* (Blanchard &Fabrycky, 2006) and people began suspecting them to be, to some extent, responsible for many external problems that the systems are not designed for.

b) No goal seeking behaviour **-** *a goal seeking system responds differently to events until it produces a particular state or outcome.., it has a choice of behaviour,* (Hitchins, 2007).

c) Failure to explain the property of emergence at different hierarchies in some systems, processes etc. – *the principle that whole entities exhibit properties which are meaningful only when attributed to the whole, not its parts – e.g. the smell of ammonia* (a product of the odourless Nitrogen and Hydrogen), (Checkland, 1999; Hitchins, 2007).

d) Limited strength in dealing with natural systems and systems with high human social issues. The *machine age – reductionists* approach seemed silent to such systems – with emergent properties (Checkland, 1999).

e) The strictly *bottom-up* approach failed to bring out the bigger picture or neatly align integrating parts upon attempting to assemble - pulling together the broken up pieces (Blanchard &Fabrycky, 2006, Hitchins, 2007).

f) Causality was unidirectional - The world on the other had proved different; causality was multi-casual, meaning things worked together to result in something, most of the time completely different from the expected. Hitchins, (2007 p.7) clarifies …*in real file, a bacterium caused one disease which is not necessarily true if there is a combination of bacterium in action.*

g) Dependence on the original developers (designers), as solutions were based on detailed component equations. In other words there was no overall system architecture on which new developers could learn. This made attempts to improve very costly, as they were many modelling elements and very little visualisation, (Marvel, 2005)

Contrary to these shortcomings the world has struggled to move away from this problematic approach largely because this is how life problems have been addressed whether by default or by design. Hitchins, (2007 p.1) puts it differently as the author attempted to contextualise this notion by relating it to everyday events, suggesting that ...every time items are disassembled, disaggregated or decompose…*we pay implicit homage (respect) to Rene Descartes and his Cartesian Reductionism.*

The history of development of system engineering as extracted and combined from different sources (Checkland 1981; Lake, 1996; Marvel, 2005; Hitchins, 2007, et al) is presented in Appendix B.

2.3 The Systems Engineering Approach

2.3.1 *The Systems Approach*

This research is anchored on the *Systems Approach*. Checkland, (1981) views the systems approach as that which is not reductionist. Blanchard and Fabrycky, (2006:15) interprets reductionist as a, *the belief that everything can be reduced, decomposed, or disassembled to simple indivisible parts*. Contrary to the reductionist approach, the *systems approach* does not breakdown the complex problems to study them but concentrates on the relationships and the emergent properties that evolve within these systems interactions (Checkland, 1999; Hitchins, 2007; Boardman & Saucer, 2008). In other words, this can be explained as seeing the total picture and not just an entity, item, or sub-system in an environment under analysis. The premise being that viewing the total provides more sustainable solutions than narrowing down to the problem area without reflecting on other systems, the particular system in question is interacting with and its environmental concerns in general. Ackoff, (1981) cited in Boardman & Sauser, (2008) puts it another way by saying "…this follows from the fact that the sum of the functioning parts is seldom equal to the functioning of the whole"

The systems approach, being the framework of the *systems engineering methodology*, is important that it is reflected upon. The gap though lies in understanding the SEA, to an extent of exposing its underlying structure, quantifying its value and implementing it formally like the many widely accepted philosophies like *Lean Manufacturing*, *Total Quality Management* and *Reliability Centred Maintenance* to mention a few. Bonnema et al (2008) commenting on the application of the SEA agrees ...*literature on how the design process should be conducted is abundant. Also literature on how the design process is performed in practice can be found. An issue that has received less attention is how to keep overview while the design process evolves.*

2.3.2 *The Systems Engineering*

Systems engineering is defined from many angles in literature and to date there is still confusion around one universal acceptable definition, (Lake, 1996; Sage and Armstrong, 2000; Hitchins, 2007; Bahill and Dean, 2009).

To try to come to a conclusion on an acceptable definition these authorities followed a similar path that is;

i. Stating the aim or purpose of systems engineering as a discipline
ii. Outlining what SE is comprised of (that is what it does)
iii. What SE systems engineering is not or what it is limited to.

This research used a similar approach to synthesise a definition to guide the study. Step 1 and 2 above were used to come up with a working definition.

Step 1: **Aim of Systems Engineering**

Three aims from key authorities are presented below;

a) "…to ensure that the customers' needs are satisfied throughout a systems entire life cycle" (Bahill and Dean, 2009)

Emphasis is on a broader purpose of continuously addressing a customer's need which is consistent with the systems approach.

b) *"…to ensure that information and knowledge is organised that will assist clients who desire to define, design and develop total systems to achieve a high standards of overall quality, integrity and integration as related to performance, trustworthiness, reliability, availability, maintainability … of the related systems"* (Sage and Armstrong, 2000)

The two authorities' narrow down the purpose of SE to that of *information* and *knowledge management* to achieve the required results in specific measurable areas. This can be argued to be reductionist – breaking down into smaller manageable parts (Checkland, 1981). This aim moves the thinking away from a *Meta* level.

c) *"… to provide and ensure a consistent vision of stakeholder expectations"* (Buede et al, 1999; Martin, 2000)

To an extent this definition is preferred as it is consistent with the systems approach as described by Churchman, (1968); Ackoff, (1981); Checkland, (1981); Hitchins, (2007).

Of the three aims the synthesised aim of systems engineering to be adopted is;

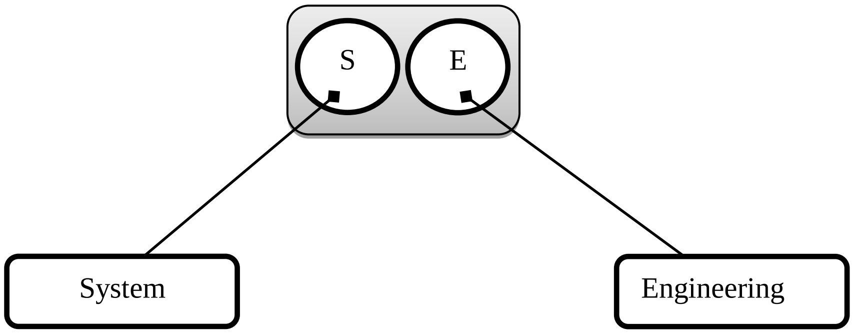
To ensure that a consistent vision of stakeholders expectations (customers included) is met and satisfied throughout a systems life cycle.

Step 2: **What does Systems Engineering Comprise of**? (*What SE does?)*

Appendix C attempts to simplify and outline the individual activities of what SE consists of as synthesised from Sage and Armstrong's framework and other systems thinkers Hall, (1962); Checkland, (1981); Bahill & Gissing (1988); Lake, (1996); Martin, (2000); INCOSE SE Handbook, (2007); Hitchins, (2007); Haskins, (2007); Bahill & Dean, (2009). It is important to state categorically that these steps are not necessarily followed in the linear fashion presented. The activities and process included are outlined in Appendix C.

Now that the SE aim and process has been outlined, an attempt to locate a working definition is explored. Several definitions from key authorities are stated.

Figure 2.2 guides the definition synthesis starting with defining the word *system* followed by the *systems approach* then ***S**ystems **E**ngineering.*



- ❖ What is a system?
- ❖ <u>Systems Concepts/ Thinking</u>
  - Understand the whole - bigger picture first:
    - *The whole is more than the sum of parts*
    - *The whole drives the nature of the parts*
  - Perception is key:
    - *Stakeholders perspectives are important*
    - *Everyone has their own interpretations*
  - Know the Systems Input & Outputs:
    - *The key structures and processes*
    - *The flow of information and material*
  - Emergence properties of some systems:
    - Appreciate that there are properties that emerge when systems interact at given level of complexity
  - The systems are dynamically Interrelated

- ❖ What is *engineering* in Systems terms?
  Application of knowledge to make things work practically – The doing part (Solve, Dissolve, Resolve) – Ackoff (1968)
- ❖ <u>The Processes</u>
  - Design
  - Develop
  - Build / Modify
  - Use (test/ deploy)
  - Maintain
  - Dispose

The author's own diagrammatic illustration

Figure 2:2 Basis of the SE definition – *An Overview*

System Engineering is based on systems thinking and *this systemic way of thinking was* to a greater extent motivated by the contribution by Bertalanffy *et al* when they convened in the 1954 to form the Society of General Systems Thinking (GST). The key mandate of this society was to further the development of theoretical systems which are applicable to more than one of the traditional disciplines, (Checkland, 1981; Fleming, 2000). One of the pioneers of systems thinking – Ackoff, (1971 p661) once said, "…like surgical instruments, definitions become dull with use and require frequent sharpening and eventually, replacement". It follows that considerable effort was applied by the researcher to correctly define the key terms in SE before presenting the two dominant methodologies. Emery (n.d.) as cited by Ackoff, (1971) highlights the failure of experts to pay attention to framing the subject in one language, *…it is almost as if the pioneers (of the SEA), while respectfully noting each other's existence, have felt it incumbent upon themselves to work out their intuitions in their own language, for fear of what must be lost in trying to work through the language of another…".* With reference to earlier sections and figure 2.2 the key definitions of a *System;* the *System Approach* and *Systems Engineering* are given below:

(a) A System:

A ***systems*** *is*

i. *…is a set of parts coordinated to accomplish a set of goals*

(Churchman, 1968)

ii. *…a group of components that work together for a specified purpose,*

(Sage & Armstrong, 2000)

iii. *…a set of elements connected together which forms a whole, this showing the properties of the whole rather than properties of its component parts"*

(Checkland, 1981)

Ackoff (1999) summarises two important properties of a system;

1. Every part of a system has properties that it losses when separated from the system and
2. Every system has some properties (it's essential ones) that none of its parts do

In this study the following definition summarises the essential themes of these early system thinkers;

A system is a

…combination of interacting elements organised to achieve one or more stated purposes

(b) <u>The System Approach:</u>

In general and in this research the word *approach* means a way of going about tackling a problematic situation or addressing challenging scenarios. Similarly the systems approach is not a discipline in itself rather it is a way of enlarging perspectives obtained from other viewpoints, (Hitchins, 1992). This approach is rooted in *systems thinking*, explained in figure 2.3 which O'Connor, (1997) describes as a way of helping a person to view the world including its organisation from a broad perspective that includes its structures, patterns, and events rather than just the events. From these thoughts it can be reasoned that the systems approach;

- Entails thinking about the world outside ourselves
- Focuses on gaining and improving understanding
- Pays attention to movements and dynamics
- It is a way of packaging or framing our *world-view*

It can therefore be argued that this approach is preferable as a means to identify the real causes of issues / problems and specifying sustainable solutions (O'Connor, 1997; Checkland, 1998; Hitchins, 2007). In this study the following definition will suffice;

The Systems Approach is

…that outlook, which in a problem confronting situation steps back, takes a world view of the system in question to analyse its interactions with other systems in order to gain better understanding of how to initiate and guide the intervention strategy targeting the underlying structure of the problem

(c) <u>System Engineering</u>

As stated earlier in section 2.3.2 to this day the experts in the field and even the early system thinkers do not agree on a common definition. Hendrick W. Bode (n.d. as cited by Fabrycky 2006 p.17) agrees … *it seems natural to begin the discussion with an immediate formal definition of SE. However, SE is an amorphous, slippery subject that does not lend itself to such formal, didactic* (instructive*) treatment*. As such most authorities and institutions, INCOSE included have chosen a much broader definition, (Hitchins, 2007; IEEE-P1220, 1994). Other authorities and institutions have preferred to use definitions that are more specific to their domains (Sage & Armstrong, 2000; US-DoD Regulation 5000.2R, 2002), while others sidestepped the issue entirely and resorted to simply stating what system engineers do, (Checkland, 1998; Martin, 2000, Sheard, 1996). Some of the definitions are presented below;

The broader "catch all" definitions

Systems engineering (SE) is

1. "…an interdisciplinary approach and means to enable the realisation of successful systems", *INCOSE)*
2. " …the art and science of creating whole solutions to complex problems", *(Hitchins, 2007:100)*
3. "…an interdisciplinary collaborative approach to drive, evolve, verify a life cycle balanced system solution which satisfies customer expectations and meets public acceptability", *IEEE1220 (1994:11)*

The more specific "domain friendly" definitions

Systems engineering (SE) is

4. "…an approach to translate operational needs and requirements into operationally suitable blocks of systems. The approach shall consist of a top-down, iterative process of requirements analysis, functional analysis and allocation, design synthesis and verification and system analysis and control. System engineering shall permeate design and manufacturing, test, evaluation and support of the product. SE principles influence the balance between performance, risk, cost and schedule""

   (US – MIL STD 499B)

5. "…an interdisciplinary approach encompassing the entire technical effort to evolve and verify an integrated and lifecycle balanced set of system, people, product and process solutions that satisfy customer needs. Systems engineering encompasses a) the technical efforts related to the development, manufacturing, verification, deployment, operations, support, disposal of, and user training for, system products and processes; b) the definition and management of the system configuration; c) the translation of the system definition into work breakdown structures; and d) development of information for management decision making"",

   NASA – (SE-Handbook, 2007)

6. " …is the definition, design, development, production and maintenance of functional, reliable and trustworthy systems within cost and time constraint"

(Sage & Armstrong, 2000:9)

Looking closely at the six definitions, common themes recur as outlined below;

- *'Interdisciplinary' (collaborative)* – implying a team approach through-out a system life cycle.
- *A means or way* – implying a framework to drive process to satisfy a need.
- *A holistic approach* that view the whole first (…the necessary overview that allows understanding of how other systems, subsystems fit and perform).
- Finding sustainable answers or solutions (not necessarily the correct) to the *'whole'. …realisations of successful systems* or *whole solutions to complex problems*.
- There is emphasis on initial definition of *systems requirements*. This entails understanding the true system requirements through consulting the stakeholders and baselining to drive subsequent processes.

Of all these definitions and the background information on systems concept provided, the following synthesised *all-encompassing* definition suffices to guide the study;

The Systems Engineering Approach is

"…is a holistic interdisciplinary framework to drive processes that enable sustainable whole solutions to be generated throughout a system life cycle"

The critical elements of the subject have presented and defined. More definitions are outlined in Appendix K

Classification of systems:

This section presents an overview of the types of systems in existence. Pioneering work on systems classification is owed to Kenneth Boulding, who attempted coherent classification of all systems in the world from a meta-level (Hitchin, 2007:11). This research will refer to Boulding's work but will however classify systems for convenience and for reference in the next sections.

The main <u>*system classes*</u> as presented by Checkland, (1999:110) and Fabrycky & Blanchard, (2006) are outlined below;

- *Natural systems*: these come into being by natural system, originating from the universe and the processes of evolution (e.g. the rain forest, climate, the sea, solar system and so on)
- *Designed Physical Systems*: these are physical artefacts which are a result of conscious design. These are designed/ made by man for a purpose e.g. a train, a freeway a building alike.
- *Designed Abstract Systems*: these are conceptual man-made systems designed for a purpose. Examples include ideas, plans, frameworks and blueprints)
- *Human Activity Systems* (HAS): These are systems with high human activity and are less tangible than natural and designed systems. These used to be called human-machine systems. Checkland (1999:110) advise from is thirty (30) years of experience in action research that it is better to separate the designed-physical system from the human activity system. This could be because of the risk of the human activity being left-out during in depth analysis of the system.
- *Social-Technological Systems:* The word *social* has to do with issues or things concerning group of people while the word *technological* comes from *technology* which is based on physical sciences and their application. *Social- technological systems* involve significant participation of group of people including their interests and concerns (Maier & Rechtin, 2002)
- *Transcendental Systems:* Systems beyond knowledge – not known, (Checkland, 1999). That is the realm of the unknown.

These systems have also been sub-classified as static or dynamic or open or closed (Fabrycky & Blanchard, 2006) depending on structure of the system and an interaction it has with the environment respectively. Refer to Appendix K for the definitions. It is important to note that within these main *system classes* presented above, the systems behaviour changes depending on where the system is in existence that their context. This leads to the following systems scale types;

Scale of Systems:

- *Ordinary Systems* (OS) – for example a motor vehicle *wheel* (a fairly simple system that can be satisfactorily treated as autonomous is less complex and more deterministic) with a few subsystems which include the bearing, rim and the tyre. These systems are normally manageable and decomposable (Sheard, 2011)

- *System of Systems* (SoS) – These have a system integrator (Sheard, 2011). Examples include windows operating system, a military mission, the justice system, a university etc. As such SoS are more complex and less deterministic than ordinary systems. It follows that for a SoS to exist there has to be a whole, for example a transport system would bring together the metro rail, underground rail system (Gautrain), buses and taxicabs. It follows the various elements of these subsystems would need to be harmonised, (Hitchins, 2007). These elements could be capacities, timetables, interchange points and ticketing.

- *Complex Systems* (CxS) – "…a system with self-organisation analogous to natural systems, that grows without explicit control, and is driven by multiple locally operating, social technical processes, usually involving adaption (Braha et al, 2006 as cited by Sheard, 2011). Distinguishing attributes of CxS include operational and managerial independence of the elements or the constituent systems (Maier, 1996: 567-574). The other attribute is the geographic extent of the component systems is large for example a tanker in a military mission could be 30km away from while a fighter jet or a ground-force battalion. Examples of such systems include human civilisation, a military mission (which is SoS) it follows a complex system (CxS) can be a SoS and the opposite is always true – a SoS is complex, (Sheard, 2011)

- *Complex Adaptive Systems* (CAS) – A form of system containing many autonomous agents who self-organize in a co-evolutionary way to optimise their separate values, Lucas (2006). Examples include an activist group e.g. the green movement, nation governments or political parties. It is important to note that this complexity status changes all the time as such systems are dynamic. Complexity is relative, when we understand something; we no longer see it as complex or chaotic (Gharajedaghi, 2006:114).

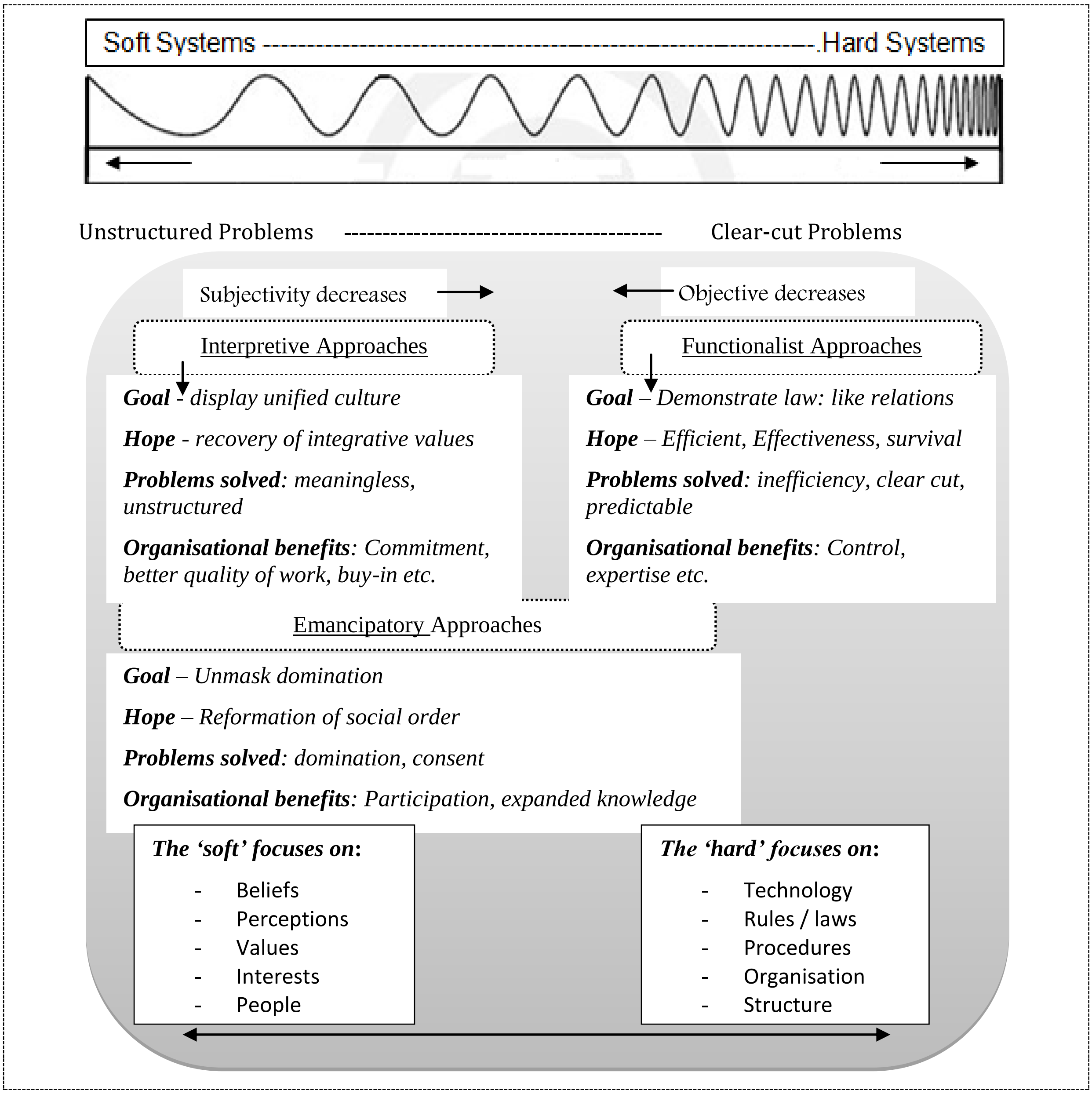
Some characteristics of **Complex System** were synthesised from literature are (Lucas, 2006; Sheard, 2011):

- Systems evolve by adaptation, cooperation and competition
- All complex systems include aspects of simpler systems
- They are inefficient
- All complex systems are dynamic and they self-organise.
- They have enough flexibility to communicate and adapt
- They have the property of emergence in nature (refer to Appendix K for full definition of the property of emergence)

It is important that systems be classified and their types recognised before intervening to avoid undesirable *emergence* behaviour and to know which intervention strategy to specify.

The Systems Engineering Spectrum

The SE spectrum has two extremes, the *soft* and the *hard* side. Real world problems however present themselves in different proportions of the two sides (Hitchins, 2007; Siriram, 2011). Figure 2.3 presents an overview of the SE spectrum with some elements adopted and distilled from (Alvesson & Deetz, 1996 as quoted by Jackson, 2000:42).



The author's own diagrammatic illustration, some elements adopted from Jackson, (2000 p.42)

Figure 2.3 Overview of the SE Spectrum

The left side is for soft problems. A problem is described as soft if *it cannot be formulated as a search for an efficient means of achieving a defined end.* That is a problem in *which the end, goals, purposes* *are themselves problematic* (Checkland, 1999:316). This refers to problems in which the outcome cannot be clearly defined or rather can be viewed by others as subjective. This is in sharp contrast to problems or equations which have a definite solution. The soft side of the spectrum is true for problems which involve political, social, psychological and cultural elements. That is those systems that have a high human activity component or social-technological systems. The goal of such approaches that aim to solve such *soft* problems is to display a unified culture, (Checkland, 1999). Alvesson and Deetz, (1996 as cited by Jackson, 2000 p.42) prefer to call these approaches interpretive. From the literature reviewed the most commonly used of these soft approaches, is Peter Checkland's SSM.

The right side of the spectrum houses what Alvesson and Deetz, (1996 as quoted Jackson 2000:42) call the functionalist approaches. These are objective approaches that aim to demonstrate law. Checkland, (1999 p.316) describes a 'hard' problem as that which can be formulated as a search for efficient means of achieving a defined end. In simpler terms this refers to problems with an *end* that can be taken as given, all things being equal. That is a problem that can be framed to give a clear cut solution.

To avoid confusion and ensure alignment of the study the next sections will outline the SSM (as specified by Peter Checkland) and then the *hard system methodology* (HSM) guided by the INCOSE SE principles. Finally the methodologies are compared and hybrid approach is synthesised.

Part B: High Level Analysis of the Soft Systems Methodology

2.4 The soft Systems Methodologies

The review of literature showed that various soft systems methodologies have been developed and proven in industry by several early systems thinkers. These problem solving approaches include;

- ***Ackoff's*** Interactive Planning, (Ackoff, 1981)
- ***Checkland's*** Soft Systems Methodology, (Checkland, 1981)
- ***Churchman's*** Social Systems Design (Churchman, 1968)
- ***Friend & Hickling's*** Strategic Choice Approach (Friend & Hickling, 1987)
- ***Jackson's*** Systems of Systems Methodology (Jackson and Keys, 1984)
- ***Mason & Mitroff's*** Strategic Assumption Surfacing& Testing (Mason & Mitroff, 1981)
- ***Midgley's*** Total Systems Intervention (Midgley, 1997)
- ***Senge's*** Soft Systems Thinking (Senge, 2006)
- ***Schoemaker's*** Scenario Planning (Schoemaker, 1998)

Some of these examples have been taken from Blair *et al*, (n.d. as referenced by Edson, 2008). Other alternative methods which can be considered soft approaches and are widely used in industry include; *Prototyping; Object-Oriented Methods, Soft Operational Research (Soft-OR; the SWOT analysis* and the like. This research will be limited to *Soft Systems Methodology (SSM) as* specified by Checkland in his 1981, SSM monograph.

Soft Systems Methodology (SSM) *is;*
"… a general methodology which uses systems ideas to find a structure in apparently unstructured 'soft' problems and hence leads to action to eliminate, alleviate or solve the problem or provides an orderly way of tackling 'hard ' problems, (Checkland, 1976)

It can be read from the definition above that SSM is not limited to the application of addressing soft problems. It has been applied to both hard and soft problems (Khisty, 1995; Checkland, 1999, Fairbairn & Farncombe, 2001; Reisman & Oral, 2003; Hitchins, 2007; Haskins, 2008; Clayton et al, 2009; Lubega & Ayoo, 2009). "...the methodology per se does not differentiate between 'soft' and hard' problems but essentially gives a framework to solve problematic situations which the outcome is not given", (Hitchins, 2007). Nonetheless in the practical world (the real world), problems are neither exclusively hard nor soft. Checkland, (1999 p.318) clarifies his definition "… SSM is a systemic approach for tackling real world problems in which known to be desirable ends cannot be taken as given". It is notable in this definition that the words *soft* or *hard* have been left out.

2.4.1 *Rationale behind SSM*

SSM was developed by Checkland and his colleagues at Lancaster University (UK) in the 1970s. It was a response to the challenges in applying the 'hard' systems thinking (as applied in high tech engineering projects) to business/ management problems (as prevalent in social technological systems alike). Checkland and his team embarked on a program of *action research* (a combination of organisation interventions and academic reflection) which began trying the traditional SE methods to address managerial problems (Hitchins, 2007). The research group faced challenges in trying to use the SE approach as they could not always determine the purpose of the system or organisation they were trying to assist. Checkland, (1999 p.A54) explains "...it was found to be too naïve in questions like …<u>what is the system</u>… <u>What are the objectives</u> to cope with managerial complexity? SE as developed for technical well-defined situations had to be abandoned and SSM emerged in its place".

Several limitations and issues were noted with application of the hard systems approach to managerial problems, (Checkland 1999; Jackson, 2000);

- *It was difficult to get some '**what's**' and '**how's**' of certain organisational problems.*
- *Emphasis was on the measurable and objective criteria which was vague in human activity systems.*
- *Too much emphasis was put on limiting the problem – isolation and control over variables. The aim was to have a quick freeze on the design and pursue one option thereby narrowing down the problem with minimum reflection on other systems.*
- *Emphasis on the top down decomposition of a system into subsystems in order to move fast towards a known desired state. For human activity systems this usually conceals the problem.*
- *The enquiry methodology was itself limiting as it ignored practical concerns like perceptions, commitments, human interactions and some participants*

It follows that SSM was designed to shape interventions in the problematic situations where there are no straightforward 'problems' or easy solutions. Hitchins, (2007) concurs, "…many projects have failed due to failure to consider various perspectives, cultures, politic, motivations and vested interests of stakeholders". SSM was found therefore fitting as a framework to close the systems engineering methodological gap and to curb the resultant complexities.

2.4.2 *Assumptions of SSM*

The following is an outline of assumptions of SSM synthesised form different authorities which include Patching (1990), Howell (1997), Checkland (1999), Jackson, (2000) and Hitchin (2007);

- A more sustainable outcome is learning and better understanding rather a solution, (Checkland, 1999)
- The background and history of the problem is always useful (Jackson, 2000; Hitchins, 2000)
- Organisational problems are messy or poorly defined, (Checkland, 1999, Walker et al, 2003)
- Stakeholders interpret problems differently (no objective reality), (Checkland, 1999). Checkland's thinking is that the *world-view* (or interpretation) used as the basis for any action must be declared.
- Human factors are important in addressing problems (hence human factors first and foremost). "SSM encourage investigators to view organisations from a cultural perspective", (Walker et al, 2003:313)
- Every situation in real world systems involves humans that are trying to take purposeful action which is meaningful to them (that is the goal seeking behaviour of every system and the resultant emergent property of purposefulness of the interacting systems, (Checkland, 1999:A7).
- Human systems are always multivalued and have informal intentionality's related to establishing or modifying relationships in terms of power structures, roles, norms, and value concepts etc., (Clayton &Radcliffe, 1996).
- Most management and organisational problems <u>cannot</u> be seen as pure systems problems as the system is far too complex to analyse.

2.5 The Basic *Soft* System Methodology

It is important to note that Checkland's SSM is more of a *learning* and *meaning development* tool rather than a solution generator, (Hitchins, 2007; Checkland, 1999). The classic SSM enquiry has seven stages 1 to 7 as presented in figure 2.4. The key point to note is that the problem is analysed from two perspectives;

1) The ***Real World*** (*what is actually happening in the situation being analysed)* – that is stage 1, 2, 5, 6 and 7 (Figure 2.4 refers).
2) The ***Ideal World*** (*the models of the best possible – driven by logic and systems thinking*) – that is stage 3, 4, 4a and 4b (see figure 2.4). Checkland, (1999:163) refers to this world as high level meta-language.

The outcome of this approach is a better understanding of the situation under analysis and some ideas of improvement, (Checkland, 1999). Checkland's seven-stage model shown in figure 2.4 (below) is outlined in detail in tables 2.1 to 2.8 below as distilled and summarised from (Checkland & Smyth, 1976; Checkland, 1999; William, 2005; Hitchins, 2007).

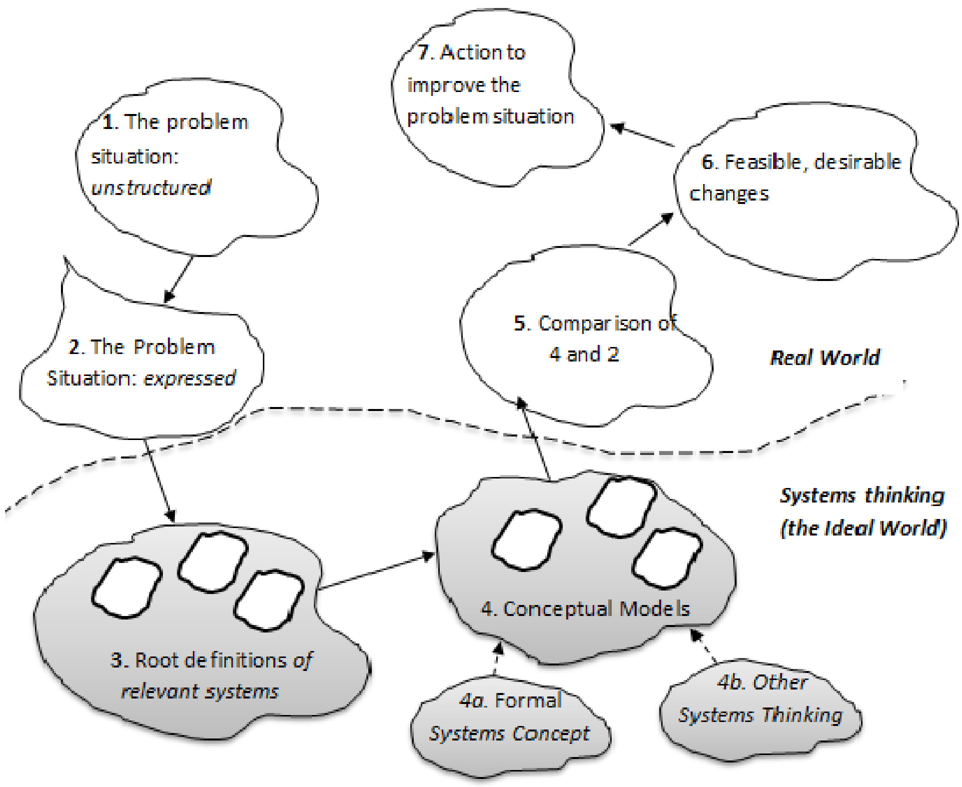


Figure 2.4 The Original 7- stage SSM (Checkland, 1981)

2.5.1 ***Stage 1****: Problem Situation - Unstructured*

This involves finding out what the issues are. This is normally done by those involved in or affected by the problem situation. Lester, (2008) warns that, “care should be taken not to formulate the issue as a problem to be solved, as this can lead to too narrow an approach at too early a stage”. This is consistent with the systems approach which seeks not to be reductionist. The table 2.1 below summarises stage 1 of Checkland’s SSM.

Table 2.1: *Stage 1*: Problem Situation - Unstructured:

Aim	❖ Assess the general situation
Objectives	i. Collect as many perceptions of the issue as possible from a wide range of stakeholders ii. Identify the issue/problem space as it exist in the real world
Tools / Methods	• Use a wide range of methods surveys, interviews, observations, measurements, studying reports etc.) • Outline of *Naïve Picture* statements • *Naïve picture* systems map • *Systems Hierarchy* diagram
Outcomes	▪ Statement of the problem
Notes ***(Hints from experts) :***	- This requires the researcher to be an actor and an observer (note that this stage is to some extent subjective) hence need to be kept as wide as possible. - Collect as much data as possible (both qualitative and quantitative) - Keep it as wide (and vague) as possible within the problem space– avoid being reductionist, jumping to conclusions or ignoring the current scenario focusing on preconceived ideas, (Checkland, 1999; Williams, 2005)

Note: Stages 1 and 2 fall under the *real world* side – refer to figure 2.4

2.5.2 ***Stage 2****: Problem Situation Expressed*

The central task at this stage is to come up with a 'Rich Picture' of the problem situation. A rich picture is an *expression of the situation* (Checkland, 1998:317). Rich pictures also called mind maps represents what we know about messy situations – the issues, the actors, problems, relationships, conflicts and motivations. Checkland (1981 as quoted by Monk, 1998) recommends that the rich pictures be made via use of diagrams or visual representation. The *rich picture* should be as neutral as possible while expressing the views of the actors.

Table 2.2: *Stage 2*: Problem Situation Expressed:

Aim	❖ Build a deep representation of the situation in which the intervention is desired
Objectives	i. Display the situation so that a range of possible and hopefully relevant choices can be revealed (Checkland, 1998:166). ii. List of the relevant systems which must be analysed in the next step (stage 3)
Tools / Methods	• *Interrelation diagrams; Affinity diagrams;* • *Tree Diagrams; Activity Networks* • *Failure Mode & Effect Analysis (FMEA)* • *Ishikawa Diagrams* • *SWOT and SWOTE Analysis*
Outcomes	▪ A schematic (visual representation) showing the *rich picture* ▪ A shortlist of the relevant systems (to be defined in stage 3)
Notes ***(Hints from experts):***	- Spend the greatest time on this stage to build the richest picture possible (Hitchin, 2007). - *The choice of the relevant systems will represent a particular outlook on the problem situation …* it follows that care should be exercised here. Get as many versions (viewpoints) as possible of the system to be engineered or improved (Checkland, 1999).

The advantage of the rich picture is that it draws together information and perspectives form the widest possible range of sources. Checkland, (1981) provides some guidelines as what should be included and the questions to be answered for the rich picture building process to be considered complete **- elements of an effective rich picture** (William, 2005:4)**:**

- **Structures**: *what are the key structures?*
- **Processes**: *what are the key processes – doing what, following which procedures?*
- **Climate**: *what is the operational environment and the wider systems impacting this system?*
- **People**: *what are the key and kind of people (in general) in this organisation?*
- **Issues expressed by people**: *What is the operational context – the key concerns?*
- **Conflicts:** *what is the culture and the political climate of the organisation?*

(William, 2005:4)

How can the situation be expressed in an unstructured form? In general a rich picture therefore can show the boundaries, structures, the resources being deployed, the main actors, the environment (wider systems), and information flow. Most authorities agree that rich pictures are generally constructed by interviewing relevant actors. Drawing up the rich pictures then will be an iterative process of understanding and refining that understanding, (Monk, 1998). From the discussion and arguments presented above, the intention of the rich picture can be summarised as follows;

- Sums up the important elements or key issues associated with the problem situation
- It reveals the relevant activity systems to model or focus on in the next step (stage 3)
- Shows the key concerns (quotes) of the main actors for further analysis
- Exposes the inter-related picture of the overall problem situation.

2.5.3 ***Stage 3***: *Root Definition of Relevant Systems*

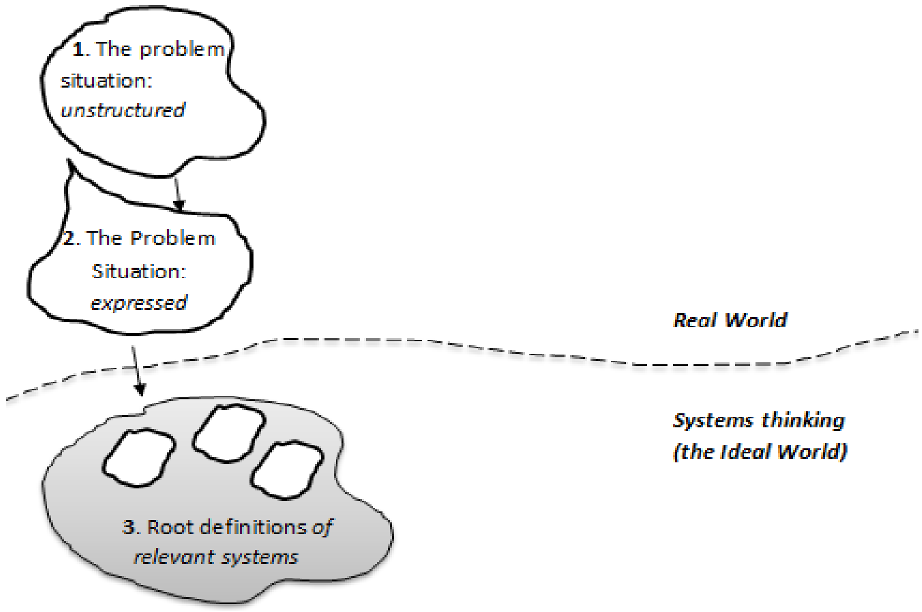


Figure 2.5 Extract showing stage 3 of the 7-stage SSM, (Checkland, 1981)

This stage moves out of the real world and into the *systems thinking world* as shown in figure 2.5, above. The purpose of coming up with the root definition is to understand the concept of different perspectives that can be derived, to arrive at the different desirable choices, Williams, (2005). Checkland (1976 p.62) defines a *root definition* as "…a condensed representation of the system(s) in its most fundamental form". A root definition in essence captures different perspectives of the problem in one explanation – a condensed form. In this regard Checkland (1999 p.167) advises that several root definitions may be chosen. This should ensure diversity of views. Checkland (1999 p.176) further cautions the system analyst that, "…a relevant system does not… imply that the selected system is necessarily desirable. The argument here is to provide the foundation of an insightful inquiry.

Checkland, (1981) developed the mnemonic CATWOE to help ensure the root definition of the relevant systems is complete. The mnemonic - CATWOE essentially represents a structured rigorous definition development process, the components of which are listed below as outlined in (Hitchin, 2007:193);

C - Customers: of the system (the beneficiaries, or victims of the transformation)

A - Actors: within the system (those who carry-out the transformation - *inputs into outputs*)

T – Transformation process: carried out by the system (what the system does)

W – ***W****eltanschauung*: the world view that makes the transformation meaningful

O – Owners: of the system (those with authority to stop the transformation process)

E – Environmental constraints: these are external constraints that must be considered (constraints that influences but do not control the system)

In line with the systems concepts principle of expansiveness, Checkland (1999 p.319) defines the *Weltanschauung* as, "… the (unquestioned) image or model of the world which makes the … system (with its particular transformation process) a meaningful one to consider. 'Weltanschauung' is a German word meaning *world-view*. The important point to note, as highlighted by Checkland is that people see things and justify things differently. That is to incorporate everyone's perception might imply the final solution could be found all encompassing. Hitchins, (2007 p.44) puts it differently, "...neither *Weltanschauung* is either right or wrong, and neither is logical or illogical – they are what they are; philosophical viewpoints. The implications of adopting and expressing such viewpoints might prove important. In constructing the CATWOE, William (2005:6) recommends that the following order is followed;

1. Transformation
2. Weltanschauung
3. Customer
4. Actors
5. Owners; and finally
6. Environment

It follows that all the other activities (2 to 6) follow from the transformation. Checkland *et al.*, (1990 p.33) suggests a way of structuring the final short textual statement that summarises the root definition;

A system to do ***P****, by (means of)* ***Q*** *in order to do* ***R*** *... (1)*

It should be noted that in line with the systems approach and the *Weltanschauung* explanation given above that there can never be a purely (100%) correct definition because such a definition represents only one view of the world. However the root definition should be well formed to capture insight into the situation (Checkland, 1999:166). Checkland, (1999 p.A25) argues that the concept of *measure of performance* needs to be implemented early to test the <u>transformation</u> of the relevant systems unlike the original approach that delayed this deferred this exercise to the conceptual model stage. Checkland claims forms part of the continuous lessons that are part of the action research. This performance measure includes, "checking that the output is produced, checking whether minimum resources are used to obtain it, checking at a higher level, that the transformation is worth doing…"(Checkland, 1999:A25). Patching (1990) outlines the referred to measure of performance (with reference to the transformation:

E1 - Efficacy: Does the system work, is the transformation effected?

E2 - Efficiency: Will it work with minimum resources?

E3 - Effectiveness: Is the long term goal achieved (Z) – does it contribute to the firm?

E4 - Ethical: Is it morally sound?

E5 - Elegance: Is it beautiful (elegant)?

The table 2.3 summarises this important stage of Checkland SSM.

Table 2.3: *Stage 3: Root Definitions of Relevant Systems*

Aim	❖ Define important elements of the relevant systems
Objectives	i. Capture insight into the situation, (Checkland, 1998:166) ii. Gain understanding of the concept of different perspectives that are possible to arrive at the different desirable choices.
Tools / Methods	• Using the **CATWOE** (Checkland, 1981) • **CAPETOWN** an extension of Checkland's mnemonic (Siriram, 2007). The added letters here, ***P*** and ***N*** respectively stand for **P**erformance (*that is the performance criteria that is used to measure how well the system is doing*) and **N**ature of the System (for example *open system, closed system* and so forth) • **5E's (measures of performance)**
Outcomes	▪ Short textual statements that adequately defines the chosen relevant system
Notes ***(Hints from experts) :***	- Spent the considerable amount of time on this stage to build the adequate definitions considering all the elements given by the mnemonic CAPETOWN above (Siriram, 2007; 2011)

2.5.4 ***Stage 4**: Conceptual Models*

This stage still falls in the ideal world. Checkland (1999 p.313) defines the conceptual model in the context of systems engineering as "…a systematic account of human activity system, built on the basis of that systems root definition, in the form of a structured set of verbs in the imperative *(*authoritative*)* mood". This means that the conceptual models are descriptive rather than prescriptive and developed strictly with reference to the relevant systems' root definitions that come out of stage 3. This stage therefore demonstrates the formal use of systems thinking (see item 4a in Checkland 7-stage SSM presented earlier in figure 2.4). With reference to the use of verbs William (2005 p.9) concurs with Checkland (1999) and advises, "...use verbs in the imperative … write down activities necessary to carry out the transformation (T in CATWOE). Aim for 7±2 activities that are at the same scale". It follows that only key activities that can be carried out should be included. Examples of common verbs that have been used include *decide, determine, identify, use, find, explore, conduct, design, formulate develop,* etc.

With reference to item 4b in Checkland 7-stage SSM presented earlier in figure 2.4 Checkland (1999 p.176) invites other forms of systems thinking, "… because the methodology was developed at the level of *principles of method,* rather than a technique, it was essential that it should not in principle exclude any systems thinking being developed elsewhere". Here Checkland reiterates the inclusivity principle which is one of the values of the systems approach. As such the SSM is designed to accommodate other views. Different systems thinking approaches have been developed. Hitchins (2007 p.195) presents what he calls the *rigorous soft method* (RSM) and which he argues; it is an improvement of Checkland SSM. Other academics are therefore open to add on to the original SSM.

Nonetheless two main problems that the system analyst faces at the conceptual model stage as highlighted by Checkland (1999), Hitchins (2007), Patching (1990) are;

1. The tendency to slide into continual reference to the real world or organisation processes and activities.
2. Agreeing on the criteria for choosing and deciding on the best model/s to propose and carrying forward to the next steps.

With reference to point 1, Checkland, (1999:170) cautions, "…this need to be resisted because it negates the whole purpose of the approach (the 7-stage SSM), which is to generate radical thought by selecting some view of the problems situation…" The argument here is that this oversight kills innovation and creativity which are together key ingredients for continuously improving a system.

Checkland goes on to say, "…the step from the root definition to conceptual model is the most rigorous in the whole methodology", referring to the SSM. This emphasises the importance of stage 3 and 4 of the SSM as they present an *all new* way to problem solving. To counter point 2 Patching (1990) references the use of five E's (5E's) again to verify the decision criteria. This stage 4 of the 7 stage SSM is summarised below in Table 2.4

Table 2.4: *Stage 4: Developing Conceptual Models*

Aim	❖ To build a conceptual activity model that includes the core activities required to go into the system
Objectives	i. Elaborate each root definition to produce activity models, (Hitchins, 2007:194) ii. Identify any meta-processes needed to manage the overall transition, and develop them into mini high-level project plans iii. Build the best possible – *ideal* models to be compared with the real world in stage 5.
Tools / Methods	• Logical linking of verbs (Checkland, 1999; William 2005) • Using the **5E's** (measure of performance to propose the best model) The 5E's for decision criteria are *Efficacy; Efficiency; Effectiveness; Ethics and Elegance.*
Outcomes	▪ Ideal activity model/s

Notes ***(Hints from experts) :***	- "…elaboration (of the root definitions) should be a result of systems thinking rather than reference to existing organisations and processes and should expose only those activities that are logically necessary" (Hitchins, 2007:194) - "…an error which sometimes survives the effort to weed out errors is to include model activities which hopefully arise as a result of doing other things but are not themselves something an actor can carry-out." (Checkland, 1999:292). The examples given include 'generate profit' and 'gain a high reputation' - Indicate any flow (using arrows) which are essential to express what the system does (Checkland 1999:191; William, 2005:5) - "The model should contain the minimum number of verbs necessary for the system to be the one named and concisely described in the root definition", (Checkland, 1999:286) - "A frequent elaboration is to ask of each activity: What information is needed to carry out this activity? From what source? With what frequency? In what form? The basic activity model then becomes the origin of an information-flow model which can be used to enquire into present information flows or to design new information systems" (Checkland, 1999:287).

2.5.5 ***Stage 5****: Comparison of Stage 4 and 2 (Gap Analysis)*

The model is compared to reality – the *real world* as shown in figure 2.6, below. This stage is important in that it uses the conceptual models developed in stage 4 to stimulate thinking about organisational changes that may improve the status-quo. This is done by comparing stage 4 (the activity models of relevant systems) and stage 2 (the rich picture as is). In other words this means comparing the perceived realities (as expressed in the rich picture) and the predictions of the ideal world in the form of systems models.

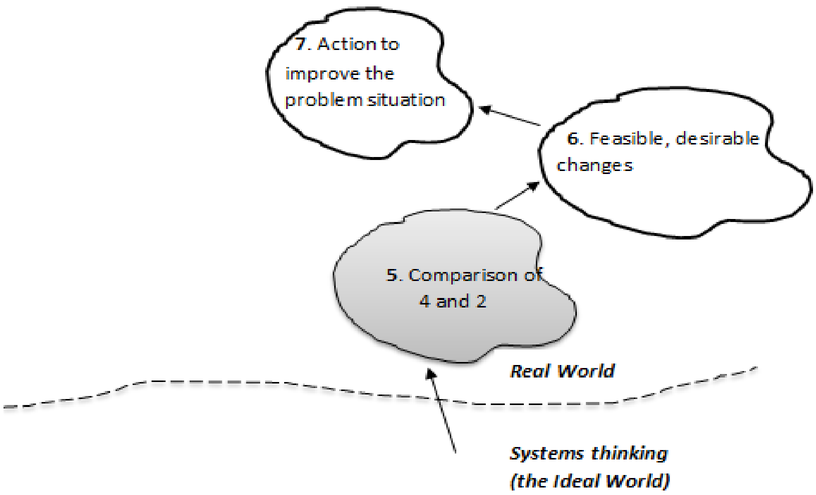


Figure 2.6 Extract showing stage 5 of the 7-stage SSM, (Checkland, 1981)

It is advised that this be done with participation of the stakeholders in the problem situation in order to create debate about the possible changes that might evolve and be introduced to address the problem, (Patching, 1990; Checkland, 1999). Checkland suggest four ways of doing this based on his action research experience:

1) Unstructured discussions
2) Structured questioning of the model using a matrix approach
3) Scenario or dynamic modelling
4) Trying to model the real world using the same structure as conceptual model

(Patching, 1990; Checkland, 1999)

William (2005 p.16) recommends using a matrix approach (method (2) above), the authority points out that it is the most common of the four (4) ways to compare stage 4 and 2 of the SSM. The structured questioning of the model using a matrix approach looks at each component be it an activity or link) and asks;

- ✓ Does it exist in the real world?
- ✓ How does it behave or *how is it done*?
- ✓ How is its performance identified and measured or *how it judged*?
- ✓ Is this process any good?

Table 2.5 below summarises stage 5.

Table 2.5: *Stage 5:* Comparison

Aim	❖ Develop insights into possible improvement opportunities
Objectives	i. Compare stage 4 and 2 (component by component) ii. Generate debate about possible changes which might be made within the perceived problem situation, (Checkland, 1999:180). iii. Develop a common understanding of the change and the change processes among the key actors and stakeholders (Lester, 2008). Checkland *et al.*, (1990), "the dialogue phase should be looking for accommodation or broad acceptability, not total consensus" which may be impossible to achieve in human activity systems because of differing views. iv. Expose any reservations and seek to take account of them, "this may involve exploring the assumptions and perspectives behind them and looking for higher order solutions that go beyond compromise"
Tools / Methods	• Unstructured discussions • Structured questioning of the model using a matrix approach • Scenario or dynamic modelling
Outcomes	▪ Table/s showing comparison information and recommendations ▪ Outline of the possible changes to be implemented
Notes ***(Hints from experts) :***	- Different approaches to the comparison stage works for different organisations or type of projects – (Checkland, 1999). The project could be a *green-fields* or *brown-fields* project or it could be a development project, *mandatory project* or *stay in business* project.

2.5.6 **Stage 6**: *Feasible and Desirable Changes*

It is important to note that at this stage Checkland's – 7 stage SSM methodology stops to being sequential and starts swinging back and forth … in order to gain the greatest leverage, William (2005 p.17). Hitchins (2007 p.195) conquers, "…a single iteration of the SSM may resolve the problem while several may be needed to solve the problem…" It can therefore, be argued that SSM is more of a learning and meaning development tool rather than a problem solving methodology. Stage 6 and stage 7 are primarily concerned with either change management or with situations where the system design effort forms part of a wider (e.g.) business re-engineering program, (Hitchins 200 p.194). Stage 6 comprises of mainly two tasks;

1) Selection of the feasible and desirable changes (based on the outcomes of the possible changes to be implemented outlined in stage 5)
2) Design of the agreed change

Hitchins (2007 p194) describe *feasible changes* as those changes that "…can be started and hopefully carried through given the existing culture in the target organisation". The point here is that chosen interventions should withstand the different systems dynamic that evolve with change. Desirable in this context implies, therefore, that whatever the intervention is, it should bring beneficial changes to the organisation or wider system/s. In examining point 2 above – *design of the agreed change*, categorizing the changes is recommended, (Checkland, 1999). If the system to be designed is '*plant maintenance'*, it is important to consider questions like;

→ *How to implement it…?*

→ *What to implement…?.*

Checkland (1999) and Patching (1990) suggest examining the changes as summarised in the table below;

Table 2.6 *Stage 6 –* *<u>categorization of agreed changes</u>*

Kind of change	Possible change agents	Action involved
- **Structural changes**	○ External forces	▪ Decree
- **Procedural changes**	○ Management	▪ Exhort or set an example
- **Attitudinal changes**	○ Internal forces	▪ Persuade (directly or indirectly)
		▪ Await the recognition of need

Elements from Checkland (1999) and Patching (1990)

Checkland (1999 p.180) defines structural changes as those parts which do not change in the short term and gives reporting structures and organisational groups as examples. The same authority describes procedural changes as, "…changes to the dynamic elements: the processes of reporting and informing …all activities which go on within the (relatively) static structures". Attitudinal changes refers to change in the state of the mind of people in the organisation regards the acceptance or dislike of something. This can be picked up from surveys. Checkland (1990) suggests attitudinal change to be the most difficult of the three. The table below summarises the stage 6:

Table 2.7 *Stage 6:* Feasible and Desirable Changes

Aim	❖ Develop courses of action (concrete plans) that are both feasible and desirable given the culture of the organisation
Objectives	i. Classify (categorise) the shortlisted possible interventions ii. Analyse the different shortlisted interventions iii. Assess the feasibility of the interventions iv. Design the agreed change
Tools / Methods	• Run through the model again using different CAPETOWN, different perspectives, different scales (i.e. sub-systems) • Undertake alternative systems based analysis • The 'owner' analysis (who has the veto power) • Social systems analysis • Political analysis – how is power expressed in the situation studied
Outcomes	▪ List of changes to be made ▪ Outline of how the changes will be implemented (phasing approach, impacts (*who, when and how*), etc.) ▪ Stakeholder impact analysis report
Notes ***(Hints from experts) :***	- The discussions at this stage should be with peoples in the problem situation who care about the perceived problem – (Checkland, 1999)

2.5.7 ***Stage 7:*** *Action to improve the Problem Situation*

The primary focus of this final stage is to implement the necessary changes. Checkland (1999) carefully uses the word '*improve'* at this stage as the outcome of the SSM from a systems approach perspective is to *dissolve, resolve* or *solve a problem, (*Ackoff as quoted Hitchins, 2007). Some changes may be impractical and are dropped or postponed. This can be due to political, culture, financial or ethical reasons alike. The table below summarises this last stage of the 7-stage original SSM:

Table 2.8 *Stage 7:* Action to Improve the Problem Situation

Aim	❖ Implementation of the agreed interventions
Objectives	i. Gain better understanding (of the system/s in question) ii. Derive lessons learnt iii. Target to match the planned change
Tools / Methods	• Formal project management methodologies (PMBoK; Prince 2 etc.) • Less structured approaches may also be used • Change Management (Adoption /Transition plans)
Outcomes	▪ Better understanding and knowledge of the system/s under analysis - Problem situation *dissolved, resolved or solved*, (Ackoff, 1981 as quoted by Hitchins, 2007)
Notes ***(Hints from experts) :***	- Monitoring and evaluation to keep track of the effects of the project (Lester, 2008). - These changes must be desirable as a result of insight gained in earlier stages of the SSM - The changes must be culturally feasible within the context of the organisation in question

2.6 Criticism of the SSM

Questions have been raised; does Soft Systems Methodology actually work in practice? Just like any new way of doing things, systems thinking the idea behind the SSM, what (Boardman and Saucer, 2008) call a *way of coping with 21st century problems,* has been criticised on many platforms. The literature has revealed criticism in four areas;

- Theoretical development of SSM
- Methodology
- Process
- Practical Application

<u>Theoretical development of SSM:</u> Criticism arose from the implied assumption that all members in an organisation have choice, in-fact equal power (Holwell, 1997 as quoted by Graham, 2003). On this SSM ignores issues of power. In practice this has raised issues whether SSM is really practical in real life scenarios. Organisational members do not have equal choice and it is naïve to think that everyone can openly raise, discuss issues, problems, perceptions and needs freely (Stockholm Environment Institute, 2005:10). Holwell (1997) and Graham (2003) arguments are valid and it is important to reflect on them as one uses the SSM. Contrary to this several advocates of the systems approach, Ackoff (1981), Churchman (1968), Patching (1990), Checkland (1999) and Hitchins (2007) differ, as they claim that by first understanding and learning, each stakeholders view point, it forms a good foundation to align the organisational objectives with the lowest system in the hierarchy of systems. Churchman (1968) clarifies "… it is the subsystem that thinks about the overall plan and implements its thinking" The open-door culture and supported decision making is more likely to encourage innovation and creative thinking. This forms a good platform for joint problem solving which is crucial for buy-in and sustainable issue / problem resolution. Hitchins (2007 p.195) summarises as an advocate of SSM, "…there are two major points that differentiate SSM from other methodologies or methods that might be used at the start of a design exercise: the ability to abstract and the ability to surface issues related to the purpose to be served by the wider system"

<u>Methodology (Approach) of SSM:</u> It is **not** a *'how to build a system guidebook'* Holwell, (1997 as cited by Graham, 2003). The outcry here is that the constitutive rules are too loose and not extensive. The main query highlighted was that SSM's open-endedness makes it difficult to manage. However this non-restrictive approach is consistent with the systems approach in which the methodology is rooted. It is important, at this juncture, to highlight that SSM is heuristic not an algorithmic tool. The

argument that SSM has no real method is, therefore, reduced by the findings that many other prescriptive methods failed to work in human activity systems and in intervening chaotic, complex problem situations, (Checkland, 1999; Hitchins, 2007; Stockholm Environment Institute, 2005). Rose, 1997 p.14) points out four uses of SSM as methodology, "as a problem-structuring, good-fit, triangulation and coordinative tool. This '***how** to build a system guidebook'* criticism is in principle a reductionist way of approaching a problematic situation. "SSM seeks to answer the …**what, where** questions Checkland (1999).

Process (with reference to the 7-stage SSM)

The literature reviewed has not shown any criticism of stages 1, 2, and 6 of Checkland's original 7-stage SSM. However, queries have been centred on stages 3 (root definition of relevant systems) and stage 4 (development of conceptual models). Critics have argued that the activity of the *conceptual model* is over-valued. Salner (2000 as quoted by Graham, 2003) believes researchers should concentrate on what modelling was intended to produce, that is, to enhance debate and discussion about what is and what should be (ideal situation). To an extent it is true that this activity model building stage is pivotal in Checkland's SSM, as it is the stage that is used to motivate change by checking the gap that exists with the real world, Hitchins (2007) agrees. On the other hand Checkland (1999 p.A24) does not downplay the importance of this stage, but argues, "given the preliminary thinking expressed in the root definition, CATWOE and the 3Es (now 5Es) and the equation – *PQR* (presented in stage 3), assembling an activity model ought not to be too difficult…, and the task ought not be elaborate one either …the tasks should be captured in Miller (1986) *magical number* of 7±2 individual activities". This stage therefore calls for high-level thinkers with experience or real world experience to participate in the model building activity exercise. This is because models in SSM are the basis of structuring debate.

Three problematic issues have been highlighted in the literature concerning the CATWOE. These are (Basden and Harper 2003);

- *Issue 1*: It is not always easy to understand what the elements of the CATWOE are?
- *Issue 2*: The notion of the owner 'O' has been found to be difficult and confusing
- *Issue 3*: The Weltanschauung – the perspective that gives 'T' its meaning has been seen as problematic and confusing in that there is only one 'W' in the CATWOE although in practise there a wide range of W's.

Basden and Harper 2003

Issue 1: The misunderstanding and the resultant difficulties in outlining the contents of the particular elements in the CATWOE can be argued to be because of the way the letters in the mnemonic are presented or arranged. Checkland (1981, 1999) recommends that the analysis be started with T – the transformation. William (2005 p.6) concurs and recommends the following: T, W, C, A, O and then finally E.

Issue 2: Checkland, (1999 p.A23) suggested that 'O' is in fact part of a wider system, the environment. If the owner is the one with veto power to stop the process as described in the original 7-stage SSM then viewing it from Checkland's recent suggestion adds complexity. This is because the environment can be as wide as the analyst can view. The researcher believes it is impractical for the owner to be considered from an environmental perspective especially that the world has become more liberal and capitalist. Basden and Harper (2003 p.4) attempt to put the matter to rest, "…the clue to its meaning (referring to 'O' in mnemonic CATWOE) might lie in the original definition *having a prime concern* for the system which speaks of responsibility" as in the person in charge of the system.

Issue 3: The issue emanates from the fact that the way the original CATWOE (Checkland, 1976, 1981) was presented suggested that it had one 'W' – a *world view* of the transformation. This confused several academics as it is only normal that people view the world differently. Fairclough, (1982 as cited by Basden & Harper, 2003) found eight (8) types of 'W' in the original SSM. The result could be conflicting 'Weltanschauung'. To clarify the concept Checkland and Davies (1986 as quoted by Basden and Harper, 2003) distinguished three different types of W – W_1, W_2, W_3. Referring to the original Checkland 7- stage SSM (figure 2.4),

$\boldsymbol{W_1}$: The society's *world-view* of the problematic situation that gives 'T'

$\boldsymbol{W_2}$: The perspective from SSM itself (above the line – during finding out, stages 5, 6)

$\boldsymbol{W_3}$: The perspective from SSM itself (below the line – during model building, where is it believed that the proposed system and the changes it brings about will be effective in stage 4)

The challenge though is that the difference between a Weltanschauung ($\boldsymbol{W_2}$) and ($\boldsymbol{W_3}$) is not always clear in practise and many simple world-views may be trivial, (Basden and Harper, 2003). This study will not seek to complicate the *root definition* step and as such will be limited to there (3) world views as recommended by Checkland and Davies, (1986).

Notwithstanding the issues raised the use of CATWOE and the ***- PQR*** equation (presented in stage 3), to define the system under analysis encourages a process approach where participants can test their assumptions, positions and the integrity of data. Checkland, (1981) does acknowledge the limitations of the *root definition,* "no root definition can ever provide a unique description of any actual manifestation of human activity system... there will be other feasible Weltanschauung", (Berg et al, 2011 p.236). The formal aim of this kind of thinking prior to building the conceptual model is to ensure that there is clarity of thought about the purposeful activity (Checkland, 1999p.A23)

Practical Application

Critiques of SSM have raised several queries or *Weltanschauung (Worldviews)* which has cast doubt in its application and to an extent slowed its adoption industry wide. These include;

- *It offers no standard for human conduct (Mingers 1992a; Berg et al, 2011:236)*
- *No-one has ever proved that conflicts cannot be resolved or dissolved without the use of force, (Ackoff, 1978:49 as cited by Berg et al, 2011:238)*
- *SSM imposes values of openness and niceness which are more suitable to middle class academics than to managers or workers, (Anonymous)*
- *SSM as a problem solving methodology, purports a weak solution on how to perform the actual work (Berg et al, 2011:238)*
- *"…word 'solution' is too generalist for a methodology that adopts a cyclic learning process of enquiry encouraging discussion and debate as central to an unending process", (Bronte-Stewart, 1999 as cited in Berg et al, 2011:238)*
- *SSM offers no instruction of how the learning should take place (Holwell, 1997; Lester, 2008; Graham, 2008; Berg et al, 2011)*
- *SSM has been reported as too complex as an interaction approach for participants (Patching, 1990)*
- *"SSM is only valid as a an action research model as the same it was invented", (Lester 2008)*

The above perceptions and criticism are testimony of why there has been slow adoption of SSM. Three distinct points were synthesised from the above critiques;

1) Overdependence on organisational behaviour resulting in failure to address the problem head-on: The point here is that when SSM is applied in certain cases it becomes too constrained by organisational and other interacting systems (that is ever evolving systems) for instance the trade unions, green movement, equality pressure groups alike. This too democratic approach can be argued to be misaligned with the reality in industry where these systems operate in liberal and capitalist environments. This result in resolution of immediate disputes or problems but leaving the situation that gave rise to problems essentially

unchanged, (Lester 2008). SSM also ignores material interest, plays down conflict of interest of key stakeholder and stockholders making this methodology more idealist than real, (Jackson, 2000 p.269).

2) Transferring the principles of SSM into practice has been problematic: The difficulty in adopting SSM principles can be attributed to two reasons; a) *limitations and difficulties in the understanding of the SSM ideas* or rather the systems concepts, *(Ledington & Donaldson, 1997 as quoted by Graham, 2003:8)* b) *larger time frames required to teach and transfer SSM principles, (Graham 2003:9)*. The researcher believes these two reasons can be managed and addressed via application of the appropriate change management processes, institutionalising the SSM the same way interventions like TQM or TPM have been entrenched. That is by giving employees training, and incorporating systems principles in procedures and business processes.

3) It is viewed as Weak Solution to perform the actual work: This can be attributed to the iteration and interactive nature of learning and consensus seeking methodologies like SSM. Lester, (2008) has argued that *soft systems methodologies are* more practical at the issue based level than as tools to address a problem. The premise here is that problems generally start as an issue, develops into a problem before it gets to critical levels that demand intervention. The critiques argue therefore that, if the primary objective of SSM is to understand … (Checkland, 1981, 1990, 1999). It follows the SSM applicability is limited to that primary objective – *to understand.* This is contrary to the demands of a problem that has matured into the *critical level* where the goal is immediate action (putting a solution in place even if it is short term), (Graham, 1997).

These adoption issues are understandable judging from the founding principles of which the methodology was designed – (*the systems approach), a way of attacking problematic situations which is designed* to *changing our mind-set and finding patterns in chaos and complexity, (Churchman, 1968; Checkland 1999;Gharajedaghi, 2006; Hitchins, 2007; Sheard 2008)*

2.7 Application of SSM

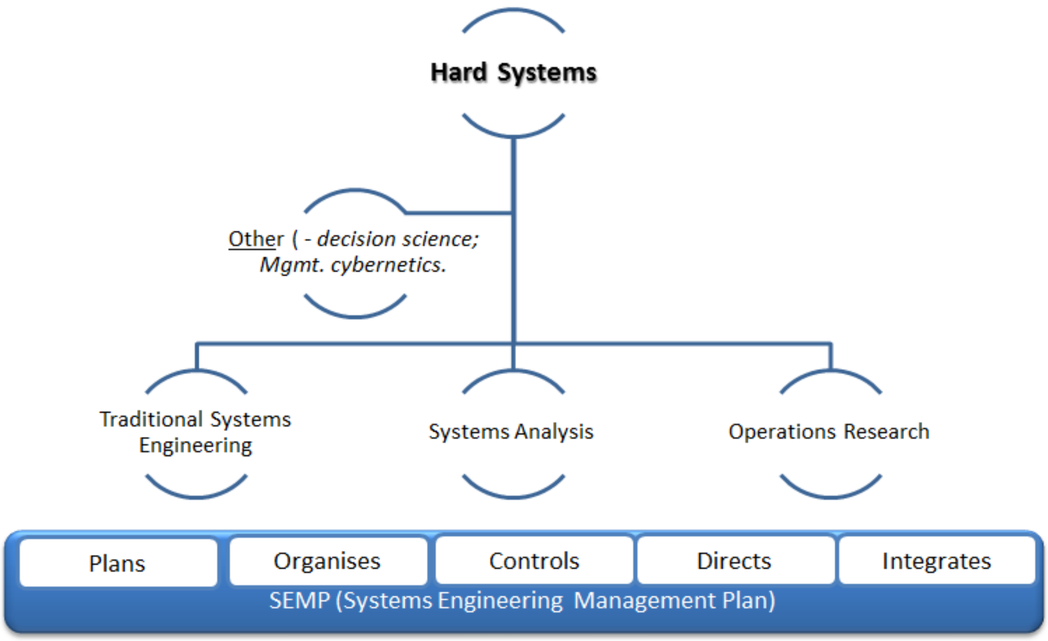
SSM has been applied in a wide range of industries all over the world. Appendix D shows some examples of *where* (the particular industry, sector and country) it has been applied, *how* it was applied, and some remarks on the application.

The next section focuses on the Hard Systems Approaches (HSA).

Part C - A High Level Analysis of the Hard Systems Methodology

2.8 Overview of the Hard Systems Approaches

Hard systems approaches to problem solving make use of the tools that are commonly used in the several disciplines of engineering (be it civil, structural, electrical, mechanical, process engineering alike). The hard systems approach, as explained by Checkland (1999) and Hitchin (2007), has been used to determine how to address better defined problems. That is where the problem is clear or less ambiguous. The term *hard systems* is a generic name given by Checkland to classify the various reductionist approaches for solving real world problems developed during and immediately after the Second World War (Jackson, 2003). Checkland (1978, 1981 as cited by Jackson, 2003 p.127) originally included in his category of hard systems approaches 1) *System engineering* (as framed by Hall, 1962; 1969 as cited in Checkland, 1999:130) and Bell Telephone Laboratories *system analysis*, (as framed by Hunt, 1954 as cited in Checkland, 1999:130). To date *operations research*, *decision science*, *cost-benefit analysis*, *management cybernetics* (as distinguished from organisational cybernetics) are now grouped under 'hard systems' (or functionalist approaches) because of the nature of these problem enquiry methodologies (Jackson, 2000; Hitchins, 2007).The meta-level view of these methodologies is summarised below in Figure 2.7:



The author's own diagrammatic illustration

Figure 2.7 Meta-level views of the Hard Systems Approaches

It is important to note that the *Systems Engineering Management Plan* known as the SEMP hereafter has been included as a guide to implement these approaches. Since systems engineering is a high-level responsibility a SEMP is preferred as opposed to the focus area specific *project management plan* - PMP, (Fabrycky & Blanchard, 2006:664). Martin (2000) describes the SEMP as, "the primary top-level management document for the integration of all systems engineering activities within the context of and as an expansion to, the project plan". It follows the SEMP should be derived and developed in parallel with the PMP. The primary objective of the *systems engineering management plan* is to "facilitate the timely integration of numerous design considerations into a functioning system that will be of high value to the customer", (Martin, 2000; Fabrycky & Blanchard, 2006). The full SEMP generic approach as adopted from Fabrycky & Blanchard (2006 p.664) is shown in Appendix E. The following are some of the standards that expand on the SEMP; INCOSE-TP-2003-016-02; EIA/ IS-632 and IEEE-1220.

This study will, however, focus only on the parent hard systems – the traditional (original/ classical) systems engineering approach and systems analysis as it has been argued that *systems analysis* is a sub-set of systems engineering, (Sage & Armstrong, 2000; Martin, 2000). Systems analysis (SA) is said to have emerged out of operations research (OR) and is broader in scope, (Jackson, 2003). As such this study will centre on the classical (traditional) systems engineering. It has been termed traditional SE for convenience in this study. Traditional in the sense that it was the predominant distinct systems engineering approach before Checkland *et al.*, (1981) and Ackoff (1981) formalised the soft approaches, (Hitchins, 2007).

Hard systems methodology has been defined/ described variously in literature. Radcliffe & Clayton, (1996) described this approach as a *problem solving sequence*. Kirk (1995) describes it as a model which has precise objectives which can be expressed in quantitative terms allowing the development of mathematical models. Jackson (2000 cites Checkland, 1978) and describes these methodologies as those that assume that they were developed to maximise efficiency. These definitions suggest that this approach starts at a defined point (X) and follows systematic steps to get to a known achievable end (Y) and as such a metric can easily be designed to measure performance. However the following '*catch all'* definition by Checkland will be used in the study. Checkland (1999 p.318) defines the hard systems methodology (HSM) as an approach for "… tackling real world problems in which an objective or end-to-be achieved can be taken as given". Checkland (1999) referred to hard system methodology as a *systems engineering* approach that engineers a system to achieve a stated objective.

2.8.1 Assumptions of Hard Systems Approaches

The section begins by contextualising the assumptions of the hard systems approaches (HAS) before outlining them. The hard systems approaches emerged out of World War Two war-time pressures to deliver consistently in a short space of time with efficient use of resources, (Checkland, 19981, 1999; Jackson 2000, 2003, Hitchin, 2007). It was, therefore, required that the goal of the system of concern be clearly established before analysis could proceed. The goal was to win a war, (Jackson, 2003). These approaches worked very well to the extent that saw Bell Telephone Laboratories managing to solve its networking challenging, the USA - NASA Apollo space project succeeding, and remarkable efficiency being recorded in the defence and aerospace industries, (Churchman, 1968; Hitchin, 2007). Post war time, 1950s to 1960s saw the migration of the *hard systems* approaches SA, OR and the original SE to universities for further refinement but the obsession with mathematical modelling remained (Jackson, 2003). The list below summarises the assumptions embedded in hard system approaches (HS Approaches). HS approaches assume;

- A well-defined problem to be solved
- Problem contexts are simple – unitary in character and recommends intervening accordingly
- A problem is simplified by reducing it
- Systems are simple enough to be mathematically modelled
- Assumes people share values and beliefs and consensus can easily be reached
- The world is systemic and is studied systematically
- To address a problem, technical factors foremost
- An ideal solution.

(Patching, 1990; Checkland, 1999; Jackson, 2003; Hitchins, 2007)

The notion of putting a problem in context with control conditions assuming equilibrium (no input or outputs into and out of the system) simplifies the problem and works well to deliver a product (with reference to designed physical systems) but could be problematic with social-technological systems. Since such systems requires social participation, interest and concerns to be considered seriously. Maier & Rechtin, (2002 p.295) argue that such systems have social considerations that equal or exceed the technical one. This is contrary to assumptions outlined above.

2.9 Systems Analysis

Systems Analysis (SA) as outlined by the pioneer at the *RAND (Research and Development) Corporation* can be described as a set of techniques that support decision making. Quade (1963 as cited in Jackson 2000 p.130) defined *SA* "…as analysis to suggest a course of action by systematically examining the costs, effectiveness and risks of alternative policies or strategies and designing additional ones if those examined are found wanting". It follows therefore from this definition and from the phrase *"Systems Analysis"* that the use of this technique is broad and interdisciplinary. The definition also suggests that for any system under analysis be it a business system, an ecological system or a military system, it has to be broken-down and a *change-impact analysis* done for each subsystem. This definition also suggests the aim of systems analysis to be a broad economic appraisal of different means of meeting a defined end (Hitch, 1955 and Quade, 1963 as cited in Jackson, 2000:130). Figure 2.9 below summarises the generic *SA* methodology;

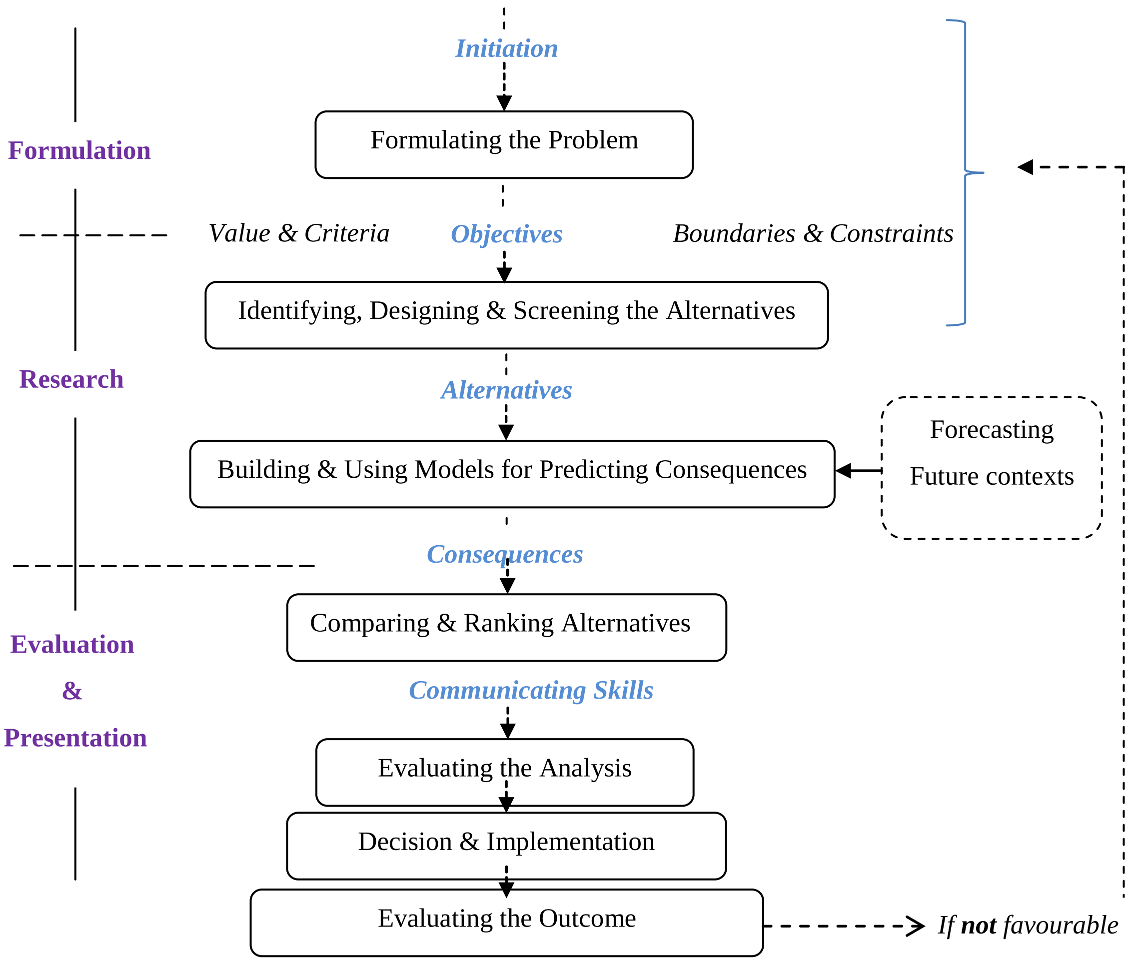


Figure 2.8 Systems Analysis Methodology (adopted from Jackson, 2000:130)

In simple terms if there is a problematic situation (typical of complex systems –CxS or systems of systems - SoS) this tool (SA) will be used to dissect the systems in order to study and better understand how the sub-systems, components, or elements interact and work. This breaking down and narrowing the problem space can be judged to be reductionist or to be contrary to the systems approach as specified by Churchman (1968) and Ackoff (1971). It is important to note that the SA methodology outlined in figure 2.8 has many variations or strategies. These include *structured analysis; information engineering (IE); prototyping* and *business process redesign* - see *Appendix K* for explanations / descriptions. Other SA strategies found in literature include, *object oriented analysis* (OOA), *joint application development* (JAD). The common denominator of all these strategies is that the systems analysis methodology aims to find an acceptable solution to be further developed or to improve the system. The rationale of system analysis can be argued to be based on the premise that making changes without exploring the effects on subsystems or working practice could result in a worse state due to the intervention.

2.10 Systems Engineering (*Classical –hard approach*)

The researcher has chosen to call this 'hard approach' - ***classical systems engineering*** to differentiate it from the modern system engineering which cover both the hard and soft systems approaches. The classical SE takes elements of the SE processes outlined *Appendix C* but in a sequential fashion. "It comprises of a set of activities which together lead to the creation of a complex man-made entity and / or the procedures and information flows associated with operation", (Checkland, 1999:138). It follows that the focus of SE is from the origin of a need to the final product and more importantly the full system life cycle. According to Hunt (n.d. as cited by Checkland, 1999) most of the work on SE is attributed to the experiences of the USA telecommunications company - Bell Telephone Laboratories.

The widely accepted definition of the *classical systems engineering* is that of G. Jenkins (as cited by Ackoff, 1971; Checkland, 1999; Jackson; 2000) and suffice for this study;

> Classical system engineering*…is the study of complex systems in their totality so that the component systems can be designed and fitted together so as to achieve the overall objective in the most efficient way.*

A few points can be highlighted form this definition;

1. The perception that SE was limited to address problems of complex systems
2. An element consistent with the systems approach of addressing the 'whole'

3. A reductionist attribute of analysing the smaller components and then synthesising
4. Working on a target known objective or desired state.
5. An element of optimisation of resources - mainly money, machine, materials and human resources, (Jackson, 2000:134)

Hall (1962 as cited by Checkland, 1999) summarises the *classical system engineering* as a problem solving sequence. Several authorities have outlined their system engineering process sequences but for the purpose of this study Hall's process (1962; 1969 as cited by Checkland) suffice as the reference hard systems approach. Table 2:9 (next page) maps three recognised SE processes to Hall's problem solving sequence.

Bahill & Gissing's (1998) process does not clearly show step 5.1 of Hall's SE process, instead it suggests that this step is part of step 4.1 (*model the system).* That is models will be developed for alternative designs and the preferred alternative will be expanded or further developed. Martin's, (2000) SE process on the other hand combines step 4.1 and 5.1 but does not give sufficient detail on the system selection step. It can be seen from the mapping that Sage & Armstrong's (2000) process more or less closely follows the classical systems engineering process as specified by Hall. An attempt was therefore made to explore the process further. Sage and Armstrong (2000) argue that the process should be repeated on the three *time dimension* levels of product life cycle; *systems definition; system development* and *system deployment* hence do not explicitly show step 6 in their process.

Table 2.9 Mapping of Different Approaches to Hall's classical SE Process

	(Hall, 1962; 1969)	**(Bahill & Gissing, 1998) –** *Acronym of process – SIMILAR*	**(Martin, 2000)**	**(Sage & Armstrong, 2000)**
Step 1	***1.1 Problem definition***	*1.1* ***S****tate the Problem*	*1.1 Explore the Need* *1.2 Explore Operational Concept*	*1.1 Problem definition*
Step 2	***2.1 Choice of Objectives***	*2.1 ------------------------------------*	*2.1 Functional Requirements*	*2.1 Value System Design (selection a set of objectives that guide the search for alternatives)*
Step 3	***3.1 Systems Synthesis***	*3.1* ***I****nvestigate the Alternatives*	*3.1 System Architecture*	*3.1 System Synthesis*
Step 4	***4.1 Systems Analysis***	*4.1* ***M****odel the System*	*4.1 Allocated Requirements*	*4.1 System Analysis & Modelling*
Step 5	***5.1 System Selection***	*5.1 ------------------------------------*	*5.1 -----------------------------------*	*5.1 Refinement of the Alternatives* *5.2 Decision Making*
Step 6	***6.1 System Development***	*6.1* ***I****ntegrate Systems/ Sub-systems*	*6.1 Detail Design*	*6.1 --------------------------------*
Step 7	***7.1 Concurrent Engineering*** *(or System Deployment)*	*7.1* ***L****aunch the System* *7.2* ***A****ccess Performance* *7.3* ***R****e-evaluation*	*7.1 Implementation* *7.2 Test & Verification*	*7.1 Planning for Action*

Sage and Armstrong (2000 p.12) gives a very useful high-level outline of what makes up a SE framework in the form of a nine element matrix structure as shown in figure 2.9.

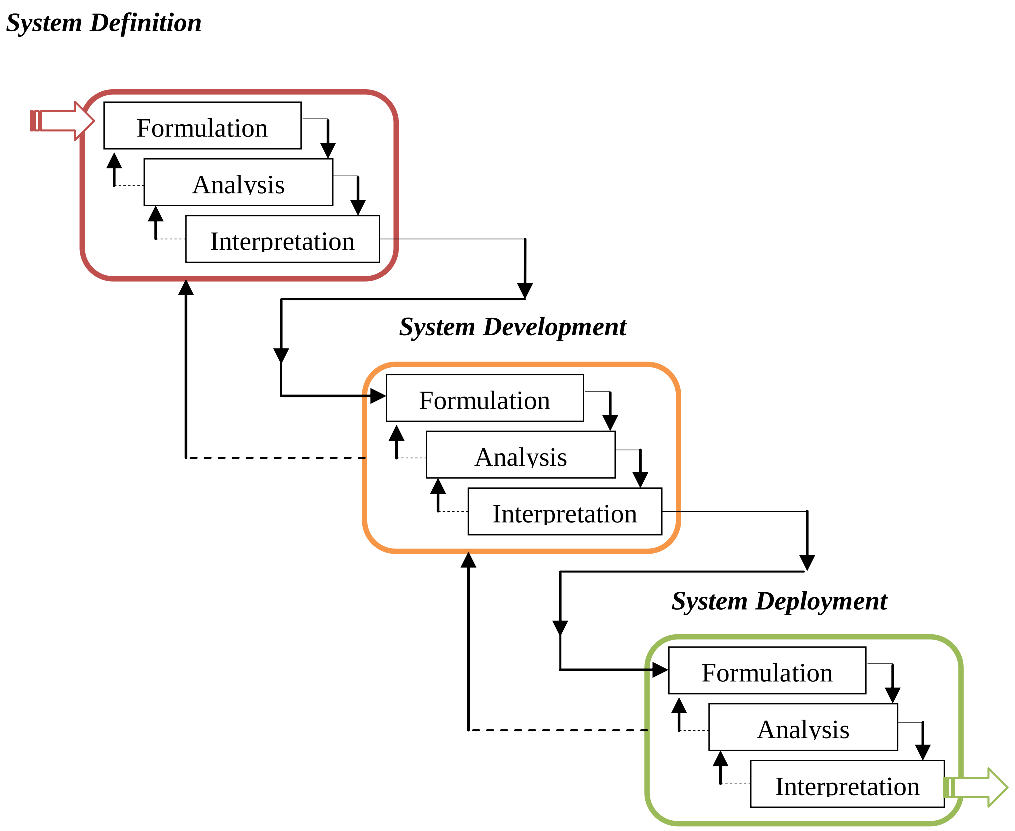


Figure 2:9 Systems Engineering Framework - adopted form (Sage and Armstrong, 2000:12)

The systems engineering framework demonstrates the iteration and cyclic nature of the methodology. Of significance is the feedback at each life-cycle phase and within the steps of each phase. The two authors (ibid) argue that within [1] the ***formulation step*** of each life-cycle phase there is *a) problem definition b) value system design* and *c) system synthesis;* and within [2] the ***analysis steps*** of each life-cycle phase there is *a) system analysis* and *b) refinement of the alternatives* and lastly 3) within ***interpretation step*** there is *a) decision making* and *b) planning for action.*

On the other hand Martin (2000) summarises the architecture of the *SE process* in practice by presenting a top level view with these sub-process with interfaces to design, integrated logistics support; production and deployment processes. These sub-processes are a) *SE management* b) *Requirements and Architecture Definition (R&AD)* c) *System Integration & Verification (SI&V)*, see figure 2.10 below:

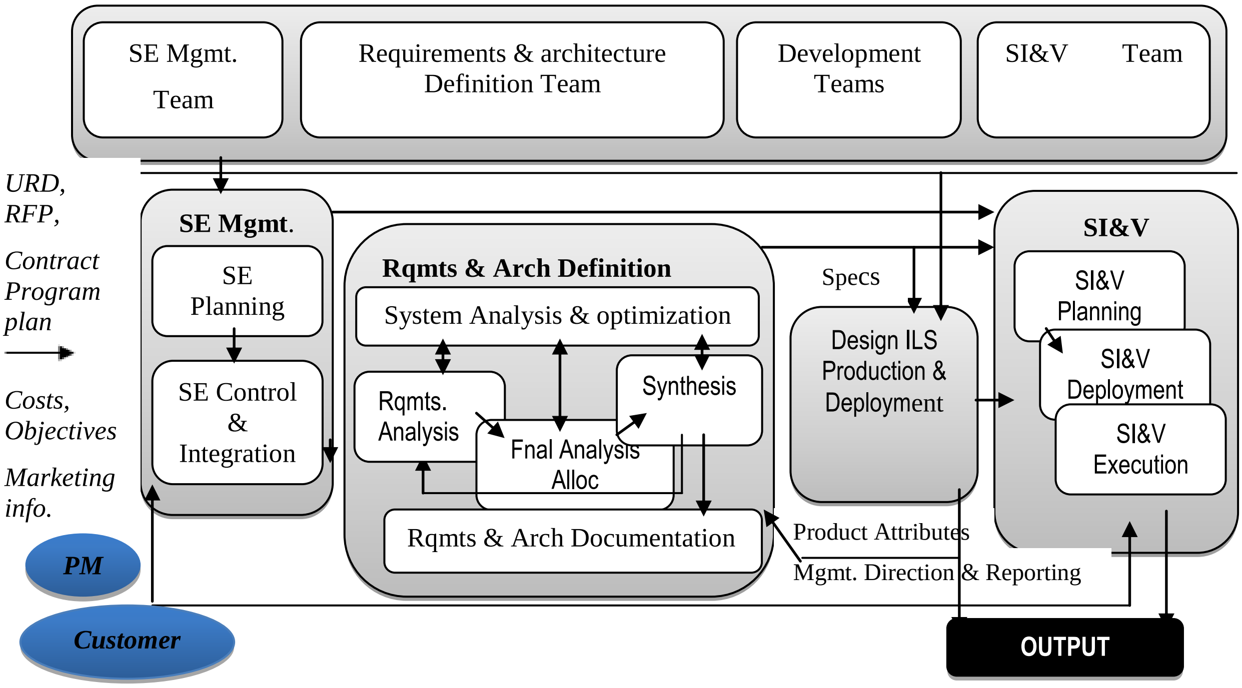


Figure 2:10 Systems Engineering Process adopted from (Martin, 2000:77)

The output of this process according to Martin (2000 p.77) includes an *integrated* and *qualified system; deployed systems* and the *system design package*. It is important to highlight that the SE process can begin at any point in the process depending on what has been achieved in the previous phases, contract or proposal preparation activities. It can also be argued that the herein present process is rather complex or resource intensive for a small organisation. Also see *Appendix E* for the SEMP checklist. Some important points to note from the mapping presented, the frameworks presented and the earlier literature review around systems analysis;

I. *System analysis* (step 4 of Hall's process) – a procedure by which explanation is sought by breaking down into manageable parts is essentially a subset of the SE process.

II. The outlined steps (in table 2.9 and figure 2.9) are not conclusive of what describes the SE process but are simply meant to show alignment of key authorities and to provide a framework to deal with problematic situation, whatever the level of complexity.

III. Understanding the problem before designing the solution is vital and the SE process emphasis this. The SE process by itself is structured in such a way to facilitate problem definition.

IV. The SE process involves all relevant disciplines. Essentially it is the bonding media – the glue that holds together all functional areas (technical and non-technical) and stakeholders.

V. Finally SE is a way of thinking that uses the system approach anchored on working from the whole's perspective.

This leads to the *systems engineering process models* which will be outlined in coming sections.

2.11 Systems Engineering Process Models

Several authorities (Martin, 2000; Adamsen, 2000; Sage & Armstrong; 2000; Fabrycky & Blanchard, 2006; Hitchins; 2007) agree, in principle, regarding fundamental concepts and processes of SE as a subject. The point of departure is on the process approach and steps (implementation model). *Table 2.9* which attempted to map different approaches to Hall's classical SE Process bears testimony. Adamsen (2000:8) agrees after he attempted to map the SE processes as cited in different standards (*IEEE; EIA/IS-632; DSMC - SE Management Guide; Mil-Std-499A and the Army Field Manual*). The outcome of this exercise was consensus on what Adamsen termed the *Systems Development Framework (SDF) organising concept;*

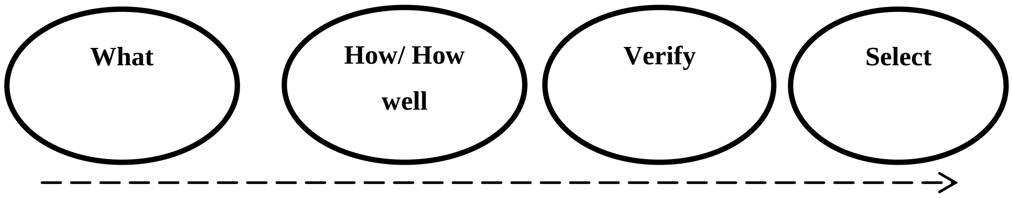


Figure 2:11 Systems Development Framework (SDF) courtesy of (Adamsen, 2000:8)

This study proposes use of Fabrycky & Blanchard, (2006)'s *life cycle* systems engineering process as the baseline frame of reference, refer to Appendix F. This framework is essentially a waterfall model which is applied to generate requirements using a top-down prioritisation criterion. That is application of the waterfall model (*to be explained in the next section)* at every logical step from concept design to system disposal starting with the system in question; the subsystem; the component level up to the modification for improvement level as and when required. The next section looks at the models commonly used and their variations.

2.12 Common Systems Engineering Process Models

The commonly used *SE - process models* include; (Martin, 2000; Sage & Armstrong, 2000; Fabrycky & Blanchard, 2006; Hitchins; 2007);

(a) The Waterfall Model; b) the Spiral (or Helical) Model and c) the Vee – Model.

Hitchins (2007 p.356) prefers to call these models systems engineering strategies. The outlined strategies (models) are just part of the many available in literature. The strategies presented are however notably distinct. Other strategies - variations of the above include the *incremental model; the evolutionary development model; reusable components model; technology application model; the Vee- model with prototyping.* According to Sage & Armstrong (2000) and Blanchard & Fabrycky (2006) the Waterfall model is the parent model after which the other models where synthesised. Nonetheless preference as which model to use is subjective (Blanchard & Fabrycky, 2006).

a) **The Waterfall Model**: was introduced in 1970 by Royce initially for software development, (Fabrycky & Blanchard, 2000). Figure 2:12 below shows a version of the generic waterfall model, sometimes referred to as the traditional model because it is the oldest (Grady, 1994)

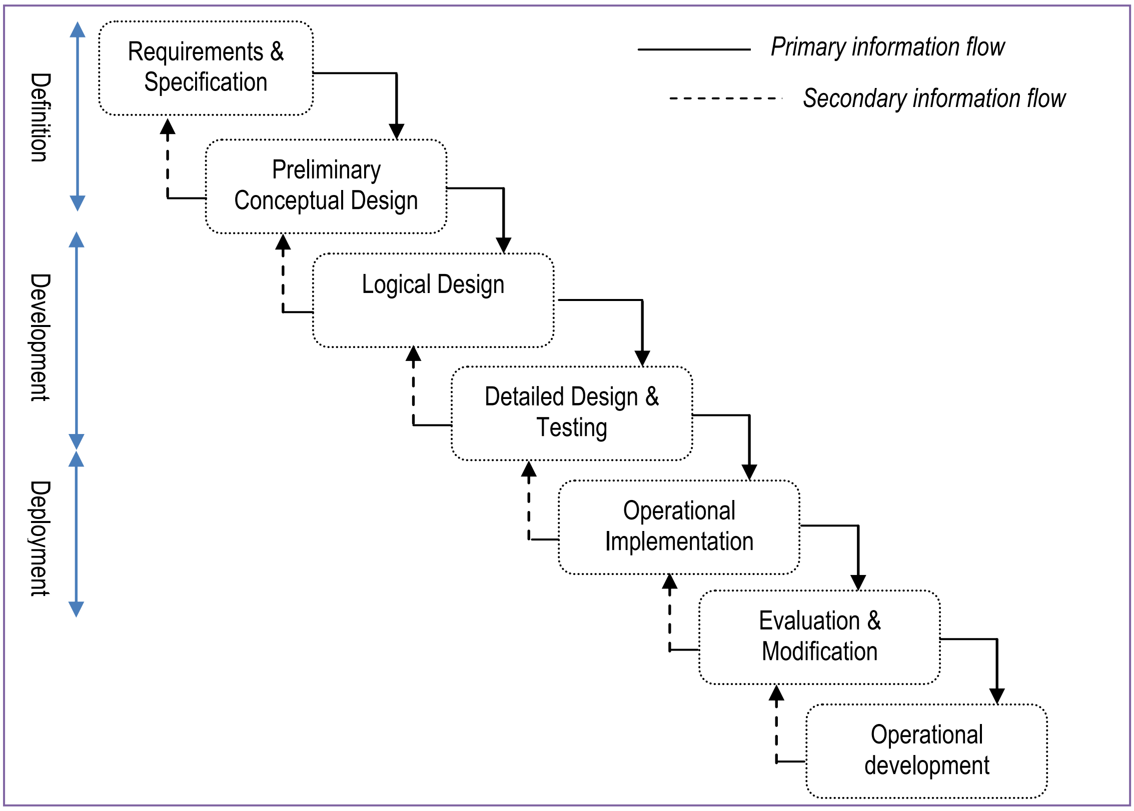


Figure 2:12 Waterfall SE Process Model (Sage & Rouse, 1999)

"The *Waterfall model* is based on a top-down development approach and is an ordered set of phases that are performed in sequence. The output from one phase becomes the input of the next" (Martin, 2000:265). It derives its name from this cascading effect from one phase to the next. The model usually has 5-8 steps as found in literature. A seven (7) - step model is sufficient for guide in this study as outlined in figure 2.12. Goals are established for each phase, and work-to-date is reviewed at the end of each phase against these goals. In Figure 2.12 there is iteration due to lessons learnt and queries from the previous steps and the interplay between successive steps, (Grady, 1994; Hitchins, 2007).

<u>Pros and Cons of the *Waterfall Model*</u>*:*

Pros:

- The orderly approach, in a step by step manner, enforces project discipline and is effective if the prime goal is control the cost risk between major review and decision events, (Adamsen, 2000; Martin, 2000; Sage & Armstrong; Fabrycky & Blanchard, 2006) This is because goals are established for each phase
- "It is a top-down development method that is compatible with top-down functional analysis/ allocation and bottom-up synthesis", (Martin, 2000:265). Refer to Hall's SE process in table 2.9
- It is document driven as documentation is produced at each stage, (anonymous). Only when a final version of the blueprint of respective steps is published can the team proceed to the next step.

Cons:

- The schematic (figure 2.12) can be argued to imply that work or steps downstream cannot begin until the upstream major reviews or control gates have been satisfied. In real life there is need to initiate, as an example software coding or hardware modelling, earlier in the project cycle to ensure user requirements are understood, (Forsberg & Mooz, 1995)
- Real projects are rarely as straight forward and sequential as implied by this model. The customer usually starts adding value when a working version, be it a prototype or a limited version, is engineered or coded, especially when it comes to completely new products. The waterfall model, however, is too rigid to accommodate these dynamics, (Forsberg & Mooz, 1995; Martin, 2000)
- It encourages a communication gap between the customers and the designers/ developers. The model forces the customer to specify the desired systems up front and wait until the last phases before they can test drive it which is not very cost effective, (Martin, 2000). This then puts this model at a disadvantage when applied to a project (typical in social-technological systems and

complex adaptive systems) where understanding of the problem evolves as the solution is being developed.

b) The Spiral Model: is a risk driven meta- model (a model that generates other models) developed by B. W Boehm in 1986 and uses Hall's 1969 work in SE (Martin, 2000; Fabrycky & Blanchard, 2008). This model sometimes called the doctrine of successive refinement combines the iterative nature of prototyping with the controlled and systematic aspects of the parent waterfall model affording the potential for rapid development see figure 2.13 below. According to Martin (2000 p.268), this model is based on repeating a basic five stage process; *a) Determine objectives, alternatives, constraint; b) Evaluate the alternatives, identify and resolve risks; c) Develop and verify the next level product or process; d) Plan the next cycle; e) Review the outcome of the cycle.* It is important to note that this model was initially developed for the software development industry as reflected by Boehm's (1988b) model presented below. This model has had wide application in this sector because of the nature of the customer requirements which become clearer and generally evolve as the development process advances. The model however still has limited application elsewhere, ((Forsberg & Mooz, 1995; Fabrycky & Blanchard, 2006).

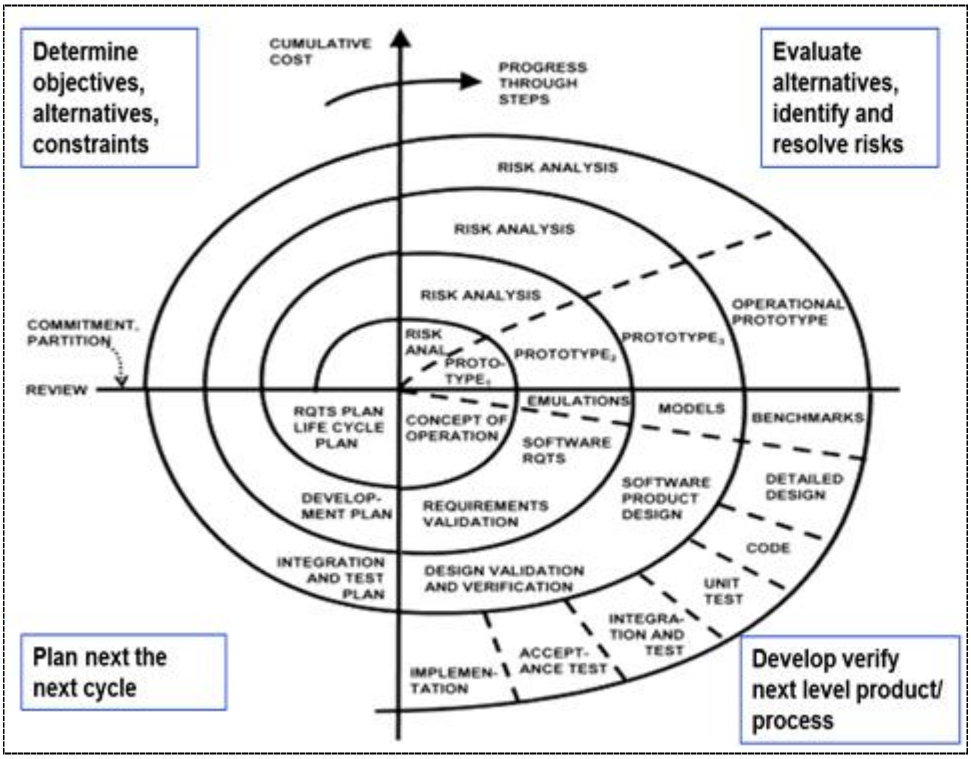


Figure 2:13 Boehm's Spiral SE software Process Model (Forsberg & Mooz, 1995)

Some writers argue the radius of the spiral represents the cost accumulated as the project progresses (*anonymous*). This seems to be true as the more interactions the designers/ developers have the more prototypes and hence, it can be argued that the cost follows the same trend.

<u>Pros and Cons of the *Spiral Model*</u>*:*

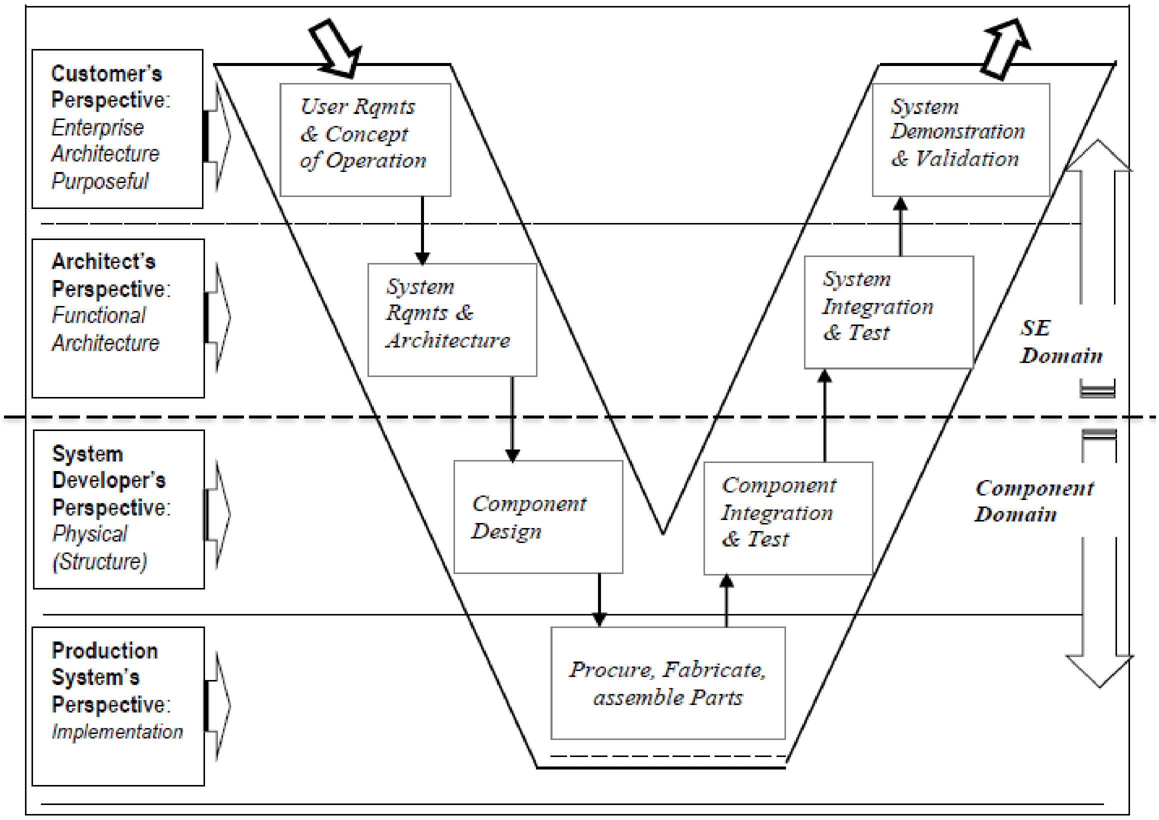
Pros:

- It is an evolutionary development approach in that it uses prototyping as a tool for requirement analysis and hence allows execution of several increments of the system products and processes earlier.
- It is more capable of coping with changes in requirements/design because it incorporates the prototyping in the original classical waterfall model in a cyclic –iterative fashion maintaining the systematic stepwise approach which is good for control.
- It introduces risk management and uses the prototype as a risk reduction mechanism, (Martin, 2000; Maier & Rechtin, 2002).
- Estimates (i.e. budget, schedule alike) get more realistic as work progresses because pertinent issues are discovered earlier (*anonymous*). The element of progressive elaboration, PMBoK(2008)

Cons:

- It is more involving than both the Waterfall and the Vee- model and demands risk assessment expertise.
- It lacks clear milestones as compared to the documentation driven process (the Waterfall model)
- It is difficult to convince customers that the evolutionary approach is controllable

c) The Vee – Model: is essentially the classic waterfall model folded on its centre to form a Vee as in the alphabetic letter V. Forsberg and Mooz (1996) described the *Vee Model* as the technical aspect of the project life cycle. This strategy starts with the user needs on the upper left and ends with a user validated system on the upper right, see figure 2:14. On the left of the chart *decomposition* and *definition* of activities resolve the system (enterprise) architecture. On the right hand side i*ntegration* flows up as successively higher levels of subsystems are verified and synthesised to the system level. Forsberg and Mooz (1996 p.12) explain "… the risk addressing, user requirements clarification models, operations feasibility models and technical feasibility models are illustrated in the downward, off the Vee core, these are risk management activities". Customer/ user evaluation of the technical solutions is shown in the upward off-core activities. It is important to note that figure 2.14 shows only the general nature of this concept.



(Elements adopted from (Forsberg & Mooz, 1994; Sage & Armstrong, 2000, Martin, 2000, INCOSE, 2007)

Figure 2:14 The 'Vee' Process Model

Several authorities have summarised the systems engineering process using this model hence the name *SE life-cycle process model*, (Forsberg & Mooz, 1995; Sage & Armstrong, 2000, Martin, 2000, INCOSE, 2007). This is attributed to the way this model allows viewing of the project cycle or product development cycle from all aspects. That is, from the customers/ users perspectives, architects perspectives, the systems developers' perspective and the production systems view point as shown in figure 2.14 above.

<u>Pros and Cons of the *Vee - Model*:</u>

Pros:

- The V-model inherits the advantages of the parent model – the waterfall model (that is of introducing risk management early, capable of coping with changes in requirements/design, and producing more realistic estimates for budgets, schedule etcetera.)
- It encourages participation of all stakeholders by providing the framework to view the product development project from all perspectives hence can be seen as a flexible strategy.

- The V-model supports a wide range of development strategies especially those that support structured and object-oriented system development yet reflecting always to the stakeholder requirements and expectations.

Cons:

- This model addresses development within a project rather than a whole organisation. It is a project life cycle process model hence it can be argued that it does not address the whole organisation (Bucanac, 1998)
- It is project oriented as such there is no organisational institutionalisation of the processes in the V- Model. The processes are abolished when the project is finished.

2.13 Appraisal of the Hard Systems Approaches

All the three hard systems approaches (SE, SA and OR) and the various systems engineering process models examined earlier take what is required (*the end and objectives*) as being easy to define at the beginning of the system study. The system analyst's responsibility then would be to find an optimum *how* – the most effective and efficient means to realise predefined objectives (Checkland, 1998 and Jackson, 2000). Hard systems thinkers make use of the kind of thinking which is natural to design engineers (Checkland, 1981).

2.13.1 *Some strengths of hard systems approaches*

- The careful setting of objectives, the search for alternative means of reaching those objectives and the evaluation of the alternatives in terms of a measure of performance allows the efficient step by step control of projects feasible, (Checkland, 1998)
- Hard systems allow prototypes and alternative models to be built without interfering with the real world
- Hard systems approaches have been widely viewed as practical because they have enjoyed much use in industry from the intensive use of operations research (OR) to the wide use in the aerospace industry all over the world, (Jackson, 2000)
- In tackling actual management problems hard system thinkers pioneered the use of multidisciplinary teams. The use of such teams is referenced by many authors (Senge, 1986; Martin, 2000; Hitchins, 2007; Checkland, 1998) as vital in reducing the costly re-work common in many projects.

2.13.2 *Criticism of Hard Systems Approaches (HSA)*

The hard systems approaches (HAS) have a limited domain of applicability: the underlying assumptions that objectives are easy to define or rather put different a pre-requisite that demand objectives to be clearly defined at the start of the process is constraining. In the vast majority of managerial situations "…the very definitions of objectives will constitute a major part of the problem faced. Involved parties are likely to see problem situations differently and to define objectives according to their own world views, values and interests" (Jackson, 2000 p.136). This will then create a myriad of objectives which can be in conflict. What *HSA* proponents do to counter this is then to twist the problem or formulate an equation to make it fit the requirements of the preferred methodology. This has led some early system thinkers like Churchman (1968), Ackoff (1979), Checkland (1981) and Jackson (2000) to think that the applicability of hard systems thinking is limited to scenarios where world views converge and hence objectives are easy to define. The other argument that Jackson brings is that modelling is about simplification, but a follow up question which is rarely addressed in literature is how can complex problems be simplified without bias creeping in?

Failure to pay attention to special attributes of the human components inherent in social technological system. The machine metaphor is dominant "…people are treated as components to be engineered just like mechanical parts of the system" (Jackson, 2000 p136-137). Several important facts are ignored. These include the fact that human beings are in themselves complex adaptive systems in that they possess understanding and they can be motivated hence they have dynamic – evolving behaviours.

Hard systems approaches focuses a lot on the model to generate optimum solutions. The model however, is built on assumptions made about the system which can be misaligned with reality especially for high human activity systems. The aim is to construct a model that accurately captures the behaviour of the real-world. Jackson (2000) argues that it is convenient and costly to play with… and it is not uncommon for results to be out of date and answer to the wrong questions.

HSA focuses a lot on quantification and optimisation such that there is a tendency to ignore factors in the problem situation that are not amenable to quantification or perhaps even more seriously tailor them in the quest for quantification (Jackson 2000 p.137). Similarly problematic situations requiring value interpretations are ignored or put aside in the quest for optimisation (Checkland, 1999). It follows, therefore, that one of the major faults of hard systems thinking is its inability to deal with subjectivity.

Hard systems approaches, to some extent hide the conflict. Key (1987) and Jackson (2000) suggest that differences of opinion and interest can be rationally dissolved by experts using the latest tools and techniques. Most of these tools fall under the soft approaches, an example being Checkland's SSM. Unlike SSM hard approaches do not encourage participation from ordinary stakeholders but rather experts and, especially, the most powerful stakeholders.

2.14 Application of HS Methodology

- The HS methodology was found to be useful when dealing with a significant set of operational problems especially at the tactical level (Jackson, 2003). As an example if a boiler plant management system detects wet steam in a power plant steam reticulation system, *system analysis* – a step by step problem solving technique can be used to get to the bottom of the problem.
- The HS methodology has found extensive use in many industries especially in defence, aerospace, power generation, petrochemical and mining. This because, the use of a systematic methodology to tackle organisational problems is usually easy to sell to executives and preferable *as compared to a seemingly* ad-hoc and never ending approaches…, (Jackson, 2000).
- HS methodology can be very helpful where models, mathematical or not, can be built and assumptions on which they are built are explicitly outlined, (Jackson, 2000, Hitchins, 2007)

From the literature reviewed several papers have been published that bear testimony to the application of HAS in its strict sense, following the step by step process. The SE - Vee model has been used as one of the primary tools by the NASA, (Sage and Armstrong, 2000; INCOSE, 2007). HS approaches have also been applied in manufacturing, IT and other industries, (Hitchins, Jackson, 2000).

The next sections – Part D focuses comparing the SSM and the Hard Systems Approaches (HAS) with the aim of synthesising a hybrid approach that harness the merits of both frameworks.

Part D: Comparison of the 'Soft' & 'Hard' to propose a hybrid approach

2.15 *Summary:* Hard and Soft Approaches Compared

In this section an attempt is made to distinguish the two approaches to establish the basis of an integrated hybrid approach. Neither one the approaches has supremacy over the other (Kirk, 1995; Cama, 2008; Rees, 2011; Siriram, 2011). The 2.10 compares the two approaches. Elements adopted form (Pidd, 1996; Checkland, 1998; Jackson, 2000; Blockley, 2002; Hitchins, 2007; Bredillet, 2003).

Table 2.10 Table Side by Side Comparison of "Soft" and "Hard" Systems Approaches

		HARD Systems Approaches	**SOFT Systems Approaches**
1	***Philosophical approach***	Positivist: *the premise being that scientific approach is the best approach (Jackson, 2000)*	Constructivist: *peoples experiences generate knowledge, meaning and sustainable solutions, (Jackson, 2000)*
2	***Vision***	*A desired outcome (Checkland, 1999; Hitchins, 2007)*	*Create dialogue around a desired outcome (Checkland, 1999)*
3	***Insights to***	*How and Why?, (Checkland, 1999)*	*What? (Checkland, 1999)*
4	***Type model***	*A presentation of the real world, (Pidd, 1996)*	*A way of generating debate and insight about the real world (Pidd, 1996)*
5	***Extent of truth***	Objective*: independent of the observer. Ignores issues of subjectivity, (Jackson, 2000)*	Subjective to an extent: *as observers' input is important. Admits multiple perceptions of reality, (Jackson, 2000)*
6	***Nature of goals***	*Easy to define – clear purpose and well defined boundaries, (Checkland, 1999)*	*Hard to define – purpose and boundaries not so clear (Checkland, 1999)*
7	***Problem Definition***	*Seen as straight forward and unitary to an extent (Pidd, 1996)*	*Seen as problematic and pluralistic (Pidd, 1996)*
8	***Complexity***	*Can be technically complex, (Jackson, 2000, Hitchins, 2007)*	*Human complexity (Jackson, 2000, Hitchins, 2007)*
9	***Divergence of views***	*Low (unitary – in agreement), single Weltanschauung (Checkland, 1999)*	*High (plural – multiple views), many Weltanschauung, some conflicting (Checkland, 1999)*
10	***The language***	*'Dealing with goals…', (Checkland,*	*'Dealing with views…', (Checkland,*

	that dominates	*1999, Hitchins, 2007)*	*1999, Hitchins, 2007)*
11	***Emphasis and focus***	*The outcome or prediction and maximising efficiency (Checkland, 1999, Jackson; 2000)* ✓ *focus is on machines*	*Understanding and managing a process to achieve desired outcomes, (Checkland, 1999; Jackson, 2000)* ✓ *focus is on people*
12	***The organisation***	*Taken for granted, (Pidd, 1996)*	*Has to be negotiated, (Pidd, 1996)*
13	***Change Management***	✓ *Name the change* ✓ *Manage the event*	✓ *Experience the transition* ✓ *Facilitate the change process*
14	***Outcomes***	*Product or recommendation (Pidd, 1996)*	*Progress through learning (Pidd, 1996)*
15	***Common tools***	▪ *Equations* ▪ *WBS* ▪ *Gantt Charts; PERT*	▪ *Rich pictures* ▪ *Concept maps* ▪ *Brainstorming; Debates*
16	***Use areas-relevance:***	o *Relevant where functionality is the prime objective; (Checkland, 1999; Jackson, 2000; Hitchins, 20007)* *Where tangible results are desired and where (preferably those that can be mathematically modelled) over others (especially those that are pliable to quantification), (Jackson, 2000)*	o *Relevant where ethical considerations are critical (Checkland, 1999; Jackson, 2000; Hitchins, 20007).* *Where there is a need for radical change (Jackson, 2003) and also where there is extreme complexity as a result of high human activity e.g. Social-technological system and Complex adaptive systems.*

The two approaches can be summed up by the fact that ***soft systems methodologies*** seek to understand while the ***hard systems methodologies*** seek to implement or get an outcome, (Checkland, 1999; Jackson, 2000).

2.16 Hybrid Approaches (Combined '*Hard*' and '*Soft'* Systems)

The hard and soft approaches both have their own strengths and weaknesses as intervention methodologies in problematic areas from a variety of perspectives. However, a gap lies in the lack of a clear methodology for integrating the two approaches to harness the benefits from both worlds, (Kirk, 1995; Blockley, 2000; Canas et al, 2008; Siriram, 2011). For example a case study where a hybrid systems approach was used in public sector projects in Sydney, Australia revealed that a combination of ‘hard’ and ‘soft’ systems management tools are essential in planning and implanting strategic projects. In this study hard systems tools (standard project management tools) like the WBS and milestone plans were used to plan and control the projects while the soft tools provided an effective mechanism for understanding stakeholders and engaging in purposeful action to deliver the project outcomes (Bredillet, 2003). Several authorities agree, (Checkland, 1981, 1999; Jackson, 200; Hitchins, 2007) as Blockley (2002) summarised, *all designed hard system processes are embedded in one or more soft systems processes*. Jackson (2000) in particular has been singled out as an advocate for multi-methodology or integrated approaches, (Daellenbach, 2004; Mingers & Grill, 1997). Jackson (2000) calls such approaches methodological pluralism.

The thinking behind integrated approaches is that by careful reflection on the strengths and weaknesses of different methodologies (in this case the *hard* and *soft* approaches), the most appropriate elements can be chosen to address (individually or in parallel) a wide range of problematic issues than a single can. Several authors are in agreement that problems in the real world neither exists as purely hard nor purely soft and concepts such as systems boundaries are abstract -artificial (Kirk, 1995; Rees, 2000; Canas et al, 2008; Siriram, 2011).

2.17 How have the Hybrid Approaches been framed?

The hybrid approach has been referred to variously in literature and several authorities have acknowledged the value of an open approach to the choice of methodology (Kirk, 1995; Daellenbach, 2004; Canas et al, 2008; Siriram, 2011). Often what appears to be a technical problem usually turns out to have a large behavioural dimension (Kirk, 1995). As such the approach commonly adopted in literature is to use soft systems approach as a front-end tool for the system under analysis. Balle (1994 as referenced by Kirk, 1995) argues that this approach provides a discipline of thinking before making decisions in business and as such is of value to all involved in management. “…using offsets systems methodologies as a front-end tool reduces the chances of incorrect identification of the problem” (Kirk, 1995). *Appendix F* shows an attempt to map different hybrid approaches. It is apparent from *Appendix F* that attempts to combine the two methodologies are not so clear. This is complicated by the soft systems approach which allows progress to be made without the prerequisite of defining the problem fully in terms of the means-end schema. Therefore to integrate both perspectives into some kind of *hard-soft* methodological framework is not a straight forward matter (Miles, 1988). Miles (1998) proposes two approaches a) grafting and b) embedding as options to integrate the two methodologies.

The first option entails grafting the soft systems approach on the front end of the traditional SE approach (the classical hard approach) which is consistent with Hitchins (2007) and Canas *et al*., (2008). In simple terms, SSM is applied to a fuzzy problem situation without the outcome being a clearly defined problem. The HSM is then applied to this clearly defined problem with the outcome being a useful solution. Miles, (1988) calls this the *defuzzification* process.

The second option is the embedding approach. This essentially, means SSM is applied at the meta-level to expose the problem, implement what does not require hard systems methodology directly, and otherwise implement changes that need to be efficiently executed using the hard systems methodology. These changes are normally at the subordinate level and they constitute for example design goals. The interactions of SSM at the *meta- level*, however, may constitute or start according to the wishes of the investigation participant (Miles, 1988). This second approach, therefore, entails embedding hard systems practise within the systematic framework of SSM. This approach unlike the grafting approach aligns the systems objectives or goals with the organisational goals. This approach is consistent with Rees (2000) and Siriram (2011).

Thus, with the embedding approach, organisational effectiveness of the intervention takes precedence over technical efficiency. The grafting approach on the other hand can be taken as adding the SSA to the left hand side of the Vee model presented in *figure 2.14*. This is, then, rooted in the basic problem solving sequence typical of classical SE approach. As such the grafting approach does not harness the catalogue of benefits inherent in the SSM.

Notwithstanding the difficulty in linking the HSM to the SSM, this study will base its hybrid approach on implanting HSM tools on Checkland’s *Soft Systems Methodology* that is the embedded approach. The challenge though is to build a practical hybrid framework that has the key elements for the target application area.

Part E: Contextualising the study (the *real-world* – LMT manufacturing SMEs)

2.18 Rationale of Targeting manufacturing SMEs

The issue of what constitutes an SME is well researched and well acknowledged in literature. SMEs are often described as efficient and prolific job creators; the seeds of big businesses and the fuel of national economic engines (Abor & Quartey, 2010). In SA it is estimated that 91% of the formal business entities are Small, Medium and Micro Enterprises, SMMEs, (Hassbroeck, 1996, Berry et al, 2002 as cited by Abor & Quartey, 2010). SMEs in particular contribute 56% of private sector employment and 36% of the gross domestic product (Ntsika, 2002 as cited by Olawale & Garwe, 2010). However, despite the noted contribution their failure rate in SA is 75%, one of the highest in the world. Several reasons have been noted in literature of which the following have been emphasised. A study by experts from the Centre for Global Development (2008) on the business environment in sub-Saharan Africa revealed several challenges and constraints faced by SME's in Southern Africa. These included among the top concerns, electricity outages, out-dated technology, access to capital, management and technical skills deficiencies, socio-political threats impacting on macroeconomics, anti-competitive practices, limited access to international markets, supply chain challenges, burdensome regulations, crime and unethical business practices in particular corruption. Abor and Quartey (2010) in their article on the challenges faced by SME's in Ghana and South Africa agree.

2.19 What is a SME?

The issues of what constitutes an SME have been widely debated in literature and different governments have different criteria (Abor & Quartey, 2010). This research will be guided by the quantitative definition as outlined in the government gazette of the republic of SA, 2003. Table 2:11 below refers;

Table 2:11: Schedule of Size Standards for the Definition of SMEs in SA

Type of Definition	Employees	Turnover (ZAR)	Balance (ZAR)
Small	1 – 50	Maximum R13m	Maximum R5m
Medium	51 – 200	Maximum R51m	maximum R19

Adopted from (*Government Gazette of Republic of South Africa, 2003*)

Note that Falkena *et al.*, (2001) defines *micro* firms consistently with National Small Business Act 102 of 1996 as those with a turnover less than R150 000 per year and a gross asset value excluding property of R100 000 employing less than 5 people. These firms usually lack the formality in terms of registration, (Abor & Quartey, 2010).

2.20 Characteristics of Manufacturing SMEs in SA

The characteristics of Manufacturing SMEs can be broadly classified as follows; (Fisher & Reuber, 2000 as cited by Abor & Quartey, 2010; Thomas et al, 2006; Olawale and Garwe, 2010)

- *Ownership & Management:* SMEs are known for failing to separate the ownership role from the management role. Most SMEs operate with one or two owners, with families that tend to be unpaid but active in the enterprise (Olawale &Garwe, 2010). This to an extent limits the skills base and quality of leadership as most management positions are acquired based on experience or simply by virtue of being a family member of the owner (Ahmed et al, 2011)

- *Labour:* The environment in SMEs in SA and other developing nations is generally labour intensive yet there are limited skills both technical and managerial, (Abor & Quartey, 2010; Olawale & Garwe, 2010). There is also limited effort to train the workforce (Olawale & Garwe, 2010). Mahadea (2008 as cited by Olawale & Garwe, 2010) explains that it is difficult and expensive for SMEs to hire skilled labour in SA. The SMEs are further constrained in that the labour can only be hired at a cost and within the confines of labour regulations that include the minimum wage regulations that are closely watched by aggressive unions.

- *Manufacturing Technology Pressure:* The rapid changing face of the manufacturing industry is forcing smaller players like SMEs to be innovative and leaner as they struggle to satisfy a highly affluent customer in a volatile market environment (Thomas et al, 2006; Siriram 2011). This has resulted in the need for a high quality product at lower product cost. The pressure has been exacerbated by the increased competition from the East, in particular, China with its low labour cost impacting heavily on the final product price. The solution to this crisis has been singled out to be the introduction of advanced manufacturing technology (AMT) and adopting agile tools like rapid prototyping to improve efficiency and customer responsiveness (Ahmed, et al, 2011). But can SMEs in developing countries adopt such in the face of the many financial challenges they face, (Olawale & Garwe, 2010; Ahmed, et al, 2011)?

- *Enterprise Wide Systems (EWS):* SMEs are overwhelmed by pressure to adopt EWS due to the close to saturation of such systems adoption in large enterprises (LEs) (Haddara & Zack, 2011). Vendors are now targeting SMEs and the need of such systems in SMEs cannot be ignored or underplayed because of globalisation, partnerships, value networks and huge information flow across and within SMEs and LEs. This is however complicated by the unique characteristics of SMEs that do not allow a blinkered scaling down of a EWS to prescribe it to a SME, (Lankhuizen & Woolthuis, 2006; Ahmed et al, 2011). SMEs interventions should be designed keeping in view the specific nature of SMEs and ought to be simple, comprehensive and more practical to support them, (Ahmed, et al, 2011).

- *Rapidly Innovating World:* SMEs are often argued to be more innovative than LEs, (Lankhuizen & Woolthuis, 2006; Ahmed et al, 2011). However, the contribution of innovations to productivity often takes time with SMEs as compared to LEs, (ACS *et al.*, 1999 as cited in Arbor & Quartey, 2010). This can be attributed to limited resources at the SMEs disposal to further develop and implement their raw ideas and concepts. In other words SMEs operate in an environment where they lead in innovation but struggle in sustaining the innovativeness. Ahmed *et al.*, (2011) argue that this gap is a result of the absence of research and development (R&D) in most SMEs. It follows SMEs rarely add value to the concepts and ideas they initiate.

- *Information & Communications Technologies (ICT):* For companies to succeed regardless of size they need a reliable ICT infrastructure to enable their everyday operations and support their future developments (Lankhuizen & Woolthuis, 2003). High speed ICT infrastructure for example broadband is emphasized in the field of innovation (Smith 1999 as cited by Lankhuizen & Woolthuis, 2003). SMEs, however operate in an environment where such infrastructure is limited that is they have poor ICT infrastructure, (Olawale & Garwe, 2010).

- *Financial Constraints:* A study by Olawale & Garwe in 2010 on the perceived obstacles to the growth of SMEs ranked financial constraints highest. Out of the 30 obstacles analysed lack of access to finance, lack of collateral and insufficient owners' equity top the list in descending order, all of which are monetary related. Abor & Quartey (2010) who conducted a similar study in a comparative study of SMEs in Ghana and SA agree.

- *Generalised Policy Frameworks:* SMEs, in most developing countries, SA included are limited by what Lankhuizen and Woolthuis (2003) call *hard institutional failures.* These are government engineered policy frameworks designed for LEs which for the purpose of consistency and enforcement are scaled down and directly administered to SMEs without due consideration of the characteristics and environment within which SMEs operate (Abor & Quartey, 2010). This down-scaling of policy frameworks to suit smaller players can be argued to be myopic as the context within which SMEs operate is a key part of the overall policy (Lankhuizen & Woolthuis, 2003; Abor & Quartey, 2010). There is, therefore, the need for SME - *specific* policies. Denmark as an example has a national innovation policy specific to SMEs (Lankhuizen & Woolthuis, 2003).

- *Project Management & Transition Strategies:* It is hypothesized in this research and is supported by literature (Lankhuizen & Woolthuis, 2003; Thomas et al, 2006) that most SMEs fail to bridge the gap in technology transfer and accelerate their potential because they lack clear guidance in strategy institutionalisation and project management knowledge. This entails, among other meta-level tasks, aligning the particular project strategy with the overall manufacturing strategy. Smith (1999 as cited in Lankhuizen & Woolthuis, 2003) describes the resultant failure of not aligning specific project strategies with overall manufacturing strategy as *transition failure.* In other words this is essentially the inability of firms to adapt to new technological developments. The major reason being the absence of a complete adoption mechanism (Lankhuizen & Woolthuis (2003).

2.21 Systems Engineering Metrics

Little has been published on the topic of identifying the right metrics for measuring the systems engineering effort, yet the right metrics make the organisation more cost effective and consequentially provide a competitive edge (Kasser, 2007 p.4-5). Very few papers / articles cover the value of systems engineering, (Honour and Mar, 2002; Honour and Valerdi, 2006), yet as a result of heuristic understanding both practitioners and managers intuitively understand the value of SE (Sheard, 2000). In day to day business it is a rule of that if one cannot measure, it is difficult to manage / control. It follows that determining the correct metric of an intervention is critical. Below is an outline of some reasons why measuring the systems engineering effort is important (INCOSE - SE Handbook v.3.2.2: 243). SE measurement assists in:

1. Communicating effectively (for example reporting effectively)
2. Identifying and correcting problems early (to limit the impact of problems on the SE effort)
3. Making trade-offs (objectively choose among alternatives based on the set metrics)
4. Track specific project objectives
5. Defend and justify decisions

It should be noted that there is no generic *one-size fits all* guide to what to measure and when. Specific measures are based on information needs, the target implementation areas, and the level of tailoring from the rigorous approach and how that information will be used (Kasser, 2007). However the following describes characteristics of good measures (Kasser, 2007; INCOSE – SE Measurement Primer v.2.0, 2010):

→ *Relevance* - provides an agreed basis for decision making
→ *Understandable* – Simplicity: keep it as simple and logical as possible
→ *Applies broadly and is repeatable* – this is important in project comparisons
→ *Cost Effectiveness* – Does it provide more value than cost
→ *Completeness* – Identify balanced set of measures to avoid overemphasising on what parameter
→ *Accuracy* – Accuracy of a measure is the extent to which the numeric value of a measure truly represents the entity being measured.
    - *Kasser, 2007; INCOSE – SE Measurement Primer v.2.0, 2010*

A strategy of how the systems engineering effort will be measured forms part of the proposed SEA model developed for manufacturing SMEs.

2.22 Summary of the Literature Review

The literature review covered the detailed theory that make up the two extremes of systems engineering – Soft and Hard Systems approaches. Separate high-level analysis of the common frameworks for the two extremes was carried out with a view to illustrate the imbedded merits, benefits and issues of each side. This formed the basis for the development of the tailored hybrid systems engineering approach (SEA) presented in the next chapters.

The literature review showed that the underlying principles of *systems engineering* span across industries and make it possible to be tailored regardless of complexity or sophistication of the target implementation area. Several research papers / articles are cited in literature regarding the value of systems engineering. On the other hand numerous studies have flagged the lack of attention given to challenges faced by SMEs and the failure of existing interventions to address these challenges. This research report intends to address that gap.

Chapter 3 Model Conceptualisation

"All philosophies, if you ride them home, are nonsense, but some are greater nonsense than others"

Samuel Butler, 1564 – 1616, 'First Principles'

3.1 Introduction

The purpose of this chapter is to;

1. Outline the key findings from the literature review
2. Provide a brief summary of the systems dynamics in the target case Manufacturing SMEs
3. Develop a road-map to build the *systems engineering approach* (SEA) model to address specific problems in SMEs

3.2 Key Themes from the Reviewed Literature

3.2.1 *Key Elements of a Soft Systems Methodology (SSM)*

The methodology is informed by an *intellectual construct* which aims for learning as an overall outcome. The referred to learning makes use of systems ideas to formulate basic mutual acts of (Checkland and Davies, 1986; Pidd 1996; Graham, 2003):

- **Perceiving** – observing in one's context – the world-view (*Weltanschauung*)
- **Predicting** – informed forecasts – calculated guesses
- **Comparing** – the ideal from the real-world
- **Deciding** – recommending the desirable and feasible reflecting on the organisational culture and environment.

Several important points/ phrases are noted from the literature reviewed that outlines attributes and application areas of the *Soft Systems Methodology* (Ackoff, 1971; Checkland, 1981; Checkland and Davies, 1986; Pidd 1996; Monk, 1998; Checkland 1999; Fleming, 2000; Jackson, 2000; Martin, 2000; Graham, 2003; William, 2005; Hitchin, 2007; Siriram, 2011):

→ *A problem structuring approach*

→ *A learning and better understanding approach*

→ *An approach to assess the general situation*

→ *A triangulation method*

→ *A coordinative approach*

→ *A mind mapping and brainstorming method*

→ *A method to align human-values (via strong reflection on Human Activity Systems – HAS)*

→ *A big-picture reflecting approach*

→ *An approach for understanding and capturing different world-views (Weltanschauung)*

→ *A method to define important elements of the relevant systems*

→ *A stakeholder management tool*

→ *A consensus seeking approach*

→ *A meaning development tool*

→ *A change management tool – transition vehicle*

→ *A method to build a deep representation of the situation in which intervention is desired*

→ *An approach anchored on a participative/ collaborative process which encourages debate*

→ *An approach that develops insights into possible improvement opportunities*

→ *A way of orchestrating / coordinating the process of learning*

→ *A conceptual framework used to provoke debate*

(Ackoff, 1971; Checkland, 1981; Checkland and Davies, 1986; Pidd 1996; Monk, 1998; Checkland 1999; Fleming, 2000; Jackson, 2000; Martin, 2000; Graham, 2003; William, 2005; Hitchin, 2007; Siriram, 2011)

<u>Implications to Management:</u>

1) SSM leaves room for personal style and strategies of problem solving in the target application area. Because off this the SSM is more suitable as the front-end approach to other more specific strategies.

2) The methodology moves away from the analytical approach of being reductionist but rather seeks to explore the problem space by searching for common themes or patterns across a system or situation. In the real world this is done by listing all the issues or opportunities separately, then finding the common theme/s or pattern/s. According to Bartlett (2001 p.7) "…this common pattern (theme) is the *performance-limiting problem* (for issues) or the *systemic breakthrough solution* (for opportunities). Addressing the *performance-limiting problem* or the *systemic breakthrough solution* will improve situation.

3) SSM provides a holistic (all encompassing) basis to approach issues / problems and a basis of the chosen intervention strategy. “Having a systemic (universal) focus enables the team to focus on the element of the situation that will improve the entire situation the most rather than on the element of the situation that can be improved the most” Bartlett (2001 p.9).

4) Since the main objective is learning – learning leads to a new situation which is not necessarily the end point. Learning changes the system since it broadens the viewer’s perspective. It follows there is no end to learning but just cycles of learning, (Checkland, 1999).

5) The learning is about complex, problematic *human activity systems (HAS), eventually* leading to purposeful action aimed at improvement, Khisty J (1995 p.105). This is done through recording the elements of the structure of the situation; the elements of the process (including inputs and outputs); the roles of the key actors and the values by which the performance will be judged among other factors.

6) SSM can therefore be a useful mechanism or tool to handle and address challenges in manufacturing SMEs. It can be used to:

   1. ***gain better understanding and generate meanings***
   2. ***capture, explore and analyse system requirements***
   3. ***introduce new methods and to change the existing work culture***

3.2.2 Key Elements of a HSM

A 'hard' system methodology (HSM) is one which is exclusively concerned with a providing the answer to the 'how' type of questions. *'Problem solving'*, according to this view, consists of defining the present state and the desired state and selecting the best means of closing the gap. This therefore can be often referred to as a goal-seeking model, a *means-end* approach, Checkland (1999). The *‘end’* in this case can be described as the desired outcome which can be broadly classified as:

- **A Goal –** which should be achieved after a period X
- **An objective** – which may or may not be achieved within the planned period
- **Ideals Outcomes** – that may never be realisable but progress can be made towards them.

Several important points/ phrases are noted from the literature reviewed that outlines key attributes and application areas of the hard systems methodology (Checkland 1999; Jackson, 2000; Graham, 2003; William, 2005; Hitchin, 2007):

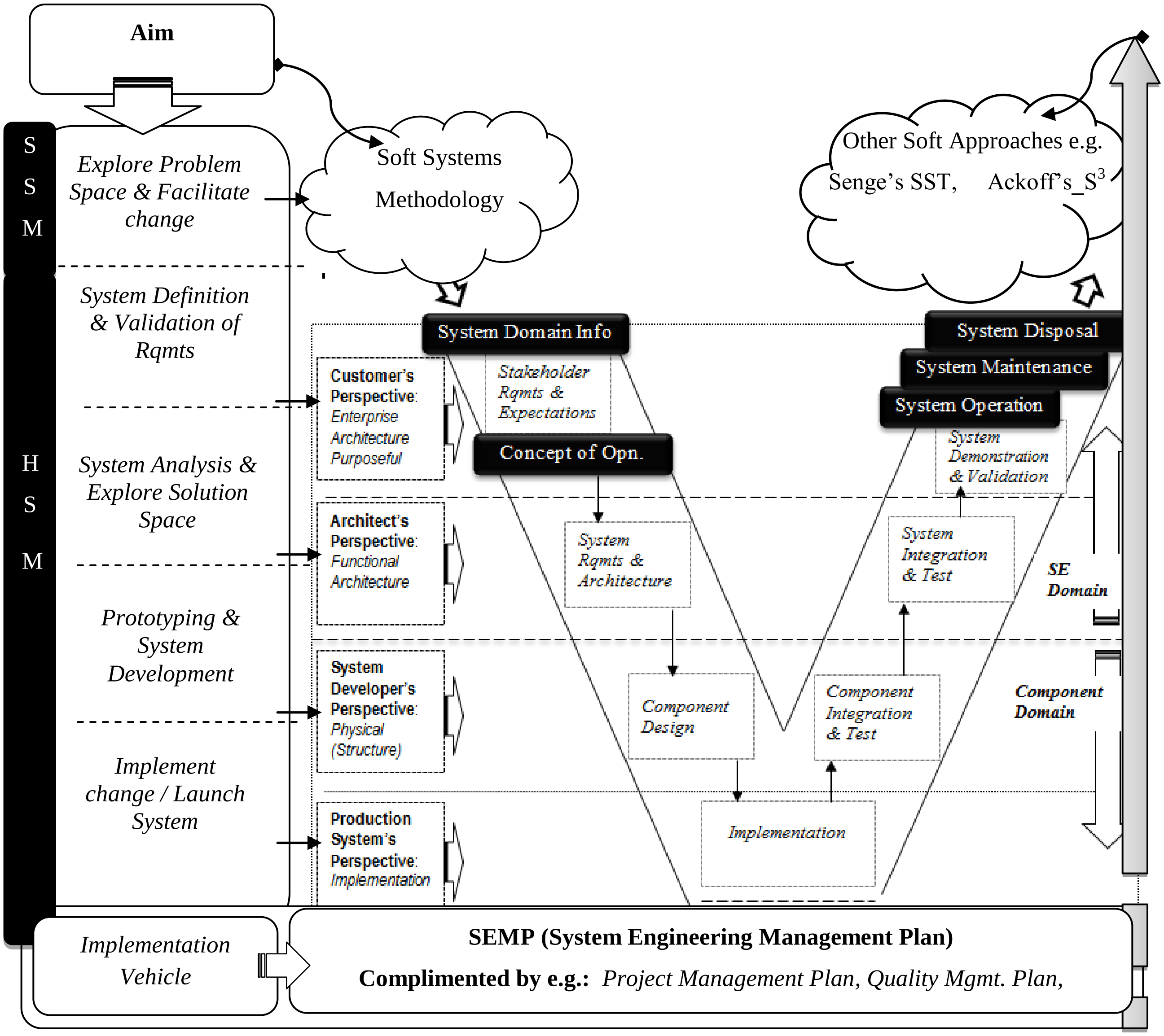
- *A problem solving approach (the desired outcome is known and objectives clearly defined)*
- *A decision making approach (based on the realisation of the desired end)*
- *An approach to assess the special cases and specific scenarios*
- *A set of methods to get things done (provide a result)*
- *A set of approaches for choosing the best solution from alternatives*
- *A set of methods that specifies the efficient way (low cost; time… etcetera.)*
- *A step by step approach to control projects*
- *Equations and models in representing different scenarios*
- *Systematic way of addressing problems*
- *Methods that have a clear structure and roadmap*
- *The means of achieving the end is more important than anything else*
- *Interdisciplinary effort to derive, evolve, generate and verify solutions*

(Checkland 1999; Jackson, 2000; Graham, 2003; William, 2005; Hitchin, 2007)

In summary the HSM is applicable where functionality and tangible results are the prime objective,

3.3 Hybrid System Engineering

Based on the above high-level summary of the key elements of both hard and soft approaches it is evident that the two are complimentary and have different emphasis. This school of thought forms the basis of the hybrid approach. A *hybrid - system engineering approach* can be modelled as shown in figure 3.1 below. The model has been built around the Vee – Model because the Vee model has the inherit advantages of the parent model (*the waterfall model*) and it encourages participation of all stakeholders by providing the framework to view the product development from all perspectives. This continuous reflection to stakeholder requirements and expectations can be argued to be critical in manufacturing SMEs because of the sensitivity of production variables to any external or internal disturbance.



Elements of the composite model adopted from (Forsberg &Mooz, 1994; Sage & Armstrong, 2000, Martin, 2000 and INCOSE, 2007)

Figure 3.1 Overview of the Hybrid Systems Engineering Conceptual Model

The SSM will be front-end methodology to explore problem space and facilitate change while the HSM (the imbedded – waterfall model) with its step by step approach will become the primary method to address the specific challenges that is system analysis, development and production. The soft systems approaches will also be used at the back-end to assist with transition, market research activities and product support. The SSM approaches will be used at the front and back-end because of the *problem structuring, learning, coordinative, transition vehicle* attributes. Cantered on these reasons is the SSM methodologies strong reflection to *human activity systems.*

3.4 Nature of Systems in SMEs

The SSM methodology as presented by Checkland will be used partially to gain a deeper understanding of the nature of systems in the target cases. Understanding the problems and challenges is fundamental to expand and strategize SME's to future progress (Omar et al, 2009).

3.4.1 The Naïve Picture - *Unstructured Problem Situation Elements*

The reviewed literature revealed several fundamental and far-reaching challenges faced by *manufacturing SMEs in South Africa*. The following points outline the problem situation as it exists and is viewed in the real world (Omar et al 2009; Abor and Quartey, 2010; Bititci et al, 2011; Scheers & Tonder, 2012)

Table 3.1: Naive picture list detailing the problem situation as it exists

The Naïve Picture	***The Naïve Picture** (continued...)*
• *Lack of finance, capital/ project funding* • *Little track record to warrant project finance* • *Inadequate financial statements and business plans* • *Lack of formal accounting systems* • *Poor record keeping* • *Cash-flow challenges* • *Poor capital structure* • *Lack of modern equipment and machinery* • *Lack of access to technology* • *Lack of e-commerce* • *Lack of ICT infrastructure* • *Lack of strategies to enhance knowledge, skills and expertise* • *Lack of growth prospects for employees* • *Lack of innovation management* • *Use of labour intensive out-dated methods* • *Insufficient effort to develop skills and*	• *Less competitive remuneration packages relative to larger firms* • *Insufficient managerial skills* • *Lack professional training of management* • *Limited access to international markets* • *Insufficient marketing efforts* • *Regulatory issues* • *Lack of leadership* • *Lack of strategic planning* • *Unmotivated personnel* • *Lack of succession plans* • *Poor business networks and networking efforts* • *Not fully compliant with environmental laws (waste management and pollution)* • *Problems with availability of inputs supply chain problems* • *Struggle to offer competitive prices* • *Insufficient supply chain integration*

competencies • *Overall economic inefficiency* • *Low productivity* • *Inconsistent product quality* • *Inefficient production methods* • *Limited access to human capital (competent human resources)* • *Lack of adequate logistics infrastructure* • *Problems with labour law compliance and high cost of labour* • *Multi-tasking – no room for specialist roles* • *Insufficient systems thinking* • *Insufficient customer focus and orientation* • *Unrelenting pressure for price reductions form power customers and competitors*	• *Lack of energy efficient systems* • *Insufficient agility (ability to quickly reconfigure production systems and other resources)* • *Insufficient process automation (covering manufacturing; information & communication)* • *Little access to international partners* • *Absence of research and development (R&D)* • *Poor documentation of strategy; policies; procedures and plans* • *Inadequate market research* • *Poor electricity supply* • *Reworks and material wastages* • *Crime and corruption*

(Omar et al 2009; Abor and Quartey, 2010; Bititci et al, 2011; Scheers & Tonder, 2012)

The outlined issues were then categorised into internal and external issues. These were further classified into symptoms and problems, see Appendix I. The intention of this research effort is to design a Systems Engineering problem solving conceptual framework targeting internal problems faced at micro-level by manufacturing SMEs.

3.4.2 *Typical Naïve Picture Interrelationship Diagram*

Figure 3.2 below illustrates the complex relationship of the internal challenges faced by SMEs and how they result in the overall economic inefficiencies of these entities. **Model Framing Problem Statement as** derived from the Naïve picture systems dynamics**…**

→ *Manufacturing SMEs in developing countries face several operational challenges due to their approach to business. The lack of good leadership hence the systems thinking perspective and poor management skills are the primary constraints to high productivity; high sales and a competitive position for these firms.*

This statement is derived from the presented Naive picture (*figure 3.2* – on the next page) guided by Stage-1 of Checkland Soft Systems methodology (Checkland, 1999)

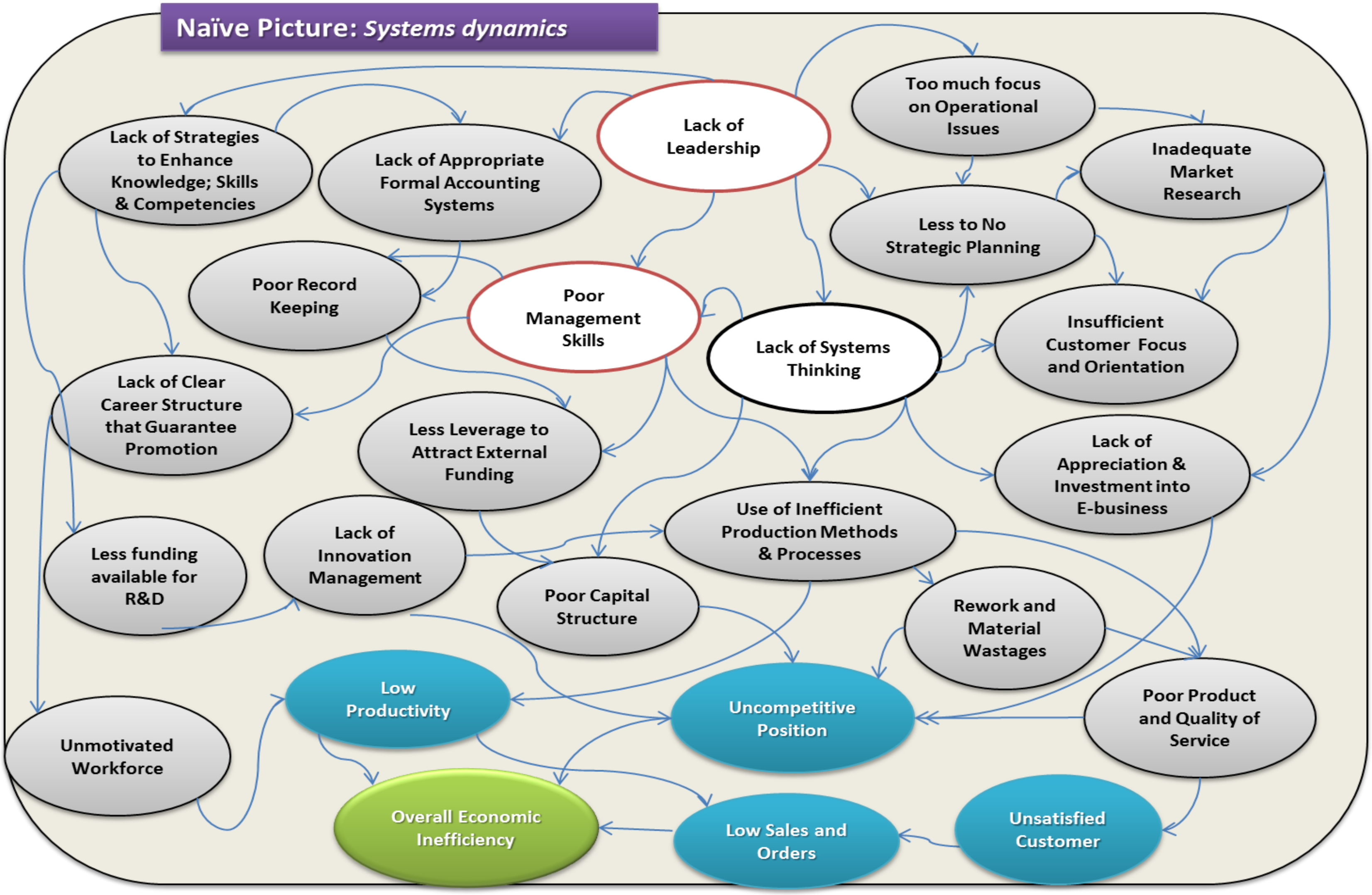


Figure 3.2 Typical Naïve Picture Diagram for Manufacturing SMEs Internal Problems

3.5 Common Problem Interventions Tools, Techniques & Strategies

Several problem intervention tools and techniques have been found in literature, these include:

→Brainstorming*: a technique used in a group situation to enable participants to generate solutions*

→Cause and Effect Analysis *(the fishbone diagrams also referred to as the Ishikawa Diagram)*

→Pareto Analysis*: (known also as the 80/20 rule – vital few versus the trivial many)*

→The problem definition sheet*: a tool to develop an understanding of the problem under study*

→Solution matrix*: a tool for guiding the team to make choices between potential solutions*

→Gantt chart*: a simple aid to action planning*

It can be argued that none of these tools and techniques has been specifically framed to be used in SMEs (Roisum, 2000). It is also important to note that most formal problem solving approaches from the literature reviewed outlined a series of steps (also referred to, as the scientific method) that must be taken, for example: *1. Define the problem; 2. Determine what factor influence the problem, 3. Evaluate the option; 4. Decide and action.* These approaches have actually been used loosely and rigidly. In other words, these formal problem solving techniques are too rigid and too general to be especially useful in complex and detail rich environment of a manufacturing plant, (Roisum, 2000). None of what was seen in the reviewed literature sought to find the problem of the *problem intervention strategies in* SMEs. The study seeks to close that gap by providing the necessary framework to address operational problems in SMEs.

3.6 Model Criteria

Any model to be developed for SMEs must consider the motivations, constraints and uncertainties facing smaller firms and recognize that these differ from those facing larger firms (Omar et al, 2009). It is logical therefore to differentiate SMEs from large businesses before specifying the model criteria to ensure that the prescribed model is pitched at the right level and in context. Table 3.2 below outlines the key differences between large businesses and SMEs as distilled form literature.

Table 3.2: Key Characteristic Differences between SMEs and Larger Businesses

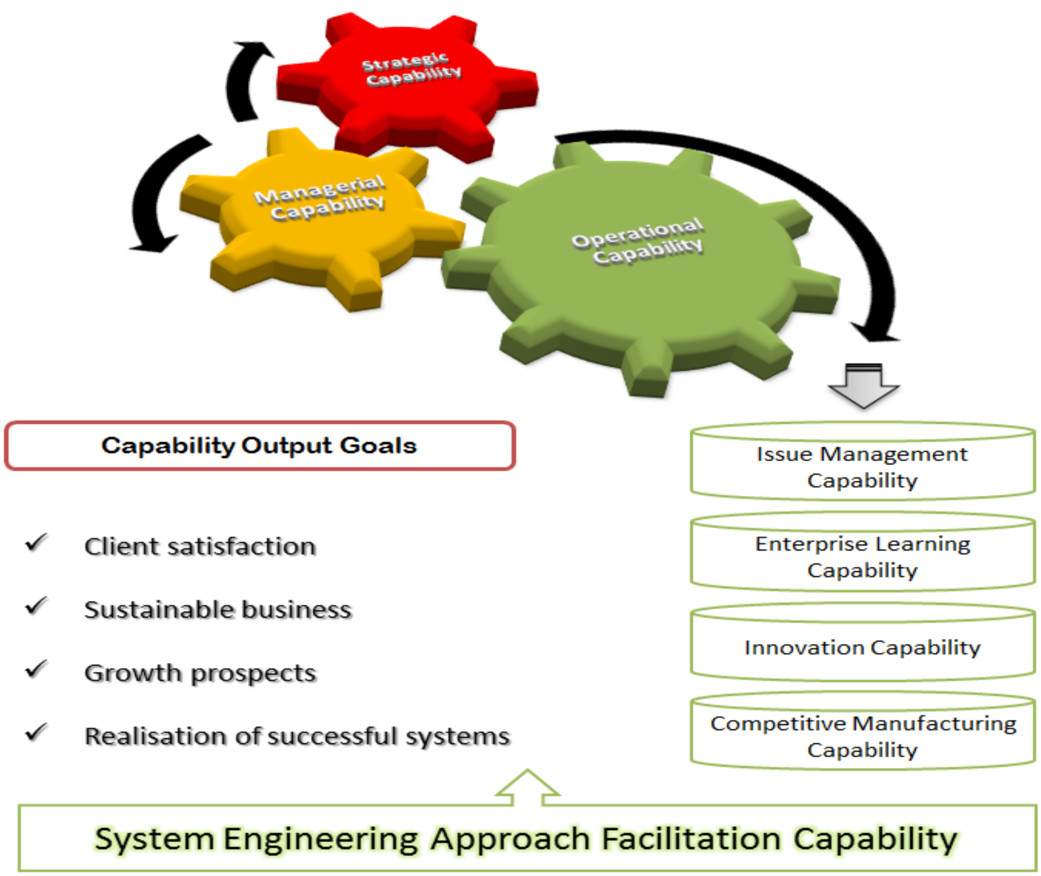
	Small and Medium Enterprise (SME)	**Large Business**
1	Mainly private / family owned and managed – the majority is one person businesses	Mainly corporate or public ownership with professional management teams
2	Predominately operational focused (short term) – with little to zero focus on strategic issues	There is a balance between strategic and operational focus (both short and long-term)
3	High degree of uncertainty – an example could be lack of power on influence the market	Medium to low degree of uncertainty – example adapt better to globalization challenges
4	Limited by scale – for example limited access to financial resources	Benefits form scale – can easily access funds resources for investments
5	Labour intensive – relying mostly on family, friend first and other semi-qualified people	Less labour intensive – relies mainly on skilled workforce and technology
6	Decision making is centralized and unstructured, however faster	Decentralized, structured decision making – with hierarchies
7	Most are innovative but the contribution to productivity takes time	They are less innovative but have the resources to quickly bring innovation into productivity
8	Opportunity seeking behaviour with little consideration to risk and C-B Analysis	More systematic approach to responding to external opportunities and threats
9	Sort-term view: lack of time due to limited specialization and owner – manager approach	More time – specialists: have opportunity to stand back and take a long view
10	Informal business processes and management systems – due to low investments into such	Formal business processes and management systems
11	Command and control culture	People are empowered within the scope of their responsibility area
12	Limited resources (time, money, materials, labour)	In general there are considerable resources in large businesses

Table 3.2 Note: Elements adopted from different readings (Omar et al 2009; Abor and Quartey, 2010; Bititci et al, 2011; Scheers & Tonder, 2012)

From table 3.2 it is clear that two entities are vastly different and this complicates the *one-size-fits-all* models intended to improve business performance. There is considerable evidence in business and management literature that a lot of effort has been put in designing models and frameworks to enable companies to compete efficiently and effectively (Abor and Quartey, 2010; Bititci et al, 2011). The real concern is on the underlying thinking behind most of these strategies which allowed the design of prescriptive approaches and models which focus on solving particular areas only. Of particular concern also is that should the SMEs adopt a certain model whether by prescription or by simply benchmarking a larger organization, very few SMEs truly embrace the *philosophies, mind-sets* and *underlying thinking processes* behind the practices, tools and techniques they accept and implement (Bititci et al, 2011).

Among other objectives the proposed *systems engineering approach* pursued to address these seven (7) capabilities:

- *Managerial capability; Strategic capability; Operational capability; Issue management capability; Enterprise learning capability; Innovation capability* and the *Competitive manufacturing capability.*



- *The author's own schematic illustration of the target capabilities and how they fit together*

Figure 3.3 Typical Capabilities for Realisation of Successful Systems in the SOI – the SME

3.7 Implications of key characteristics & the Desired Capability to the SEA model

To achieve these fundamental capabilities the model should meet the following criterion with reference to the key characteristic differences of SME with LEs shown in table 3.2:

1) *Tailored to the sophistication level of SMEs (that means among other attributes should be simple to understand)*
2) *Enable the SME to innovate and be self-sustainable (that is designed to capture ideas, utilise and sustain innovation)*
3) *Solve both strategic and tactical problems (that is compensate for the limited strategic vision / focus typical of SMEs)*
4) *Must be strong on the soft approach in order to deal with high human activity systems (HAS) typical of SMEs*
5) *Affordable – (less paperwork, inexpensive technologies if any, less formal business processes and management systems… etcetera)*
6) *Cater for skills deficiency (that is cater for the limited skills in SMEs in particular Address management deficiencies and other technical expertise)*
7) *Address problems early in their life cycle (that ensure that issues are given due attention)*
8) *Address communication and record keeping challenges*
9) *Encourage learning – learn from mistakes (organizational memory)*
10) *Must have traceability – preferably bi-directional traceability*
11) *Provide the enabling environment to solve internal operational problems*
12) *Encourage communication, collaboration and coordination*
13) *Must include risk management elements to respond to external opportunities and threats*
14) *Be easy to launch and implement and not take too much time for all involved*

Above all, reflect on the principles of the Systems Thinking - *looking at <u>relationships</u> (rather than parts in isolation); <u>process</u> (rather than product); the <u>whole</u> (rather than the parts); <u>patterns</u> (rather than content) and <u>context</u>* (Ackoff, 2010). Design-wise the model must be tailored to suit the SMEs that is context concise; simple; practical; easy to follow; free of technical jargon; orderly and have the power to demonstrate and persuade.

3.8 Typical Systems in SMEs

The high-level model shown in figure 3.4 characterises the typical systems in a manufacturing SME.

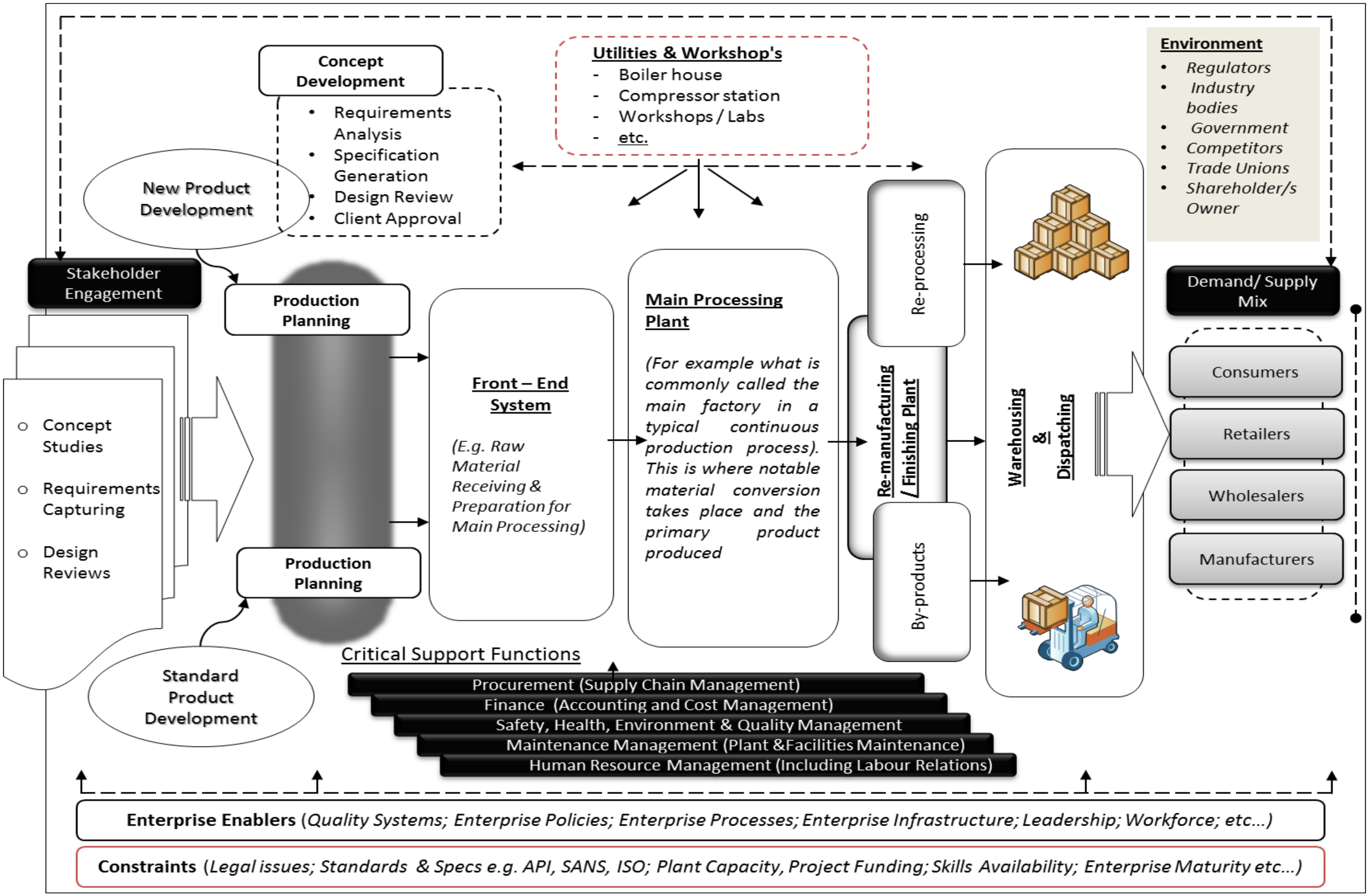


Figure 3.4 High-level Model that Characterises the Typical Systems in a Manufacturing SME (*The author's own schematic illustration)*

3.9 Path to Model Building

The following framework shows the initial effort by the researcher to develop a systematic roadmap to address problems in SMEs.

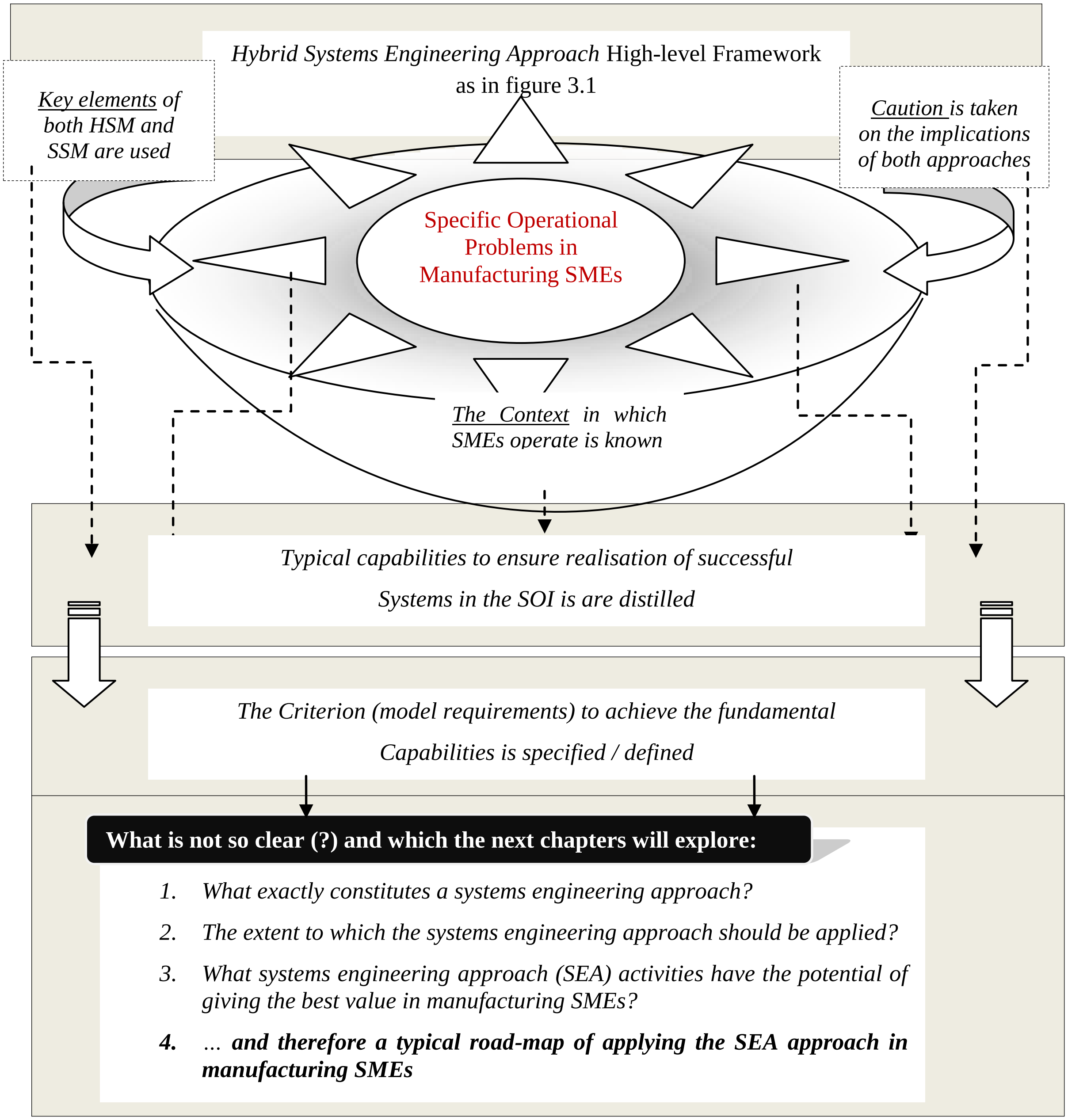


Figure 3.5 Proposed Road-map to Model Building (*The author's own schematic illustration)*

3.10 Chapter Summary

This chapter covered the applicable theories that make up the two extremes of systems engineering – '*soft'* and *'hard' systems* approaches in the context of manufacturing SMEs. The nature of the systems in the *system of interest* (the manufacturing SMEs) was explored. Typical problems referred to as internal problems were quarantined and analysed. It was then concluded (from the naïve systems dynamics map - figure 3.2) that *low productivity, uncompetitive position, unsatisfied customers* resulted in *low orders/ sales* and therefore *overall economic inefficiency*. Common intervention strategies in SMEs were explored and their shortfalls highlighted. The SEA was shown to be the preferred approach. To use the SEA, the context of the *system of interest (SOI)* – the manufacturing SMEs was put to scrutiny. From this seven (7) capabilities were proposed to ensure the realisation of successful systems upon building the SEA application model. The road-map to building the SEA model was outlined. The next chapter (*Research Method)* seeks to present the methods / instruments used to answer the questions presented in figure 3.5 (the road-map to model building).

Chapter 4 - Research Method

"Though this is madness, there is a method in it"

William Shakespeare, 1564 – 1616, Hamlet '

Introduction

The purpose of this chapter is to;

1. Describe the overall research strategy to be used in the study and the roadmap followed to achieve the objectives presented in chapter 1.
2. Introduce the research instrument - the *Delphi technique.*
3. Discuss and justify the data analysis techniques used in the study.
4. Outline some limitations and ethical considerations considered in the study.

The primary objective of the study was to develop a Systems Engineering Approach model (SEA model) tailored for use in less conventional application areas such as in manufacturing SMEs. The approach was to harness facts from the literature reviewed and frame them using the ideas gathered from experts in the Delphi technique thus providing a solid basis to develop the desired model.

4.1 Research Design

This study is an attempt to provide a framework to address specific practical problems in SMEs as outlined in the literature survey. The problems include, *out-dated technology; management and technical skills deficiency; innovation management issues; energy efficiency issues; supply chain challenges; sustainable operation challenges in an environment with burdensome regulations; anti-competitive practices; profitability issues; cash-flow challenges* and *access to capital* among many challenges.

The research was primarily qualitative hence the study strategy was anchored on constructing meaning and interpreting it *via the perspective of those who live in that space* (Davis, 2007; Sniders, 2011). This essentially means generating understanding from patterns but applying ideas across contexts. The study itself is a combination of the empirical and exploratory research methodologies. Exploratory research is undertaken to explore an area where little is known or to investigate the possibilities of undertaking a particular research study, Yin (2003).

It was exploratory in the context of basing some *systems engineering* elements used to frame the desired *SEA model* from untested facts and opinions of different authorities. On the other hand, it was empirical in the context of basing findings from first-hand field information from the experts.

This was a *four (4)* pronged research project, which began with:

A. Initial Model Development

- in-depth literature analysis at academic level
- theoretical model building

B. **Model Development** (Delphi round - 1 process)

- expert participation in the first-round of the Delphi process
- collaborative model building based on expert's input

C. **Model Refinement** (Delphi round – 2 process)

- expert participation in the second-round of the Delphi process
- model validation and verification of expert inputs

D. **Action** (Testing the Model)

- Testing the model in different SMEs test cases (*this part of the research was not covered in this study but formed part of the future work by the researcher and any other individuals or institutions who would want to adopt the model*)

4.1.1 Purpose of the Model

The main purposes of the framework were to;

1) Provide an understanding of how to frame *a hybrid systems engineering approach* (elements of both hard and soft) systems methodologies.

2) Provide a roadmap to follow when implementing a *hybrid systems engineering approach* in *low to medium technology* manufacturing SMES

3) Provide a way to cope with complexity (*Management of issues (current and potential) to reduce complexity)* – that is packaging the issues / problems/ challenges in SMEs to ensure that right prescription or problem addressing strategy or technique is administered.

4.2 The Research Instrument

Central to this study is the Delphi technique. This technique has been widely used in research studies namely for (Okoli & Pawlowski, 2003):

1. Forecasting and issue identification / prioritization
2. Concept / Framework development.

This study used the technique for the latter (2). Figure 3.1 below outlines how the Delphi was used.

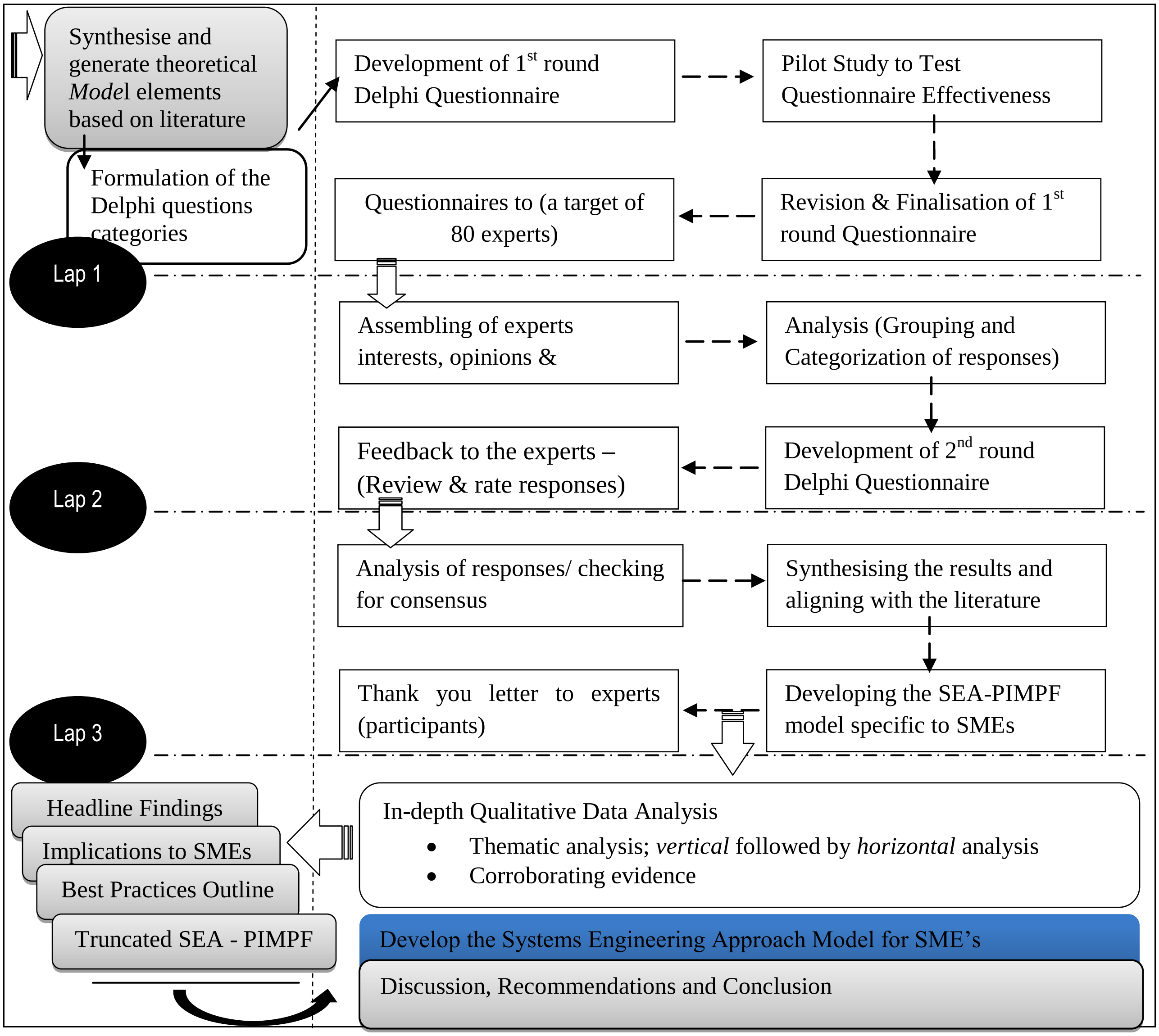


Figure 4.1 Overview of the use of the Research Instrument – the Delphi Technique

4.2.1 The Delphi technique

What is the Delphi Technique?

This is a research method that involves the use of a series questionnaires (as shown in figure 3.1) issued to participants who are usually experts in their field to seek their opinions, views on the areas of interest (Beretta, 1996; Rudy, 1996; Gordon, 2002) The Delphi method originated in a series of studies that the RAND Corporation conducted in the 1950s (Okoli & Pawlowski, 2003). Linestone & Turoff, (1975 p3.)

describe the Delphi technique as, "a method for structuring a group communication process so that the process is effective in allowing a group of individuals as a whole, to deal with a complex problem" It follows by definition this technique allows interaction of the researcher and the experts on a subject in question. In this research this method allowed experts to find a common ground regards the subject of application of systems engineering in manufacturing SMEs. The aim was to use the Delphi technique via a series of questionnaires to identify:

i. facts,
ii. issues and,
iii. the experts opinions

This provided a basis for identifying key elements required for developing the *SEA model* specific to SMEs.

Assumptions of the Delphi Technique:

The Delphi technique assumes;

- that a group view is better than a single view, Linestone & Turoff (1975 p.3)
- individual attitudes and beliefs do not form in a vacuum, Hanafin (2004)
- by inclusion of experts there is an ontological position of single reality on which experts agree (ibid)
- the environmental inputs (from different experts) to build internal representation is better than an individual's intrinsic capacities for reason, logic or conceptual processing, Gergen (1995)
- individuals will align or even change to an extend their position on the basis of the group feedback from other experts, Linestone & Turoff (1975)

In this study the primary assumption is that different views and perceptions of reality can be blended and distilled in a structured way.

Strengths of the Delphi Technique:

The Delphi technique provides a platform for geographically dispersed experts to provide insight into *not well* understood areas. The technique offers an opportunity for consensus without bias thorough the administration of survey questionnaires making it possible for all to express their views (Beretta, 1996; Rudy, 1996; Gordon, 2002). The researcher sought input from all continents of the world without subjecting the experts to peer pressure in decision making. Direct confrontation on the other hand "… all too often induces the hasty formulation of preconceived notion, an inclination to close one's mind to novel ideas, a tendency to defend a stand once taken, and sometimes alternatively, a predisposition to be swayed by persuasively stated opinions of others", Dalkey and Helmer (n.d. as quoted by Okoli & Pawlowski, 2003). It follows a key advantage of this approach is that it avoids direct confrontation with experts.

On *individual* versus *group response*, studies have consistently shown that for questions requiring experts' judgement, the average of individual responses is inferior to the averages produced by group decision processes and the Delphi technique is one such method.

Another key strength of this method is anonymity which make the respondents anonymous to each other but not to the researcher. The anonymity characteristic of the Delphi technique allows experts to make statements on the basis of their knowledge and experience, rather than a more a more 'cautious institutional position, Gupta and Clarke (1996). This also gave the researcher the opportunity to follow up for clarifications and related further qualitative data.

The iterative approach to data gathering through rounds of questionnaires and feedback allowed the collective human intelligence capability found in groups of experts to be harnessed (Linestone and Turoff, 1975), which further qualifies the notion that *a system is greater than the sum of its parts* as outlined in figure 2.3 in the literature review section.

The other important strength of this technique is that it has the potential to recognise and acknowledge the contribution of each participant by condensing opinions into a few precise qualitative statements. On the other hand when combined with rating scales like the Likert scale it also facilitates the statistical analysis of qualitative data.

Limitations of the Delphi Technique:

The approach has been argued to be time consuming, labour intensive and have a low response rate as it uses self-completion questionnaires (Linestone and Turoff, 1975; Bowles, 1999; Hanafin, 2004). Multi-round studies require a great deal of time; inevitably some participants will drop-out during the process Gordon (2002). On the other hand a great deal of attention has to be given to the choice of participants yet there is absence of a clear guideline regarding the size and composition of the exert panel (Hanafin, 2004; Gordon, 2002; Linestone & Turoff, 1975:3). A consensus approach has been argued to lead to a diluted version of the best opinion, Powell (2003 as cited by Hanafin, 2004 p.11). The arguments of people with the appropriate knowledge might be out-numbered by the number of generalists who might submit more responses. Coupled to this, critics have argued that, there is lack of participant accountability in relation to the views that they express due to anonymity, Goodman (1987).

Addressing the Delphi Limitations: The researcher addressed some of the weaknesses by employing the following strategies:

1) To counter the issue of low response rate, questionnaires in this study were meticulously designed and pilot - tested to avoid ambiguity, confusion in order to increase the response rate. The researcher also used introductory letters to ensure the target experts understood the premise and the purpose of the research – *see Appendix A1*. Reminder letters and a second copy of the same questionnaire were also sent two weeks after via time staggered reminder emails to ensure experts finalise their inputs. On the other hand the number of questions was limited to ensure focus on, only important elements related to the research question.

2) *Delphi Expert Selection:* Selecting the research participants is a critical component of the Delphi technique since it is these experts' opinions upon which the output of the study is based (Skulmoski, 2007). The advice from Duffield (1993) was adopted, "… for findings to be accepted, panel members should be representatives of their profession or professional organisation, unlikely to be challenged as experts in their field and have the power to implement the findings they choose*.*" It follows the criterion used in this study was based essentially on;

    I. Experience in the area of study under investigation
    II. Capacity and willingness to participate

    A balanced number of experts from both academia and industry were sought.

3) A diverse unbiased expert panel was required to ensure a rigorous unbiased Delphi exercise. The researcher allowed the experts which would meet as least four (4) of the outlined criteria:

    i. Professional registration (for example, Professional engineer/ technologist – Pr. Eng., Pr. Tech; Certified Systems Engineering Practitioner (CEP) or Expert (ECEP);
    ii. Membership in professional institution (for example ECSA; INCOSE; IEEE)
    iii. Known participation in similar expert based studies
    iv. Experience – at least 5 years' experience in systems engineering
    v. Authorship (books; publications) in systems engineering
    vi. Conference presenter at a systems engineering related forum
    vii. Chair of an systems engineering related committee
    viii. Lecturer or member of a faculty of systems engineering
    ix. Advanced degree - MSc; PhD

4) Pilot Questionnaires – were used to test and adjust the Delphi questionnaire. This pilot phase was important in working out procedural issues with the core purpose of improving the format and the questioning to increase participation.

Using The Delphi technique: The Delphi process took approximately four (4) months. The focus was on establishing and ranking the key elements of a hybrid (*soft* and *hard*) systems engineering framework. The Delphi technique was used as a front-end research instrument to get input to build the conceptual framework. That is:

1. Establishing the key aspects / elements fundamental in any hybrid systems engineering framework
2. Finding consensus on what constitutes the systems engineering approach (SEA)
3. Identifying the SEA activities that have the potential of giving the greatest value in a typical manufacturing SME
4. Identifying the critical success factors for systems engineering implementation
5. Understanding why and how systems engineering efforts fail in any environment

See Appendix A2 for the questionnaire used in the Delphi process. The Delphi method has been applied to a variety of situations and in various forms. Researchers have developed variations of the method tailored to specific problem types and outcome goals what Linestone and Turoff calls the evolution of the method, (Okoli & Pawlowski, 2003). According to Skulmoski *et al*., (2007) if the goal is to understand and the sample size is homogeneous then fewer than three (3) Delphi process rounds should be sufficient. This research effort was a two-round Delphi process with an aim of understanding the key elements that are essential in building theory – the systems engineering model specific to manufacturing SMEs. The researcher did not seek absolute consensus but rather the expert's view and opinions hence only two rounds of questionnaires were sent to experts. The Delphi rounds comprised of:

- <u>Delphi round 1</u> which was meant to brainstorm some fundamentals of the systems engineering approach and to test the desirability and feasibility of proposed elements of the SEA in manufacturing SMEs. The questions were semi-structured so as to widely cast the research net but focussed as guided by the research question to ensure the research remains in line.

- <u>Delphi round 2</u> was intended to work out some differences from the experts and align their thinking. Hence it used questions and remarks from Delphi round 1. The questions were categorized or grouped by frequency or similarity of response in order to reduce the number to a manageable level but yet keeping the essential meaning (Duffield, 1993, Skulmoski, 2007).

In both rounds the Delphi questionnaires comprised a mixture of open and closed questions making use of rating scales like the Likert scale. This allowed both qualitative and quantitative data to be derived. The questions were categorised to reduce the data burden (Dey, 2005, Leedy 2007).

The Participants (Experts/ Panelists): The key to a successful Delphi study lies in the selection of participants (commonly referred in literature as panelists). Since the result of the study depends on the knowledge and cooperation of the panelists, it is essential to include individuals that are likely to contribute valuable ideas, Gordon (1993). The majority of the invited experts were identified through literature searches for those individuals that have published at least two (2) articles on the subject understudy. Participants were also were selected by referral from those and other experts in industry and academia. This included renowned practitioners, consultants, authors and certified systems engineering experts. Eight (80) geographically dispersed experts were contacted to see if they would be willing to participate. Upon reaching a target of sixteen (16) names who responded positively, round-1 began. This amounted to a 20% response rate. The total years of systems engineering experience of the participants was over 325 years of which, individual experience ranged from 8 – 40 years of practising or researching in the domain.

There is no consensus found in literature on what constitutes an expert panel and the size of the panel (Hanafin, 2004; Gordon, 2002; Linestone & Turoff, 1975:3). Delphi sample sizes used in literature vary from 4 to 171 Alder & Ziglio, (1996) and Skulmoski *et al*., (2007). Group size does not depend on statistical power, but rather on the group dynamics for arriving at consensus among experts, literature recommends 10 – 18 experts on a theory building Delphi panel, Okoli & Pawlowski (2003). A total of 16 participants in this study and in line with recommended numbers from literature. The experts came from the traditional *SE* application areas in industry, research institutes and academic professional all over the world. The blended and distilled views of the experts provided the basis and a clearer indication of what key elements and directions are necessary in developing the SME specific Systems Engineering model.

Consensus: Agreement on the criteria that determines consensus is not well documented William and Webb (1994 as cited by Hanafin, 2004). "…the ultimate measure of effectiveness is whether there is a central tendency demonstrated by the group", Valerdi (2011). Longman Dictionary of Contemporary English (2010) defines consensus as "a general agreement; the opinion of most people in a group" This research did not seek absolute convergence but the generally accepted opinion of most experts without silencing the minority but giving them a chance to justify their views. Studies focussing on the number of rounds needed in a Delphi survey to achieve consensus suggest that most changes occur in the transition from first to the second round, Zolingen & Klaassen (2003 as cited by Hanafin, 2004). This study saw stability in the second round, hence the decision to make the exercise a two (2) round Delphi process. There is also an argument in literature that as the number of rounds exceed four (4), the response rate decreases sharply as the experts see the exercise as a burden, (Hanafin). Consensus in the research was said to have been reached if at least two thirds (67%) of the experts are in agreement.

4.3 Data Analysis

The challenge in any qualitative inquiry is to make sense of massive amount of data, reduce volume of information, identify significant patterns, and constructing a framework for communicating the essence, Dey (2005). This study was not unique at all. Every study has a general framework for how data is analysed, Yin (2003). The framework for data analysis and the basis of the evolution of the desired theory is outlined in *figure 4.2* (next page). The data analysis was aimed at capturing the frequent, dominant and or emerging themes from the expert responses but without restraining the important issues that came-out of the open-ended questions responses. As shown in *figure 4.2* this was done by gathering research question aligned data from various sources and using various approaches in a non-liner fashion before condensing the data it into brief statements. All this was done reflecting on the research question hence clear links between the study objectives and summary statements were established, Thomas (2003) concurs.

It is important to note that the primary vehicle in the data analysis was the development of categories from raw data into a framework that captured key themes and processes judged to be important by the researcher and those emphasised by the experts. The output of the data compressor shown in figure 4.2 - *the descriptive statements* was then tabulated allowing *vertical analysis* and then *horizontal analysis* to follow. See *Appendix G* for the analysis of the Delphi R1 responses. This process entailed constructing a table listing all questions asked in the first row and noting down the key responses in the rows below and or the quotable quotes from each expert in separate columns. The goal of the vertical analysis was to summarise and therefore reduce data. This was done by showing the key responses side by side for further analysis. Horizontal analysis was then followed where the central aim was comparison of information identified as significant at the vertical analysis stage. This was done by establishing the recurring themes, common issues, differences and some issues of interest (*thematic content analysis*). The last stage involved analysing the recurring themes and new areas of interest reflecting on the literature review and the research question / title (thematic analysis). This contributed in the evolution of key elements of the theory to which the SME specific Systems Engineering Model was framed.

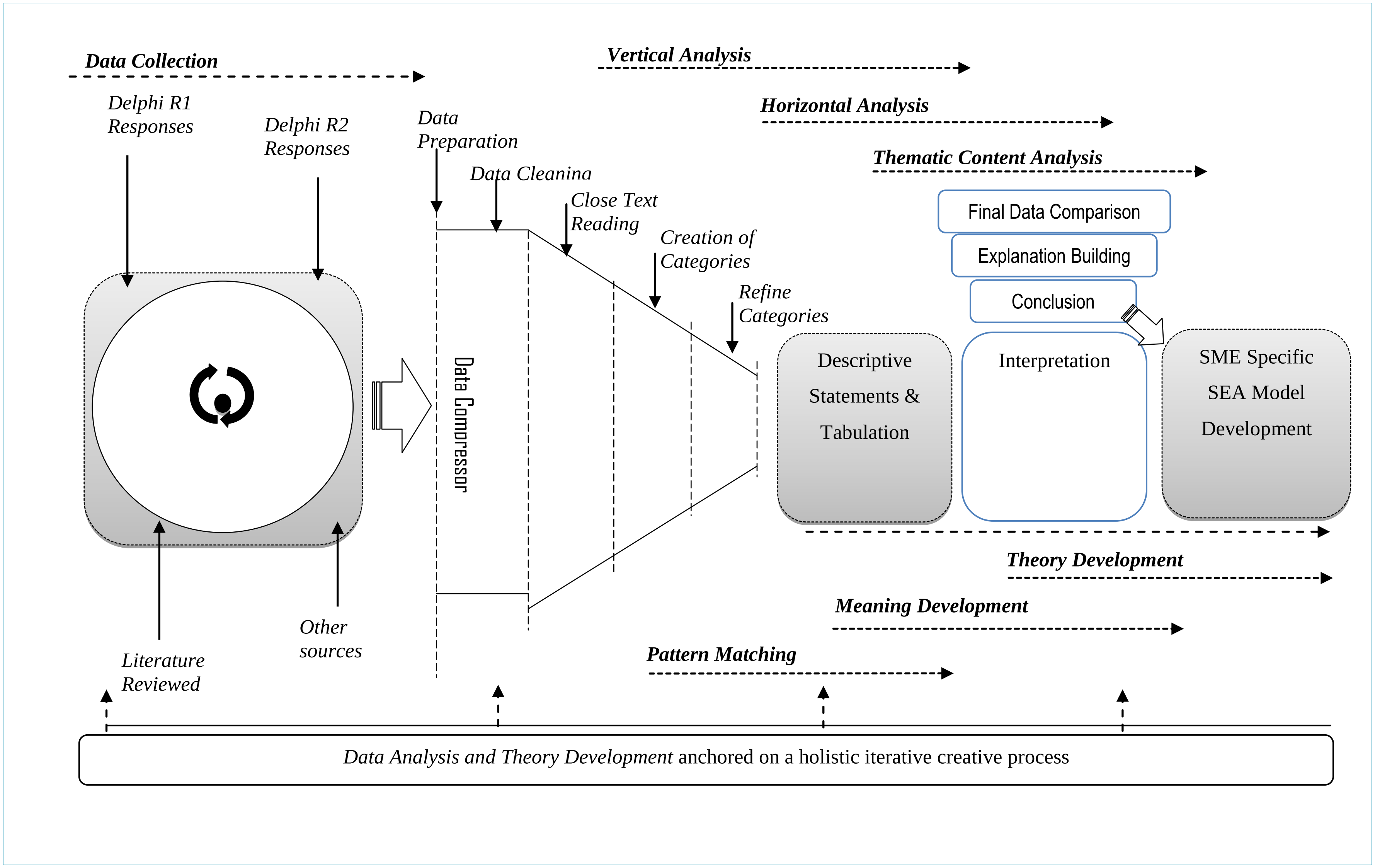


Figure 4.2: Overview of the Data Analysis and Theory Development Process

4.4 Methodology – Validity and Reliability

One of the most important features of any research instrument is that it measures the concept being studied in an unwavering and consistent way Coughlan et al, (2007). The Delphi technique applied in this research used questionnaires as the survey instruments. This survey instrument was developed by the researcher using input from literature and domain experts. The questionnaire for Delphi R2 was developed from responses to Delphi R1. The survey instrument aimed at capturing important elements of the subject and reaching convergence on structural issues of the SEA approach in order to arrive at the basis of which to develop a conceptual framework targeted to manufacturing SMEs.

***Validity**: is described as the ability of the instrument to measure what it is supposed to measure,* (Wood et al, as cited by Coughlan et al, 2007). One of the threats to validity was the sample selection. Even though experts were selected based on experience, it is possible that years of experience do not necessarily make someone an expert especially if they lack the breadth of experience, (Valerdi, 2011). To ensure validity experts where chosen from different sectors – industry, research institutions, government institutions, consulting firms and academia. Advocates of both extremes of systems engineering – the *hard* and *soft* systems participated. The other common issue in research work is construct validity. Construct validity for the Delphi technique is an intrinsic part of the process as in the subsequent round after the first round the focus will be on validation of the experts input and other inputs. The fact that the Delphi is not anonymous (to the researcher) permits also this validation step, unlike many surveys Okoli & Pawlowski (2003).

***Reliability**:* "is the instrument's ability to consistently and accurately measure the concept under study" Wood *et al*., (n.d. as cited by Coughlan et al, 2007). A notable threat to reliability is the quality of the questionnaire –To ensure reliability a pilot study was done involving three (3) experts in the field. From this the researcher adjusted definitions, altered the questions, addressed several other ambiguous statements and format issues noted by the participants of the pilot study.

Generalizability: "… concerns whether the results given by the study are transferable to other groups" Last (2001). That is application areas in this case of interest. The generalizability of this study is limited to the target application area – medium technology *manufacturing SMEs*. This is because the research instrument was designed targeting this sector. Tailoring and care may be required when applying the proposed framework (results of this study) both from a practical standpoint and from a methodological standpoint to different environments.

Anonymity Responses to the Delphi questionnaires were treated with complete confidentially. Anonymity removed some of the common biases typical of other methods of data collection especially the face to face approaches. Expert contribution was also coded (E1; E2 and so on, meaning expert 1, expert 2 in that order) to minimise biases associated with certain individuals contribution. Several authorities however have cited that lack of accountability that anonymity brings (Gordon, 2002; Okoli & Pawlowski, 2003).

Extent to which the Delphi technique has been applied:

The Delphi has been used in a variety of studies primarily for four (4) purposes:

1. Develop frameworks, or theory
2. Identify - for example main elements of issues of a domain under scrutiny
3. Forecast – for example future trends
4. Validate – as an example validation of theory; concepts; designs; proposals; propositions

Some examples of application areas as cited by Alder & Ziglio; 1996; Okoli & Pawlowski, 2003 and Skulmoski, 2007 include the few some in Table 4.1:

Table 4.1: Applications of the Delphi method in research

Researchers	**Purpose:**	**Rounds**	**Expert Panel**
Duncan (1995)	*Identify and rank the critical elements of Information Systems (IS) infrastructure flexibility.*	2	21
Czinkota & Ronkainen (1997)	*Forecast changes in the international business environment over the next decade and the impact of these changes on corporate practices.*	3	34
Namibisan et al (1999)	*Development of a taxonomy of organisational mechanisms*	3	6
Lam, Petri & Smith (2000)	*Development of rules for ceramic casting process*	3	3
Arditi & Gunhan (2005)	*Factors affecting international construction*	2	12

4.5 Research Limitations

The following limitations were expected of this research:

- The Delphi technique with its mandatory iterations is time consuming and if not followed strictly the investigation may be influenced by the subjective views of the researcher.
- Difficulties in keeping participants motivated to take part and keep them on board throughout the iterative process
- The system engineering literature is vast and not so well structured and the systems approach itself can be so all encompassing that it is difficult to focus.
- The research was value-laden in the context that, to an extent it depended on the panelist's and the researcher's interpretation. This to an extent introduces bias into the study.

To address these limitations the researcher ensured:

- The Delphi process was followed rigidly, recording information accurately and continuously reflecting on own biases and prejudices
- High degree of motivation and communication skills was employed by the researcher which included time staggered reminder emails.
- The researcher had to do a thorough literature review and continually refined the research questions to focus the investigation.
- The Delphi study by design via its iterative process reduces the individuals' biases. To add on to this, the researcher sort clarification in areas that was seen as introducing bias.

4.6 Ethical Consideration

The *1948, UN - Declaration of Human Rights*, the 1996 *Constitution of the Republic of South* Africa, and the ethical issues in research as outlined by Leedy (2005) guided the ethical considerations in this study*;*

- ***Informed consent***: expert participation in the Delphi process was voluntary
- ***Confidentiality and Anonymity***: the research study respected the right to privacy and the participant's contribution remained anonymous throughout the study.
- ***University of Witwatersrand Ethics Policy for non – medical research***

Above all, professional membership and the respective code of ethics of governing bodies ECSA, PMI and INCOSE were honoured in this study.

4.7 Chapter Summary

This chapter provided a detailed description of the research approach and the research instrument – the Delphi technique. The purpose the Delphi exercise was to provide a structured vehicle to engage expert opinion in order to collect data that assisted in clarifying issues concerning the systems engineering approach and its application. Be they controversial, unclear or complex issues. This then allowed refining and structuring the application model developed in chapter 3. The next chapter summarises the findings and provides a detailed analysis of findings from the Delphi exercise.

Chapter 5 - Results

'An expert will always state the obvious'

Murphy's Law

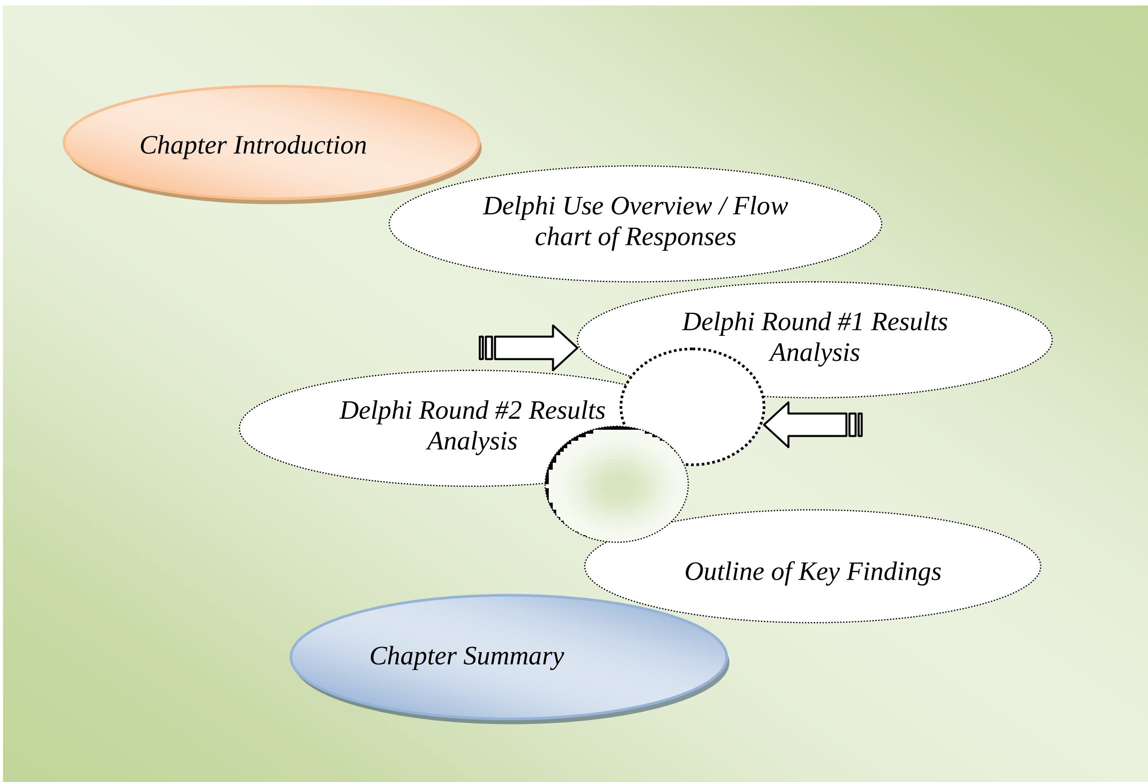


Figure 5.1 Chapter 5 (Results Presentation) roadmap

5.1 Introduction

The research question, as stated in chapter 1 is:

> ***Can a hybrid (****elements of both 'hard' and 'soft'****) systems engineering approach be framed to solve specific problems in SMEs?***

Chapter 4 – *Research Method* elaborated the question further to facilitate the development the research instrument questionnaires. The resultant drilled down topics included:

1. Establishing the key aspects / elements fundamental in any hybrid systems engineering framework
2. Finding consensus on what constitutes the systems engineering approach (SEA)
3. Identifying the SEA activities that have the potential of giving the greatest value in a typical manufacturing SME
4. Identifying the critical success factors for systems engineering implementation
5. Understanding why and how systems engineering efforts fail in any environment

This chapter contains the enriching views and experiences of the *Delphi exercise* participants, aimed at the topics outlined above. The results presentation follows the approach shown in figure 5.1

5.2 Questionnaire Responses and Implementation Overview

A total of 80 potential participants referred to here and after as experts where contacted via email. Of these, 16 responded by the final due date. This reflects a response rate of 20% for the first round which is consistent with several other studies of this kind found in literature. The responses were distributed as follows as shown in the table below (Linestone & Turoff, 1975; Gordon, 2002; Okoli & Pawlowski, 2003).

Table 5.1: Distribution of Participants across Industry

Industry of the Expert/s		Number of Experts	Percentage % Represented	Total SE Experience (Years)
Academia		5	31 %	*127*
Government related firms		4	25 %	*71*
Private firms / Consultants		7	44 %	*127*
		16	100 %	*325*

Of these experts who participated, 15 responded in the first round and 12 in the second round. This represents another attrition of 20% or a response rate of 80% in the second round. This is also consistent with the literature reviewed (*ibid*). *Figure 5.2,* below, provides a flow chart of responses via the two main steps of the Delphi process used in this study.

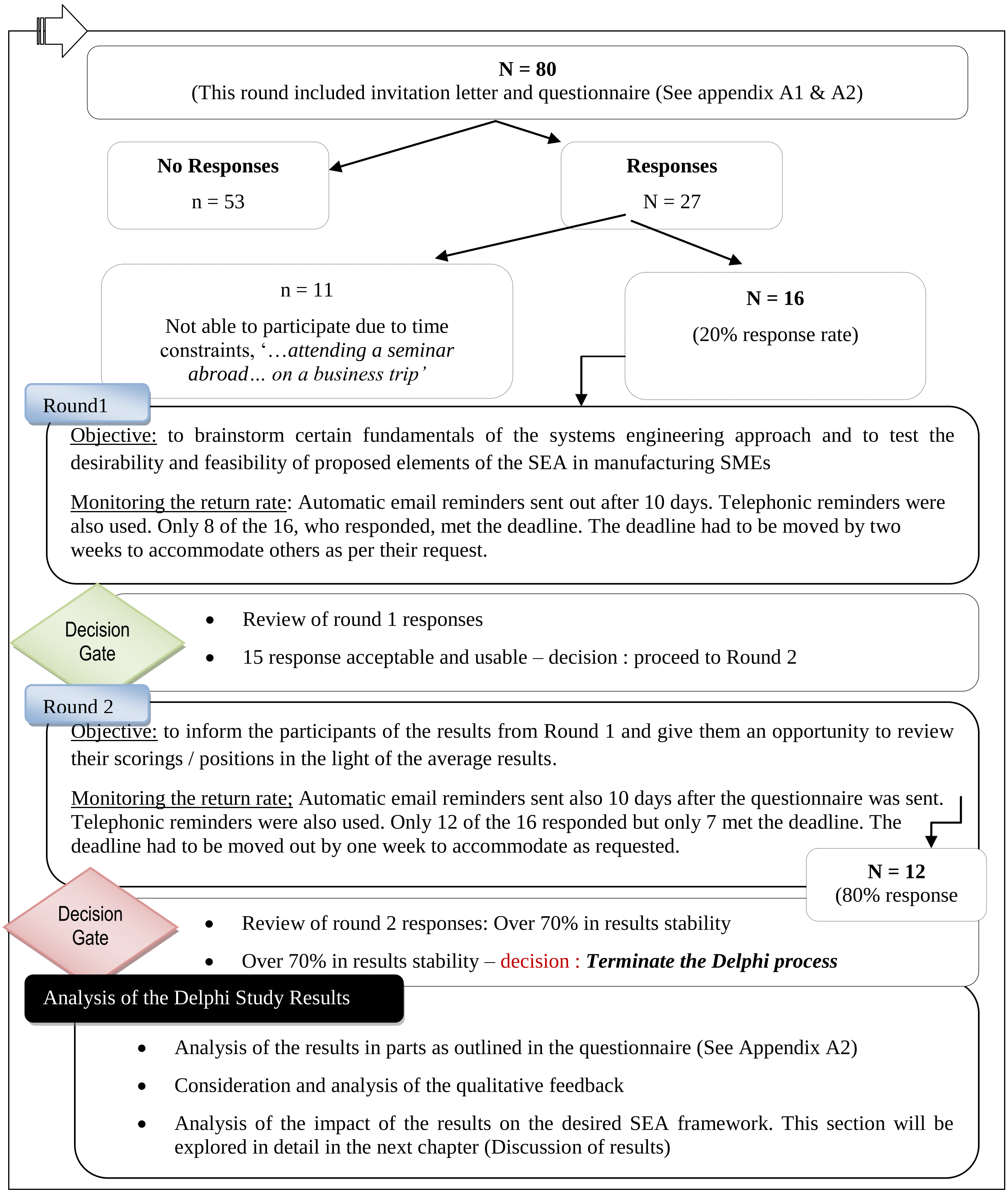


Figure 5.2 Flow chart of Responses and Implementation of the Delphi Rounds

5.3 Delphi Results Analysis

The round 1 questionnaire (appendix A2) was divided into four parts with the first part focusing on the demographics of the respondents while the other three parts focused on the subject of systems engineering and its application. Delphi round 2 questionnaire was a follow up and confirmation of round 1 results.

5.3.1 *Demographics of the Participants/ Experts*

The first part of the questionnaire was designed to collect demographic data to describe the general characteristics of the participants. This information included their position in the systems engineering world, the city and country where they are based, their job title, years of experience in the systems engineering domain, their systems engineering knowledge, INCOSE related SE professional credentials.

- **Participants Position in the systems engineering world**

  The first question in the demographic section requested the professional background of the experts. Figure 5.3 below, summaries the positions of the sixteen (16) participants in the systems engineering world. 75% of the respondents where from the private sector, academia, independent consultant included, while the balance came from research centres and government.

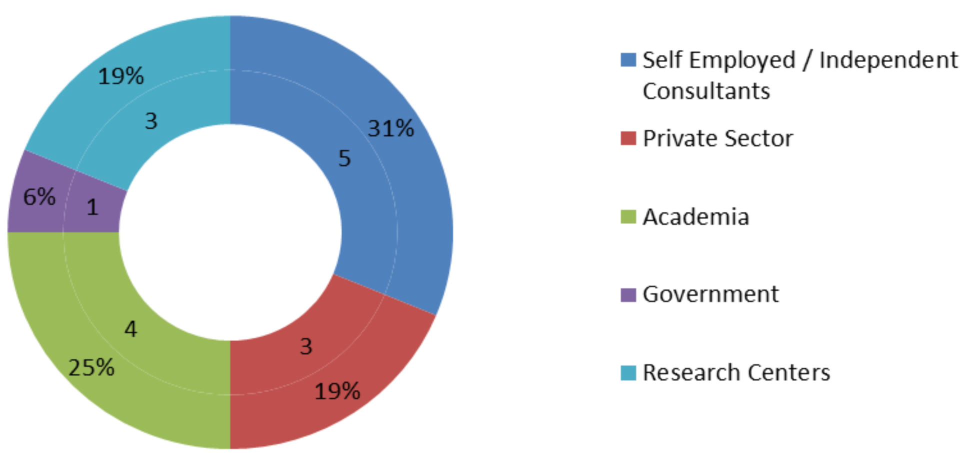


Figure 5.3 *Part One _ Demographics Question 1*

- **Location of Participants**

  Figure 5.4 below, summaries the positions of the sixteen (16) participants in the systems engineering world.

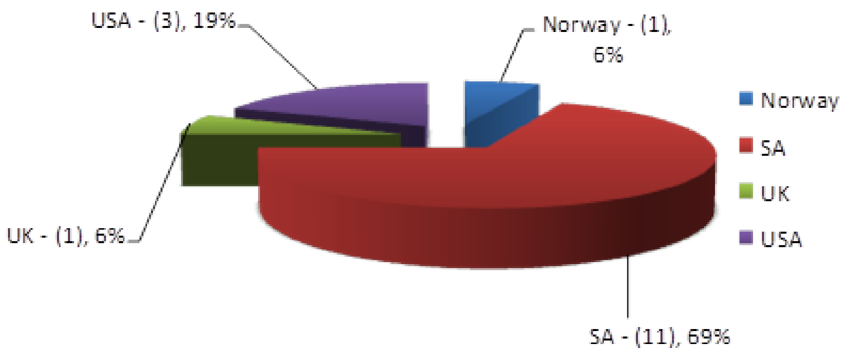
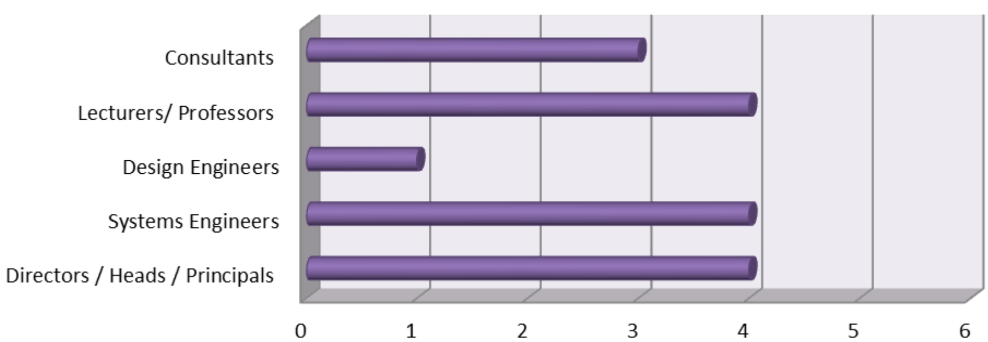


Figure 5.4 *Part One _ Demographics Question 2*

For this question 69% of the participants where from South Africa while 19% where from the US and the balance from United Kingdom and Norway.

- **Organisational Positions / Job Title of Participants**

  The third question elicited the job titles of the participants. Various titles / organisational positions and their distribution are shown in figure 5.5 below.



	Directors / Heads / Principals	Systems Engineers	Design Engineers	Lecturers/ Professors	Consultants
Number of Experts	4	4	1	4	3

Figure 5.5 *Part One _ Demographics Question 3*

- **Experience of Participants**

Figure 5.6 below, shows that 81% of the experts had 11 years plus experience while of that 51 % had more than 21 years' experience in systems engineering.

Figure 5.6 *Part One _ Demographics Question 4*

- **Location of Participants**

This question requested participants to describe their systems engineering knowledge as either very good or excellent. The chart below summarises how the participants rated themselves, 69% (over two thirds) claimed they had excellent SE knowledge and experience while 31% conservatively described their SE knowledge and experience as very good.

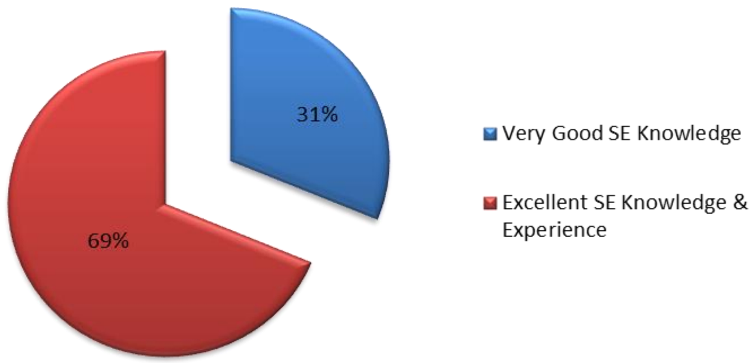


Figure 5.7 *Part One _ Demographics Question 5*

- **INCOSE accredited SE certification**

  The last question on demographics sought to establish whether the participants had any of the INCOSE accredited certifications – ASEP; CSEP or ESEP. Note all participants responded to this but of all participants – three (3) were *Certified Systems Engineering Practitioners* – CSEP while one (1) was an *Expert Systems Engineering Practitioner*.

5.3.2 Summary of Responses Delphi Round 1 & 2_Theoretical Question 1

This second part of the questionnaire details the views and comments of the participants on - *what constitutes the Systems Engineering Approach*, see *Appendix A2*

5.3.2.1 Part Two (2) - Question 1: Definition of the SEA

Participants were asked to review and comment on the presented definition of systems engineering:

- Systems Engineering Approach (SEA):

  …is a top-down interdisciplinary framework to drive processes that enable sustainable whole solutions to be generated throughout a system's life cycle"

After the first round, seven (7) of the sixteen (16) experts agreed with the above definition, 4 were neutral and 5 disagreed. This means 44% of the experts agreed with the definition while 31% disagreed, 25% where neutral, it follows the set limit of consensus of 67% or 2/3 majority was not reached. This prompted the question to be taken to Delphi round 2. The details, comments and summarised feedback on the particular points of departure in understanding the definition are detailed Appendix G. Worth noting note were the points that …*systems engineering is not necessarily a top-down approach* and the… *absence of risk management* in the definition. The inputs from Delphi round 1 definition were collated and a new definition presented in round two (2):

> *Systems Engineering Approach (SEA) is a holistic trans-disciplinary structured approach with a number of frameworks and methodologies used to drive processes that enable delivery of value to / or of the system of interest with acceptable risk throughout a system's life cycle"*

A slight increase in consensus was recorded, 50% agree with the definition as compared to 44% in the first round, 25% remained neutral will those who disagreed dropped by 6%. Comments from the experts who participated in final round led to this working definition:

***SEA** is a holistic interdisciplinary structured approach with a number of frameworks and methodologies used to pragmatically configure or select applicable processes that enable delivery of value to the customer via the system of interest while pursuing opportunities with acceptable risk throughout the system's life cycle.*

→ *This approach considers both the business and technical needs focusing on requirements analysis, baseline management, risk management, interface management, trade-off studies and quality management.*

<u>The summary of headlines findings on the definition of SEA</u>:

- There was no clear consensus on the definition of the systems engineering approach in as much as 50% of the respondents in final round 2 agreed with the modified definition as a result of Delphi round 1 feedback. This is consistent with the literature reviewed …*systems engineering is a slippery subject that does not lend itself to such a formal instructive treatment (Section 2.3.2 page 15).*

5.3.2.2 Part Two (2) - Question 2: Evaluation of the importance of the SEA principles

Participants were asked to evaluate the importance of given systems engineering principles and state other principles based on their knowledge and understanding. The results from the Delphi round 1 are presented below in *figure 5.8.*

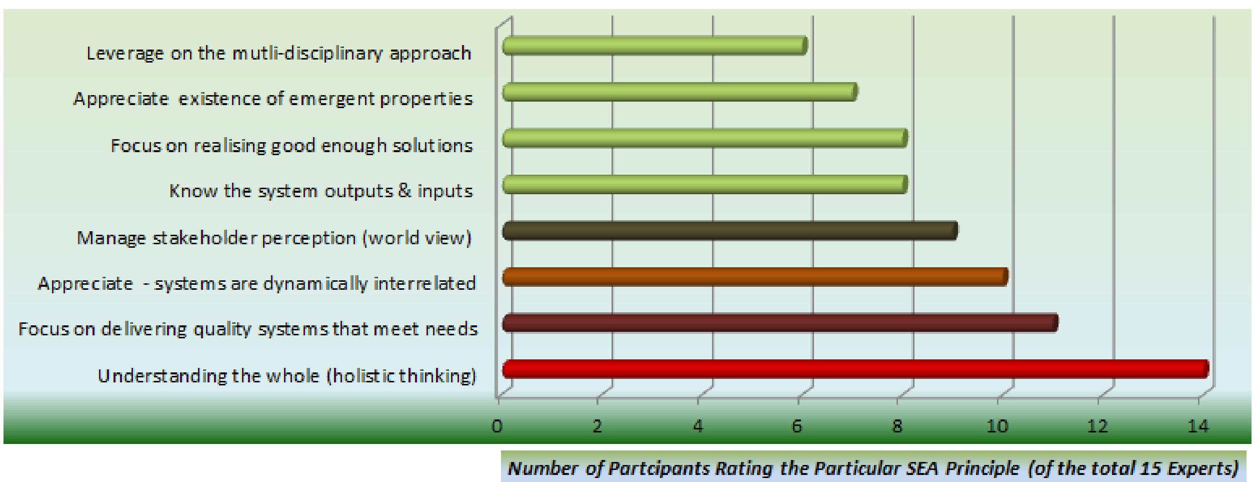


***Figure 5.8** Part Two _ Principles of the SEA: Delphi R1 Question 2*

Four principles were rated the top most important – that is the first four from the bottom of the Y-axis in figure 5.8 above. The experts also suggested other principles which were rated in Delphi round 2 as presented in figure 5.9 below.

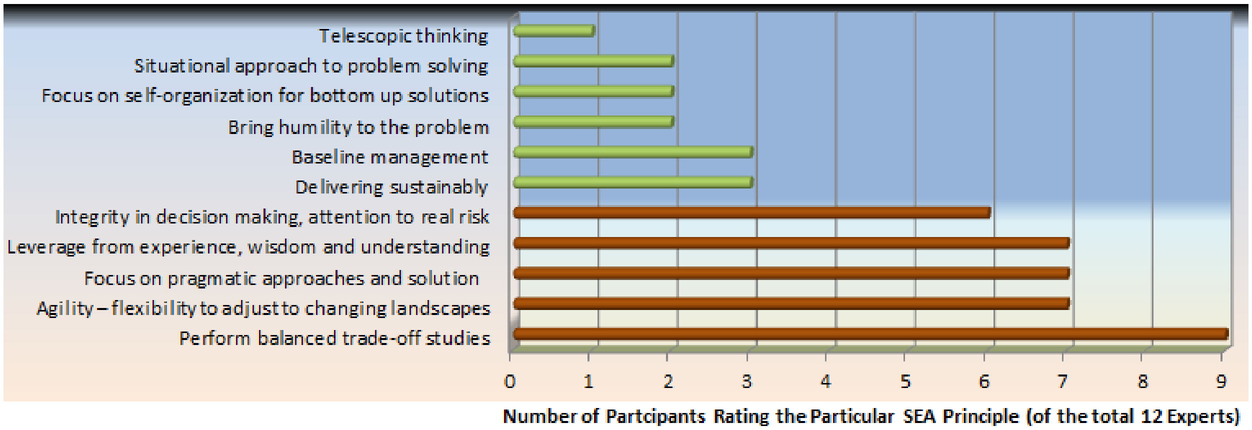


Figure 5.9 *Part Two _ Principles of the SEA: Delphi R1and R2 Question 2*

It follows the combination of the most popular, given and suggested SEA principles are:

1. *Understanding the whole (holistic thinking)*
2. *Perform balanced trade-off studies*
3. *Focus on delivering quality systems that meet needs*
4. *Appreciate - systems are dynamically interrelated*
5. *Manage stakeholder perception (world view)*
6. *Agility – flexibility to adjust to changing landscapes*
7. *Focus on pragmatic approaches and solution*
8. *Leverage from experience, wisdom and understanding*
9. *Integrity in decision making, attention to real risk*

The summary of headlines findings on the key principles of the SEA:

- Participants reached consensus on the key principles of the systems engineering approach. Nine (9) SEA principles were distilled from the Delphi iterations. These key principles are consistent with the elements distilled from literature as outlined in section 3.2

5.3.2.3 Part Two (2) - Question 3: How best can SS and HS approaches be applied together

The presented approaches of how *soft* and *hard systems approaches* can be emphasised in a typical manufacturing SME production process is shown below:

Fornt end Processes		Main Processes		Back End Processes	
Concept Studies	Rqmts Studies	Design/ Develop	Production	Utilisation	Retirement/ Disposal

Some of the comments from the experts in seeking to reach consensus on this question are shown below:

- *"In the back end, the intention is to design the utilisation and supports systems, so there is a definite end goal in mind therefore HAS are more appropriate - dominant" SSA may be used to understand ..."*
- *"The utilisation and support of a system including disposal utilises the HSA. Logistic support & disposal specifications are developed on which the support system & disposal systems are designed".*

In general the experts agreed on the following dominance of the two approaches – HAS and SSM as shown in the table 5.2, below.

Table 5.2: *Part Two:* Application of SS and HS approaches:

	Fornt end Processes		Main Processes		Back End Processes	
System Life Cycle	Concept Studies	Rqmts Studies	Design/ Develop	Production	Utilisation	Retirement/ Disposal
Dominant Approach	*Soft Systems Approaches (SSA)*		*Hard Systems Approaches (HSA)*		*Hard Systems Approaches (HSA)*	

These details were further interrogated by the follow-up question whose results are shown in table 5.3 below. Of the 12 experts who participated in the second round 11 agreed fully or partially with the process shown above. This amounts to an acceptance of 92%. The actual results from the two rounds are shown in table 5.3 below.

Table 5.3: Proportion of Dominance of the two Extremes of the SEA – Soft and Hard

	Concept Studies	Rqmts Studies	Design/ Develop	Production	Utilisation	Retirement/ Disposal
Actual # of experts for - SS	12	10	3	2	7	6
Actual # of experts for - HS	3	5	12	13	9	11
% of dominance SS	80.0%	66.7%	20.0%	13.3%	43.8%	35.3%
% of dominance HS	20.0%	33.3%	80.0%	86.7%	56.3%	64.7%
Overall dominance	Soft	Soft	Hard	Hard	?	?

There was no clear agreement on which approach should dominate in the *utilisation and disposal* stages. Several arguments comments were given for each of the stages:

Utilisation and Support:

- *'Soft' to capture new requirements from the user / support behaviour*
- *'Soft' to validate the value of the logistic support and to identify opportunities for logistic support improvement*
- *'Soft'- Manufacturing SMEs often produce components / replacement parts – utilisation and support is not as important as marketing and sales at the backend*
- *'Soft' - … soft system approaches should play a large role in utilisation and support because that phase deals so heavily in people interactions*
- *'Hard' to verify logistic support against requirements*
- *'Hard' - In the backend the intention is to design the utilisation and support systems, so that there is a definite goal in mind*

Disposal / Retirement:

- *'Soft' to capture new requirements from retirement*
- *'Hard' to verify successful requirements*

The dominance bias still resides with the hard approach 56.3% versus 43.8% for the soft approaches for the utilisation stage and 64.7% versus 35.3% respectively for the retirement stage.

General comments from experts who agreed with the representation:

- *The agile approach is preferred (a situational blend of the two approaches)*
- *Emphasis depend on the nature of the system of interest (SOI)*
- *Challenges of each phase of the life are situational*
- *I can leave with such a representation, which I can tailor for the problem at hand. … One size does not fit all – tailor in a pragmatic way*
- *My support for the above is in the context of manufacturing SMEs where I assume that the focus is on systems that are technology- dominant and not people or process dominant*
- *I would assess requirements studies closer to 50/50. This moves from concept / elicitation to design and draws heavily from both approaches*
- *Although market research is soft approach during concept and requirements studies, the actual system design that follows is a hard approach*

<u>The summary of headlines findings on the application of a hybrid SEA</u>:

On the application of a hybrid approach (*soft* and *hard* systems approaches) there was a 92% consensus that:

- Generally the <u>front-end processes</u> of a generic life cycle presented in section 5.3.2.3 (market studies and concept development) should emphasise more use of *soft systems approaches* and <u>main processes</u> (design & development and production) should emphasise in *hard systems approaches*. The same emphasis on hard systems approaches was also recommended on the back-end processes (utilisation and support)
- For the specific life cycle stages the emphasis was recommended as follows: *Concept studies – SS; Requirements Studies – SS; Design/ Development – HS; Production – HS.* There was no clear consensus on the utilisation and retirement / disposal stages which all had scored less than the required 67% that is 56.3% and 64.7% respectively. Nonetheless the bias was still on the hard approach.

5.3.3 Summary of Responses Delphi Round 1 & 2_Theoretical Question 2

5.3.3.1 Part Three (3) - SEA Activities which gives the best Value to SMEs

This part of the questionnaire was aimed at tailoring the SEA to the manufacturing SMEs context. Appendix G2 shows a detailed analysis of the responses from the participants. Below is a summary of the list of system engineering activities which gives the best value in the context of manufacturing SMEs in the fast moving consumer good area. The appropriate activities to be adopted are listed for each stage of the 11 stage SEA process.

Stage 1: ***Stakeholder Requirements Definition & Concept Development***:

1. *Define the system context*
2. *Identify stakeholders*
3. *Capture stakeholder requirements*
4. *Define the needs and operational context*
5. *Define constraints imposed by agreements/ interfaces*
6. *Develop scenarios of viable solutions & the ConOps*
7. *Identify the systems/ sub-system interacting with the SOI*
8. *Identify problems associated with satisfying the needs*
9. *Establish the critical & desired system performance*
10. *Determine affordability and funds in the long term*
11. *Negotiate modification to resolve impractical requirements*

Figure 5.10a *Part 3_ SEA Stage 1: Stakeholder Rqmts. Defn. & Concept Development*

Stage 2: ***Requirements Analysis Process***:

1. *Translate requirements from using client specific language into language technical people understand*
2. *Identify the system boundaries and interfaces*
3. *Define system functions, capabilities & performance goals*
4. *Identify all utilisation, support, disposal & environmental factors*
5. *State design considerations and identify constraints*
6. *Define, derive & refine functional/ performance requirements*
7. *Generate the top level system specification of the requirements*
8. *Perform Cost_performance trade-offs*

Figure 5.10b *Part 3 Question _ SEA Stage 2: Requirements Analysis Process*

Stage 3: **Architecture Design Process**:

1. *Develop multiple (at least two) architectural alternatives*
2. *Define / refine system elements alternatives for evaluation*
3. *Define systems functions*
4. *Allocate system functions to the physical configuration*
5. *Map system processes, activities and flows*
6. *Perform system design*
7. *Identify interfaces & interactions between system elements*
8. *Analyse & select preferred architecture using trade-off studies*
9. *Define, refine & integrate system physical configuration*
10. *Define solution reliance in the long term*

Figure 5.10c *Part 3 Question _ SEA Stage 3: Architecture Design Process*

Stage 4: **Implementation Process**:

1. *Develop the implementation (manufacturing.) strategy*
2. *Develop the market plan / strategy*
3. *Develop the material requirements plan (MRP)*
4. *Develop the production plan*
5. *Establish the scheduling plan*
6. *Develop the asset management strategy*
7. *Establish maintenance plan*
8. *Develop health, safety and environment management plan*
9. *Develop the issue / problem management plan*
10. *Develop the quality assurance strategy*
11. *Establish the quality control plan*
12. *Communicate the engineered system processes and flows (what it is and how it works*

Figure 5.10d *Part 3 _ SEA Stage 4: Implementation Process*

<u>Stage 5</u>: ***Integration Process***:

1. *Define the integration strategy*
2. *Perform integration – integrate design considerations*
3. *Show (a map) of all flows between sub-systems in a system of systems (SoS's)*
4. *Document integration*
5. *Test and monitor intearation*

Figure 5.10e *Part 3 _ SEA Stage 5: Integration Process*

<u>Stage 6</u>: ***Verification Process***:

1. *Plan verification and develop verification procedures*
2. *<u>Conduct Verification</u> –*

   - Inspection and Testing

   - Demonstration of functionality

   - Test (operability/ supportability/Performance)

   - Verification by analysis
3. *<u>Plan for / Get Certification / Accreditation</u>*

   - Health and Safety approval

   - Quality approval

   - Process approval

<u>Note</u> – Verify the process at every stage of the SEA process or manufacturing process

Figure 5.10f *Part 3 _ SEA Stage 6: Verification Process*

Stage 7: ***Transition Process***:

1. *Prepare a transition strategy*
2. *Perform transition e.g*
   - *Create a user manual*
   - *Assess the user base knowledge to tailor the traning*
   - *Train the user*
3. *Implement utilisation and support agreements*

Figure 5.10g *Part 3 _ SEA Stage 7: Transition Process*

Stage 8: ***Validation Process***:

1. *Conduct validation:*
   - *customer satisfaction surveys*
   - *Conduct customer reviews*
   - *Analyse product returns (run metrics on failures irregardless of customers perception of the service)*

Figure 5.10h *Part 3 _ SEA Stage 8: Validation Process*

Stage 9: ***Operation Process***:

1. *Prepare for operation*
2. *Finalise system process procedures (safe operating procedures etc.)*
3. *Provide operator training & maintain qualified staff*
4. *Manage operational support logistics*
5. *Report malfunctions and make recommendations*

Figure 5.10i *Part 3 _ SEA Stage 9: Operation Process*

Stage 10: ***Maintenance Process***

1. *Conduct streamlined RCM(reliability Centred Maintenance) on critical equipment*
2. *Maintain history of failures*
3. *Monitor replenishment levels of spares*
4. *Implement maintenance & problem resolution procedures*
5. *Monitor maintenance related constraints on the SOI*

Figure 5.10j *Part 3 Question _ SEA Stage 10: Stakeholder Rqmts. Defn. & Concept Dev.*

Stage 11: ***Disposal / Retirement Process***:

1. *Review the concept of disposal*
2. *Perform disposal*
3. *Decode leassons learnt*

Figure 5.10k *Part 3 Question _ SEA Stage 11: Disposal / Retirement Process*

5.3.3.2 Part Three (3b) - Evaluation of the key Enterprise Enabling and Agreement Processes

This question sought to evaluate key Enterprise Enabling and Agreement Processes relevant to the manufacturing SME's context. The results are persented below in Table 5.4.

Table 5.4: Key Enterprise Enabling and Agreement Processes

Enterprise Enabling	Agreement Processes
1) *Develop a solid enterprise strategic plan* 2) *Develop the enterprise risk management plan* 3) *Develop the enterprise health and safety management plan* 4) *Develop the enterprise environmental impact management plan* 5) *Develop the enterprise quality management policy* 6) *Conduct periodic reviews of the Standard Operating Procedures (SOPs)* 7) *Establish a sound crisis management plan - to be exercised when major system disruptions occur* 8) *Periodically analyse the infrastructure gap of facilities* 9) *Develop the enterprise skills retention strategy*	1) *Identify a list of potential suppliers* 2) *Negotiate the agreement* 3) *Establish delivery acceptance criteria* 4) *Monitor the agreement* 5) *Assess execution & negotiate changes to reduce risks* 6) *Accept the product or service* 7) *Supply Processes: Identify opportunities* 8) *Respond to tender* 9) *Initiate and execute the agreement* 10) *Maintain & manage communication with stakeholders* 11) *Develop and support the product of service* 12) *Close the agreement*

The summary of headlines findings SEA activities that gives the best value:

On SEA activities which give the best value to manufacturing SMEs – remarkable input were provided by experts as detailed in section 5.3.3. There was acceptable consensus on the different specific activities for each stage of the presented 11 stage SEA process. Appendix G2 details the extent of consensus for each specific activity.

5.3.3.3 Part Three (3c) - List of the SE process activities with the greatest impact to SMEs

Participants were asked to identify the list of the SE –process activities with the greatest impact to SMEs from the 11 stage SEA process. The following activities came top as summarised from Appendix G2.

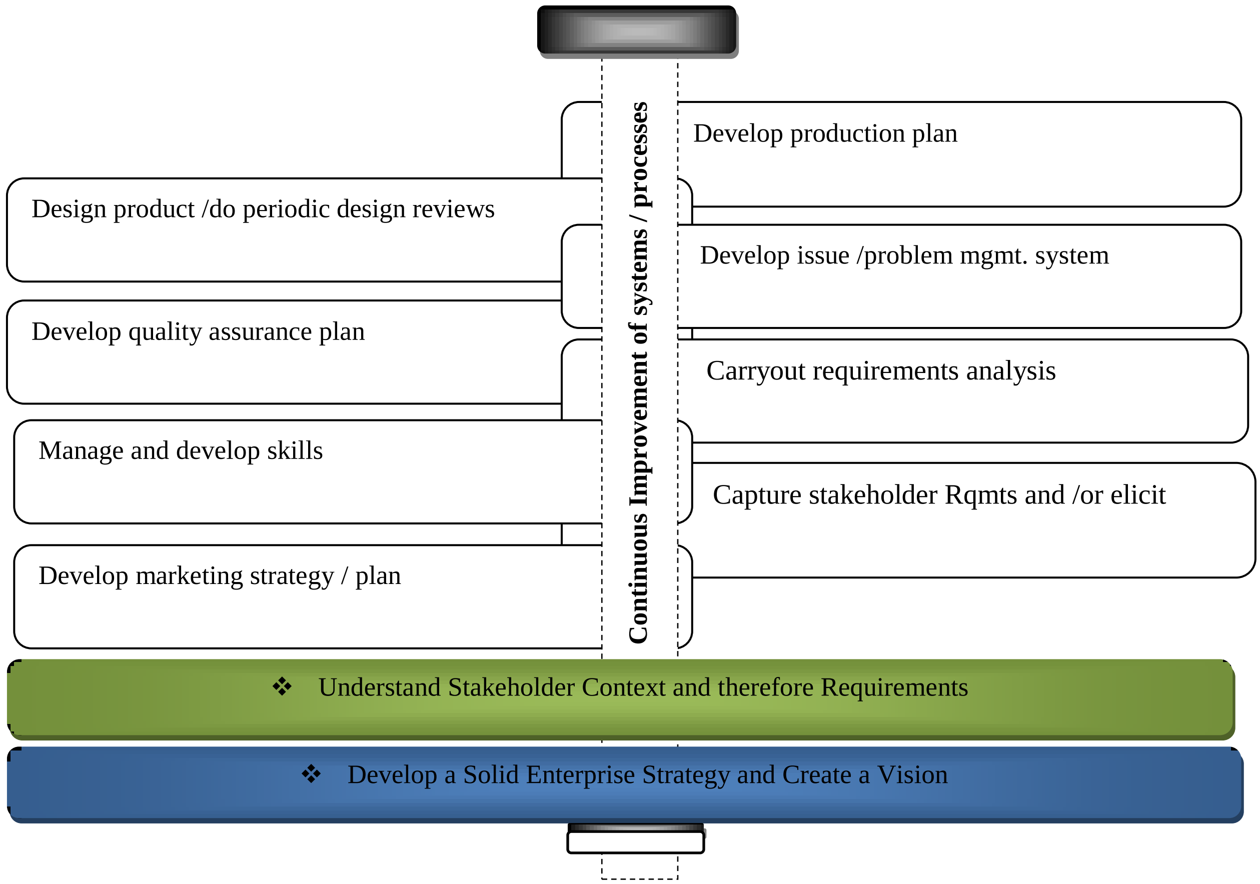


Figure 5.11 *Part 3 Question 3c_ The Contextualised Key Activities from the 11 stage SEA Process*

5.3.3.4 Part Three - Question 4: List of pillars / anchoring aspects of the SEA

This part of the inquiry sort to understand the common and fundamental '*DNA*' that any problem tackling framework, like the *SE approach* should have for it to be considered a useful. The results from the participant's responses were summarized in the seven (7) categories in figure 5.12, see next page.

Goals / Targets

- *Seek sustainable solutions*
- *Provide 'golden tread' – structure in a chaotic environment*
- *Ensure customer expectations will be met*
- *Implement workable solutions and retain product competitiveness*

Focal Point/s

- *Identify and understand stakeholders*
- *Focus on priorities rather than include all aspects*
- *Balance use of experience, people, tools & processes*
- *Perform balance trade-offs*

Provide Visibility

- *Allow for visualising the problem space (rich picture building)*
- *Allow for mapping of the problem*
- *Create visual process flow models of complex systems*
- *Create simulation models for complex risk based planning*

Approach to tackling the Problem

- *Look at the whole of the problem and the solution*
- *Formulate the problem*
- *Analyse the requirements and model the problem*
- *Provide for formal baseline management*

How to address the Problem

- *Define the problem*
- *Seek first to understand behaviour then function*
- *Follow the tailored process _ in this case the SEA process*

Things to watch out for / take advantage of

- *Manage risks and opportunities*
- *Validate early and often*
- *Allow for minimum scope creep (manage scope creep)*
- *Allow pragmatic changes based on experience of others*

Agility

- *Provide for continuous improvement*
- *Be situational in nature – (Not one size fits all)*
- *Must be flexible*
- *Manage the interfaces*

Figure 5.12 *Part 3_The basic DNA of any problem tackling framework like the SE approach*

5.3.4 Summary of Responses Delphi Round 1 & 2_Theoretical Question 3

This part of the questionnaire sought to gather from experience the challenges and lessons learnt in institutionalising the SE approach. The lessons are detailed in Appendix H, as extracted from the experts.

5.3.4.1 Part Four (Sub-question 1) – The main reasons why SE implementation Fails

The list below is shows the main categories of responses as distilled from panelist's feedback:

1) *Lack of knowledge, skills and training*
2) *Too much emphasis on process over results*
3) *Lack of leadership*
4) *Quest for quick results (unrealistic expectations)*
5) *Lack of top-level management commitment*
6) *Lack or little focus on people*
7) *Poor management*
8) *Unrealistic promises*
9) *Lack of understanding of the problem domain*
10) *Insufficient resources (time and budget)*
11) *Lack of tailoring to specific environment of the SOI*
12) *Failure to plan to deal with change management*
13) *Not enough support and emphasis for the value of SE (difficult to measure direct impact of SE)*
14) *Lack of proper incentive structures*
15) *Lack of accountability for those in charge*
16) *Over simplification of system complexity*
17) *Lack of formal baseline management*
18) *Lack of explicit specifications*

5.3.4.2 Part Four (Sub-question 2) – Challenges to be expected when rolling out SEA in SMEs

The list below is shows the main challenges in rolling out the right SEA in manufacturing SMEs as predicted by experts:

1. *Unrealistic expectations form stakeholders*
2. *Not enough time*
3. *SE is mistrusted and under valued*

4. *Inability to be agile - over emphasis on process*
5. *Misapplication of SE principles; no established processes to support SE and skills shortage*
6. *SE being the first target when cutting costs – SE seen as an overhead not investment*
7. *Convincing people to invest time in SE procedures, SE seen as an approach that slows things down. SE seen as meant for high tech systems not manufacturing SMEs*
8. *Discipline engineers seeing SE as superfluous (unnecessary)- added burden to produce extra paperwork; Low attendance to formal review meetings*
9. *Resistance to change (culture change) and management resistance to change (not interested in compiling proper strategy documents and plans)*
10. *Top management not committed (lack of support) – No full time SE i.e. SE being done over and above other tasks; Low attendance to formal review meetings*
11. *Enforcing quality control procedures*
12. *Focusing on drastic re-engineering rather than continuous improvement*
13. *Structuring incentive structures to benefit the right people / right level*
14. *Unable to show that the SE approach adds value*

5.3.4.3 Part Four (Sub-question 3a & 3b) – Lessons Learnt and Heuristics Derived

This question was aimed at getting *'hints* and *tricks'* to pragmatically apply the tailored SE approach. Some quotable quoted from the expects;

- *"Don't get hooked into SE tools, the tail does not wag the dog. Use tools for what you want, not what the tools wants or have the ability to do"*
- *"Do not apply systems engineering pedantically - (a narrow-minded approach insisting on exact adherence to a set of arbitrary rules"*
- *"Do not burden others by explaining what SE is about, just do it without too much discussions"*
- *"Attend to essence rather than overkill approach"*

The summary of the lessons learnt and the derived heuristics is presented in Appendix H

5.3.4.4 Part Four (Sub-question 4) – Main Enabler of a Sustainable SEA

This last question sought to understand the main enablers of a sustainable systems engineering approach. The layered chart below developed by the researcher and validated experts in the Delphi process shows how the researcher interpreted input from the participants.

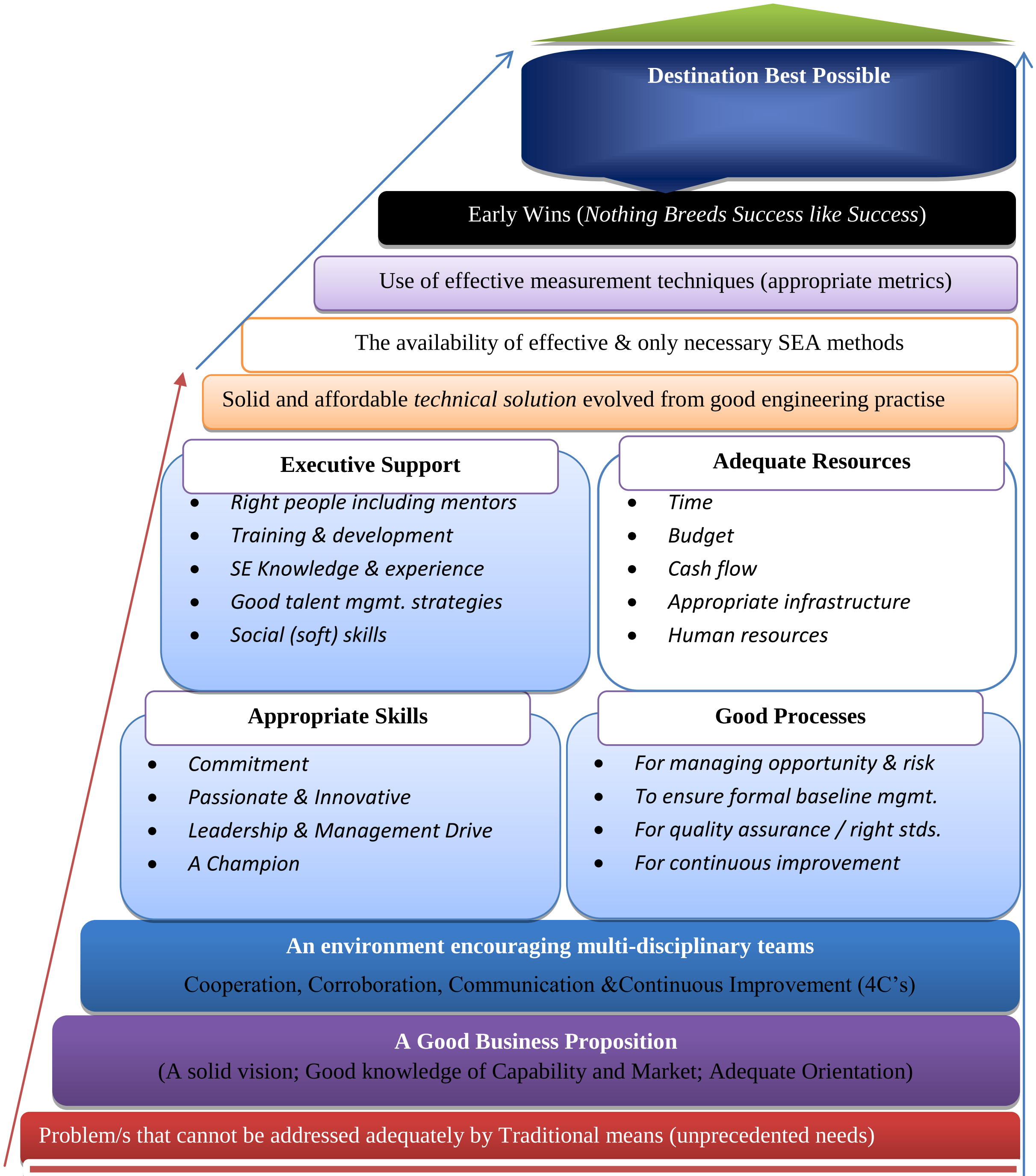


Figure 5.13 *Diagrammatic Representation of SEA Enablers in a Typical Manufacturing SME*

<u>The summary of headlines findings SEA enablers</u>:

- Lastly of key importance is the systems engineering enablers that are presented diagrammatically in figure 5.13, section 5.3.4.4. These enablers are listed below:

- ***Problem/s that cannot be addressed adequately by Traditional means*** *(unprecedented needs)*
- ***A Good Business Proposition*** *(A solid vision; Good knowledge of Capability and Market; Adequate Orientation)*
- ***An environment encouraging multi-disciplinary teams -*** *Cooperation, Corroboration, Communication &Continuous Improvement (4C's)*
- ***Appropriate Skills***
- ***Good (Effective, Efficient and Relevant) Processes***
- ***Executive Support***
- ***Adequate Resources***
- ***Solid affordable Technical Solution*** *evolved from good engineering practise*
- ***The availability of effective & only necessary SEA methods***
- ***Use of effective measurement techniques*** *(appropriate metrics)*
- ***Early Wins*** *(Nothing Breeds Success like Success)*
- ***Destination Best Possible*** *(the desire to do better all the time)*

5.4 Why the Systems Engineering Approach is the Preferred Way

The presented results have shown that the systems engineering approach is a preferred intervention approach for the following reasons:

1) It is a comprehensive all - encompassing approach that looks at the whole (that is the major systems; the relevant systems under scrutiny; the sub-systems and the other systems in that environment).
2) Provides visibility in areas which traditional methods would overlook and neglect as trivial contributors to a problem under analysis. This is critical in providing effective insights to potentials solutions.
3) The outlined process activities in section 5.3.3 are structured such that the SEA advocates first, for *understanding* the context, relationships, the stakeholders, the structures, the implications of changes, the silent noises and the extend of the problem before intervention.

4) The SEA is an efficient and effective way to transform an operational need into requirements. Some requirements are given, some implied, some deduced and some created to ensure realisation of a successful system.
5) The SEA has processes in every stage of the product and project life cycle and impacts the whole system life cycle.
6) The flexibility and agility of this approach makes it stand the test of test (sustainable) as compared to other approaches have clear rigid guidelines that must be followed. This is because the approach ensures that the *correct* problem is solved and avoids development of incomplete solutions or over-developing a good solution.
7) The process activities are structured to allow pragmatic changes and hence support continuous improvement. This compliments other approaches like TQM, TPM and Lean methods.
8) With tailoring the SEA application is not limited. As shown from the distilled process activities SEA application can be applied in small environments.
9) The SEA is an integrator of many disciplines and functional activities and is important to keep management focused and coordinated on the end goal. Studies have shown that SE reduces risk, keeps within the limits of budget and increases customer satisfaction, (INCOSE, 2011).

In summary the systems approach specifies pragmatic specifics of a problem and defines a successful path to resolve the issues effectively or to prescribe an intervention strategy. It follows the SEA is both a technical and management process.

5.5 Chapter Summary

The primary objective of this study was to develop a *Systems Engineering Approach* model tailored for use in less conventional application areas such as the manufacturing SMEs. This chapter presented the detailed results from the Delphi study. A convergence of opinion on the framework elements of applying the SEA in SMEs provided the basis for tailoring the conventional systems engineering approach. It is noteworthy to mention that the interest, comments and ratings provided by the high calibre experts were good indicators of the fact that the study was of high importance as model to advancing the systems engineering approach to less conventional application areas. The next chapter analyses and explains the findings in relation to the research objectives.

Chapter 6 - Discussion

"It requires a very unusual mind to undertake analysis of the obvious"

Alfred North Whitehead

6.1 Introduction

This chapter analyses and discusses the findings presented in chapter 5 in relation to the research objectives and in conjunction with the literature reviewed in Chapter 2.

6.1.1 Discussion Overview

The aim of this chapter is to find answers to the research question and derived sub-questions:

Central Research Question:

Can a hybrid systems engineering approach (*elements of both 'hard' and 'soft' systems****) be framed to solve specific problems in non-conventional applications such as SMEs?***

Sub-questions 1:

- *What constitutes a Hybrid Systems Engineering Approach?*

Sub-questions 2:

- *What SEA activities have potential of giving the greatest value in a typical manufacturing LMT - SME?*

Sub-questions 3:

- *What are the challenges of implementing the SEA in a LMT manufacturing SME?*

The discussion will thus be organised to address these specific questions. The findings of this research suggest that a hybrid SEA can be framed for application in non- conventional applications in particular manufacturing SMEs. The next sections will elaborate on the meaning of the findings and why the findings are important.

6.1.2 Demographics of the Participants:

It is important for any Delphi study that the respondents be experienced, as by design, the value of the Delphi-process output lies primarily in the *qualitative input* of a diverse group of experts (Okoli & Pawlowski, 2004). It was seen in figure 5.3 that the respondents came from a variety of sectors; academia, government, research centres and the private sector. It was also shown in figure 5.4 that the expert opinion came from three continents represented by Norway, South Africa, United Kingdom and the

United States. These experts (as shown in figure 5.5, came from different organisational positions. Of the sixteen who participated in the first round, four (4) were directors or heads/ principals, four (4) were professors / senior lecturers, four (4) systems engineers and one (1) design engineer. Of these respondents, it was also stated and shown in figure 5.6 that 81% had 11 plus years' experience while 51% had 21 years plus experience. Of the 16 experts, there were three (3) INCOSE certified systems engineering practitioners and one (1) expert systems engineering practitioner. This diverse and experienced expert panel was crucial in framing and guiding the study. This is also strengthened the validity of the study or the ability of the Delphi technique to measure what it is supposed to. Eleven (11) of the sixteen (16) expert-panel declared to have excellent systems engineering knowledge. This suggested that the experts were confident of their knowledge of SE. For the complete list of the experts and advisors refer to Appendix A4.

6.2 Part A. - **The Hybrid Systems Engineering Approach**

What constitutes a Hybrid Systems Engineering Approach?

Participants failed to reach acceptable consensus on the definition of the SEA approach (refer to section 5.3.2.2). This is consistent with the literature reviewed (Kasser, 2007). From the literature there are to be two distinct schools of thought, the *'soft'* and the *'hard* systems approach advocates as presented in fig 2.3. The advocates of each school of thought placed emphasis in the definition to align it with their respective bias. The reason for this could be attributed to the fact that systems engineering is not a recognised engineering discipline but is still evolving. From the iteration of the Delphi process the researcher managed to synthesise a working definition encompassing the two extremes. The definition was first presented in chapter 5 and is again presented here for further clarification.

***SEA** is a holistic interdisciplinary structured approach with a number of frameworks and methodologies used to pragmatically configure or select applicable processes that enable delivery of value to the customer via the system of interest while pursuing opportunities with acceptable risk throughout the system's life cycle.*

→ *This approach considers both the business and technical needs focusing on requirements analysis, baseline management, risk management, interface management, trade-off studies and quality management.*

The high-level clarification of this definition is presented in figure 6.2 (next page). This diagrammatical illustration was developed by the author.

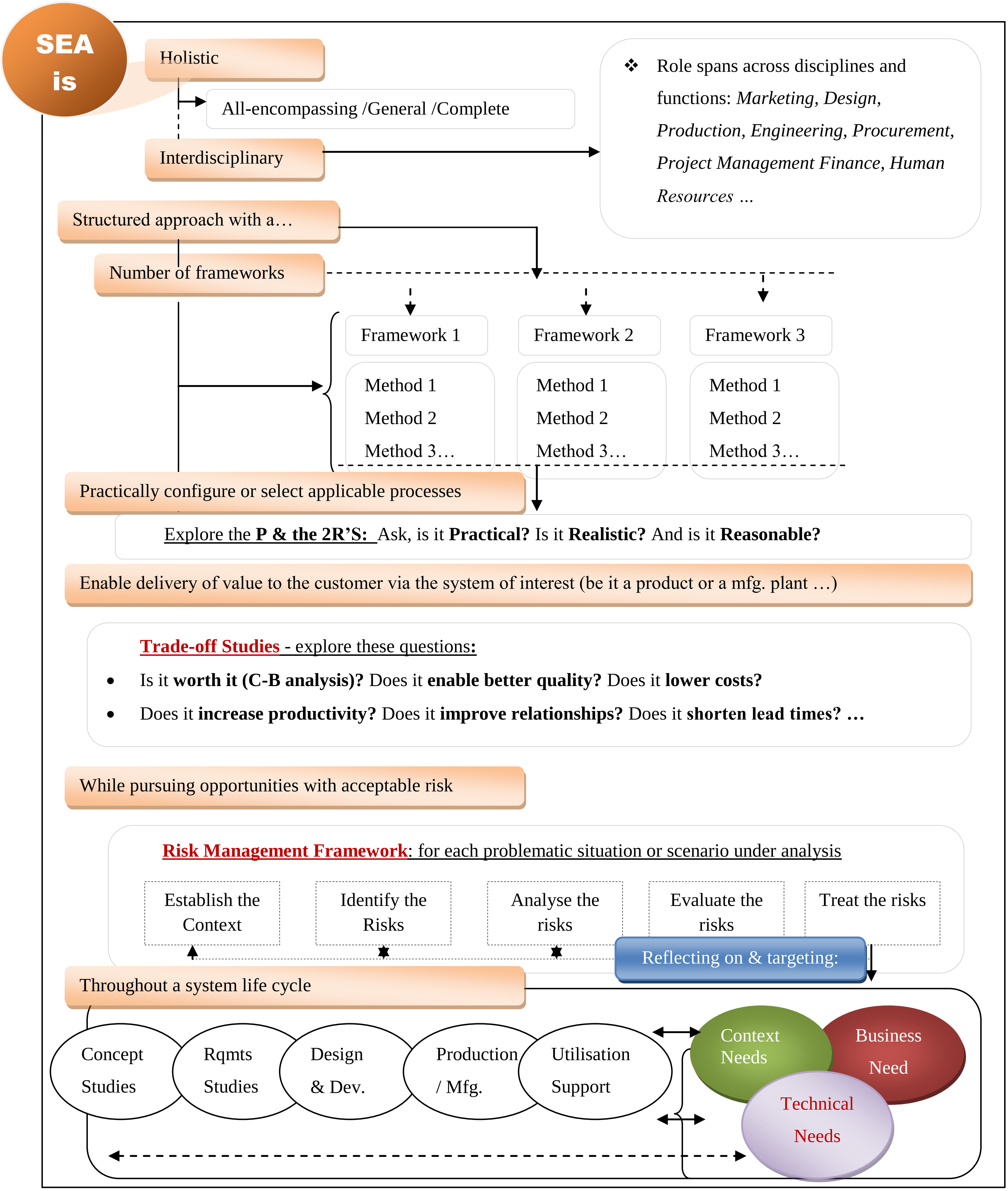


Figure 6.1 *Diagrammatic Representation of the SEA Definition*

The referred to *contextual, business* and *technical needs* elements in the extreme bottom right of figure 6.1 (which represents the target of the SEA) include:

1. *Contextual needs- are the*
    - People
    - Culture
    - Background
    - Status quo
    - General environment
    - Policies

2. *Business needs*
    - Shareholder value (return on investment)
    - Market share
    - Profit
    - Sales Volumes
    - Sustainability
    - Corporate responsibility

3. *Technical needs*
    - Concept studies
    - Requirements studies
    - Functional specification
    - Manufacturing specification
    - Product specification
    - Implementation strategy (production, quality control, SHE plans…)
    - Verification and Validation Criteria / Strategy / Procedures
    - Operations strategy
    - Maintenance strategy
    - Utilisation/ Support strategy

This high-level analysis of the SEA definition is important as a basis for the desired application framework for manufacturing SMEs.

6.2.1 Explanation of the Nine (9) SEA principles

The nine most common SEA principles as synthesised and rated by the experts (presented in *section 5.3.2.2)* are discussed below. The study has attempted to clarify the importance of each and how it fits in the SEA effort.

6.2.1.1 Understanding the whole (holistic thinking)

Holism (from the word holistic) is the theory that a complex entity or system is more than the sum of its parts, Chambers Dictionary (n.d. as cited by Hitchins, 2007 p.14). In problematic situations the tendency is to quickly decompose or breakdown a problem to understand it better, in the contrary, the principle of holism seeks to broaden the problem space before narrowing down. This allows a reflection on the relationship of the subsystems and the emergent properties as a result of the interactions. This is particularly critical with high human activity systems like the targeted manufacturing SME. The reasoning here is that by definition of *holism*, the parts might be free of any malfunction, issue or problem but the real problem still surfaces or evolves as a result of the interactions between the systems. It follows that separating the systems might lead to a null solution as a disturbance on the interactions of systems working together might lead to them not achieving the common objective. A systems approach to a problematic situation would entail <u>not</u> breaking down the systems but seeking to understand the components that make up the bigger systems. For example, in manufacturing SME (refer to the typical systems shown in Chapter 3, figure 3.4.), a problem in the *front-end system* might reflect there but the solution lies somewhere in the bigger manufacturing system. This, therefore, means checking the following components of the bigger system (one or two levels up on the system hierarchy);

- The structural components (that is the static parts)
- The operating components (the processing parts)
- Flow components (the materials, energy, information)
- The social components (the people, the stake/ shareholders, the politics, the relationships)
- The patterns of change rather than events

It follows the importance of this principle cannot be underestimated hence the experts rated it top of the SEA principles.

6.2.1.2 Perform balanced trade-off studies

These are decision making actions that select from various requirements and alternative solutions on the basis of the net benefit to the stakeholders (INCOSE, 2011). These involve choosing from alternative courses of actions each time a decision has to be made. This is consistent with the *systems approach* which seeks not to narrow down the problem but explore the problem space (refer to section 2.3.1 in the literature review). The trade-off studies in the manufacturing SME's context are used for example to:

- Resolve conflicts (labour, quality issues…)
- Launch a new product
- Diversify the product mix
- Make a call projects (plant re-designs, institutionalising processes – e.g. RCM, TPM, TQM)

The level of detail or formality (that is the level of documentation) of the trade studies needs to be proportionate and balanced with, *costs, time (schedule), performance, risk,* reflecting always on the contextual needs, technical needs and business needs as per the *SEA* definition presented in figure 6.3. The balance is schematically illustrated below:

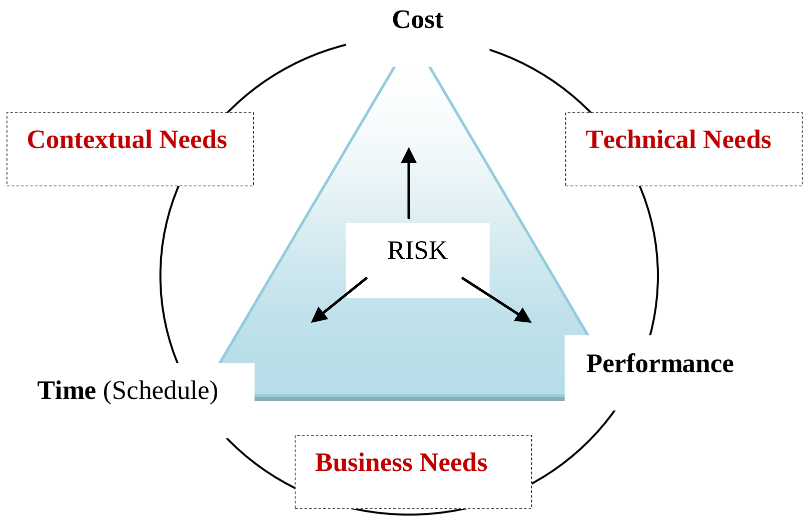


Figure 6.3 *Schematic Illustrations of the Trade Studies Constraints (The authors own)*

Below is an outline of attributes of good trade studies are:

1. Exploration of the whole problem space
2. Narrowing down on the alternatives
3. Freezing the scope on selected alternatives
4. Definition of goals, objectives and values
5. Selection of a defined criteria
6. Carrying out sensitivity analysis's
7. Documenting results (level of documentation is relative to the constraints shown in *figure 6.3*

It is therefore important that trade studies be used to support decisions throughout the SEA process.

6.2.1.3 Focus on delivering quality systems that meet needs

The *quality management process* falls under the organisational enabling processes as per the INCOSE systems engineering handbook v.3.2.2 (2011). The aim of this process is to assure that products, services and implementation of life cycle processes meet the organisations quality objectives and achieve customer specification. The International Organisation of Standards (ISO) defines quality a "… the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs", ISO 8405 (1994 as cited by Kasser, 2007 p.2-7). This definition talks to something more than just satisfying the customer but *delighting* the customer. This is done by exploring the whole solution space in pursuit of customer delight but limited by the constraints detailed in *figure 6.3* (that is *cost*, *performance* and *time*). The complexity of quality as an attribute to pursue is complicated by the fact that quality is a moving target dependent on various qualitative and subjective factors such as *perceptions*, *brand loyalty*, *trends* and *beliefs*. It follows rigid strategies that aim to satisfy only the stated objectives are not sustainable in this new era of systems thinking. In summary the attributes of a good quality strategy talks to:

- Satisfying the stakeholders (e.g. the client, end customer, shareholder, …)
- Delighting the customer (being ahead of the customer)

6.2.1.4 Appreciate - systems are dynamically interrelated

Dynamics of systems and subsystems, in any environment, has always been recognised. What has received less emphasis, however, is the consideration or appreciation that systems are dynamically interrelated before intervening to try and address a sub-system problem / issue. These dynamics are responsible for the emergent properties typically exaggerated in high human activity systems. A good example of the property of emergence is the fact that ammonia has a pungent smell, yet it is a product of the interaction of two odourless substances – hydrogen and nitrogen. Another everyday example is fact that *one can love*, but the parts cannot (Gharajedaghi, 2006). Checkland (1999) defines the property of emergence, as the principle that the whole entities exhibit properties which are meaningful only when attributed to the whole, not its parts. In the targeted context, the LMT manufacturing SME, focusing on perfecting the quality of products from one machine centre without reflecting on the whole production process is unlikely to give the desired results.

In a problem confronting situation, the recommended SE approach is to:

1. List the issues and draw up the naïve picture to know the cause and effect relationships (refer to section 3.4.2, figure 3.2 - Model Conceptualisation chapter.
2. Draw up the rich picture of the problem situation to better understand the relevant activity systems, problem elements; key concerns and context (refer to section 2.5.2).
3. Study the rich picture and the naïve picture to know the boundaries/ interfaces.
4. Then intervene upon modelling of the systems dynamics and sensitivity responses.

6.2.1.5 Manage stakeholder perception (world view)

The adopted definition for guiding the discussion is by Fredman (1984 as cited by Braun *et al.*, 2008), *a stakeholder "*…is any group or individual who can affect or is affected by the achievement of the organisations objectives". This definitions leads to asking the question, *who are the stakeholders? How are they affected? Why should management / people be worried about stakeholders? What is the benefit of considering and managing stakeholders?* These questions suggest that the first step in managing stakeholders is to **identify who they are**. From the systems engineering knowledge gathered from the Delphi exercise and the literature, this process will be done through mind-maps or rich pictures. This is done by an interdisciplinary integrated team to ensure all surprise individuals or groups are unearthed. Typical stakeholders that must not be overlooked for manufacturing SMEs include; clients, consumers unions, local government, state departments, business associations, local communities, banks and environmental groups. These stakeholders are affected and can affect the SOI in different ways. Hence know **their level of involvement,** who are, the 'movers and shakers' (Braun *et al.*, 2008). For example the regional steels industries union could have bargained a particular man-hour rate for their shop-floor workers and one may be working on a higher or lower rate which can be viewed as confrontational by the unions or ones fellow employees. Another example could the particular relevant state department could have been working on a long-term plan to phase out a particular product in the whole manufacturing sector at a future date because of certain pre-agreed international obligations. Contrary one might be planning to build more production lines to support those products. It follows for enterprise sustainability relevant stakeholders should be known and **engaged**. Management should **appreciate and consider the involvement and validity** of the diverse stakeholder interest as some have the *veto power* to interrupt or stop the process. A few benefits of stakeholder management are outlined below;

- Supports the communication process

- Early engagement helps in business readiness
- Early identification of the risks and obstacles

6.2.1.6 Agility – flexibility to adjust to changing landscapes

*Agile system*s are concerned with response ability for both reactive response and proactive response scenarios (Dove, 2005). Myburgh, (2010) prefers to call it the *situational approach*. This essentially talks to the speed at which changes are made to delight the customer with minimum disruption to the triple constrain triangle of *cost, time and quality.* Examples of *reactive* and *proactive responses* are given below in Table 6.1.

Table 6.1: Agile Approach – Outline of Reactive and Proactive Responses

Reactive Responses	Proactive Responses
• Correcting malfunctioning system	▪ Development of new range of products
• Response to quality variation	▪ Migration to better ways as new possibilities emerge
• Responsive to production decrease	▪ Modification of a systems to enhance capability
• Response to an warning system	▪ Continuous improvement

Some elements extracted from Dove (2005)

Market demands have become so unpredictable and dynamic that these agile (responsive) ways of doing business are no longer an option. Globalisation is now a reality. It is now easier than ever to do business in any place, virtually or by actually starting up new factory. Customers are global and competition, technology and information are no longer bound by geography. This means the world is open for business to all and *customers know that*. Customers / clients know they have the choice and the options. The onus then rests with the manufacturers to design their systems structural elements and systems capabilities for this new trend and customer behaviour. The options to do this include;

- Designing and instituting production systems that are ready for change – for example engineer systems with a high degree of customisation in products
- Designing systems with the ability to deliver value to the customer with minimum *time-to-market*
- Design systems with capabilities to revamp products quickly to meet market expectations
- Design systems that value knowledge and skills (knowledge culture / a learning enterprise)

- Create a culture of unprecedented transparency in the operating philosophy and business climate
- Form virtual partnerships that strive to enrich the customer and continuously improve existing networks

6.2.1.7 Focus on pragmatic approaches and solutions

These approaches are sometimes referred to as solution based approaches. As show in figure 6.1 some questions have to be asked:

Explore the **P & the 2R'S:** Ask, is it **Practical?** Is it **Realistic?** And is it **Reasonable?**

As echoed by most of the panelists (form the Delphi exercise), the goal is to use strategies that are effective and not to blindly focus on the traditional SE process. This research effort strives to move away from this traditional approach to what can be referred to as *strategic sustainable systems engineering*

Some of the efforts that build a framework for pragmatic solutions include;

1. *Focusing on issues early in the issue life cycle*
2. *Have a system of capturing and attending to issues before they develop into problems*
3. *Tailor the process and parameters for each issue*
4. *Prioritise – focus on the vital few*
5. *Focus on planning, looking ahead and doing, not reporting*
6. *Solving problems and not just build capability – instituting turnaround time for issue resolution or escalations*

6.2.1.8 Leverage from experience, wisdom and understanding

Figure 3.3 outline of capabilities include – *enterprise learning capability* and *innovation capability* among other objectives of the proposed SEA model. This study uses leveraging from experience, wisdom and understanding as essential input to these capabilities. This is complimentary to the principle of focusing on pragmatic solutions. The lessons learnt and the derived heuristics detailed in appendix H are a cursory guide to what works and what doesn't work and this would not have been possible with the experienced panel that were part of this study. Examples of the lessons learnt as extracted from the expert's responses in the Delphi exercise include (see Appendix H);

- *Assign the right people; People are key*
- *Tailor SE for the value it brings, it is not an end itself*
- *Get and publish learn lessons from each project*
- *Never blindly apply the process always tailor for the specific application*
- *Focus on value to the stakeholder*

But experience without a framework of harnessing the wisdom and knowledge management is wasted experience. Some things that can be done to ensure leverage from experience, wisdom and understanding as inferred from the expert's responses and experience include;

1. *Having scheduled monthly brainstorming seasons with integrated teams.*
2. *Recording and documenting lessons learnt in pre-planned team quarterly sessions.*
3. *Have an easily accessible knowledge management database.*
4. *Incentivise innovation and task* - *execution excellence to encourage employees to make use of the knowledge management infrastructure.*
5. *Engage the seniors and experienced individuals regardless of their positions to work as mentors and offer properly scheduled periodic training to their junior colleges, sanctioned and supervised by top management.*

This study proposes harnessing from the knowledge capital in a well-designed and planned manner.

6.2.1.9 Integrity in decision making, attention to real risk

Decision making can be described generally as a mental process that results in the selection a course of action among several options. This statement implies that to make a choice there must be clearly defined objectives or a guiding criterion. This also implies that to evaluate against this criterion or standard there must be alternatives. In practise consequences of the alternatives need to be evaluated in an organised fashion for the decision maker to make a call. This is involves *trade-off* and *risk management* studies which weighs the risks, the pros and cons, and the impacts of the alternatives, refer to figure 6.2. If this is linked to figure 3.3 – desired *Typical Capabilities* of the proposed model, this principle falls under the *strategic* and *managerial* capabilities which drive the *operational* capabilities and subsequent capabilities. As explained in section 2.2.1, the sensitivity of SMEs to wrong decision is more exaggerated as compared to larger enterprises, because the impact of good or poor strategic decisions cascade down the capability train (figure 3.3). It is important that decisions are based on some laid down sound and practical criteria.

6.2.2 How Best Can the *Soft* and *Hard* Systems Approaches be Applied Together?

As shown in table 5.3 and *figure 6.4* below, there was general agreement among the participants on the proportion of the two extremes of the SEA on the generic system life cycle.

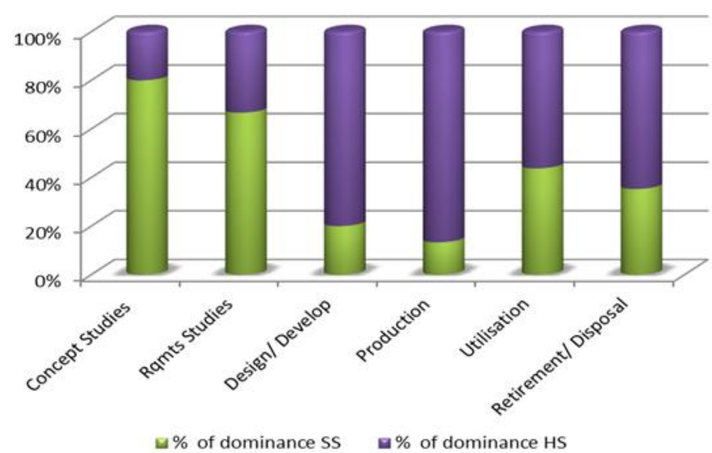


Figure 6.4 *Percentage of Dominance of the Two Extremes of SE*

<u>*Concept Studies and Requirements Analysis Process*</u>*: Soft systems approaches* dominated the front-end processes with level of emphasis decreasing from concept studies to requirements studies (that is from 80% to 66.7% dominance), the balance being the dominance of the *hard systems approaches*. This can be attributed to the level of continuous stakeholder engagement that happens at concept and requirements capture stages to come up with an agreed specification. These two stages are among the slowest and most difficult to fix a time frame as they are driven by several diverse stakeholders, from marketers, specialities to consumers. The key steps for concept studies are *identifying, eliciting, clarifying and documenting the requirements.* The main output of this effort is a concept document which details *the stakeholder requirements, the requirements traceability, the validation criteria, the concept of operation* and *the measures of effectiveness.* The main steps for requirements analysis process studies are *defining the system requirements and analysing and maintaining the systems requirements.* The main output of this effort is a system requirements document which details *the system requirements, the systems requirements traceability, the validation criteria, systems functions* and *the measures of effectiveness.* The systems requirements form the basis of the systems architecture and downstream designs, hence, it must be

agreed, thus, the dominance of the soft approaches to assist in fixing (freezing) the scope of work. It is important that these requirements must be *necessary, implementation dependent, clear and concise, complete, consistent, achievable, traceable, verifiable and be free from superlatives (words like user friendly, good, best…), vague pronouns, ambiguous verbs, open ended non-verifiable terms and other indefinites such as… etc., and so on, (INCOSE, 2011)*

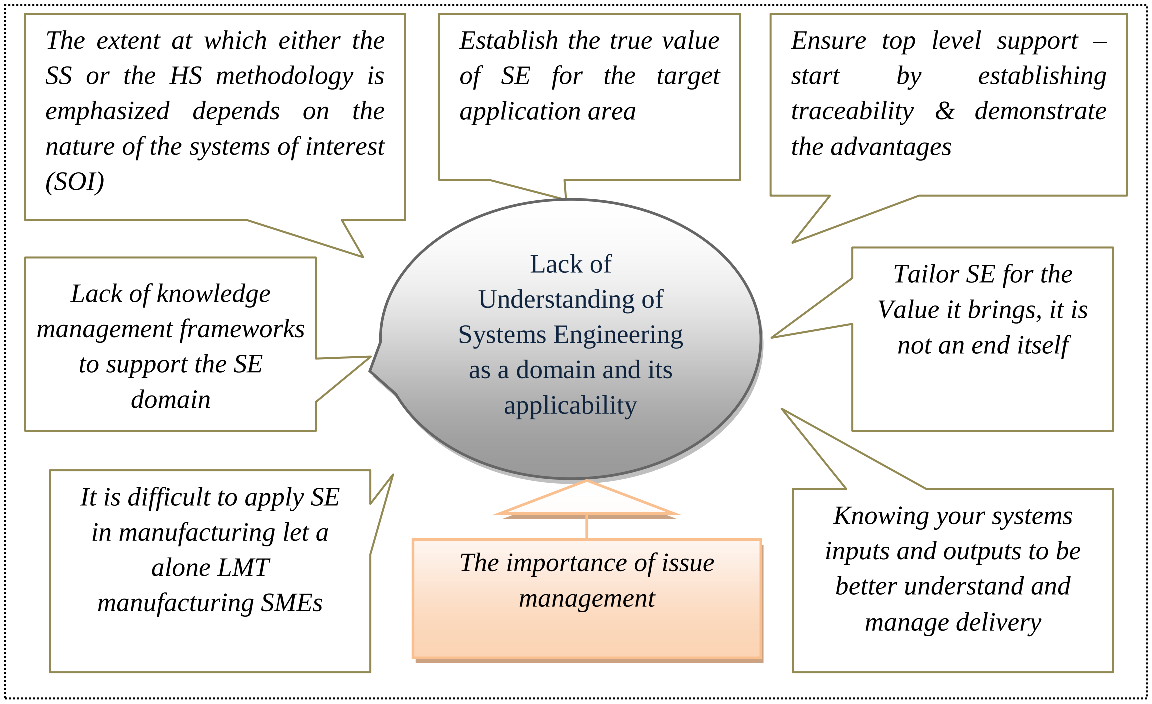
<u>*Design/ Development and Production Processes:*</u> *Hard systems approaches* dominated the develop and production stages with level of emphasis increasing from design / development to production (that is from 80% to 86.7% dominance), the balance being the dominance of the *soft systems approaches*. This can be attributed to fact that once the scope has been fixed the obligation will now be on the development and production teams to deliver as per the agreed deliverables. They will still be interactions at the design and development stage, mostly design review meetings and HAZOPs (20% soft interactions as per the Delphi results). The main outputs from the **design/ development stage** include*; the systems architecture, system element descriptions, the final designs, validation and verification criteria, the interface requirements* and *the system element requirement traceability, system maintenance and retirements plans.* The main outputs from the **production (implementation) stage** include *the product manufactured to spec, product support specification, product quality data* and *as-built specification (drawings, codes, material specification).*

<u>*Utilisation and Retirement stages*</u>*: There was no clear consensus on what which approach* dominated these back-end processes although the majority of the experts preferred the hard approaches to dominate 56.3% to 43.8% for the *soft approach* for utilisation and 64.7% to 35.3% for retirement respectively. This can be explained by the balance which is required in supporting products that is both a *soft* and *hard* approach. *Soft* is the sense of capturing new requirements and *hard* in designing the utilisation and support systems. *Hard system approaches* are dominant for the *retirement / disposal* stage because fixed specifications have to be designed and implemented to dispose a product within the confines of the law and also successful requirements have to be verified in retirement. The *soft* part is the balance of the continuous interactions that happens with relevant stakeholders to support behaviour, seek relaxations of specifications and identify opportunities for logistical support improvement.

<u>Concluding remarks</u> – the dominance of the two extremes of *system engineering* is useful as a guide to tailor the SE approach but the emphasis depends on the systems of interest (SOI) and the challenges experienced at each stage.

6.2.3 Reflection on the Emerging Themes

Figure 6.5 highlights the emerging issues that evolved as the research progressed. Some of the issues were found to be recurrent concerns from literature and some from the Delphi exercise panelist's response.



(The authors own schematic illustration)

Figure 6.5 *Schematic Representations of the Emerging Issues*

The common threads on all these issues include;

1. *The need to tailor the systems engineering effort to suit the target application area*

2. *They are all related to the things "to watch out or plan for" when thinking of institutionalising the SEA*

Central to this is *lack of understanding of the SEA as a domain* and the *importance of issue management.* These will be explained further below.

6.2.3.1 Lack of understanding of the SEA as a domain

Is has been shown in the literature reviewed that systems engineering as a discipline is loosely framed and critics of SE have mentioned this as one of its main drawbacks. This lack of clearly defined boundaries of a process that advocates for boundaries and interface management further puts doubt on the domain. The INCOSE SE-handbook V3.2.2 (2011) seems to be written in a way that exercises caution to avoid bias on any extreme side of the systems engineering spectrum (HS or the SS extreme). Probably because the working group responsible for the various editions are aware of the two camps even among experts. The INCOSE SE -handbook is also written in a way that describes the subject of systems engineering around project environment which, in itself, is also limits the application of SE and amplifies the confusion. In South Africa a study to assess the SE knowledge in industry revealed that *systems engineering was a fairly new field even though many understood the basic concepts of SE they were uncertain of the actual functions of SE . There was also evidence that skills shortage in SE existed,* (Surju, 2009)

This lack of understanding and training can also be attributed to the myth that SE is only suited for large enterprises with *complex* (in this case meaning - advanced) technology. It has been shown thus far that the anchoring nine (9) principles of the SEA approach can essentially be adopted by any organisation of any size and *complexity* only differing in tailoring the level of detail or emphasis or the SEA process activities.

6.2.3.2 Importance of issue (risk) management

Issue management which can be argued to be a subset of risk management is one of the key points that the study emerged in this study and was prioritised as a useful way to curb and better manage problems. The premise being that problems have a life cycle, just like the *life cycle of a mosquito* and similarly to address them sustainably and in time you need to intervene at the 'right' stage. For the purposes of this study an issue (*matured issue*) will be described as unsettled matter which is formally recorded. Figure 6.6 below illustrates the development and different maturing levels of an issue. The issue starts as a simple mismatch in understanding or failure to detect a defect or any other *unsettled matter* – there it will be classified as a *potential issue (mismatch).* If it is not addressed, settled or detected for correction and communicated at this stage it degenerates as a function of time, depending on the system in question, to a level 2 issue which is a concern (an emerging issue). Here stakeholders start talking about the issue although not formally but the presence of the issue is more amplified. If no effective intervention takes place here the issue further develops to be a fully *matured issue* (which is a level-1 problem). Level-1 problems have the potential impact negatively in operations. If again the problem/ issue is left unresolved in the subsequent stages, the problem develops further in complexity, into a level two (2), three (3) and four (4) in that fashion.

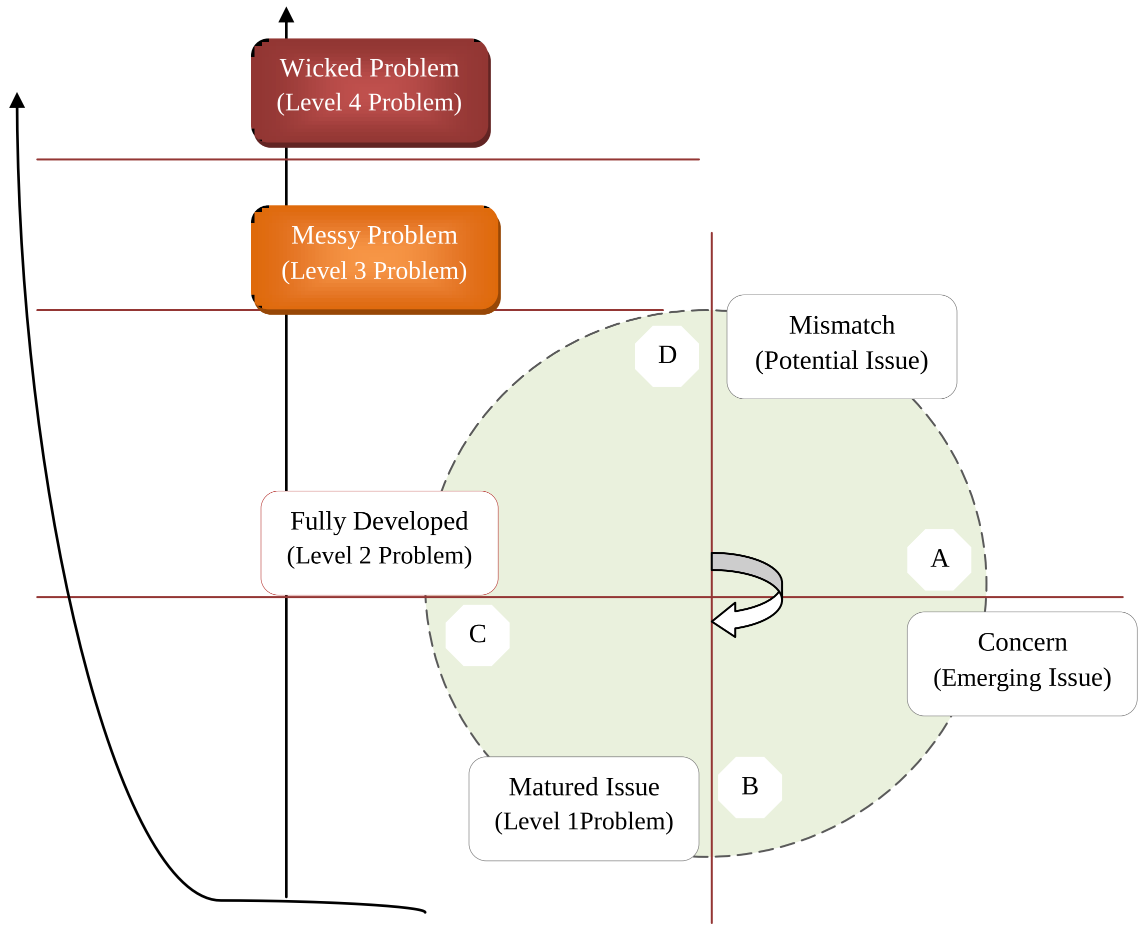


Figure 6.6 *The life cycle of an Issue*

Messy problems are defined as situations in which there are large differences of opinion about the problem or even on the question of whether there is a problem (Ackoff, 1971). As stated in the literature review – *messy problems* are ill-structured and ill-defined problems. A *wicked problem* is that which is difficult or impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognize (Churchman, 1968). If a problem is left to these levels it can either be disastrous or require high-level attention with resource consuming interventions like lengthy collaborations based on *soft approaches* with the aim only to find a better compromise. The other option is to intervene in such a scenario in an authoritative manner. For the purposes of this study – problems in quadrants A, B and C in *figure 6.6* above can be addressed at the plant management level while those in quadrant D and the *messy problems* require those with the veto power to start of stop the manufacturing process. The *wicked problems* signal a crisis; hence they require all stakeholders to engage with an aim of a compromise. As inferred from expert advice and experience fundamentals that should be instituted in a manufacturing SME to curb the spiral degeneration of issues include simple mechanisms like;

- Issue register
- Suggestions boxes
- Weekly issues team talks
- Change control processes
- Integrated all inclusive issue management committee which validates and tracks issues
- Recording and formulating action plans with due dates on the issues

The fact that *issue management* looks into the future, captures and tracks issues that may affect the organisation makes it intersect with the risk management which is an integral part of the SEA as shown in figure 6.2.

A Summary Reflection on the Research Questions

Sub-questions 1:

▪ *What constitutes a Hybrid Systems Engineering Approach?*

What constitutes the SEA has been explored. The nine (9) key SEA elements were explained in relation to their applicability in a manufacturing SMEs context. The emphasis of elements of both *hard* and *soft* approaches in a typical manufacturing SME was shown and discussed as distilled form the expert opinion. The emerging SEA issues were also discussed and their fit in the manufacturing SMEs explained. It can thus be argued that the research sub-question 1 has been answered.

Sub-questions 2:

▪ *What SEA activities have potential of giving the greatest value in a typical manufacturing LMT - SME?*

Sixty Five (65) *SEA process activities* were prioritised by the experts and are outlined in section 5.3.3.1 in the results chapter. Seven (7) *enterprise enabling processes* and twelve (12) *agreement processes* were also prioritised. This gives a total of eighty-four (84) SEA process activities. It can be assumed and argued that, if all these activities are carried out in the targeted manufacturing SME, they will assist in meeting the *contextual*, *technical* and *business* needs, which is essentially the basis of realisation of successful systems in the SOI.

Of these sixty five (65) process activities 11 were identified as those that have the greatest impact in the targeted SMEs. These include the following activities – *develop a solid enterprise strategy and create and vision; understand stakeholder context and therefore Requirements*; *developing a marketing strategy; managing and developing skills; developing a quality assurance plan; design and its related design reviews; capturing and or eliciting the requirements; carrying out the requirements analysis; developing the issue/ problem management system and developing the production plan.* These have been reflected on in the earlier sections of the results chapter (*figure 5.10*). These 11 (elven) activities were critical anchors of the proposed SEA implementation framework.

<u>Sub-questions 3:</u>

What are the Challenges of Implementing the SEA in a LMT manufacturing SME?

The challenges presented in section 5.4.3.1 were categorised into seven (7) statements:

a) **Perception Issues**: This refers to the thinking that the SEA is not practical in *non-traditional* application areas but only in its traditional targets like aerospace and defence. There is a, '*this also shall pass'* syndrome in many organisations when it comes to major paradigm shift projects.

b) **Lack of Tailoring:** Too much emphasis on process over results, resulting in a documentation overkill thereby alienating the neutrals.

c) **Commitment Issues:** This occurs where SE is compromised by lack of leadership support and therefore not enough resources (time and money) are devoted to the SE effort.

d) **Lack of knowledge or Skill**: This is not surprising for a domain in its infancy but the problem is easily exaggerated by poor management and thereof lack of sound training and skills development structures within the company. This also fuels the problem of unrealistic expectations.

e) **Little Focus on People:** Failure to involve people early and continuously and get their buy-in but expect people to comply and perform SE can be problematic for a process that is people driven like the *systems engineering approach*.

f) **Failure to Plan for Change:** *Failure to plan is a plan to fail'* (Anon, 1999). This is common everyday slogan for most planning and change management managers. Planning is essential to better manage the risks associated with the launching, growth and stabilisation phases of any project.

g) **Poor understanding of the Problem domain:** This has resulted in several failures of systems engineering and perpetuated the perception that SE is not practical in non-high technology or non-aerospace or defence industries (the traditional application areas).

Overcoming these Challenges and the Critical Success Factors:

Several factors were identified as critical to the successful implementation and sustainability of the SEA. These include;

1) Develop a SE vision and mission
2) Secure commitment from top management for the launch and communicate the decision.
3) Early involvement of all stakeholders including employees, suppliers, clients and contractors.
4) Secure buy-in by outlining the gap between the current and the wanted state and generate a plan to bridge the gap.
5) Framing the SEA for the value it brings, not to justify its existence. Tailoring for the specific application.
6) Assign adequate resources: that is the right people (skilled/ experience/ knowledgeable), otherwise outsource the project champion.
7) Start with a pilot implementation in one department and analyse the results for the full launch
8) Avoid framing the SEA effort as a '*silver bullet'* but focus on creating a *mark* in the enterprise and measure that difference (that small *delta*) as selling point to roll-out the SEA company-wide.
9) Train, educate and up-skill continuously to ensure all teams understand the processes and the essence of the SEA
10) Employee systems engineering champions with the relevant domain experience
11) Find the right incentive mix to launch a sustainable SEA approach. People need incentives to do it.

6.2.4 *SEA implementation Enablers*

It is important that the systems engineering enablers presented in *figure 5.13* under the results chapter be reflected upon when framing and launching the systems engineering approach. The most important enabler's are *executive support*, *adequate resources, appropriate skills, a good business proposition* and *an environment encouraging multi-disciplinary teams.* The other enablers presented in figure 5.15 are implied by these core enablers. Their purpose of these core enablers is to provide the resources and infrastructure necessary to support the SEA implementation and sustainability.

6.3 Insights from Discussion

The effort spent to provide structure to the systems engineering approach, distil its key elements and gather the experiences of the experts allowed the basis for which the implementation framework was developed. As noted in the literature review there is evidence of studies that proved the importance of *systems engineering* as a systems integrator and as a field with high value. Scholars like Honour (2002); Kasser (2007); Hitchins (2007); Boehm (2008) and Valerdi (2011) have demonstrated that systems engineering can be framed and tailored for specific application and the value of the effort quantified. The tailoring aspect has been shown from the output of the Delphi exercise which produced 65 process activities; prioritised 11 as critical and managed to reach consensus on the dominance of emphasis of both *soft* and *hard* systems approaches on the LMT manufacturing SMEs' life cycle. (Boehm, Valerdi and Honour, 2008) have managed to draw inferences in models of costing the value of the SE effort in software projects. The researcher believes their efforts can be benchmarked for future studies to measure the systems engineering efforts in SMEs.

The following are some of the insights from the discussion of the results:

1. Visibility on *what constitutes* the SE was exposed although there is still disagreement as to what is systems engineering. It is suggested that efforts should not be put on seeking a *'silver bullet'* definition as this will divert research and application/ adoption efforts to further develop a domain still in its infancy which on the other hand has consensus on the value it brings. The study managed to explain why there is this disagreement. It is recommended that future studies should rather focus on the value of systems engineering.
2. An explanation of the holistic and iterative nature of the systems engineering approach was shown. It is recommended that the proportion of emphasis of the tailored approach be situational although the study has shown a guide to percentage of the emphasis. It is also recommended that future specific models to be built in manufacturing SMEs be based on the tailored process activities.

3. The study has also shown that a hybrid (elements of both *soft* and *hard*) systems engineering) is possible. It is recommended that the benefits of both extremes of SE be explored in building implementation frameworks.
4. The Role of SE as an integrator which drives issue resolution was shown. Because the SE spans disciplines and functional areas, by design it captures issues and ensures that they are addressed at the right levels and within acceptable time. This issue management capability constraints the potential of issues to mutate or grow as shown in figure 6.6.
5. It was shown by consensus of the Delphi experts that domain experience, people focus and skill is critical for a sustainable systems engineering effort. Lessons learnt and challenges summarised in section 5.4.3 should be reflected on to increase the chances of adoption on the SEA.
6. A road of institutionalising of systems engineering can be framed. Change has to be planned. The next chapter focuses on building this road map to answer the forth secondary objective of the research: *make recommendations by developing a roadmap of institutionalizing the developed SEA in low to medium technology (LMT) manufacturing SMEs.*

6.4 Chapter Summary

The intention of the Delphi exercise was to extract expert wisdom and knowledge to establish the practicality of framing a hybrid systems engineering approach for application in a typical LMT manufacturing SME. This chapter explained the meaning of the results. The Delphi technique was successful as front-end instrument to get input to build the conceptual implementation framework presented in the next chapter.

Chapter 7 – Implementation Framework

"Society is always taken by surprise at any new example of common sense"

Ralph Waldo Emerson

This chapter gives a high-level view of the conceptual framework for implementing the SEA approach in LMT manufacturing SMEs. The main purpose is to package the relevant elements and applicable methods for ease of institutionalisation and launch, designed for sustainability (a 'living' systems engineering approach). This chapter serves a useful guide not as a prescription because no two systems are identical.

7.1 *Managing the* Change

It should be noted that SEA implementation should be treated as a project and therefore a project management methodology should be used. If follows the launch of the SEA approach should not only have a *SE – champion* but also a project manager. This means that all the fundamentals of launching a project must be in place. This includes the *project charter; the work breakdown structure (WBS); the project management plan and its subsidiary plans –; the quality assurance plan; the risk management plan; the communication plan; the change management plan* and *the human resources plan with its organogram for the project team.* To implement, sustainably, the proposed SEA model in manufacturing SMEs, it is important that a cursory reflection on some aspects of the change management process be done.

7.1.1 *The Iceberg Effect*

One important and relevant aspect to look out for is the *Iceberg effect*. Just like an iceberg where two thirds is underwater, systems engineer and project manager should not be blinkered to consider only the general metrics or issues concerning *cost, time* and *quality* (the triple project management constraints) in their campaign to institutionalise the SEA. There are other critical *human activity system* related aspects that if not considered can either derail or halt the whole campaign. These are illustrated in figure 7.1 below. Questions that starts with *what, where, who when, how* should be asked for each the items below the water surface.

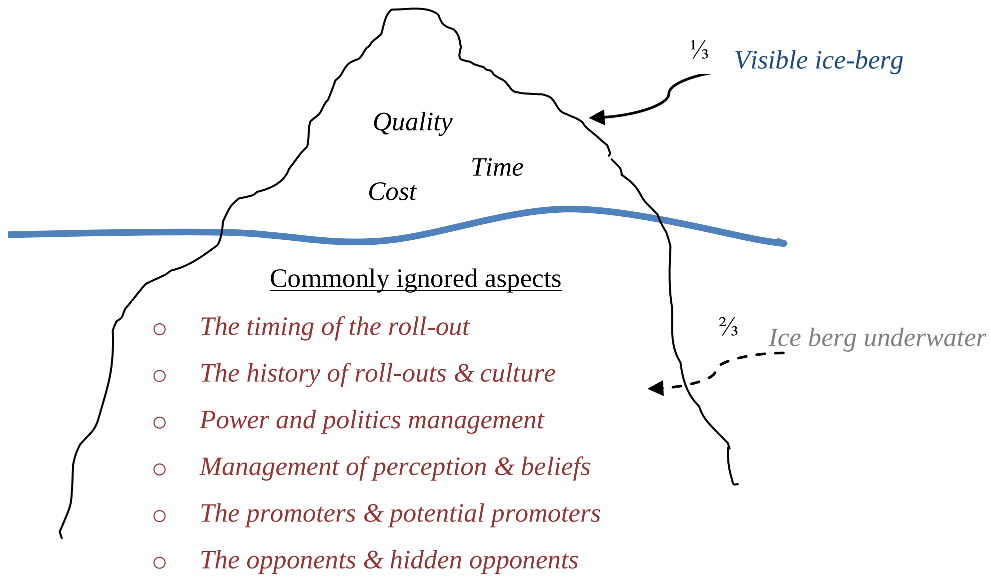


Figure 7.1 *Illustration of the Ice-berg Effect in Managing Change*

7.2 Requirements of the Conceptual Model

The requirements of the model are a combination of the elements presented in *section 4.1.1; figure 3.3 and elements outlined in section 3.6.1*. These elements have been explained in *chapter 3, 4* and *6* of this report. Figure 7.2 below, shows the relationship between the seven (7) *desired capabilities* presented in figure 3.3; *the implications of SME characteristics* presented in 3.6.1 and the model purpose presented in section 4.1.1.

Figure 7.3 shows the conceptual framework of the proposed SEA approach. The process starts with a desired goal to *deliver sustainable value to the customer using the SEA*. The framework shows **Gap-1,** which is the difference between what is desired for optimum performance and what is delivered to the customer from the current capabilities. **Gap-2** is that extra value perceived to be embedded in the systems engineering approach that delights the customer. The 7 - desired capabilities referred to above are the focal points of the SEA principles distilled form the Delphi study feedback. Figure 7.4 show the launching reference model simplified for the targeted SMEs. It is essentially a truncated version of figure 7.3

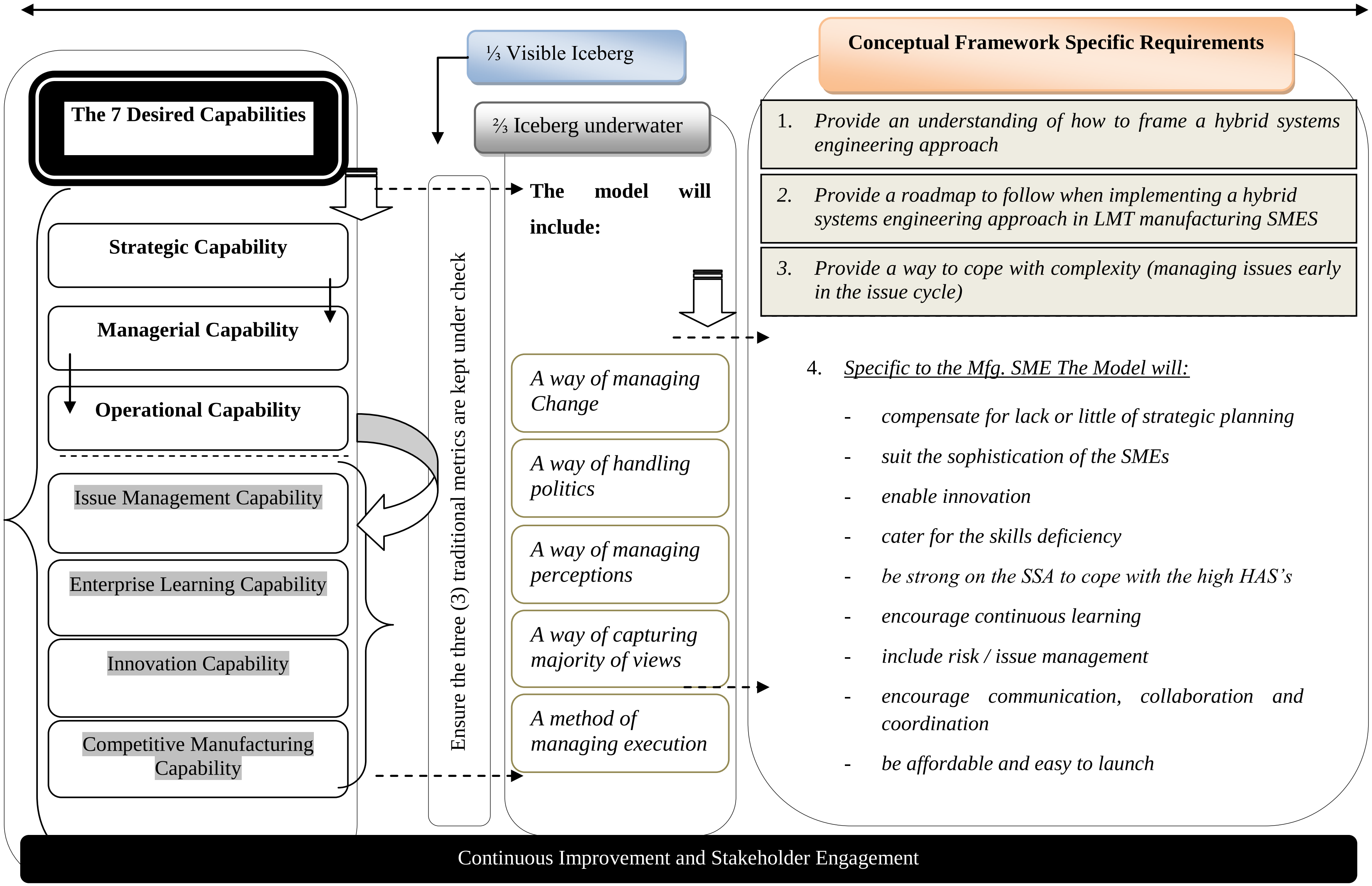


***Figure 7.2** SEA Frameworks - Model Requirements Overview*

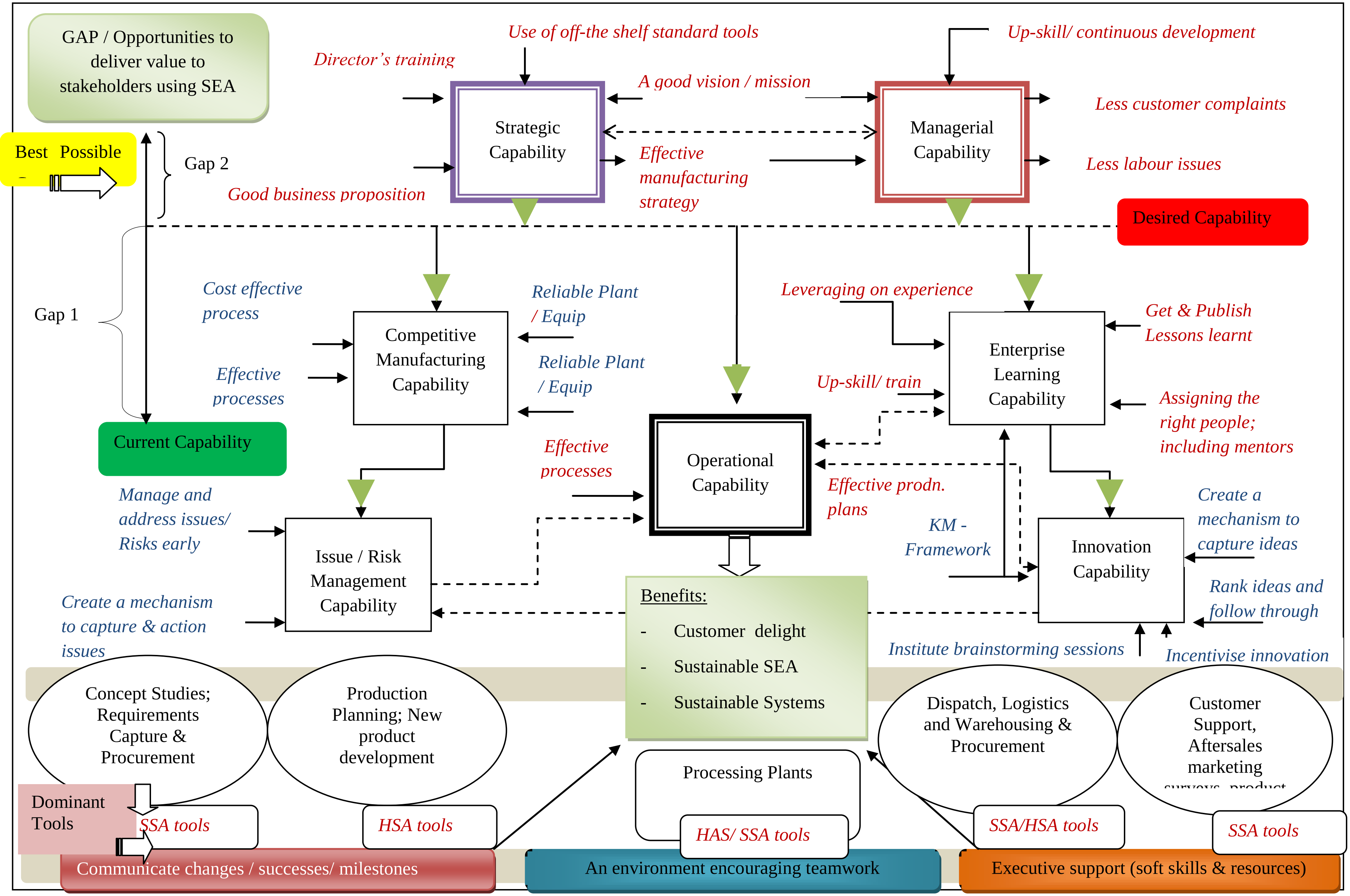


Figure 7.3 *Conceptual Model of the SEA Implementation on each SOI (1 of 2)*

The presented capabilities work each as sub-system for the chosen SOI in the target manufacturing SME; as such sub-optimisation will not bring the desired results. There is need to find the balance to optimise the seven (7) capabilities in an incremental manner to move first towards the desired and finally to customer delight stage. The simplified application framework for ease of adoption in SMEs is shown below in figure 7.4.

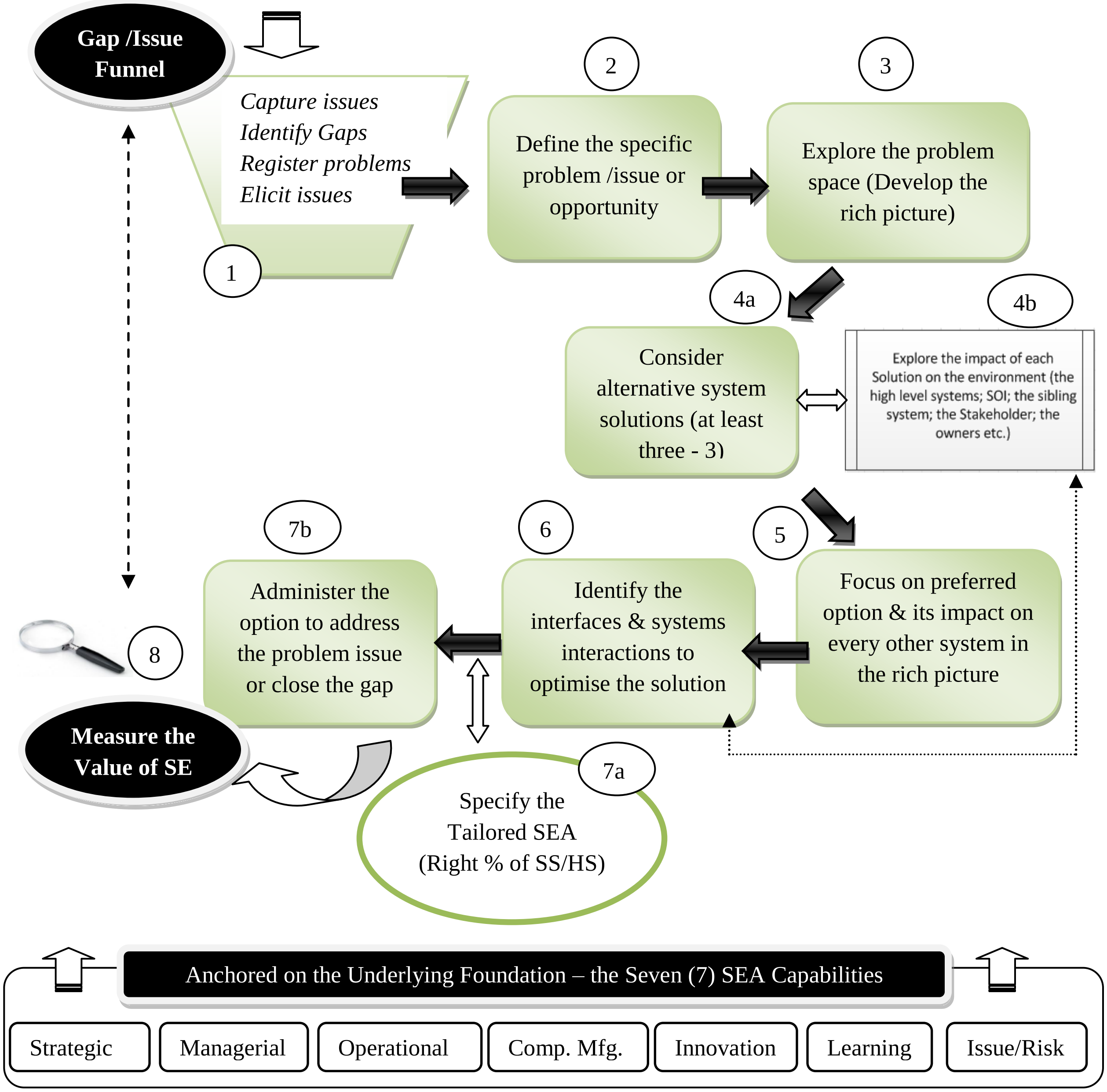


Figure 7.4 *Truncated 8 Step Conceptual Model of the SEA Implementation in a Typical SME*

7.3 Key Model Steps

As hinted by the experts in the Delphi exercise, it is often argued to that the number of objects an average human can hold in working memory is 7 ± 2 (Miller, n.d.). This commonly referred to as Millers Law will hold as a guide for the model design. The model implementation steps are;

1. **Stage 1 –** Preparing to fulfil the vision/ goal / objectives
    - *Concept studies*
    - *Bankable feasibility study*
    - *Stakeholder analysis*
2. **Stage 2 –** Preparing for change management
    - *Develop change management plan*
    - *Prepare change management team*
    - *Diagnose gaps and manage resistance*
3. **Stage 3 –** Pre to launch the SE approach
    - *Train employees and up skill management*
    - *Campaign, market the SEA and the resultant continuous value adding it brings*
    - *Develop the implementation final master plan*
4. **Stage 4 –** Launch pilot SEA in a small department or section (like – procurement or engineering)
5. **Stage 5 –** Monitor and evaluate performance – over at least a year (document lessons learnt)
6. **Stage 6 –** Review the SEA approach and the related benefits and make a call to roll-out

Figure 7.3 attempts to show how these steps fit the bigger picture. The arrows in the diagram represents interconnectivity of the tasks, implying the proposed steps need not be applied in a step by step (go – no go) manner but rather via progressive iterations moving forward. The suggested mix of use of *hard* and *soft* approaches serves as a guide the actual mix depends on the SOI of interest needs.

Figure 7.5 below shows how the SEA will be launched using an external expert. Once established the plant team will then follow the guide lines of the truncated model presented in figure 7.4

Model Implementation Overview

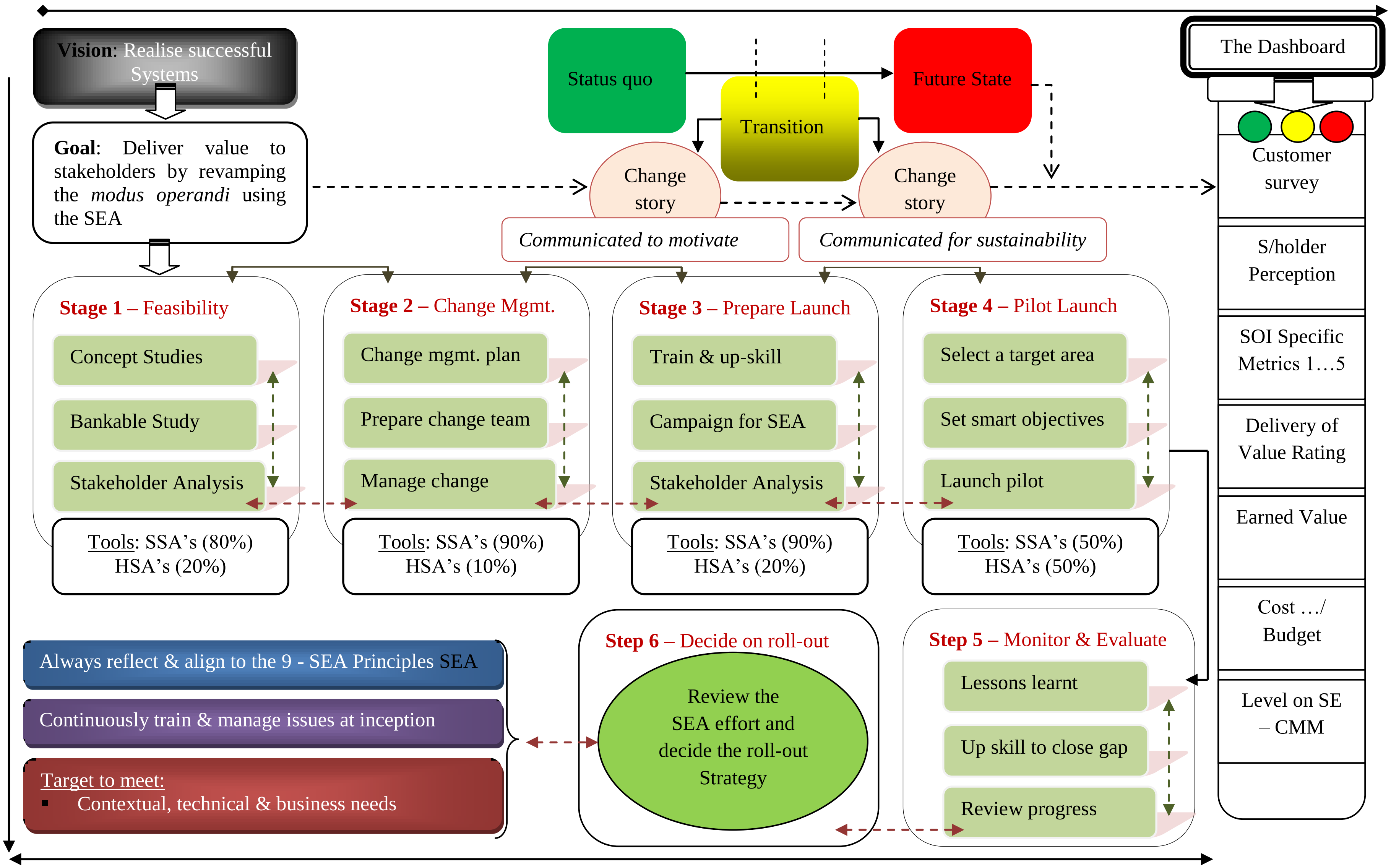


***Figure 7.5** Model Implementation Overview (2 of 2)*

7.4 Performance Monitoring

A strategy for measurement of how the systems engineering approach effort will form part of the proposed SEA model developed for manufacturing SMEs. The generic metrics for example; *increased in productivity, plant reliability, plant availability and overall equipment effectiveness* will not be discussed in this section. What will be shown is the high-level SEA effort maturity framework over time. The commonly used guide is the SE-CMM (Systems Engineering Capability Maturity Model), which describes the evolutionary improvement path from ad-hoc, chaotic processed to a mature disciplined process. The table is read starting from below (Level 1) upwards.

Table 7.1: SEA_ Capability Maturity Model (SEA_CMM)

Level	Focus	Process Area	Overall Perception on SEA
Level 5 (Optimising)	*Continuous Improvement*	- Continuously improve through (zero defects, zero customer complains, zero machine breakdowns)	Full buy-in and adoption. Work is easy because of less issues
Level 4 (Managed)	*Quantitative Management*	- Comprehensive SE measurements including external process audits and accreditations	More encouraging as small wins are seen
Level 3 (Defined)	*Process Standardisation*	- Following strictly the 84 Process activities for SE as prioritised by the Delphi exercise. - Using standard SE templates	Neutral but concerns with “too much documentation”
Level 2 (Repeatable)	*Basic Systems Engineering Process*	- Concept development - Stakeholder requirements analysis - Routine risk assessments	Not good - “necessary, too much paperwork”
Level 1 (Initial)	*Stabilisation of the environment*	- Work processes and systems are more of ad-hoc	Bad – (wait and see attitude)

7.5 Chapter Summary

This chapter has shown that it is possible to combined elements of both hard and soft systems for application in a specific environment. The model steps developed together with the frameworks were culminations of integrating and synthesising elements of the SEA approach from literature and feedback form the Delphi participants. The next chapter concludes the study and provides some recommendations.

Chapter 8 – Conclusion and Recommendations

"Sometimes when I consider what tremendous consequences that comes from little things,
I am tempted to think… there are no little things"

Bruce Barton

This chapter presented the conclusion to the research including the final evaluation of the research objectives which were met. It also outlines recommendations for future research.

8.1 Conclusions

The primary objective of this study was to develop a SEA model that can be used in less conventional application areas such as in SMEs. The premise of this objective was that the systems engineering approaches have been widely used; benefits well documented and visible in high-tech systems such as weaponry, aerospace and nuclear power plants yet its application in other industries have been very limited (Sage and Armstrong, 2000; Hitchins, 2007). This limited application has been explained to be primarily because SE as a domain is still in evolutionary stages and the absence of a clear guide for to apply systems engineering in non-conventional high systems.

This research was aimed to cover that gap, targeting manufacturing SMEs. Manufacturing SMEs are known for their significant contribution to the gross domestic product (GDP) of many developing countries. In South Africa they contribute 51 – 57% of the GDP yet they are marred with several unstructured problems they seem not to understand, (Kongolo, 2010). This research proposed to use the SEA approach (a hybrid of soft and hard systems methodology) as a tool to better understand, address and manage specific problems in SMEs.

To meet this primary objective the study used the Delphi technique as the primary research instrument complemented by and in-depth review or related literature. To structure the study to manageable levels three (3) secondary objectives were generated from this primary objective:

The first secondary objective was

1. *Study the systems engineering literature and distil the underlying structure or key elements of the approach common across industries.*

An extensive literature review was done which split the literature review chapter into (5) sections, starting with *an overview of systems engineering as subject* followed *by a high-level analysis of the SSM*; *a high-level analysis of the HSM; comparison of the soft and hard systems (the hybrid approach)* and finally *contextualised the study by reflecting on the issues of the manufacturing SMEs.* The literature review showed that the underlying principles of SE span across industries and makes it possible to be tailored regardless of complexity or sophistication of the target implementation area. Regarding the context – the targeted SMEs literature revealed that several strategies to intervene in SMEs are essentially scaled down frameworks meant for large enterprises (LEs). There is also no follow up on the failures of these interventions. *The SEA approach proposed tailoring* rather than simply reducing down in size (scaling down). Tailoring is about looking at each individual element or issues and proposing a way of handling it.

2. *Develop a hybrid (soft and hard) systems engineering conceptual framework applicable to the medium technology manufacturing SMEs.*

   The hybrid systems engineering approach framework specific to the SME environment was developed in *chapter 3* (Model conceptualisation) starting with an overview of the hybrid systems engineering model (figure 3.1) followed by use of Checkland *soft systems method*ology stages 1 and 2 to understand the issues and problems in SMEs. This allowed the generation of the desired capabilities (figure 3.3) for the implementation framework presented in chapter 7. The typical systems in manufacturing SMEs were shown in figure 3.4 and the typical roadmap to validate the model in figure 3.5

3. *Validate the developed model via the Delphi process by bringing together existing but fragmented expert knowledge in an interactive process and re-engineering the developed model as necessary*

   Expert knowledge and experience was extracted via two- round Delphi process. First a pilot round commonly called round 0 was done to test the questionnaire and get expert advice as to the content and design of the questionnaire. The Delphi technique was found very useful as it connected geographically dispersed experts in providing insight in not-so-well understood subject of systems engineering. Acceptable consensus as per the set criteria of a 67% majority was reached in the majority of categories. Of significance is the consensus on the hybrid SEA processes applicable to manufacturing SMEs that is the SEA 84 processes activities outlined in chapter 4.

4. *Make recommendations by developing a roadmap of institutionalising the developed SEA in LMT manufacturing SMES*

The proposed frameworks in chapter 7 (figures 7.4 and 7.5) were presented to be adopted by manufacturing SMEs. It is proposed though that SEA launch be taken as project to ensure all project management activities which include *stakeholder management, change management, human resources management, integration management, quality scope and time management* is part of the launch to ensure its sustainability.

8.2 Implications to SE Application research

This study is a good starting point for institutionalising the SEA in non-conventional application areas. It also contributes in way to structuring the understanding of the applicability of the two extremes of systems engineering (harnessing the strengths of both worlds) – the *hard* and *softs systems*.

8.3 Recommendations for Future Work

The research concentrated on the overview of the SE field and structuring a hybrid systems engineering approach few areas that require further study include;

1. Examining the impact of the actual launch and the true value of the SEA in the target application area.
2. Establishing what can be deduced from institutionalising SEA where they are already sound supporting systems like RCM, TQM or TPM.
3. Based on the results provided, the conclusions cannot be generalised beyond the manufacturing SMEs' context. A replication study should therefore be conducted in SMEs in other sectors. This means expanding the research by building frameworks for applying the right mix of SE principles in for example - local government structures – municipalities; mining SMEs and agriculture SMEs

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APPENDICES

Appendix A: The Delphi Process Questionnaire Pack

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Appendix A*:* The Delphi Exercise _ Questionnaire Pack

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Appendix A1 – *Delphi Exercise Introductory Letter*

**"TOWARDS A SUSTAINABLE FRAMEWORK
FOR APPLICATION OF THE SYSTEMS ENGINEERING APPROACH (SEA)
IN NON-TRADITIONAL IMPLEMENTATION AREAS"**

Aug 15, 2012

Dear Sir/ Madam

We are writing to ask for your assistance with a study we are conducting focusing on the application of the Systems Engineering Approach in less traditional application areas in particular in manufacturing SMEs. More specifically the purpose of this research is to tailor the *hybrid* systems engineering approach (*elements of both 'hard' and 'soft' systems*) approach in order to provide a useful framework to address specific problems in manufacturing SMEs.

This research is employing the Delphi technique as the primary methodology to assist in developing the desired SE framework tailored for the SMEs. This method uses a consensus building approach among individuals referred to as experts – that is with recognized experience and advanced knowledge in a particular subject area. Please regard this letter as an invitation to participate in this research exercise in your capacity as a subject area expert. The study will be conducted utilizing two Delphi rounds over the next two months. After the first round we will send you a summary of your input and that of the other participants, along with the final round's questionnaire to answer.

Thank you for taking time to read this letter please follow the link for the online questionnaire or see attached for the soft copy for you to fill in your spare time. Please note we expect to have your feedback by 18 September 2012, the sooner the better. We recognise that you have many demands on your time; we however hope you will give just a small bit of your time to help expand the badly needed Systems Engineering Body of Knowledge (SE-BoK) to other industries.

We look forward to hearing from you. Should you need more information please feel free to contact the undersigned preferably the researcher directly.

Sincerely,

Mr. Thabani Mudavanhu Researcher: *MSc. Candidate*	**Ms. Bernadette Sunjka** Advisor (Post grad Coordinator)
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Appendix A2 – *Delphi Exercise Questionnaire*

Appendix A3 – *Delphi Exercise Typical Responses (R1) and R2)*

Appendix A4 – *List of Participating Experts*

expert # Used in Study	Name of Expert	City / Country	Experience (years) and Affiliation	Title
Expert 1	*Dr Cecilia Haskins (CSEP)*	*Trondheim - Norway*	*35 years INCOSE*	*Post Doc Researcher*
Expert 2	*Dr Mark Holton*	*Johannesburg – South Africa*	*25 years WITs University*	*Independent consultant*
Expert 3	*Dr Brian White*	*Sudbury, MA – USA*	*8 years Independent Cons.*	*Principal Consultant*
Expert 4	*Mr David Long*	*Blacksburg, VA – USA*	*20 years INCOSE, ViTech*	*President*
Expert 5	*Mr David Walden (ESEP)*	*Minneapolis, MU – USA*	*29 years INCOSE*	*Principal Consultant*
Expert 6	*Ms Carel van der Merwe*	*Capetown – South Africa*	*25 years SKA*	*Systems Engineer*
Expert 7	*Dr Gerrit Vilgeon*	*Centurion – South Africa*	*25 years CSIR, Denel Dyna.*	*Chief Design Engineer*
Expert 8	*Dr L. Erasmus*	*Pretoria – South Africa*	*19 years, INCOSE University of PTA*	*Senior Lecturer*
Expert 9	*Ms Suja Joseph M*	*Johannesburg – South Africa*	*6 years , CSIR INCOSE*	*Senior Engineer*
Expert 10	*Ray Jenkins*	*Johannesburg – South Africa*	*25 years , REUTECH Solutions*	*Design/ Systems Engineer*
Expert 11	*Daniel Malherbe*	*Stellenbosch CT – South Africa*	*5 years , Letter 27, INCOSE*	*Executive Officer*
Expert 12	*Rudolph Louw*	*Johannesburg – South Africa*	*20 years , Transnet – SE Centre, Wits*	*Head of Centre*
Expert 13	*Barry Myburgh*	*Johannesburg – South Africa*	*28 years , Insyte – Wits and UJ*	*MD – Principal Consultant*
Expert 14	*Prof Barry Dwolatzky*	*Johannesburg – South Africa*	*35 years , JCSE and Wits*	*Director*
Expert 15	*Alwyn Smit*	*Cape Town – South Africa*	*15 years , CSIR*	*Systems Engineer*

NB. List generated based on the date and time of receipt of responses

Other External Advisors

1. ***Prof Richard Bawden*** *- Prof Emeritus – University of Western Sydney – Australia; University of Michigan - USA ; Director and Fellow – Systemic Development Institute, Australia (exp:40)*
2. ***Prof Graham Winch****: Professor Emeritus in Business Analysis, University of Plymouth Affiliate Professor, ESC - Rennes Business School (exp:35*

   Continued (next page)…
3. ***Prof Ricardo Valerdi:*** *He is in the Systems & Industrial Engineering Department at the University of Arizona. Dr. Valerdi is a two-time recipient of the Best Thesis Advisor Award in the MIT Technology & Policy Program, the Best Article of the Year Awards in the Systems Engineering Journal and Defence Acquisition Journal (exp:35).*

Total Experience *– 430 years of SE experience (18 Experts)*

Appendix B*:* Summary of the History of the Systems Engineering Approach

Period	**Highlight**	**Development / Focus**	***Outcome***	**Impact on the subject**
Early 1940s	*A new approach (essentially -Hard Systems)*	Advent of SE (*Bell labs*)	*A new approach – untested*	Not known
1940s-1950s	*World War 2* *Rand Co. founded (1946)*	Application of SE *(essentially Hard Systems*).	*Accelerated understanding. The Rand Co. - Invention of Systems Analysis*	+; Good
1954	*GS Theory Team was formed*	Development of a multi-disciplinary General Systems Theory	*Failed early attempt to frame systems engineering as subject*	-/+ Good as a basis for future work
1950s- 1960s	*Apollo program*	Complete systems developed to go to the moon and back	*Successful mission to the moon* **SA is developed*	+; Good
1970s- 1990s	*Too much focus on Hard Systems Approach*	Linear mechanistic business management approach	*Failure to cope with high human activity systems resulting in unsustainable systems*	- ; Bad (*core ideas of SE subverted)*
1981	*Checkland SSM Monograph published based on work by mainly Russell Ackoff and C. West Churchman*	Increased focus on the whole and interrelationships with other systems. The focus moved to *general object oriented* unlike the specific equations	*Increased understanding of human activity systems and specification of sustainable solutions or approaches to problem solving*	+; Good, (*Turning point*)

Appendix C: Summary of Activities that make-up the SE Process

Step *Description*	**Activities / Processes** *Outline*	**SE Effort:** *Some of the Outputs:*
Understanding Needs & Problem space	- Identifying stakeholders - Workshops to get perceptions of the need - Identifying the systems and subsystems - Identifying the types of systems (SoS, CxS, CAS, etc.) - Defining the needs and operational context	a. *Needs matrix* b. *Systems map* c. *Stakeholders matrix*
Define Problem & Requirements	- Stating the problem - Quantifying the problem - Identifying the alterables and the major constraints - Outlining the main system systems - Documentation of requirements	a. *Problem Statement* b. *Project charter* *c. Rich picture* *d. Requirements documentation*
Issue Analysis	- Evaluation of the feasibility of the requirements - Investigating Alternatives - System optimisation - Preliminary concept design - Develop issue register	a. *Requirements documentation* b. *Change Requests* c. *Concept document* d. *Acceptable deliverables*
System Architecture	- Architecting - Logical design - Functional analysis - Prototyping the desired system, product models	a. *System, Architecture* b. *Logic diagrams* c. *Prototype*
Decision Making	- Design Reviews - Decide to bid or to go ahead with project	a. *Proposal* b. *Source Selection*
Planning for action	- Preliminary project plan (high level) - Project Management Plan - Preliminary Cost estimate - Prepare preliminary SEMP	a. *Draft project plan* b. *Draft SEMP* c. *Rough order-of-magnitude cost estimate (class 3- ACE)*
Program Planning	- Program planning Workshops - Prepare the SEMP *(**NB**. SEMP is the description of the fully integrated effort)*	a. *Project Mgmt. plan* b. *Program schedule* c. *Risk Management Plan* d. *Budget forecast* e. *Working SEMP*

Project Planning	- Project planning Workshops - Prepare Communication Plan - Prepare schedules - Prepare UAT (testing) plans, Adoption plans , etc.	*a. Project scope* *b. Program schedule* *c. Communication plan* d. *Project Budget*
System Design	- Modelling the System - Technical Analysis & Evaluation - Integrating the System/s (manage interfaces) - Verification and Validation - Prepare the detailed architecture - Prepare detailed drawings / bill of materials	a. *Final drawings* b. *Construction drawings* c. *Detailed architecture* d. *Bill of Materials*
Production / Construction	- Build the system/s - Configuration management - Data/ knowledge management	a. *Desired system*
Decision Making	- Design reviews - Seek approvals to continue - Decide to freeze the launch the system - Re-evaluate capacity / Decide to continue / modify etc.	*a. Blue-print* *b. Tactical plans* *c. Strategic plans*
Planning for action	- Prepare implementation / deployment/ handover plan - Stakeholder Management - Migration/ deployment plan finalisation	a. *Execution reference documents / plan* b. *Final SEMP*
Launch System (operation & disposal)	- Change management - Distribution functions (marketing, sales etc.) - Project management	a. *System Migrated (to* ***resolve****,* ***dissolve*** *or* ***solve*** *a problem/ issue*
Assess Performance (Audit / Verification)	- Conduct reviews - Evaluate the systems with the pre-built test plans - Conduct customer satisfaction surveys	a. Audit report for - *negative feedback* so as assure a sustainable solution b. Lessons learnt
Re-evaluation & Retirement	- Continuously iteration targeting the *best possible system*	❖ A systems that satisfies present and future needs of the stakeholders

Appendix D: Application of the Soft System Methodology

Where			How was it applied	Some remarks
Country/ Industry		***Company***		
USA **High-Tech Chip Manufacturing**		*Intel*	*Used a front end tool for a subsequent hard methodology – systems analysis to design and manufacturing of chips. Aim: to improve utilisation of their development and manufacturing resources*	(Stavrakis, 2005). Outcome: *Form understanding the system a new framework was put in place for continuous improvement and new technologies*
India	Retail	*Generic study*	*Applied Stages 1 – 4 of the SSM in service environments physical surroundings at service delivery site which included malls and standalone retail shops. The aim was to understand and deal holistically with the strategic issues of designing, improving, and managing the physical service environments for these places.*	Siddiqui & Tripathi (2005). Outcome: *A conceptual framework to be used as basis to provoke debate and find the gaps on application*
UK	Hospitality	*Faraway Hotel*	*SSM (stages 1 to 7) was applied with aim to understand the complexity of the business and therefore encourage the owner of the hotel to think more objectively about improving the business*	Ingram (2000). Outcome: *Was found useful in ensuring the hotelier does not lose the "big picture "and recommended for modelling hotel operations as a basis of reviewing strategy.*
Coastal Zones of South Asia	Environmental Studies	*EU Environment arm*	*A 4 year study used the full 7- stage SSM to manage costal resources to reduce impacts of natural hazards on the vulnerable communities. The objectives were 1) to improve understanding of mangrove ecosystems, communities and conflicts; 2) to develop knowledge-based approaches; 3) to reconcile the multi-demands on mangrove and adjacent coastal zones.*	The EU Sixth Framework Program – Mangrove (2005). Outcome: *Could not be established*
New	Services	*XY*	*SSM was used to identify competence*	(Brocklesby, 1995)

Zealand	Industry (Recruitment Companies)	*Recruitment*	*requirements in a Human Resource Management company – XY. (A case specific to the recruitment of project managers). The competence profile in question aims to define the set of skills attitudes and knowledge which contribute to effective job performance, (Brocklesby, 1995)*	Outcome: *SSM produce information superior to that obtained through conventional methods. Of note was the addition of a range of softer relationship building competencies for the project managers.*

Other applications found in the reviewed literature include application of SSM in

- ❖ Construction project management
    - "*A Soft Approach to Solving Hard problems in construction Project Management",* (Walker et al, 2003)
    - *"Providing Structural Openness to Connect with Context – seeing the project entity as a human activity system and social process"* (Walker & Small, 2011)

- ❖ A basis for understanding knowledge management and as a tool to innovate sustainable practises
    - "SSM as a Method for Conceptualising the UK construction Industry Knowledge Environment", (Venter et al, 2004)

- ❖ Addressing academic challenges
    - "A Systems Approach to Education in the Secondary Sector ", - A UK case study (Richardson, 1999)

Applications of SS continued – next page…

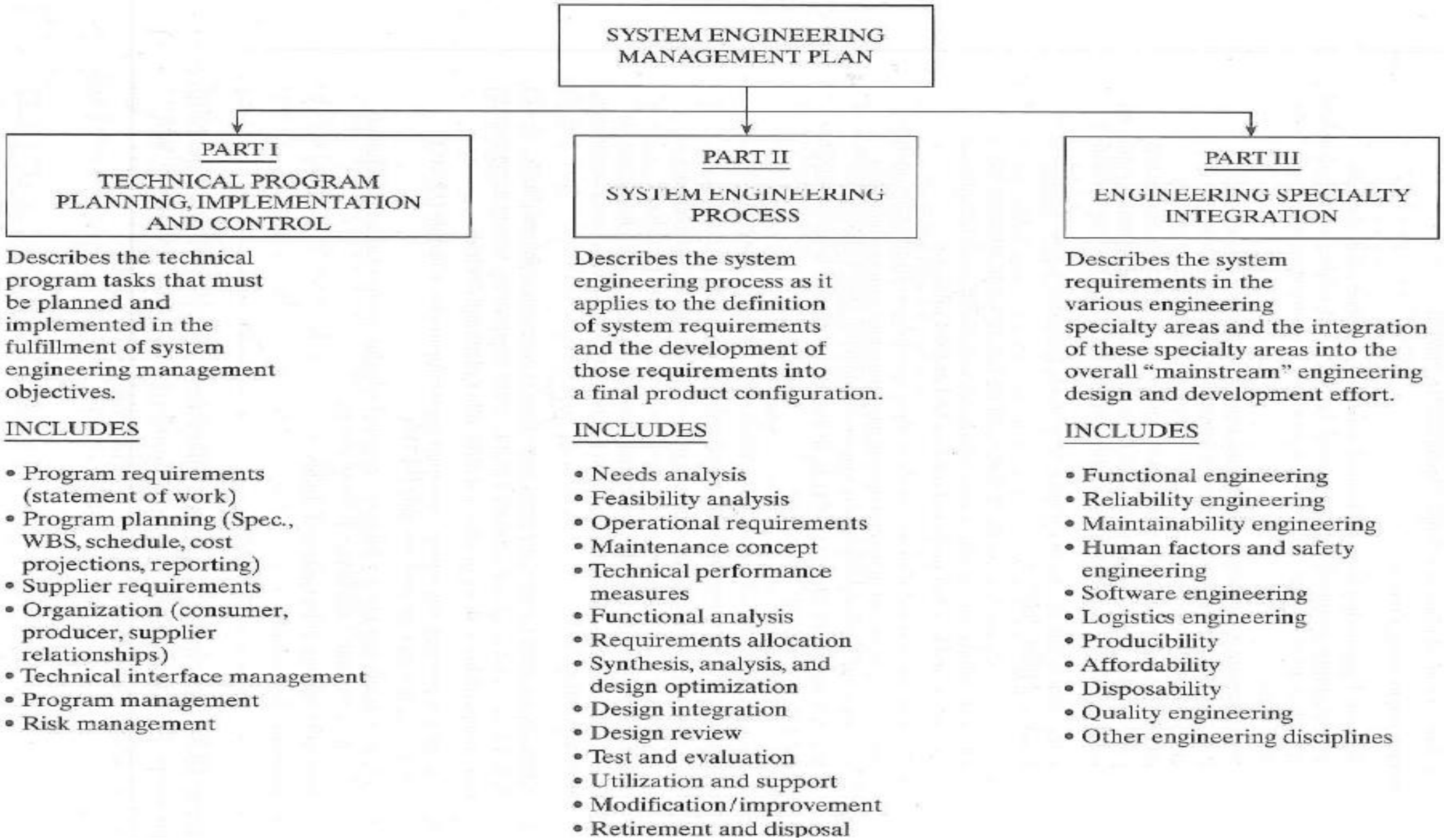
- ❖ Enterprise Business Process Re-engineering
    - "Transforming the Enterprise Using the Systems Approach", - A USA case study (Martin, 2011)
- ❖ Addressing challenges in government institutions

"Systems Thinking application in Municipalities", - A UK case (Brown & Lerch,

Concluding Note:

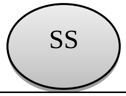
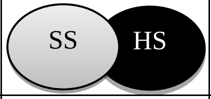
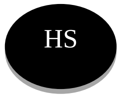
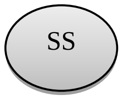
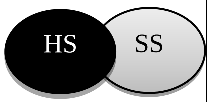
SSM has also been applied in addressing and understanding hospital operations as well as terrorist activities among its various application

Appendix E: The Full SEMP Generic Approach



(Fabrycky and Blanchard, 2006 p.31)

Appendix F: Mapping the different hybrid approaches

	Dominate methodology	**Flood & Jackson's Total Systems Intervention,** (Daellenbach, 2004)	**Walker's Framework,** (Walker et al, 2002)	**Lake's Model,** (Walker et al, 2002) as applied in a city council case
1		*Creativity phase*: identification of the dominant and dependent issues	System description through stakeholder participation	Awareness/ Engagement which transforms expressed views into shared understanding
2		*Choice phase*: identification of the main system based methodology for the dominant issues	Scenario planning: identification of possible future trajectories of the system	Vision / Leading: which transform desired options
3			Quantitative analysis of the system	Research and evaluation
4			Participatory & integrated assessment of policy management implication	Service delivery – option development
5		*Implementation phase:* Use other support methodology to bring about change		Service delivery

Appendix G: Analysis of Delphi Exercise Responses:

- **Appendix G1** – *Responses to Theoretical Question 1*
- **Appendix G2** – *Responses to Theoretical Question 2*
- **Appendix G3** – *Responses to Theoretical Question 3*

Appendix G1 – *Responses to Theoretical Question 1*

APPENDIX G1 - Theoretical <u>Question # 1:</u> *What constitutes a Systems Engineering Approach (SEA)?*

Expert's Responses	<u>Sub Question 1a&b:</u> Comment on the definition of the SEA	<u>Sub Question # 2:</u> List the important SEA principles: (The list contains only important and very important plus the additional. The additional (+) and very important principles as suggested by the expert are all in bold)	<u>Sub Question # 3 a & b:</u> Comment on the definitions of, HSA and SSA	<u>Sub Question # 3c:</u> How can the HS and SS approaches be applied?
<u>Expert # 1</u>	✓ *<u>Agrees</u> with the presented definition.*	✓ *Understanding the whole (holistic thinking)* - *Manage stakeholder perception (world-view)* - *Know the systems out-put and inputs* ✓ *Appreciate that systems are dynamically interrelated* - *Focus on realising complete solutions – what & how?* - *Leverage on the multi-disciplinary approach* - *Focus on delivering quality systems that meet needs* ____ + *Integrity in decision making, attention to real risk* + *Flexibility to adjust to changing landscapes in the lifecycle*	*<u>Agrees</u> with the presented definitions.* *<u>Remarks</u> – " these appear to be the generally held definitions"*	× *<u>Do not agree</u> with the sequential emphasis of the HS and SS approaches in the project life cycle.* *<u>Suggestion / Comment:</u>* *" I am a fan of agile approaches that blend both Hard and Soft in I iterative increments over time"*
<u>Expert # 2</u>	✓ *<u>Agrees</u> with the presented definition in principle.* *<u>Remarks</u> – " Holistic solutions should also include bottom up engagement of operations people (as in lean thinking)"*	✓ *Understanding the whole (holistic thinking)* ✓ *Manage stakeholder perception (world-view)* ✓ *Know the systems out-put and inputs* - *Appreciate the existence of emergence properties* ✓ *Appreciate that systems are dynamically interrelated* ✓ *Focus on realising complete solutions – what & how?* ✓ *Leverage on the multi-disciplinary approach* ✓ *Focus on delivering quality systems that meet needs* ____ + *… none*	*<u>Agrees</u> with the presented definitions.* *<u>Remarks on the SSM</u> – " Engineering people and their tacit knowledge is important as engineering explicit (hard) processes and technologies "*	✓ *<u>Agrees partially</u> with the sequential emphasis of the HS and SS approaches in the project life cycle.* *<u>Suggestion / Comment:</u>* *" HS and SS approaches cannot be separated in the same way that people cannot be separated from technologies and systems processes"*

Continued … page 2 of 8 (Experts 3 & 4): **Theoretical Question # 1:** *What constitutes a Systems Engineering Approach (SEA)?*

Expert's Responses	Sub Question # 1a&b: 1. Comment on the definition of the SEA	Sub Question # 2: 2. List the important SEA principles: (The list contains only important and very important plus the additional. The additional (+) and very important principles as suggested by the expert are all in bold)	Sub Question # 3 a & b: 3. Comment on the definitions of, HSA and SSA	Sub Question # 3c: 4. How can the HS and SS approaches be applied?
Expert # 3	× *Disagrees with the presented definition.* *Remarks – " …this does not work well in complex (people) environments where one is not in control and cannot pre-specify or predict outcomes)"*	✓ *Understanding the whole (holistic thinking)* ✓ *Manage stakeholder perception (world-view)* - *Know the systems out-put and inputs* ✓ *Appreciate the existence of emergence properties* ✓ *Appreciate that systems are dynamically interrelated* ~~✓ *Focus on realising complete solutions – what & how?*~~ ✓ *Leverage on the multi-disciplinary approach* ✓ *Focus on delivering quality systems that meet needs* + *Bring humility to the problem Humility* + *Focus on Self-Organization for bottom-up solutions*	✓ *Agrees with the presented definitions.* *Remarks on SSA & HAS respectively– "Yes these are imperative; …Politics Operations, Economics and Technical (POET)"* *HSA: "Works only in well in stable environments where one is in control"*	✓ *Agrees partially with the sequential emphasis of the HS & SS* *Suggestion / Comment: " More Yes than No – Focus on SS and use HS only when you are in control which is rarely the case in complex systems engineering"*
Expert # 4	- *Neutral view on the presented definition in principle.* *Remarks: "Captures interdisciplinary perspective but not systems perspective (vs. component) stated (incorrectly) as process centric. Focus must remain on delivery of business value of SOI*	✓ *Understanding the whole (holistic thinking)* ✓ *Manage stakeholder perception (world-view)* ✓ *Know the systems out-put and inputs* ✓ *Appreciate the existence of emergence properties* ✓ *Appreciate that systems are dynamically interrelated* ✓ *Focus on realising complete solutions – what & how?* ✓ *Leverage on the multi-disciplinary approach* ✓ *Focus on delivering quality systems that meet needs* + *… none*	✓ *Agrees fundamentally with the presented definitions.* *Remarks on the SSA – " …but we don't stop at understating, we intervene to make positive inputs, stop negative ones "* *HSA: " Agreed nothing to add"*	✓ *Agrees to a greater extent with the sequential emphasizes of the HS and SS* *Suggestion / Comment: " In the main process, I understand you are not excluding SS, but SS could be dominant depending upon the nature of the system of interest"*

Continued … page 3 of 8 (Experts 5 & 6): **Theoretical Question # 1:** *What constitutes a Systems Engineering Approach (SEA)?*

Expert's Responses	Sub Question # 1a&b: 1. Comment on the definition of the SEA	Sub Question # 2: 2. List the important SEA principles: (The list contains only important and very important plus the additional. The additional (+) and very important principles as suggested by the expert are all in bold)	Sub Question # 3 a & b: 3. Comment on the definitions of, HSA and SSA	Sub Question # 3c: 4. How can the HS and SS approaches be applied?
Expert # 5	✓ *Agrees with the presented definition in principle.* Remarks – *" Not necessarily top down in all cases"*	✓ *Understanding the whole (holistic thinking)* ✓ *Manage stakeholder perception (world-view)* ✓ *Know the systems out-put and inputs* ✓ *Appreciate the existence of emergence properties* ✓ *Appreciate that systems are dynamically interrelated* ✓ *Focus on realising complete solutions – what & how?* ✓ *Leverage on the multi-disciplinary approach* ✓ *Focus on delivering quality systems that meet needs* + *Manage interconnections* + *Preform balanced trades at the systems level*	✓ *Agrees to an extent with the presented definitions.* *Remarks on SSA & HAS respectively– "Yes – would add socio technical and political)" HSA: "Partially – end is not always known – but is typically achievable"*	✓ *Agrees with the sequential emphasis of the HS and SS* *Suggestion / Comment:* *" But the mix is key"*
Expert # 6	✓ *Agrees with the presented definition in principle.* Remarks – *"part of SE process is bottom up such as system integration and during operational deployment … rather use holistic and remove 'top down'."*	✓ *Understanding the whole (holistic thinking)* ✓ *Manage stakeholder perception (world-view)* ✓ *Know the systems out-put and inputs* ✓ *Appreciate the existence of emergence properties* ✓ *Appreciate that systems are dynamically interrelated* ✓ *Focus on realising complete solutions – what & how?* ~~✓ *Leverage on the multi-disciplinary approach*~~ ~~✓ *Focus on delivering quality systems that meet needs*~~ + *Delivering sustainable systems*	✓ *Agrees fundamentally with the presented definitions.* *Remarks on SSA & HAS respectively– "Agree – messy system also includes the non-core (PME) systems such as support & ancillary systems. HSA: "also tend to focus on prime mission equip – the HS"*	✓ *Agrees with the sequential emphasizes of the HS and SS* *Suggestion / Comment:* *"One issue to take into account is the created system vs. the creating system". Even during the main process the key is people.*

Continued … page 4 of 8 (Experts 7 & 8): **Theoretical** **<u>Question # 1:</u>** *What constitutes a Systems Engineering Approach (SEA)?*

Expert's Responses	<u>Sub Question # 1a&b:</u> 1. Comment on the definition of the SEA	<u>Sub Question # 2:</u> 2. List the important SEA principles: (The list contains only important and very important plus the additional. The additional (+) and <u>very important</u> principles as suggested by the expert are all in bold)	<u>Sub Question # 3 a & b:</u> 3. Comment on the definitions of, HSA and SSA	<u>Sub Question # 3c:</u> 4. How can the HS and SS approaches be applied?
<u>Expert # 7</u>	✓ *<u>Agrees</u> with the presented definition in principle.* *<u>Remarks</u> – " I would drop the word sustainable as it is not true in general. Whole may be replaced with holistic"*	✓ *Understanding the whole (holistic thinking)* ✓ *Manage stakeholder perception (world-view)* ✓ *Know the systems out-put and inputs* ✓ *Appreciate the existence of emergence properties* ✓ *Appreciate that systems are dynamically interrelated* ✓ *Focus on realising complete solutions – what & how?* ✓ *Leverage on the multi-disciplinary approach* ✓ *Focus on delivering quality systems that meet needs* ____ + *Understand that the output of the SE process is specifications*	✓ *<u>Agrees</u> to an extent with the presented definitions.* *<u>Remarks on SSA & HAS respectively</u>– "Agree – SSA are used where the metrics are difficult and subjective". HSA: "Agree – … HSA can only work if you can measure and control all aspects of the system in an accurate and repeatable manner"*	✓ *<u>Disagrees</u> with the sequential emphasis of the HS and SS* *<u>Suggestion / Comment:</u> "Market studies may benefit form a more soft approach, but concept development should be a hard approach for a manufacturing SME. This may be different in other markets like financial markets but don't think so"*
<u>Expert # 8</u>	✓ *<u>Strongly Disagrees</u>* *<u>Remarks</u> – "SEA is a structured and transparent inter-disciplinary framework to structure engineering activity based on extensive experience informed by processed that enable sustainable whole solutions …."*	✓ *Understanding the whole (holistic thinking)* ~~✓ *Manage stakeholder perception (world-view)*~~ ✓ *Know the systems out-put and inputs* ✓ *Appreciate the existence of emergence properties* ✓ *Appreciate that systems are dynamically interrelated* ✓ *Focus on realising complete solutions – what & how?* ✓ *Leverage on the multi-disciplinary approach* ✓ *Focus on delivering quality systems that meet needs* ____ + *Practitioners own experience and understanding* + *Focus on pragmatic approach and solutions*	✓ *<u>Agrees fundamentally</u>* *<u>Remarks on SSA & HAS respectively</u>– "The prime objective is to understand how to influence such systems. It is also aims at detecting weak signals for early assessments for the effect on the system". HSA: "Agree"*	✓ *<u>Disagrees</u> with the sequential emphasis of the HS and SS* *<u>Suggestion / Comment:</u> "The backend processes are hard systems with HSAs, for improvement … one follows a similar pattern of SSAs for the front end. The operations of any firm must be predictable to make the stakeholders happy".*

Continued … page 5 of 8 (Experts 9 & 10): **Theoretical Question # 1:** *What constitutes a Systems Engineering Approach (SEA)?*

Expert's Responses	Sub Question # 1a&b: 1. Comment on the definition of the SEA	Sub Question # 2: 2. List the important SEA principles: (The list contains only important and very important plus the additional. The additional (+) and very important principles as suggested by the expert are all in bold)	Sub Question # 3 a & b: 3. Comment on the definitions of, HSA and SSA	Sub Question # 3c: 4. How can the HS and SS approaches be applied?
Expert # 9	✓ *Agrees with the presented definition* *Remarks – "SE … even though appearing to operate at a higher level of abstraction, is still design … it is both a technical and management process"*	✓ *Understanding the whole (holistic thinking)* ✓ *Manage stakeholder perception (world-view)* ✓ *Know the systems out-put and inputs* ✓ *Appreciate the existence of emergence properties* ✓ *Appreciate that systems are dynamically interrelated* ✓ *Focus on realising complete solutions – what & how?* ✓ *Leverage on the multi-disciplinary approach* ✓ *Focus on delivering quality systems that meet needs* ______ + *Design the technical development strategy which is part of the SEMP*	✓ *Agrees with the definitions.* *Remarks on SSA & HAS respectively– "Perhaps say 'messy' or poorly defined and the outcome is better understanding and learning… mostly used to improve …problems" HSA: "Yes– … technical factors of the problem is rather important here"*	✓ *Disagrees with the sequential emphasis of the HS and SS* *Suggestion / Comment: "In the back end, the intention is to design the utilisation and supports systems, so there is a definite end goal in mind therefore HAS are more appropriate - dominant" SSA may be used to understand …"*
Expert # 10	✓ *Disagrees with the given definition* *Remarks – "a basic ingredient of the SEA is the management of engineering baselines i.e. the acceptance of a formal baseline before we can proceed to the next process. This definition does not include this"*	✓ *Understanding the whole (holistic thinking)* ✓ *Manage stakeholder perception (world-view)* ✓ *Know the systems out-put and inputs* ~~✓ *Appreciate the existence of emergence properties*~~ ✓ *Appreciate that systems are dynamically interrelated* ✓ *Focus on realising complete solutions – what & how?* ✓ *Leverage on the multi-disciplinary approach* ✓ *Focus on delivering quality systems that meet needs* ______ + *Baseline management – moving incrementally from approved baseline to baseline management*	✓ *Agrees with the definitions.* *Remarks on SSA & HAS respectively– "Agree – e.g. in Software Development processes were the users are not really sure of what they want…" HSA: " I agree … the outcome is evaluated against the specifications"*	✓ *Disagrees with the sequential emphasis of the HS and SS* *Suggestion / Comment: "The utilisation and support of a system including disposal utilises the HSA. Logistic support & disposal specifications are developed on which the support system & disposal systems are designed".*

Continued … page 6 of 8 (Experts 11 & 12): **Theoretical <u>Question # 1:</u>** *What constitutes a Systems Engineering Approach (SEA)?*

Expert's Responses	<u>Sub Question # 1a&b:</u> 5. Comment on the definition of the SEA	<u>Sub Question # 2:</u> 6. List the important SEA principles: (The list contains only important and very important plus the additional. The additional (+) and <u>very important</u> principles as suggested by the expert are all in bold)	<u>Sub Question # 3 a & b:</u> 7. Comment on the definitions of, HSA and SSA	<u>Sub Question # 3c:</u> 8. How can the HS and SS approaches be applied?
<u>Expert # 11</u>	✓ *<u>Neutral view of the definition</u>* *<u>Remarks</u> – "it is not necessarily top-down or also middle-out, it is not a framework but more of an approach – with a number of methodologies and frameworks that can be tailored … "*	✓ *Understanding the whole (holistic thinking)* ✓ *Manage stakeholder perception (world-view)* ✓ *Know the systems out-put and inputs* ✓ *Appreciate the existence of emergence properties* ✓ *Appreciate that systems are dynamically interrelated* ✓ *Focus on realising complete solutions – what & how?* ✓ *Leverage on the multi-disciplinary approach* ✓ *Focus on delivering quality systems that meet needs* ________________________________ + *Advances telescopic thinking* + *Enforces rigour, increasing meticulousness* + *The process validates all of the above principles*	✓ *<u>Agrees? (</u>Yes and No)* *<u>Remarks on</u> SSA & HAS <u>respectively</u>– "Yes people but not limited to. SSAs should refer to fail-safe experimentation that seeks new solutions" HSA: ""Don't agree… HSAs refer to the SE rigour & and not to analysis per se.""*	✓ *<u>Disagrees</u> with the sequential emphasis of the HS and SS* *<u>Suggestion / Comment:</u>*
<u>Expert # 12</u>	✓ *<u>Disagrees</u> with the presented definition* *<u>Remarks</u> – "…requires discussion"*	✓ *Understanding the whole (holistic thinking)* ✓ *Manage stakeholder perception (world-view)* ✓ *Know the systems out-put and inputs* ✓ *Appreciate the existence of emergence properties* ✓ *Appreciate that systems are dynamically interrelated* ✓ *Focus on realising complete solutions – what & how?* ✓ *Leverage on the multi-disciplinary approach* ✓ *Focus on delivering quality systems that meet needs* ________________________________ + *… none*	✓ *<u>Agrees</u> with the definitions.* *<u>Remarks on</u> SSA & HAS <u>respectively</u>– "Correct but not necessarily complete…" HSA: "Agreed with the exception of always having well defined boundaries."*	✓ *<u>Disagrees</u> with the sequential emphasis* *<u>Suggestion / Comment:</u>* *"The two apply concurrently throughout the product lifecycle – dominance … in each phase depends on the particular challenges of the phase and not necessarily on the specific phase "*

Continued … page 7 of 8 (Experts 13 & 14): **Theoretical Question # 1:** *What constitutes a Systems Engineering Approach (SEA)?*

Expert's Responses	Sub Question # 1a&b: 9. Comment on the definition of the SEA	Sub Question # 2: 10. List the important SEA principles: (The list contains only important and very important plus the additional. The additional (+) and very important principles as suggested by the expert are all in bold)	Sub Question # 3 a & b: 11. Comment on the definitions of, HSA and SSA	Sub Question # 3c: 12. How can the HS and SS approaches be applied?
Expert # 13	✓ *Disagrees with the given definition* *Remarks – "agile systems approach can be a bottom-up approach…"*	✓ *Understanding the whole (holistic thinking)* ✓ *Manage stakeholder perception (world-view)* ✓ *Know the systems out-put and inputs* ✓ *Appreciate the existence of emergence properties* ✓ *Appreciate that systems are dynamically interrelated* ✓ *Focus on realising complete solutions – what & how?* ✓ *Leverage on the multi-disciplinary approach* ✓ *Focus on delivering quality systems that meet needs* ____________________ + *Adopt a situational approach to systems engineering*	✓ *Agrees with the definitions.* *Remarks on SSA & HAS respectively– "SSA are essential when the system to be delivered involves People; Process and Technology" HSA: "are appropriate when the system to be delivered is system to be delivered is mainly about Product – (including turnkey solutions)".*	✓ *Disagrees with the sequential emphasizes of the HS and SS* *Suggestion / Comment: "… as explained in (a) and (b), it depends on the system to be delivered. Hence different approaches for different systems (Situational)*
Expert # 14	✓ *Agrees with the given definition* *Remarks – "none"*	✓ *Understanding the whole (holistic thinking)* ✓ *Manage stakeholder perception (world-view)* ✓ *Know the systems out-put and inputs* ✓ *Appreciate the existence of emergence properties* ✓ *Appreciate that systems are dynamically interrelated* ✓ *Focus on realising complete solutions – what & how?* ✓ *Leverage on the multi-disciplinary approach* ✓ *Focus on delivering quality systems that meet needs* ____________________ + *… none*	✓ *Agrees with the definitions.* *Remarks on SSA & HAS respectively–* *SSA: "Agree – yes"* *HSA: " Agree - yes*	✓ *Agrees with the sequential emphasize of the HS and SS* *Suggestion / Comment:* - *none*

Continued … page 8 of 8 (Experts 15 & 16): **Theoretical** **__Question # 1:__** *What constitutes a Systems Engineering Approach (SEA)?*

Expert's Responses	Sub Question # 1a&b: 1. Comment on the definition of the SEA	Sub Question # 2: 2. List the important SEA principles: (The list contains only important and very important plus the additional. The additional (+) and very important principles as suggested by the expert are all in bold)	Sub Question # 3 a & b: 3. Comment on the definitions of, HSA and SSA	Sub Question # 3c: 4. How can the HS and SS approaches be applied?
Expert # 15	✓ *Neutral with the presented definition* Remarks – *"SE is an approach rather than a framework… SE is ultimately about risk reduction – how to deliver sustainable solutions with acceptable risk "*	✓ *Understanding the whole (holistic thinking)* ✓ *Manage stakeholder perception (world-view)* ✓ *Know the systems out-put and inputs* ✓ *Appreciate the existence of emergence properties* ✓ *Appreciate that systems are dynamically interrelated* ✓ *Focus on realising complete solutions – what & how?* ✓ *Leverage on the multi-disciplinary approach* ✓ *Focus on delivering quality systems that meet needs* ___ + *Understanding the problem that is to be solved*	✓ *Agrees with the definitions.* *Remarks on SSA & HAS respectively*– *SSA: "Agree – yes"* *HSA: " Agree - yes*	✓ *Agrees with the sequential emphasize of the HS and SS* *Suggestion / Comment:* *"Whenever humans form an integrated part of the operation and support of the system , the SSA gives a better means to understand the complexity"*

Appendix G1 – *Responses to Theoretical Question 2*

Theoretical Question # 2: *What SEA activities have the potential of giving the best value in atypical FMCG manufacturing SMEs context?*

1. **What type / kind of systems engineering is more appropriate or should be more dominant at each stage of the generic system life cycle?**

Concept Studies	Rqmts Studies	Design/ Develop	Production	Utilisation & Support	Disposal
"Soft A" ☐	"Soft A" ☐	"Soft A" ☐	"Soft A" ☐	"Soft A" ☐	"Soft A" ☐
"Hard A" ☐	"Hard A" ☐	"Hard A" ☐	"Hard A" ☐	"Hard A" ☐	"Hard A" ☐

SE - Expert	Concept Studies	Rqmts Studies	Design / Develop	Production	Utilisation / Support	Disposal	*Comment*
Expert # 1	*Soft A*	*Soft A*	*Soft A*	*Hard A*	*Hard A*	*Hard A*	*Hard A dominate at end*
Expert # 2	*Soft A*	*Soft A*	*Hard A*	*Hard A*	*Hard A*	*Soft A*	*Soft A dominate at start*
Expert # 3	*Soft A*	*Soft A*	*Hard A*	*Hard A*	*Soft A*	*Both H & S*	*Soft A dominate at start*
Expert # 4	*Soft A*	*Soft A*	*Hard A*	*Hard A*	*Soft A*	*Hard A*	*Soft A dominate at start*
Expert # 5	*Soft A*	*Soft A*	*Hard A*	*Hard A*	*Hard A*	*Hard A*	*Soft A dominate at start*
Expert # 6	*Soft A*	*Soft A*	*Both H & S*	*Both H & S*	*Both H & S*	*Both H & S*	*Soft A dominate at start*
Expert # 7	*Hard A*	*Hard A*	*Hard A*	*Hard A*	*Soft A*	*Soft A*	*Hard A dominate at start*
Expert # 8	*Hard A*	*Soft A*	*Hard A*	*Hard A*	*Hard A*	*Hard A*	*Hard A dominate at end*
Expert # 9	*Both H & S*	*Both H & S*	*Hard A*	*Hard A*	*Hard A*	*Hard A*	*Hard A dominate at end*
Expert # 10	*Soft A*	*Soft A*	*Hard A*	*Hard A*	*Hard A*	*Hard A*	*Hard A dominate at end*
Expert # 11	*Soft A*	*Both H & S*	*Both H & S*	*Both H & S*	*Both H & S*	*Both H & S*	*Mixed dominate*
Expert # 12	-	-	-	-	-	-	*Did not respond on this*
Expert # 13	*Soft A*	*Hard A*	*Hard A*	*Hard A*	*Hard A*	*Hard A*	*Hard A dominate*
Expert # 14	*Soft A*	*Soft A*	*Hard A*	*Hard A*	*Soft A*	*Soft A*	*Soft dominate at extremes*
Expert # 15	*Soft A*	*Hard A*	*Hard A*	*Hard A*	*Soft A*	*Hard A*	*HA - dominate in the middle*
Expert # 16	-	-	-	-	-	-	
Overall Dominance S/H	*12/3 (soft)*	*10/5 (Soft)*	*3/12 (Hard)*	*2/13 (Hard)*	*7/9 (Hard)*	*6/11 (Hard)*	*Pink – shows areas that need more clarity in R#2*

Stage 1 of 11: **Stakeholder Requirements Definition and Concept Development -**

- *The purpose is to explore the problem space and define requirements.*

ID	SE Process Activity expert responses out of 13 panelists who responded to the question	Importance in Traditional SE Application Area						Importance in Manufacturing SMEs					Researcher's Comments
		Irrelevant	Minimal Importance	Some Importance	Important	Very Important		Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Anything = or > than 6/13 in the important and very important columns is considered critical to SMEs context. Or the total of the two = or > 9
1.1	Identify stakeholders			1/13	4/13	8/13				2/13	2/13	9/13	*Critical*
1.2	Capture stakeholder requirements			1/13	4/13	8/13				2/13	2/13	9/13	*Critical*
1.3	Define the needs and operational context			1/13	4/13	8/13				2/13	6/13	5/13	*Critical*
1.4	Define constraints imposed by agreements/ interfaces			1/13	5/13	7/13				2/13	6/13	5/13	*Critical*
1.5	Develop scenarios of viable solutions & the ConOps			1/13	4/13	8/13				4/13	5/13	4/13	*Critical*
1.6	Identify the systems/ sub-sys. interacting with the SOI				7/13	6/13				2/13	5/13	6/13	*Critical*
1.7	Identify problems associated with satisfying the needs			2/13	5/13	6/13				5/13	4/13	6/13	*Critical*
1.8	Establish the critical & desired system performance			2/13		11/13			1/13	3/13	2/13	6/13	*Critical*
1.9	Analyse Rqmts for clarity, completeness & consistency		1/13		5/13	7/13			3/13	2/13	3/13	5/13	
1.10	Negotiate modification to resolve impractical Rqmts			1/13	6/13	6/13			2/13	4/13	5/13	4/13	*Critical*
1.11	Validate, record and maintain stakeholder Rqmts			1/13	4/13	8/13			2/13	3/13	4/13	4/13	
1.12	Establish and maintain traceability			1/13	4/13	8/13			4/13	4/13	2/13	3/13	

Summary of important activities relevant to SMES as informed by expert opinion input:

1. Identify stakeholders
2. Capture stakeholder requirements
3. Define the needs and operational context
4. Define constraints imposed by agreements/ interfaces
5. Identify the systems/ sub-sys. interacting with the SOI
6. Identify problems associated with satisfying the needs
7. Establish the critical & desired system performance

Stage 2 of 11: **Requirements Analysis Process -**

The purpose is to transform the stakeholder – driven view of desired services into a technical view of a required product that could deliver those services.

ID	SE Process Activity expert responses out of 13 panelists who responded to the question	Importance in Traditional SE Application Area						Importance in Manufacturing SMEs					Researcher's Comments
		Irrelevant	Minimal Importance	Some Importance	Important	Very Important		Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Anything = or > than 6/13 in the important and very important columns is considered critical to SMEs context. Or the total of the two = or > 9
2.1	Select the appropriate standards		1/13	1/13	6/13	5/13		1/13	1/13	5/13	3/13	3/13	
2.2	Identify the system boundaries and interfaces			1/13	4/13	8/13				2/13	4/13	7/13	*Critical*
2.3	Define system fns. capabilities & performance goals			1/13	5/13	7/13				3/13	7/13	3/13	*Critical*
2.4	Identify all utilisation, support, disposal & envi. factors			1/13	6/13	6/13			1/13	3/13	3/13	6/13	*Critical*
2.5	State design considerations and identify constraints			2/13	8/13	3/13			2/13	4/13	6/13	1/13	*Critical*
2.6	Define, derive & refine functional/ performance Rqmts			2/13	3/13	8/13				5/13	6/13	2/13	*Critical*
2.7	Develop specification trees	1/13		4/13	2/13	6/13		1/13	5/13	4/13	2/13	1/13	
2.8	Generate the system specification		1/13		5/13	7/13		1/13	3/13	3/13	5/13	2/13	
2.9	Allocate Rqmts & establish traceability		1/13		8/13	4/13		1/13	3/13	2/13	5/13	1/13	
2.10	Define verification criteria			2/13	5/13	6/13			1/13	4/13	5/13	3/13	
2.11	Define system Rqmts verification criteria			1/13	6/13	6/13			2/13	3/13	4/13	4/13	

Summary of important activities relevant to SMEs as informed by expert opinion input:

1. Identify the system boundaries and interfaces
2. Define system functions, capabilities & performance goals
3. Identify all utilisation, support, disposal & environmental factors
4. State design considerations and identify constraints
5. Define, derive & refine functional/ performance Rqmts

Stage 3 of 11: **Architecture Design Process -**

The purpose is to synthesise a solution that satisfies the systems requirements.

ID	SE Process Activity expert responses out of 13 panelists who responded to the question	Importance in Traditional SE Application Area						Importance in Manufacturing SMEs					Researcher's Comments
		Irrelevant	Minimal Importance	Some Importance	Important	Very Important		Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Anything = or > than 6/13 in the important and very important columns is considered critical to SMEs context. Or the total of the two = or > 9
3.1	Define the consistent logical architecture			1/13	6/13	6/13			1/13	5/13	4/13	1/13	
3.2	Define systems functions			1/13	2/13	10/13				1/13	9/13	3/13	*Critical*
3.3	Identify interfaces & interactions between sys. elements			1/13	5/13	7/13				4/13	6/13	3/13	*Critical*
3.4	Define selection criteria			3/13	3/13	7/13				5/13	4/13	4/13	
3.5	Define/ refine system element alternatives			2/13	7/13	4/13				8/13	1/13	4/13	
3.6	Synthesize multiple system architecture		1/13	3/13	4/13	5/13			3/13	5/13	2/13	3/13	
3.7	Analyse & select preferred arch using *trade-off studies*		1/13	1/13	5/13	6/13			2/13	2/13	3/13	6/13	*Critical*
3.8	Model, simulate & prototype system arch.			2/13	5/13	6/13			2/13	4/13	5/13	2/13	
3.9	Define, refine & integrate sys. physical configuration			2/13	4/13	7/13				4/13	5/13	4/13	*Critical*
3.10	Document & maintain the architecture			2/13	6/13	5/13			2/13	4/13	4/13	3/13	

Summary of important activities relevant to SMEs as informed by expert opinion input:

1. Define systems functions
2. Identify interfaces & interactions between system elements
3. Analyse & select preferred arch using trade-off studies
4. Define, refine & integrate sys. physical configuration

Stage 4 of 11: **Implementation Process –**

The purpose is to release a specified the system element.

ID	SE Process Activity expert responses out of 13 panelists who responded to the question	Importance in Traditional SE Application Area					Importance in Manufacturing SMEs					Researcher's Comments
		Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Anything = or > than 6/13 in the important and very important columns is considered critical to SMEs context. Or the total of the two = or > 9
4.1	Develop the implementation (mfg.) strategy			1/13	4/13	8/13			1/13	1/13	11/13	*Critical*
4.2	Develop the market plan / strategy		4/13	4/13	2/13	3/13		2/13	2/13	3/13	6/13	*Critical*
4.3	Develop the material Rqmts plan (MRP)			5/13	3/13	5/13			2/13	3/13	8/13	*Critical*
4.4	Develop the production plan			2/13	5/13	6/13		1/13	1/13		11/13	*Critical*
4.5	Establish the scheduling plan			4/13	5/13	4/13		1/13	1/13	4/13	7/13	*Critical*
4.6	Develop the asset management plan / strategy		1/13	4/13	5/13	2/13	1/13		3/13	7/13	2/13	*Critical*
4.7	Develop the issue / problem management plan			4/13	6/13	3/13	1/13		4/13	6/13	2/13	*Critical*
4.8	Develop the Safety Health and Environment plan		2/13	4/13	4/13	3/13	1/13	1/13	4/13	5/13	2/13	
4.9	Develop the HR and Labour Relations plan/ strategy	1/13	3/13	4/13	3/13	2/13	2/13	1/13	3/13	4/13	2/13	
4.10	Establish the quality control plan		1/13		6/13	6/13		1/13	1/13	4/13	7/13	*Critical*

Summary of important activities relevant to SMEs as informed by expert opinion input:

1. Develop the implementation (mfg.) strategy
2. Develop the market plan / strategy
3. Develop the material Rqmts plan (MRP)
4. Develop the production plan
5. Establish the scheduling plan
6. Develop the asset management plan / strategy
7. Develop the issue / problem management plan
8. Establish the quality control plan

Stage 5 of 11: **Integration Process –**

The purpose is to assemble a system that is consistent with the architectural design

ID	SE Process Activity expert responses out of 13 panelists who responded to the question	Importance in Traditional SE Application Area					Importance in Manufacturing SMEs					Researcher's Comments
		Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Anything = or > than 6/13 in the important and very important columns is considered critical to SMEs context. Or the total of the two = or > 9
5.1	Define the integration strategy				5/13	8/13		1/13	3/13	2/13	7/13	*Critical*
5.2	Schedule integration testing tools and facilities			2/13	6/13	5/13			5/13	4/13	4/13	
5.3	Perform integration – integrate design considerations				4/13	9/13			3/13	2/13	8/13	*Critical*
5.4	Document integration testing and analyse results			1/13	5/13	7/13		2/13	5/13	3/13	3/13	

Summary of important activities relevant to SMEs as informed by expert opinion input:

1. Define the integration strategy
2. Perform integration – integrate design considerations

Stage 6 of 11: **Verification Process –**

The purpose is to confirm that the specified design requirements are fulfilled by the system.

ID	SE Process Activity expert responses out of 13 panelists who responded to the question	Importance in Traditional SE Application Area						Importance in Manufacturing SMEs					Researcher's Comments
		Irrelevant	Minimal Importance	Some Importance	Important	Very Important		Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Anything = or > than 6/13 in the important and very important columns is considered critical to SMEs context. Or the total of the two = or > 9
6.1	Plan verification and develop verification procedures			2/13	4/13	7/13				4/13	3/13	6/13	*Critical*
6.2	*Conduct Verification* – Inspection/ Quality Checks		1/13	1/13	4/13	7/13			1/13	2/13	2/13	8/13	*Critical*
6.3	- Analysis (including simulation)			1/13	6/13	6/13			3/13	5/13	2/13	3/13	
6.4	-Demonstration of functionality			2/13	2/13	9/13				5/13	2/13	6/13	*Critical*
6.5	-Test (operability/ supportability/Performance)			1/13	3/13	8/13			1/13	3/13	2/13	7/13	*Critical*
6.6	-Certification (written assurance of conformity)		1/13	1/13	1/13	10/13			3/13	3/13	2/13	5/13	

Summary of important activities relevant to SMEs as informed by expert opinion input:

1. Plan verification and develop verification procedures
2. Conduct Verification – Inspection/ Quality Checks
3. Demonstration of functionality
4. Test (operability/ supportability/Performance)

Stage 7 of 11: **Transition Process –**

The purpose is to establish a capability to provide services specified by stakeholder requirements in the operational environment.

ID	SE Process Activity expert responses out of 13 panelists who responded to the question	Importance in Traditional SE Application Area						Importance in Manufacturing SMEs					Researcher's Comments
		Irrelevant	Minimal Importance	Some Importance	Important	Very Important		Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Anything = or > than 6/13 in the important and very important columns is considered critical to SMEs context. Or the total of the two = or > 9
7.1	Prepare a transition strategy			2/13	5/13	6/13			1/13	7/13	2/13	3/13	
7.2	Develop installation procedures			1/13	8/13	4/13			1/13	4/13	4/13	4/13	
7.3	Perform transition e.g.– *train the user*			2/13	3/13	6/13			1/13	3/13	2/13	7/13	*Critical*
7.4	Get written confirmation that the sys. meets the needs			3/13	6/13	4/13		2/13	2/13	6/13	1/13	2/13	
7.5	Document post installation / production problems			2/13	8/13	3/13		1/13	2/13	4/13	2/13	4/13	

Summary of important activities relevant to SMEs as informed by expert opinion input:

1. Perform transition e.g.– train the user

Stage 8 of 11: **Validation Process –**

The purpose is to provide objective evidence that the services provided by a system when in use comply with stakeholder requirements, achieving its intended use in its intended operational context.

ID	SE Process Activity expert responses out of 13 panelists who responded to the question	Importance in Traditional SE Application Area						Importance in Manufacturing SMEs					Researcher's Comments
		Irrelevant	Minimal Importance	Some Importance	Important	Very Important		Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Anything = or > than 6/13 in the important and very important columns is considered critical to SMEs context. Or the total of the two = or > 9
8.1	Develop a validation strategy			1/13	5/13	7/13			1/13	6/13	2/13	3/13	
8.2	Support in process validation throughout development			1/13	6/13	6/13			3/13	5/13	2/13	3/13	
8.3	Conduct customer satisfaction surveys		2/13	2/13	6/13	3/13			2/13	2/13	4/13	5/13	*Critical*
8.4	Document integration testing & analysis results			3/13	3/13	6/13			4/13	4/13	2/13	3/13	

Summary of important activities relevant to SMEs as informed by expert opinion input:

1. Conduct customer satisfaction surveys

Stage 9 of 11: **Operation Process –**

The purpose is to use the system in order to deliver its services

ID	SE Process Activity expert responses out of 13 panelists who responded to the question	Importance in Traditional SE Application Area						Importance in Manufacturing SMEs					Researcher's Comments
		Irrelevant	Minimal Importance	Some Importance	Important	Very Important		Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Anything = or > than 6/13 in the important and very important columns is considered critical to SMEs context. Or the total of the two = or > 9
9.1	Prepare for operation			3/13	6/13	4/13		1/13		3/13	6/13	3/13	*Critical*
9.2	Provide operator training & maintain qualified staff			1/13	6/13	6/13		1/13		2/13	4/13	6/13	*Critical*
9.3	Execute ConOps for the system of interest (SOI)			2/13	7/13	4/13		2/13	2/13	2/13	5/13	2/13	
9.4	Perform operational analysis			3/13	5/13	5/13		1/13	4/13	3/13	2/13	3/13	
9.5	Track system performance & account for opnal availability			3/13	6/13	4/13		1/13	3/13	4/13	2/13	3/13	
9.6	Manage operational support logistics	1/13	1/13	2/13	4/13	5/13			3/13	1/13	4/13	5/13	*Critical*
9.7	Document system status and actions taken			4/13	5/13	4/13		1/13	4/13	4/13	2/13	2/13	
9.8	Report malfunctions and make recommendations			2/13	8/13	3/13			3/13	1/13	5/13	4/13	*Critical*

Summary of important activities relevant to SMEs as informed by expert opinion input:

1. Prepare for operation
2. Provide operator training & maintain qualified staff
3. Manage operational support logistics
4. Report malfunctions and make recommendations

Stage 10 of 11: **Maintenance Process –**

The purpose is to sustain the capability of the system to provide the service.

ID	SE Process Activity expert responses out of 13 panelists who responded to the question	Importance in Traditional SE Application Area						Importance in Manufacturing SMEs					Researcher's Comments
		Irrelevant	Minimal Importance	Some Importance	Important	Very Important		Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Anything = or > than 6/13 in the important and very important columns is considered critical to SMEs context. Or the total of the two = or > 9
10.1	Establish a maintenance strategy			3/13	2/13	8/13			1/13	2/13	4/13	6/13	*Critical*
10.2	Define maintenance related constraints on the SOI			1/13	6/13	5/13			1/13	3/13	5/13	4/13	*Critical*
10.3	Monitor replenishment levels of spares	1/13	1/13	2/13	6/13	3/13			2/13	2/13	5/13	4/13	*Critical*
10.4	Manage the skills & availability of trained personnel	1/13		4/13	5/13	3/13			2/13	3/13	4/13	4/13	
10.5	Implement maintenance & problem resolution procedures	1/13		1/13	7/13	4/13			1/13	3/13	5/13	4/13	*Critical*
10.6	Maintain history of failures, actions taken & trends	1/13		3/13	4/13	5/13			3/13	4/13	2/13	4/13	
10.7	Monitor customer satisfaction with system maintenance	1/13		7/13	2/13	3/13			3/13	4/13	3/13	3/13	

Summary of important activities relevant to SMEs as informed by expert opinion input:

1. Establish a maintenance strategy
2. Define maintenance related constraints on the SOI
3. Monitor replenishment levels of spares
4. Implement maintenance & problem resolution procedures

Stage 11 of 11: **Disposal/ Retirement Process –**

The purpose is to end the existence of a system entity.

ID	SE Process Activity expert responses out of 13 panelists who responded to the question	Importance in Traditional SE Application Area						Importance in Manufacturing SMEs					Researcher's Comments
		Irrelevant	Minimal Importance	Some Importance	Important	Very Important		Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Anything = or > than 6/13 in the important and very important columns is considered critical to SMEs context. Or the total of the two = or > 9
11.1	Plan/ review the concept of disposal			3/13	3/13	7/13		1/13		4/13	6/13	2/13	*Critical*
11.2	Define the disposal strategy			1/13	4/13	8/13		1/13	1/13	3/13	5/13	3/13	
11.3	Impose associated constraints on the sys Rqmts		1/13	1/13	6/13	5/13		1/13	1/13	6/13	2/13	3/13	
11.4	perform disposal			2/13	4/13	8/13				4/13	5/13	4/13	*Critical*
11.5	Maintain & doc. all disposal activities and hazards			5/13	2/13	5/13		1/13	1/13	6/13	2/13	3/13	

Summary of important activities relevant to SMEs as informed by expert opinion input:

1. Plan/ review the concept of disposal
2. Perform disposal

Other Comments

- Depends on nature of the system

Enterprise Enabling Processes

The purpose is to define, maintain and assure availability of policies, processes, models which are consistent with the company objectives and work as a common reference.

ID	SE Process Activity expert responses out of 13 panelists who responded to the question	Importance in Traditional SE Application Area						Importance in Manufacturing SMEs					Researcher's Comments
		Irrelevant	Minimal Importance	Some Importance	Important	Very Important		Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Anything = or > than 6/13 in the important and very important columns is considered critical to SMEs context. Or the total of the two = or > 9
12.1	Develop a solid enterprise strategic plan	1/13		4/13	1/13	7/13		1/13	2/13	3/13		7/13	*Critical*
12.2	Conduct periodic reviews of the SOPs	1/13		5/13	3/13	4/13		1/13	2/13	2/13	6/13	2/13	*Critical*
12.3	Carryout periodic audits of all functional areas	1/13	1/13	4/13	2/13	5/13			3/13	5/13	2/13	3/13	
12.4	Periodically conduct & doc. lessons learnt sessions	1/13		4/13	5/13	3/13			2/13	4/13	4/13	3/13	
12.5	Periodically analyse the infrastructure gap of facilities	1/13		4/13	4/13	4/13			2/13	2/13	5/13	4/13	*Critical*
12.6	Formally initiate, evaluate, implement & close projects			3/13	4/13	6/13		1/13	2/13	6/13	3/13	2/13	
12.7	Develop the enterprise skills retention strategy	1/13	1/13	4/13	4/13	3/13			2/13	2/13	4/13	5/13	*Critical*
12.8	Develop the enterprise quality management policy	1/13	1/13	4/13	2/13	5/13			3/13	3/13	2/13	5/13	
12.9	Assess quality & develop corrective action	1/13	1/13	4/13	4/13	4/13			2/13	3/13	3/13	4/13	
12.10	Develop the enterprise risk management plan	1/13		2/13	6/13	4/13			2/13	2/13	5/13	4/13	*Critical*

Summary of important activities relevant to SMEs as informed by expert opinion input:

1. Develop a solid enterprise strategic plan
2. Conduct periodic reviews of the SOPs
3. Periodically analyse the infrastructure gap of facilities
4. Develop the enterprise skills retention strategy
5. Develop the enterprise risk management plan

- Other Comments: Depends on the type of enterprise and its market

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Agreement Processes

These processes define the activities necessary to establish an agreement between two firms..

ID	SE Process Activity expert responses out of 13 panelists who responded to the question	Importance in Traditional SE Application Area						Importance in Manufacturing SMEs					Researcher's Comments
		Irrelevant	Minimal Importance	Some Importance	Important	Very Important		Irrelevant	Minimal Importance	Some Importance	Important	Very Important	Anything = or > than 6/13 in the important and very important columns is considered critical to SMEs context. Or the total of the two = or > 9
13.1	Dev. & maintain acquisition plans, strategies, policies etc.			2/13	4/13	7/13		1/13	2/13	3/13	4/13	3/13	
13.2	Identify a list of potential suppliers			2/13	7/13	4/13			1/13	3/13	5/13	4/13	*Critical*
13.3	Advertise the acquisition and select the supplier		1/13	2/13	6/13	4/13		1/13	4/13	1/13	4/13	2/13	
13.4	Negotiate the agreement			1/13	6/13	6/13		1/13	1/13	1/13	5/13	5/13	*Critical*
13.5	Establish delivery acceptance criteria			1/13	4/13	8/13			1/13		8/13	4/13	*Critical*
13.6	Monitor the agreement			3/13	6/13	4/13		1/13	1/13	2/13	5/13	4/13	*Critical*
13.7	Assess execution & negotiate changes to reduce risks			2/13	7/13	4/13		1/13	1/13	2/13	7/13	2/13	*Critical*
13.8	Accept the product or service			1/13	5/13	7/13			1/13	2/13	6/13	5/13	*Critical*
13.9	Supply Processes: Identify opportunities			3/13	4/13	6/13			1/13		5/13	7/13	*Critical*
13.10	Respond to tender		1/13	1/13	4/13	7/13			3/13		5/13	5/13	*Critical*
13.11	Initiate and execute the agreement		1/13	1/13	5/13	6/13			2/13	2/13	3/13	6/13	*Critical*
13.12	Maintain & manage communication with stakeholders			3/13	3/13	7/13			1/13	3/13	4/13	5/13	*Critical*
13.13	Develop and support the product or service			3/13	4/13	6/13			1/13	2/13	6/13	4/13	*Critical*
13.14	Close the agreement		1/13	1/13	7/13	4/13			1/13	2/13	8/13	2/13	*Critical*

Summary of important activities relevant to SMEs as informed by expert opinion input:

1. Identify a list of potential suppliers
2. Negotiate the agreement
3. Establish delivery acceptance criteria
4. Monitor the agreement
5. Assess execution & negotiate changes to reduce risks
6. Accept the product or service
7. Supply Processes: Identify opportunities
8. Respond to tender

9. Initiate and execute the agreement
10. Maintain & manage communication with stakeholders
11. Develop and support the product or service
12. Close the agreement

Please turn to the next page for Part Two Question # 3 and 4.

Expert's Responses	Sub Question # 2: List any seven (7) SE – process activities which will have the greatest impact if implemented in typical fast moving consumer goods manufacturing Small and Medium Enterprise (SME).	Sub Question # 3c: 1. State any four pillars or anchoring aspects that any problem tackling framework like the SE approach should have for it to be considered a success.
Expert # 1	*a. Understand the product and its users* *b. Understand your supply chain* *c. Understand your processes for planning and production* *d. Listen to your employees* *e. Watch the bottom line* *f.* ________________________________ *g.* ________________________________	*Should be able to:* *i. Identify stakeholders* *ii. Formulate the problem* *iii. Create and analyse options* *iv. "Decide and evaluate continuously my SPADE model"*
Expert # 2	*a. Capture stakeholder requirements (Item 1.2 of the presented SE)* *b. Develop the production plan (4.4)* *c. Establish the scheduling plan (4.5)* *d. Provide the operator training and maintain qualified staff (9.2)* *e. Manage skills availability of trained personnel* *f. Respond to tender* *h.* ________________________________	*Should be able to:* *i.* ________________________________ *ii.* ________________________________ *iii.* ________________________________ *iv.* ________________________________ *(did not respond on this part of the question)*
Expert # 3	*a. Create a climate for change* *b. Architect a strategy* *c. Create a vision* *d. Reward results* *e. Develop decision making heuristics* *f. Stir the plot* *g. Implement with users*	*Should be able to show:* *i. improvements when used* *ii. the extent with which critical stakeholders were satisfied with the results* *iii. the lessons that were actually learned* *iv. to what extent was the tender (cost, schedule and performance) realistic*

Expert's Responses	Sub Question # 2: List any seven (7) SE – process activities which will have the greatest impact if implemented in typical fast moving consumer goods manufacturing Small and Medium Enterprise (SME).	Sub Question # 3c: 2. State any four pillars or anchoring aspects that any problem tackling framework like the SE approach should have for it to be considered a success.
Expert # 4	*a. Define the needs and operational context (Item 1.3 of the SE)* *b. Identify the system boundaries and interfaces (2.2)* *c. Define selection criteria (3.4)* *d. Develop the market plan/ strategy (4.2)* *e. Conduct customer satisfaction surveys (8.3)* *f. Develop a solid enterprise strategy plan (12.1)* *g. Develop the enterprise skills retention strategy (12.7)*	*Should be able to:* *i. Model the problem and the solution* *ii. Define the boundary* *iii. Seek first to understand behaviour than function* *iv. Validate early and often*
Expert # 5	*a. Stakeholder requirements analysis* *b. System constraints analysis* *c. Operational effectiveness analysis* *d. Reliability analysis* *e. Usability / HLI Analysis* *f. Availability Analysis* *g. Sustainability analysis*	*Should be able to:* *i. Look at the whole of the problem / solution* *ii. Perform balanced trade-offs* *iii. Manage risks and opportunities* *iv. Follow a Systems Engineering (SE) process*
Expert # 6	*a. Get and keeping the correct people* *b. Stakeholder communication* *c. Test and Acceptance* *d. Support and maintenance* *e. Operational deployment* *f. Use technology (e.g. internet)*	*Should be able to:* *i. Focus efforts on priorities rather than include all aspects* *ii. Seek sustainable solutions including financial and environment* *iii. Balance use of experience, people, tools and processes* *iv. Provide "Golden tread" / structure in a chaotic environment*

Expert's Responses	Sub Question # 2: List any seven (7) SE – process activities which will have the greatest impact if implemented in typical fast moving consumer goods manufacturing Small and Medium Enterprise (SME).	Sub Question # 3c: 3. State any four pillars or anchoring aspects that any problem tackling framework like the SE approach should have for it to be considered a success.
Expert # 7	a. *Competitive manufacturing capability* b. *Operational capability* c. ____________________ d. ____________________ e. ____________________ f. ____________________ g. ____________________	*Should be able to:* i. *Ensure that the customer expectations will be met* ii. *Maintain the product specifications* iii. *Retain the product competiveness* iv. *Provide the operational capability to execute the production of the product at the right price, quality and quantity*
Expert # 8	a. *Standardisation* b. *Testability assessment – emphasis on automatic testing* c. *Environment and safety assessment – direct impact on sustainability criteria* d. *Requirements analysis* e. *Functional analysis with minimal functioning architecting* f. *Physical architecting solution with minimal trade-offs* g. *Evolving the solution for new improved products*	*Should be able to:* i. *Allow for pragmatic changes based on the experience of engineers* ii. *Know what must be done / requirements* iii. *Determine how it will be done/ functions* iv. *Implement a workable solution that can be improved as necessary*

Expert's Responses	Sub Question # 2: List any seven (7) SE – process activities which will have the greatest impact if implemented in typical fast moving consumer goods manufacturing Small and Medium Enterprise (SME).	Sub Question # 3c: 4. State any four pillars or anchoring aspects that any problem tackling framework like the SE approach should have for it to be considered a success.
Expert # 10	*a. Develop the manufacturing plan (Item 4.1 of the SE)* *b. Develop the production plan (4.4)* *c. Develop the Materials Requirements Plan (4.3)* *d. Develop the Quality Assurance Plan (4.10)* *e. Develop the Asset Management Plan (4.6)* *f. Develop Issue/ Problem Management Plan (4.7)* *g. Develop Health and Safety Plan (4.8)*	*Should be able to provide:* *i. For a formal baseline management* *ii. Specifications against which the final product can be measured* *iii. Review meetings throughout the process* *iv. Minimal scope creep*
Expert # 11	*a. Requirements analysis across the value chain* *b. Documentation and configuration management* *c. Validation* *d. ________* *e. ________* *f. ________* *g. ________*	*Should be able to:* *i. ________* *ii. ________* *iii. ________* *iv. ________* *(did not respond on this part of the question)*
Expert #12	*a. ________* *b. ________* *c. ________* *d. ________* *e. ________* *f. ________* *g. ________((did not respond on this part of the question)*	*Should be able to:* *i. ________* *ii. ________* *iii. ________* *iv. ________* *(did not respond on this part of the question)*

Expert's Responses	Sub Question # 2: List any seven (7) SE – process activities which will have the greatest impact if implemented in typical fast moving consumer goods manufacturing Small and Medium Enterprise (SME).	Sub Question # 3c: 5. State any four pillars or anchoring aspects that any problem tackling framework like the SE approach should have for it to be considered a success.
Expert # 13	a. *Capture stakeholder requirements (Item 4.1 of the presented SE)* b. *Define system functions, capabilities and performance goals (2.3)* c. *Define logical architecture* d. *Develop the market plan/ strategy (4.2)* e. *Develop production plan (4.4)* f. *Establish quality control plan (4.10)* g. *Define integration strategy (5.1)*	*Should be able to:* i. *Situation in nature – "not one size fits all"* ii. *Must focus on the essence rather than everything* iii. *Must call for competent people to do the work* iv. *Must be flexible*
Expert # 14	a. *Stakeholder requirements analysis (Item 4.1 of the presented SE)* b. *Identify stakeholders (1.1)* c. *Establish the quality plan (4.10)* d. *Plan verification and develop verification procedures (6.1)* e. *Develop validation strategy (8.1)* f. *Maintain history of failure (10.6)* g. *Define a disposal strategy (11.2)*	*Should be able to:* *Establish requirements accurately* *Develop a system architecture* *Review and inspect all work procedures* *Evaluate all aspects of the project where its ends*

Appendix G1 – *Responses to Theoretical Question 3*

Theoretical Question # 3:

What are the challenges of implementing the systems engineering approach (SEA) in any environment?

Expert's Responses	Sub Question # 1: 1. List five (5) reasons why SE implementation fails?	Sub Question # 2: 2. What challenges can be expected in rolling-out the right Systems Engineering in a typical fast moving consumer goods manufacturing SME?	Sub Question # 3: 6. What enablers are necessary for implementation of a sustainable Systems Engineering Approach in a typical manufacturing SME? (state at least five)
Expert # 1	× *Lack of patience leading to short cuts* × *Failure to listen to everyone* × *Fear of losing contracts leading to unacceptable compromises or unrealistic promises* × *No-one watching to make sure it succeeds*	*h. Not enough time – training, mistakes, listening* *i. Top management not committed* *j. Failure to involve supply chain partners* *k. Failure to allow corrections over time* *l. Unreasonable expectations by 'anyone'.*	*Time, commitment* *Money* *Mentors* *Urgency – it is about having a problem that needs fixing, SE for the sake of SE is waste.*
Expert # 2	× *Numerous - depends on the environment MARS mission versus SME*	*a. Convincing people to invest time in SE Procedures* *b.* ________________________________ *c.* ________________________________ *d.* ________________________________	*i. Passionate and innovative leadership* *ii. Good business proposition* *iii. Cash flow* *iv. Good knowledge of capability and market.*
Expert #3	× *Unrealistic expectations of stakeholders* × *Optimistic cost, schedule & performance* × *Underbidding* × *Paying up-front for perceived promises* × *Not rewarding results*	*a. SE is mistrusted and undervalued* *b. SE is often the first to go in trying to cut costs* *c. Architecture is often thought to add no value* *d. Stakeholders do not like change* *e. Stakeholders want to see proof that something new will actually work; they are likely to be risk averse.*	*i. Change the incentive structure of individual particularly those in charge* *ii. Create working environments that motivate / reward for working together, collaborating, cooperating and competing* *iii. Recognise value added contributions and team efforts* *iv. Educate & train staff continually and reward for investing time to learn* *v. Encourage workers to suggest and try improvements*

Expert's Responses	Sub Question # 1: 1. List five (5) reasons why SE implementation fails?	Sub Question # 2: 2. What challenges can be expected in rolling-out the right Systems Engineering in a typical fast moving consumer goods manufacturing SME?	Sub Question # 3: 3. What enablers are necessary for implementation of a sustainable Systems Engineering Approach in a typical manufacturing SME? (state at least five)
Expert # 4	× *Emphasis of process over results* × *Lack of training / skills* × *Poor management* × *Insufficient resources (time or budget)* × *Lack of understanding problem domain*	*a. Misapplication of SE principles* *b. Emphasis on risk / cost reduction vs. balanced risk / opportunity appraisal* *c. Over-emphasis on process* *d. Lack of understanding of lean principles* *e. Prioritization of verification rather than validation*	*i. Training SMEs management on SE* *ii. Lean SE processes* *iii. Tools aligned with Lean SE processes* *iv. Good System Engineers (training, tools, processes only go so far)* *v. Good market / problem definition team and approach*
Expert # 5	× *Lack of awareness* × *Lack of top level management support* × *Lack of training* × *Not seen as value-added* × *Lack of vision*	*a. Not responsive enough* *b. Not tailored for FMCG application* *c. Seen as overhead / not investment* *d. Lack of support* *e. Not relevant*	*i. Top level support* *ii. Solid vision* *iii. Good communication* *iv. Right people* *v. Early wins.*
Expert # 6	× *Too much focus on process and documentation versus people* × *Too much analysis versus testing* × *The devil is in the detail, domain knowledge is crucial* × *Timing e.g. get a spec / ICD on the table early in the process* × *People, People, People*	*1. Time is too short get it right quickly* *2. No "full time" SE, i.e. SE to be done over and above other tasks* *3. Stakeholders are much more critical* *4. Financial factors are more important* *5. SE is seen to slow things down and waste time*	*i. The right people (motivated with good leadership)* *ii. Take into account non-technical issues (money, environment etc.)* *iii. The content / action is more important than paperwork* *iv. Technology is here (e.g. internet) – use it* *v. Holistic approach*

Expert's Responses	Sub Question # 1: 1. List five (5) reasons why SE implementation fails?	Sub Question # 2: 2. What challenges can be expected in rolling-out the right Systems Engineering in a typical fast moving consumer goods manufacturing SME?	Sub Question # 3: 3. What enablers are necessary for implementation of a sustainable Systems Engineering Approach in a typical manufacturing SME? (state at least five)
Expert # 7	× *Lack of buy in of the project managers* × *Lack of buy in of top management and their support throughout until value can be measured* × *Not tailoring enough, do enough SE to get value for your enterprise, too much destroys value*	*a. Affordability, does the value it brings, pay for the SE cost* *b. Is the SE required for such an SME?* *c.* ______________________________ *d.* ______________________________ *e.* ______________________________	*i. Management drive* *ii. Make SE part of team and process, not something separate like QA* *iii. Support SE even if the results are -ve. E.g. if a product fails to meet spec* *iv. Adequate budget and resources* *v. Adequate orientation & training for the whole company*
Expert # 8	× *Lack of experienced Systems Engineers* × *Pedantic adherence to processes without considering for practicalities* × *Lack of management buy- in* × *Too much talk about SE and not doing SE that shows results* × *Discipline engineers e.g. electrical, mechanical etc. that think after reading a book on SE that they understand SE*	*a. Management resistance* *b. Discipline engineers seeing it as superfluous (unnecessary)* *c. Added burden perceived to produce extra paperwork* *d. The upfront cost before manufacturing could start* *e. Breaking into the culture of let's make it now and fix it later*	*i. Experienced Systems Engineers with good common sense* *ii. The necessary SE tools* *iii. A big problem that cannot be solved by traditional engineering disciplines* *iv. A good quality management system* *v. An environment encouraging cross / multi-disciplinary cooperation*
Expert # 9	× *Not giving attention in defining a technical development strategy which may consist of development methods, development, delivery and testing strategies.* × *The view of SE as merely revolving around documentation and forgetting that SE is also a design activity*	*a. The challenge of design and implementing an integrated organisation to support a systems approach* *b.* ______________________________ *c.* ______________________________ *d.* ______________________________	*i. Implementation of an easy to use and relevant data capturing system which allows for analysis for improvement* *ii.* ______________________________ *iii.* ______________________________ *iv.* ______________________________

Expert's Responses	Sub Question # 1: 1. List five (5) reasons why SE implementation fails?	Sub Question # 2: 2. What challenges can be expected in rolling-out the right SE in a typical fast moving consumer goods manufacturing SME?	Sub Question # 3: 3. What enablers are necessary for implementation of a sustainable Systems Engineering Approach in a typical manufacturing SME?
Expert # 10	× *Lack of explicit (clear) specifications* × *Lack of formal baseline management* × *Excessive scope creep* × *Lack of proper review meetings (and formal minutes)* × *Unable to show the final product conforms to the specification*	*a. Resistance to compiling proper strategy documents and plans* *b. Culture change from the old way to new way* *c. Enforcing quality control procedures* *d. HR and labour issues* *e. Attendance at formal review meetings*	*i. Explicit / definite problem statement / specification* *ii. Ensure formal baseline management* *iii. Implement proper review meetings* *iv. Minimise scope creep* *v. Ensure final product conforms to specification*
Expert # 11	× *Poor requirements analysis* × *Too much money spent on SE churn* × *Low investment in skills development* × *Mismatch between IT environment and SE kills* × *Poor selection of appropriate standards*	*a. Culture resistance* *b. Lack of demonstrated value – ROI* *c. Skills shortage* *d. No established processes for the rigorous approach* *e. Divestment due to long ROI cycle of SE*	*i. Training* *ii. Process tailoring* *iii. Organisational culture development* *iv. A champion* *v. Appropriate standards and supporting software tools*
Expert # 12	× *Too much emphasis on forcing people to follow process* × *SE approach out of touch with market demands* × *Too much emphasis on "best practise" rather than " good practise"* × *Management-by-politics (MBP) rather than engineering management* × *Scope defined is to large and involving too much change*	*a. ….. as in the first part of the question*	*i. A market that demands a SE approach* *ii. A situationally appropriate response to the market* *iii. Sufficient supply of competent people* *iv. Focus on essence rather than overkill* *v. Vibrant approach to risk management* *vi. A sense of urgency*

Expert's Responses	Sub Question # 1: 1. List five (5) reasons why SE implementation fails?	Sub Question # 2: 2. What challenges can be expected in rolling-out the right SE in a typical fast moving consumer goods manufacturing SME?	Sub Question # 3: 3. What enablers are necessary for implementation of a sustainable Systems Engineering Approach in a typical manufacturing SME?
Expert # 14	× *Lack of appropriate executive buy-in* × *Failure to deal with change- management* × *Inadequate requirements* × *Insufficient focus on quality* × *Immature processes*	*a. Human issues (lack of buy-in)* *b. Institutionalisation of processes* *c. Lack of attention to quality* *d. Inadequate review / inspection of work products* *e. Inability to be agile*	*i. Executive support* *ii. Good processes* *iii. Appropriate skills* *iv. Adequate resources* *v. Appropriate use of measurement*
Expert # 15	× *Lack of tailoring to the specific environment* × *Lack of management buy-in* × *Lack of common understanding of the purpose* × *Driving the processes instead of the value to the customer* × *Taking too big a time on the first implementation*	*a. SE typically seen as meant for systems development not manufacturing* *b. Lack of a specific stakeholder – customer need*	*vi. Risk management* *vii. Process improvement* *viii. Quality management* *ix. Skills retention* *x. Facility / infrastructure management*

Appendix H

Appendix H – Lessons Learnt in Applying SE in any Environment

"Insight, or ability to structure a complex situation in a way that greatly increases understanding of it, is strongly guided by lessons learned from one's own or others' experiences and observations. Given enough lessons their meaning can be codified into succinct expressions called "heuristics" a Greek term for ***guide****" Heuristics are an essential complement to analytics, particularly in situations where analysis alone cannot provide either insights or guidelines"*

(Maier & Rechtin, *2002:17****)***

[A] – **List of Lessons Learnt** (as stated by Delphi Panelists)

1. Only select useful SE elements that are supported by stakeholders
2. Resistance to change – *too many people like the way the world works – why should they change what made them successful as individuals.*
3. The ultimate goal for all is rarely given the highest priority
4. *What is wrong with creating jobs and income for people even if good systems don't get built?*
5. Need to understand when in refinement mode - architect first vs. SE mode (Need / Behavior)
6. Tendency to engineer documents / specs rather than the system
7. Separation of requirement architecture, Verification & Validation (V&V) concerns and team rather than understanding and reinforcing the interrelationships
8. Treat as a change initiative
9. Ensure top level support
10. Assign the right people; People are key
11. Tailor SE for the value it brings, it is not an end itself
12. Do not get hooked into SE tools, *the tail does not wag the dog.* Use tools for what you want, not what the tools wants or have the ability to do.
13. Do system design (architectural design) thoroughly, 80% of costs are fixed here as well as competitive advantage.
14. Do not apply systems engineering pedantically **-** (*a narrow-minded approach insisting on exact adherence to a set of arbitrary rules)*
15. Start of by establishing traceability and demonstrate the advantages
16. Do not burden others by explaining what SE is about, just do it without too much discussions
17. Compiling proper strategies and plans to be enforced top down
18. Culture change to be carefully managed
19. HR issues to be managed and **communicated**
20. Tune SE approach to be in tune with market
21. Keep focus on what is good for customer
22. Attend to essence rather than overkill approach
23. Focus on quality; Use reviews to achieve quality
24. Get and publish learn lessons from each project
25. Never blindly apply the process always tailor for the specific application
26. Focus on value to the stakeholder

[B] – **List of Established Heuristics** (as stated by Delphi Panelists) … Lessons Learnt Continued:

1. *Use experience and instinct and don't blindly follows methodologies*
2. *If something is good for my next promotion, that takes priority*
3. *Reorganizing buys me time before anyone can expect results*
4. *Short term focus is what matters,; no one cares about the long term*
5. *Werner Grahl / NASA curve on SE investment versus overrun*
6. *CMMI (not this goes to predictability not overall effectiveness)*
7. *Rule of 7±2 holds for design comprehension*
8. *The SE principles can be applied to any situation but with tailoring*
9. *The creating system (including people) results in the created system*
10. *Process is not a substitute for experience*
11. *Politics always wins*
12. *If anything can go wrong it will*
13. *In architecture, encapsulate complexity in the subsystems, leaving simple interfaces between them*
14. *First fix the interfaces before anything else*
15. *You cannot make something both complete and consistent, in SE make it consistent*
16. *Proceed with a SE process until understanding in the team is reached and then stop the process, there is still a system that must be build*
17. *Tailoring*
18. *Value to the stakeholder*
19. *Risk reduction*

Appendix I: Naïve Picture - List of Issues in SMEs

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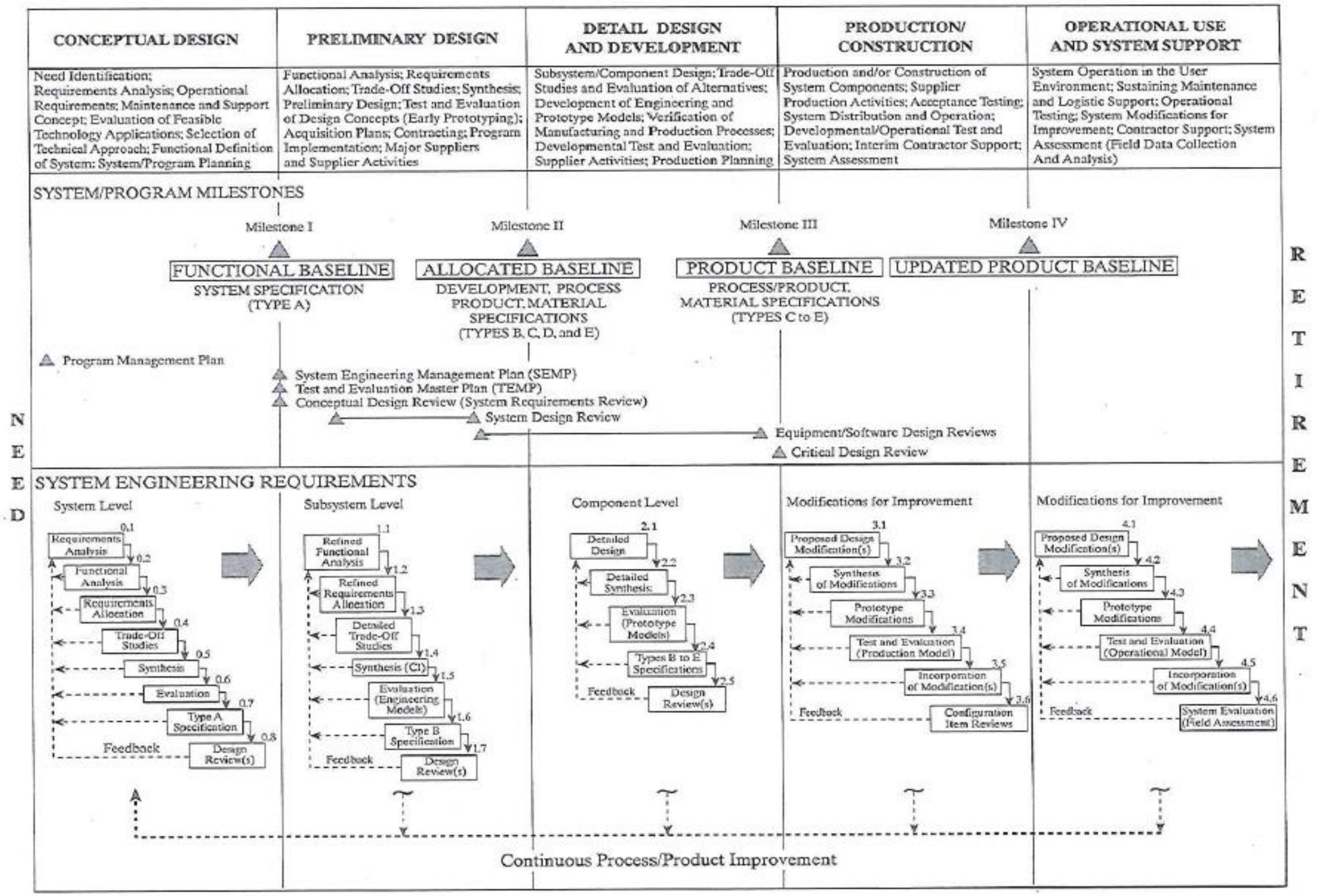
Sheet 1 – Worldview of challenges faced by SMEs (both internal and external problems)

Sheet 1 – Worldview of challenges faced by SMEs (both internal only)

Sheet 1 – Worldview of challenges faced by SMEs (both internal only and issues only

Appendix J: The Generic Systems Life Cycle



(Fabrycky and Blanchard, 2006 p.31)

Appendix K: Important Definitions in the Systems Engineering Domain

Architecting The processing of creating and building architectures.

Architecture The structure in terms of components, connections and constraints of a product, process or element

Baseline The gate – controlled step by step elaboration of business, budget, functional, performance, and physical characteristics, mutually agreed to by buyer and seller, and under formal change control.

Capability: An expression of a system, product, function or process' ability to achieve a specific objective under stated conditions.

Complexity A measure of the numbers and types of interrelationships among system elements.

Domain A recognized field of activity and expertise or specialized theory and application.

Emergent property: A system that supports a *system-of-interest* (SOI) during its life cycle stages but does not necessarily contribute directly to its function during operation.

Emergent property: A property of a system as whole which cannot be completely attributed to any particular part of that system.

Hard Clearly defined or definable and with evident purpose

Heuristic A guideline for architecting, engineering, or design.

Hierarchy The levels of organization epitomized by contained and containing systems

Model An abstracted representation of some aspect of a system.

Process A set of sequenced activities to archive some purpose.

SE effort Systems engineering effort integrates multiple disciplines and specialty groups into a set of activities that proceed from concept to production to operation.

Soft Complex poorly defined and without clear singular purpose

Tailoring The manner in which any selected issue is addressed in a particular project.

Why we need a birds-eye view first?

Why we need Systems Engineers!