

Chapter 1: Introduction

The effective execution of organisational strategies that carries the business from a current “alpha” status to a desirable, more competitive “beta” status will bring to most organisations (i.e. public, private, and non-for-profit) the challenges of translating such strategies into project-like initiatives and of relying on proper and effective project management to successfully deliver such projects, realise the strategy. (Cleland & Ireland, 2002, pp. 4-7, 67-69)

Translating strategies into project initiatives might present its own difficulties and complications. Furthermore, the planning, development and execution of such project initiatives (whether in-house or by a third party), be they primarily capital (e.g., infrastructure) or transformational (e.g., embedding of organisational change), has never been without its own share of risks, issues, challenges and disillusionments – just judging from unsatisfactory outcomes common to many projects. (Clancy, 2014 & Nevin, 2015)

Companies often need to deliver infrastructure projects that afford them competitive advantage and/or increased financial viability to the satisfaction of their shareholder(s), whereas organs of government (e.g., national/local government, development agencies) would embark on projects that foster economic growth or betterment of socio-economic conditions of the citizens.

When no other entity or organisation is mandated to provide and maintain the type of infrastructure they require for their operations, many companies (e.g. utilities, logistics corporations) will heavily depend on the successful execution of their multi-billion Rand infrastructure projects as a means of realising their strategy.

It would transpire from the widespread, persistent unsatisfactory outcomes of Large Infrastructure Projects in both private and public sectors that traditional project management has not necessarily kept pace with new developments, particularly the increasing complexity of projects. Chronic delays and costs overruns on recent multi-billion projects, locally and abroad, attest to the high prevalence and severity of the issue. (Flyvbjerg *et al.*, 2003 & Nevin, 2015)

– Thus, relying on an ineffectual project management methodology that fails to match the complexity of infrastructure projects in their capital portfolio may prove counterproductive (if not fatal) to companies and governments alike.

Persisting, chronic project failures will affect companies in terms of both strategy realisation and financial performance (e.g., adverse impact on the Income Statement and Balance Sheet of the company, as well as the overall competitiveness of the company – The same would apply to governments).

The Prosperus Report: The African Edition (Marnewick, C. *et al.*, 2013) states similar findings across various industries including the construction sector: of all projects surveyed (2003-2008), 34% failed and 39% were challenged, with very little variance as the minor standard deviation figures could testify.

Project failure is not a local disease either; the Chaos Report published since 1994 by the Standish Group in the USA suggests that far more projects fail than do succeed, especially in the IT sector – and Field (1997) contends that failed and poorly managed projects cost U.S. companies and government agencies an estimated \$ 145 billion per year. It is therefore not surprising that \$ 10 billion are spent yearly in the U.S. alone on project management training. (Philips *et al.*, 2002)

1.1 Problem Statement

The phenomenal rise of project management has not come without its share of challenges; the development of project management as a profession has been a matter of fiery debates, even within project management fraternities. Moreover, while project management has made possible the realisation of some of humankind's wildest dream (e.g., walking on the moon in 1969), its litany of spectacular failures and chronic costs and schedule overruns continue, even to this very day, to shed a questionable light to its real value. *"The megaproject market is worth about \$9-trillion each year, and globally big builds are in a mess. It is rare to have one completed on time and on budget."* (Nevin, 2015, p. 1)

According to the Independent Project Analysts (IPA), *“Data from more than 300 global megaprojects shows that 65 percent of industrial projects with budget larger than \$ 1 billion in 2010 U.S. dollars failed to meet business objectives. In some industrial sectors the failure rate was as high as 75 percent.”* (Morrow, 2011, p. vii)

Nevin (2015) also provides South African examples of “challenged” projects; *“ESKOM’s latest estimates for Medupi show that the Limpopo coal-fired project should be completed by 2019 at a cost of R 105 bn. In 2007, the parastatal said the project would be completed in 2015 at a cost of R 80 bn. But there has been speculation in the energy industry that the real cost of Medupi will be close to R 200 bn — when financing fees, currency losses, financial advisory, legal advisory and interest during construction are taken into account.”* (p. 2)

Years of delay and 150% cost overrun at Medupi could spell disaster for Eskom and RSA, this project being a key element of the National Infrastructure Plan. *“The National Infrastructure Plan is made up of eighteen Strategic Integrated Projects (SIPs) each of which consists of a large number of projects drawn from a wide range of economic sectors and stretching across all nine provinces of the country.”* (SIPs & Skills, 2014, p. 15) – Medupi is key to RSA’s economy. *“Infrastructure investment is a key priority of both the National Development Plan and the New Growth Path. We are transforming the economy, directing national growth and driving job creation by implementing a long-term, government led infrastructure investment programme.”* (PICC, 2012, p. 3, 9,10)

Large Infrastructure Projects (LIPs) are critical to, and have an impact on the macro-economy of the host country in terms of job creation, opportunities for export boost (and/or reduced import) and contributions to economic growth (e.g., the construction industry contributes up to 10% of GDP in the UK). There, thus, arises a need to consider what makes LIPs particularly vulnerable to costs and schedule overruns (or utter failure) and then proposition a remedial or alternative approach to managing Large Infrastructure Projects. (Morrow, 2011, Foreword by J.B. Porter)

Moreover, Wood *et al.* (2010, p. 1) would contend that *“It is a common statement that the construction industry process is one of the most complex and risky businesses undertaken, however it has also been suggested that the construction industry has developed great difficulty in coping with the increasing complexity of major construction projects”*. Indeed, while project complexity in itself is but one dimension of attaining project success Baccarini (1996, p. 201) still maintains: *“The significance of project complexity to project success or otherwise cannot be underestimated, hence the compelling need to allow for a thorough understanding of the inherent complexities in an infrastructure delivery system”*. Twenty years on, but a call to seek *“a thorough understanding”* of complexity in infrastructure projects was yet to be heeded.

This study has considered that the increasing complexity in the very scope and in the environment of the project could have rendered traditional project management ineffective in its application to Large Infrastructure Projects.

1.2 Motivation

Due to the increasing complexity of their projects, the [Dutch] civil engineering sector has been using Systems Engineering (SE) for a decade. As a result, the sector is undergoing a transition; the support base for and the application of SE have indeed increased in recent years. This is simply because organisations realise that SE helps them make projects more controllable and allows them to be set up more efficiently. (PWW, 2013, pp. 7-8)

Systems Engineering (SE), as a discipline and as a way of thinking, is gaining popularity and acceptance in its applications to Large Infrastructure Projects (LIPs). This follows from the benefits emerging from the ability it affords in matching the high level of complexity experienced in, amongst many others, transportation projects such as entailing railway, port terminals, and pipelines – which the industry generally classifies as Large Infrastructure Projects. (INCOSE, 2012)

Acknowledging from an initial literature review (e.g., *Systems Engineering in Transportation Projects – A Library of Case Studies*, INCOSE, 2013) that the

judicious application of Systems Engineering concepts to Large Infrastructure Projects (LIPs) will provide tremendous benefits beyond the current boundaries of the established Project Management Body of Knowledge (PMBok), this research will endeavour to establish the following:

- (1) Whether the commonly adopted project lifecycle methodologies need improvements;
- (2) What specific Systems Engineering principles and concepts, when judiciously applied, could provide enhancements to such project lifecycle methodologies. This is an important aspect of the research.

One such Systems Engineering concept could consist in the application of the Soft Systems Methodology (SSM) to address the seemingly *wicked problem* of eliciting, elucidating Owner's requirements at the earliest stages of the project lifecycle at a point when both problems and solutions are intrinsically messy, poorly structured, and therefore hard even to formulate.

Furthermore, Systems Engineering (SE) practices such as Requirement Management, Verification and Validation, Stakeholder Management, and Asset Lifecycle considerations could be embedded onto the project lifecycle methodology to improve the management of the systems requirements throughout the lifecycle, from concept to operations and eventual disposal.

1.3 Research Question

Thus, the Research Question could be paraphrased as follows:

“Can Systems Engineering (SE) concepts and principles be applied to project management methodologies for Large Infrastructure Projects (LIPs) in order to enable project managers to more effectively and successfully attain the desired outcome of a planned Project?”

Should the answer to this question be yes, then:

“How can such SE concepts and practices be integrated into a model in such a manner as to allow project managers to consistently apply SE

concepts in all projects to significantly improve any given project's chance for successful completion?"

This Research Question is important for the answer to this problem will make a substantial difference to the delivery of LIPs and to their contributions to strategy realisation and financial performance of owner's organisations.

1.4 Research Objectives

This study seeks to review the effectiveness of commonly adopted project management methodologies to determine possible areas of improvements to such through the judicious application of Systems Engineering concepts.

The purpose of this research is therefore to:

- (a) Explore the commonly adopted methodologies and their applications to Large Infrastructure Projects (LIPs) – which will be done firstly through a critical review of literature and surveys and interviews; and
- (b) Develop a theoretical Project Lifecycle Management Model (for Large Infrastructure Projects) based on Systems Engineering principles, which would indeed confirm that Systems Engineering concepts are conducive to improving project delivery performance when judiciously applied to complex infrastructure projects. This could be done by,
- (c) Comparing commonly adopted methodologies to the conceptual Project Lifecycle Model to identify area(s) of improvement and any implications to project delivery, should the status quo prevail – and put forward a number of recommendations to address any identified gaps.

1.5 Significance of the Research

Attaining these objectives will afford many benefits to the industry, to the project management community, and to the economy at large as follows:

- (i) It is thus far anticipated that the proposed SE-based Project Lifecycle Methodology, which is to incorporate appropriately selected Systems

Engineering concepts will probably reduce the rate of project delays and costs overruns, with a significant positive impact to the realisation of companies' strategic objectives, financial performance and viability – due to *right* projects (e.g., meeting owners' requirements, aligned to strategy) delivered *right* (e.g., delivered on time, on budget, to quality);

- (ii) Many organisations involved in delivering Large Infrastructure Projects (LIPs) that have adopted and therefore are relying on project lifecycle-based methodologies for the successful delivery of their portfolio of projects could in due course adopt similar enhancements, which would lead to a “mutually beneficial” advancement of project management and Systems Engineering practices, especially in the application of the latter in the particular domain considered in this study; and finally,
- (iii) This research will most probably lead to defining specific Systems Engineering roles and responsibilities by including Systems Engineers as part of the project delivery teams, with clearly defined role and mandate to ensure achievement of project goals.

1.6 Research Method

This study seeks to address issues of effective project management in terms of current practices, procedures, and policies with relevance to successful delivery of Large Infrastructure Projects (LIPs). Therefore, the research method employed hereinafter shall lean toward Applied Research, according to Leedy and Ormrod (2013).

Hence, in answering the Research Question, this study will follow a seven-step Data Analysis Framework (Adapted from B. Sunjka, 2015) as follows:

- (1) Research Question (i.e. Covered under Section 1.3 above);
- (2) Collection of Qualitative and Quantitative Data – gathered through the review of available records, industry surveys, and interviews;
- (3) Research Instrument – an approach consisting of both quantitative and qualitative data (i.e. mixed method) used to describe the phenomenon

under consideration (e.g., the revising of the current framework, which is the objective of this research);

- (4) Data Organisation – primary data collected via surveys (i.e. quantitative) and interviews (i.e. qualitative) will serve in determining the *status quo*; secondary data collected via research papers, industry publications, and project records will mostly serve as a basis for generating *enhancements*;
- (5) Analytic Methods – given the limited access to LIPs delivery entities and the unwillingness to share any details on poor performance of LIPs, this investigation will target owner-organisations and consultants involved in the delivery of LIPs in Southern Africa. Besides, given the *qualitative* nature of responses and dealing with *insubstantial measurements* (i.e. concepts, ideas, opinions, or other intangible entities) a Five-Scale Likert will be used, and a Conbach's Alpha Test will thereafter verify its results for reliability. Moreover, a Delphi Panel will seek to establish consensus among the selected SMEs over the proposed *enhancement* propositions;
- (6) Analytic Results – outcomes of investigation conducted via surveys and interviews are interpreted to clarify their significance in the context of LIPs delivery and, thence, derive *enhancement* propositions (Chapter 4);
- (7) Evidence that the Research Question has been answered (Chapter 7).

The above seven (7) steps of the Data Analysis Framework are adopted to guide the research methodology. Moreover, Chapters 1, 2, and 3 specifically followed the PLD Model (Ellis & Levy, 2009). Accordingly, Chapter 1 clarified the research-worthy problem (i.e. Research Problem [P]), which informed the approach and scope of Chapter 2 (i.e. a valid quality peer-reviewed literature survey [L]), which in turn informed the applicable research approaches covered in Chapter 3 – and the data [D] available to the researcher.

The qualitative nature of this research, it should be noted, particularly lends itself to a Thematic Analysis that “*pays greater attention to the qualitative aspects of the material analysed.*” (Marks & Yardley, 2004, p. 56).

Moreover, the content of the Structured Interview (i.e. where existing theories drive both the questions and one's understanding of the answers) and a

“model-testing” mind-set dictate that “*inductive themes, drawn from the data, are often useful in the new areas of research*”. (Ibidem, p. 58)

It will follow from the above that such “*inductive themes*” shall supplement the primary “deductive” inquiry. Therefore, both approaches of Thematic Analysis (i.e. deductive and inductive) will apply in analysing interviews.

1.7 Ethical Clearance

This research entailed surveys and interviews with project professionals and Subject-Matter-Experts whose input is required to establish the current situation as to the application of Systems Engineering principles and concepts in the delivery of infrastructure projects, as well as for the eventual validation of the proposed enhancements. For this purpose, an Ethics Application for Human Research Ethics Committee (Non-Medical) with the University was duly approved under the University Protocol No H15/0308.

The research was conducted across the project management fraternity in South Africa, particularly those project personnel involved in Large Infrastructure Projects. It was therefore the researcher’s responsibility to conduct such research in an ethical manner according to Guidelines of the University of the Witwatersrand, according to any laws and/or legal frameworks that may apply, and according to the norms and expectations of the Systems Engineering discipline.

A number of channels were used to collect input from research participants:

- (1) Completion of online questionnaires (i.e. industry survey);
- (2) Individual structured interviews (i.e. only for selected participants);
- (3) Individual follow-up questionnaires (i.e. only for selected participants).

While no financial or material interest associated with research participants was anticipated that could give rise to any conflict of interest situations, care was still taken to comply to all ethics requirements as follows:

- (a) Anonymity of participants to be protected at all time;
- (b) Letter of Consent to be attached to the online questionnaires;

- (c) Participants urged not to mention a company name or any information that may compromise its reputation, integrity, or Intellectual Property;
- (d) Whenever any company data (e.g., project records) are used by way of example, names of projects and individuals involved to be concealed.

Hence, this research is deemed to have complied with ethics requirements.

1.8 Scope

This study intends to revolve around project management methodologies (i.e. project processes) as they shall apply to Large Infrastructure Projects and their inherent propensity (or lack thereof) to reach successful outcomes. Technology and human factors will not form part of the scope of this study.

The outcomes of the literature and industry surveys will determine the status quo and will inform the development of an enhanced project lifecycle management model, which will be accordingly validated both against the literature and by a selected panel of Subject-Matter-Experts (SMEs).

Thus, the outcome of this study shall consist of developing an alternative, SE-Based Project Lifecycle Model that will form the basis of methodologies suitable for the effective delivery of Large Infrastructure Projects (LIPs), primarily, and possibly for other types of capital projects, as aptly adjusted. Although most investigations (i.e. surveys, interviews) might be confined to *local* settings, the study will seek to produce outcomes of *global* application.

In addition, experience has established that, beyond the development of an adequate project lifecycle methodology, it is generally a flawed, incorrect deployment across the organisation that constitutes a matter of great peril. Therefore, a particular attention will be given to practical deployment issues (e.g., implementation risks, benefits, and challenges; SE roles on projects) throughout the numerous reviews, discussions, and articulations leading to the development of an enhanced project lifecycle model applicable to Large Infrastructure Projects – Recommendations for future developments and to the industry will be discussed by way of conclusions.

1.9 Limitations

This study concerns itself with inadequacies and possible enhancements to lifecycle methodologies as applicable to LIPs. However, it is anticipated that the very limited number of current Large Infrastructure Projects (LIPs) in the Southern African region (and the general secrecy around their performance and outcomes) might prove a difficult challenge in terms of collecting actual data pertaining to processes applied as well as final outcomes of such infrastructure projects.

In turn, any verification between, on one hand, theories and principles as laid out in the global literature and, on the other hand, the practice and actual outcomes as experienced during the course of project delivery could prove difficult.

Secondly, this research may give rise to the contentious issue of Intellectual Property since many organisations regard project delivery methodologies as an asset and, therefore, may attempt to protect and/or conceal their Intellectual Property or any other competitive-advantage-giving knowledge.

In light of the above, a research approach was adopted that will entail a comprehensive literature review (supplemented with actual project records where available) followed by an industry survey targeting entities and organisations (not necessarily individuals, except where consultants were purposely selected) for their involvement in the acquisition or supply Large Infrastructure Projects (LIPs) across Southern Africa.

1.10 Chapter Outline

This dissertation serves to present both the subject of the research and the outcomes thereof in a logical, structured approach that allows the reader to understand the problem that gave rise to this study, the issues at stake, and the proposed solution, as well as plausible proposals for future developments. To achieve the above, the body of this dissertation will follow this structure:

- 1. Introduction** – *to introduce the purpose (i.e. propose improvements to project delivery), the objectives, and the approach of this research;*
- 2. Literature Survey** – *to determine the challenges facing the project management community, particularly those involved in the delivery of Large Infrastructure Projects, to present the notions of complexity and of Systems Thinking, and to discuss aspects of Systems Engineering that could serve as enhancements to project lifecycle methodologies;*
- 3. Research Methodology** – *to explain the rationale behind the research methodology adopted, the key activities entailed, and their outcomes;*
- 4. Data Analysis and Results** – *to analyse the outcomes of the research conducted by way of surveys and interviews and to interpret the results and establish their significance in the context of project management;*
- 5. Model Development** – *to combine outcomes and results of surveys and interviews pertaining to both the current situation and any possible application of Systems Engineering principles, concepts and practices to discuss and thereafter propose a SE-based Project Lifecycle Model;*
- 6. Model Validation** – *to discuss (and duly corroborate) the desirability, feasibility and viability of the said SE-based Project Lifecycle Model;*
- 7. Discussions** – *to establish to what extent the research question has been answered and the research objectives achieved out of this study;*
- 8. Proposed Future Developments** – *to suggest any areas of research and/or corroboration that might need further development in the future;*
- 9. Conclusions and Recommendations** – *should provide the project management community and the industry with practical advice as to the application of the proposed SE-based Project Lifecycle Model.*

The above nine (9) chapters (each of which is divided into relevant sections) actually constitute three (3) distinct “building blocks” of this study as follows: [A] Model Investigation, [B] Model Development, and [C] Model Application.

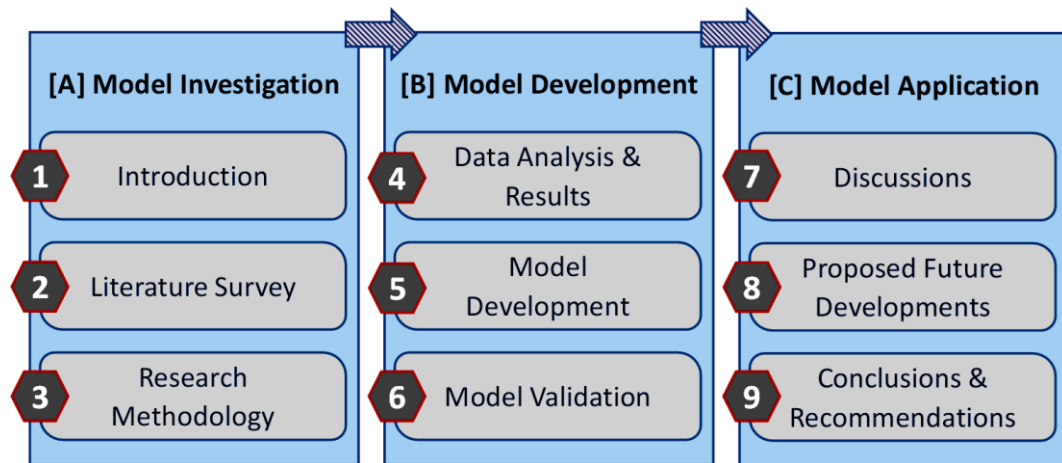


Figure 1.1 – Dissertation Structure: Three (3) Main Parts and Nine (9) Chapters

Chapter 2: Literature Survey

In keeping with the study's research objectives (Section 1.4), this literature review will explore specific theoretical concepts that are foundational to this research. The sections flow down to cover such theoretical concepts ranging from the essence of project management (and challenges leading to project failures due to increased complexity), to the implications of such failures to owner organisations and the inability of traditional project management to cope with increasing complexity, and finally to conceivable contributions of SE in developing enhancements to project methodologies.

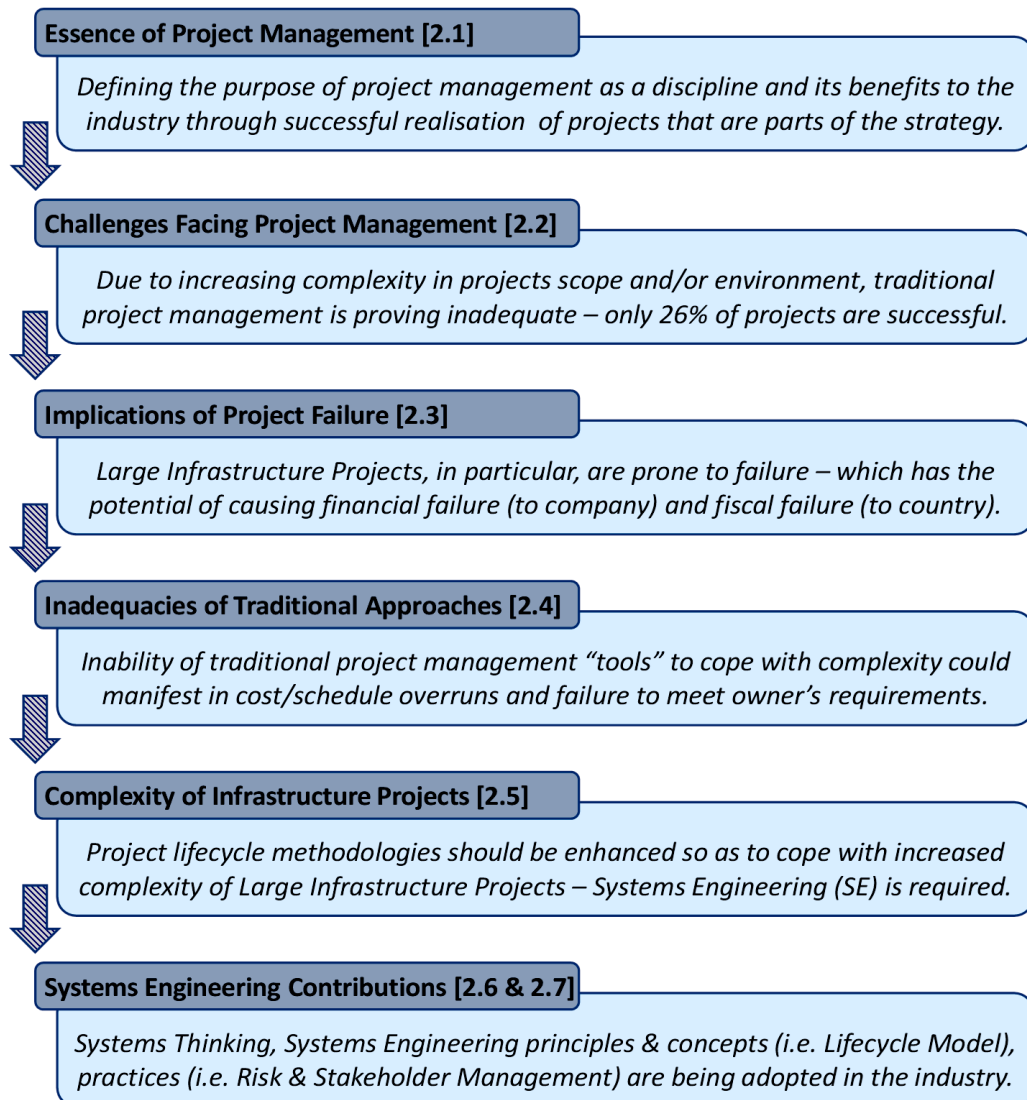


Figure 2.1 – Structure of Literature Survey and Substance of Each Section

The above *configuration* (by way of a flow diagram) allows the structuring of the narrative of this literature review in a systematic manner that links project management to Systems Engineering concepts. It flows from the current project management challenges (such as successfully delivering Large Infrastructure Projects, LIPs) to Systems Engineering concepts and practices that could serve as enhancements to project lifecycle models:

- (i) Essence of Project Management – *As the first section of the literature survey, gives an exposé of project management, its purposes, and its benefits to the industry as a means to strategy realisation. For it was crucial to establish this study in the project management context;*
- (ii) Challenges facing Project Management – *Despite its apparent maturity as a discipline, traditional project management has proven inadequate in the face of increasing complexity in project scope and/or in its environment; only 26% of projects executed are generally deemed successful – hence, the need to propose an alternative model;*
- (iii) Implications of project failure – *Large Infrastructure Projects (LIPs), in particular, are prone to failure and therefore have the potential of causing financial failure (to company) and fiscal failure (to country) – reinforcing the need for an alternative model, particularly for LIPs;*
- (iv) Inadequacies of traditional approaches – *The inability of traditional project management approaches (not necessarily its techniques) to cope with complexity could manifest in cost/schedule overruns and failure to meet owner's requirements. A systems approach is needed;*
- (v) Complexity of infrastructure projects – *In light of the above, project lifecycle methodologies should be enhanced (through incorporation of principles and concepts Systems of Engineering) so as to cope with increased complexity in Large Infrastructure Projects; so finally,*
- (vi) Systems Engineering contributions to project management – *Starting with the notion of Systems Thinking, the research will discuss to what extent SE principles and concepts (e.g., Asset Lifecycle Model) and practices (e.g., Integration, Verification & Validation, Stakeholder Management, Risk Management) are being adopted in the industry.*

2.1. Essence of Project Management

Project management has become a well-known, highly valued profession. *“Since the 1950s there has been acceleration in the development of the theory, literature, and practice of project management. Today there is a sufficient body of knowledge about project management so that this discipline has taken an important position in the lexicon of management and in the practices of modern organizations.”* (Cleland & Ireland, 2002, p. 3)

According to Buttrick (2005), Project Management provides benefits in terms of the following:

- (a) Efficiency of resource utilisation;
- (b) Better scheduling leading to greater certainty of meeting deadlines;
- (c) Recognising the critical activities in each phase of the project;
- (d) Single point of accountability that gives better control and a single point of contact with the client;
- (e) Improved customer responsiveness;
- (f) The ability to handle more complex tasks; and,
- (g) Ensure commitment of the project team to achieve the project goals and objectives.

Despite its fast-paced adoption and the benefits it may have provided, project management is still suffering from a tarnished reputation due to chronic instances of overruns and failures. Large Infrastructure Projects (LIPs) in particular have consistently failed to meet or exceed the expectations of their owners and other stakeholders. (Nevin, 2015)

2.2. Challenges Facing Project Management

A project is commonly defined in the industry’s literature as *“An endeavour in which human, material and financial resources are organised, in a novel way, to undertake a unique scope of work, of a given specification, within the constraints of cost and time, so as to achieve a beneficial change defined by quantitative and qualitative objectives.”* (Kay, 2009, p. 14)

The Project Management Institute (PMI) defines project management as “*The application of knowledge, skills, tools, and techniques to project activities in order to meet project requirements*”. (PMBoK, 5th Ed., p. 5) The key to this definition is the emphasis on “meeting project requirements.”

This point of emphasis appears to be one of the key challenges affecting contemporary project management since modern day projects consistently fail to achieve satisfactory outcomes in meeting stakeholders’ requirements (Chaos Report, 2014) or in terms of meeting such within the constraints of agreed budget, schedule, and scope. (Fox & Miller, 2006, pp. 250-258)

While there is still a debate in the literature as to the definition of project failure, for the purpose of this research the definition of “meeting stakeholder requirements (e.g., strategic or operational objectives) and attaining these within the performance constraints of cost, time and quality” will be utilised.

Hence, for the purpose of this research, Total Success is attained *if and only if* (i.e. *sine qua non* condition) both perspectives are satisfactory; a project completed on time and on budget, but that fails to produce business benefits (e.g. causing losses) is simply a Business Failure (i.e. White Elephant). In practice, however, a project could be deemed “challenged” when it has delivered its intended (business and/or operational) objectives (i.e. the key criteria) ... even though it might have had *challenges* in terms of meeting its original performance targets such as budget, completion date, and so on.

Taking a cue from the definition of project success by Kerzner (2013), this research submits a more comprehensive definition of project failure as follows:



Figure 2.2 – Project Success Failure Grid (by the author)

Whether the concept of failure is approached from a single perspective or from a combined business and performance perspectives (as argued herein), the fact remains that more projects are failing than are succeeding.

Projects are still failing and in big numbers, despite a comprehensive project management body of knowledge (e.g., PMBoK). A report published by the Business Technology Research Center in February 2004 suggests that **90%** of the executives surveyed stated they did not see project success improvements over the past 10 years.

The Chaos Report over the same period reflects:

- 46% of projects are “challenged”
- 28% are outright “failed”
- **26% are deemed “successful”**

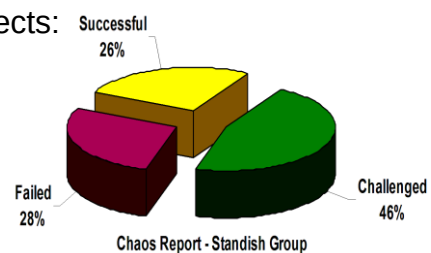


Figure 2.3 – Project Failure Rate (Adapted from *The Prosperus Report*, 2013)

According to the Independent Project Analysts (IPA) 2010 survey covering processing plants (e.g., large chemical and/or thermal processing plants), 23 out of 31 completed projects (with a total Capex of \$ 34 billion) were classified as *failures*; which represents around 74% (worth \$ 25 billion) – The report cited poor/lack of Front-End-Loading as the common cause. In actual fact, Flyvbjerg *et al.*, (2003) contend that project delivery outcome has not improved, but somewhat deteriorated (particularly in terms of cost overrun) over the last century (based on a survey covering megaprojects, also known as Large Infrastructure Projects, executed from 1910 to 2000).

A comparative review of the Chaos Report (Standish) from 1994 to 2009 reveals that there has been no major improvement in terms of project outcomes; by excluding the 1994 data of *successful* projects (16%), the remainder gives a standard deviation $\sigma = 3.5\%$, which indeed suggests that no significant improvement has been recorded thus far ... (as any apparent reductions in failure rate between 1998 and 2002 could be attributed to an heightened focus on project delivery due to the 1997/1998 Financial Crisis – there was a surge in rate of “challenged” projects over the same period).

Fifteen years on, the “causes of project failures” have remained the same (e.g., projects still fail due to reluctance, or inability, to manage Owner’s requirements) – it may seem something *structural* is probably being missed.

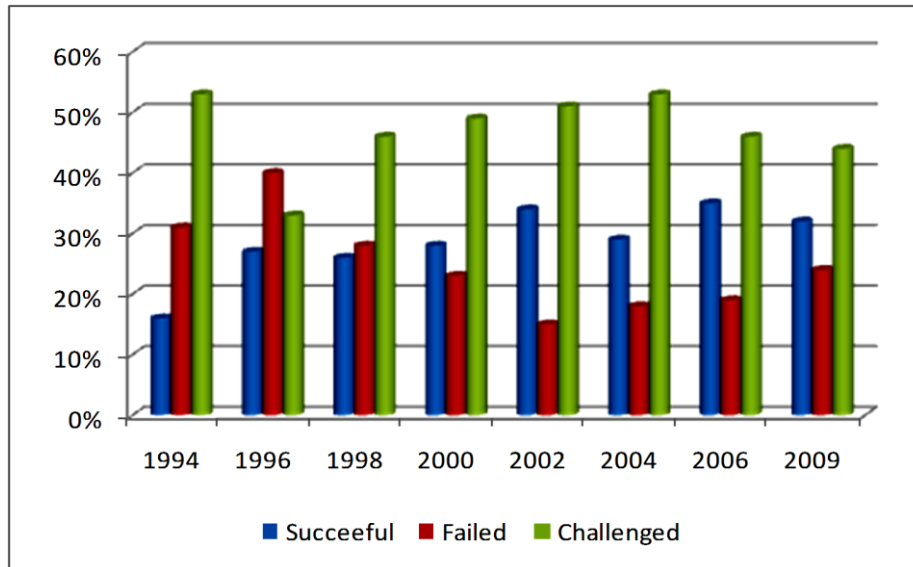


Figure 2.4 – Standish Findings on Project Outcomes Comparison by Year

In fact, a recent PwC “Trends, Challenges and Future Outlook – Capital projects and infrastructure in East Africa, Southern Africa and West Africa” (Nov. 2014) blames Budget Overruns on *inadequate* Project Management.

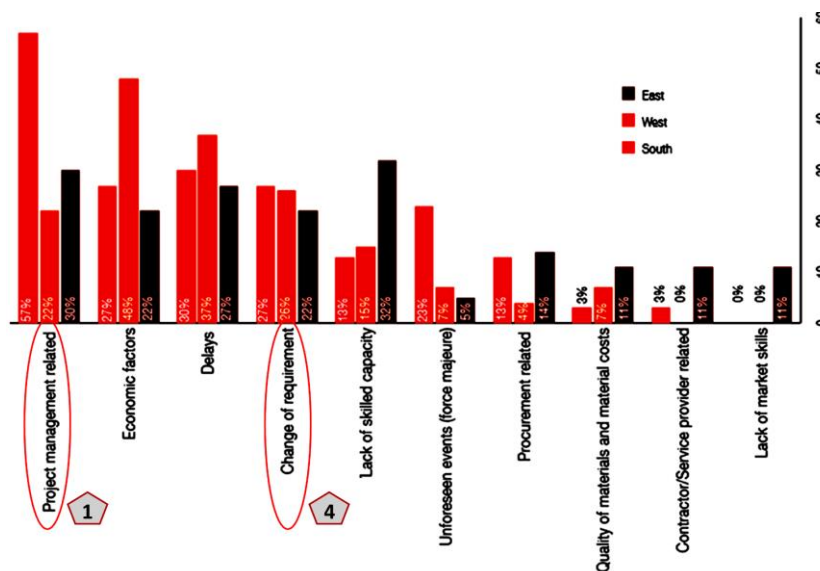


Figure 2.5 – Reasons for Budget Overruns on Infrastructure Projects in Africa

Though items [1] and [4] fall within the project managers’ control, this situation appears beyond their reach – a new *approach* to delivery of LIPs is needed.

2.3. Implications of Project Failure

Despite numerous studies pinpointing the main causes of project failures, not only have projects continued to experience major delays and costs overruns, but many have also failed to deliver any substantial value. For so long, project consultants and other researchers seemed to be focusing on causes of project failure and gave very little attention to its dire implications. Recent trends in the literature, however, have begun filling that *huge gap*, especially in terms of Large Infrastructure Projects because to their impacts to the socio-economic environment of the owner-organisations or host country.

“Infrastructure represents the largest portion of capital investment in any country, and when one considers that on a typical infrastructure project, the construction costs represent about 85% of the total costs, it is reasonable to put some effort into extending the benefits that SE has brought in its traditional domain {of defence, aerospace} to the construction industry and, in particular, to Large Infrastructure Projects.” (INCOSE-TP-2010, p. 29)

Hillebrandt (“Economic Theory and Construction Industry”, 2000) argues that construction makes up to 10% of GDP worldwide and, for example, is the largest industry in the United Kingdom and the second largest, after public health, in Sweden. LIPs contribute to national economy (i.e. GDP growth) both during construction and through their positive outcomes. (US DoS, 2012, p. 1)

The European Commission (EC) in 2003 recounted a need for enormous investments in infrastructure, especially in the countries that had recently joined or would soon join the EU. The EU needed a tool that will help them to monitor and evaluate (ex-ante and ex-post) these projects. (NETLIPSE, 2008) Closer to home, a 2013 KPMG Report suggests that the increase in annual water demand in Sub-Saharan Africa may reach 440 Billion m³ by 2030, a staggering 283% if compared to 2005 – while China or India would only increase demand in volume, therefore in infrastructure capacity, by $\pm 60\%$.

It is no wonder that infrastructure expenditure in Sub-Saharan Africa (SSA) is expected to increase by 10% on a year-to-year basis from US\$ 70 billion

in 2013 to US\$ 180 billion by 2025, with South Africa and Nigeria accounting for the bulk of this expenditure. (Business Report, RSA, Dec 3 2014) Indeed, the 2014 PwC's Capital Projects & Infrastructure in East Africa, Southern Africa and West Africa Report confirms that the global economic slowdown since 2008 had not had a major impact on South Africa's infrastructure spending, with investment in infrastructure growing relatively consistently from an estimated US\$ 7 billion in 2001 to US\$ 22 billion by 2012. Moreover, power generation could be the key priority for infrastructure investment, followed by road and rail transportation (set to grow to just short of US\$ 9 billion by 2015) and sanitation services, according to the report.

Rather than a reason to celebrate, the above facts could simply mean the continent has an opportunity to borrow capital and fund Large Infrastructure Projects (e.g., railway connections, telecommunication cables/lines, power generation and distribution, water and sanitation) to address our challenges. The danger is a high rate of infrastructure project failure (and abandonment) could put Africa in one of the failure quadrants of the Failure Grid (Figure 2.1).

Project failure (when recurrent) have dire consequences for all involved; first and foremost to the project management team themselves, whose job, reputation and morale could suffer harm; secondly, the owner or parent organisations could suffer capital loss, negative equity, forfeited business opportunities, commercial liabilities and lawsuits, or reputational damages.

Moreover, unfortunate series of failed projects – e.g., poor performance and/or schedule/cost overruns turned the *actual* NPV into a negative value, as it was the case with the Channel Canal (Legac *et al.*, 2014, p. 2) – will finally cause financial failure. It may affect the Owner's Income Statement (e.g., operating revenues cannot cover capital repayments and interests, causing losses) and Balance Sheet (e.g., bad investments resulting in liabilities, with not compensating assets). Thus, a country that has invested in a string of "White Elephant" (i.e. unproductive, economically non-viable, albeit politically laudable) or doomed projects will end up in fiscal failure, unable to honour its debt liabilities, with lost opportunities for GDP growth.

2.4. Inadequacies of Traditional Approaches

In numerous attempts to mitigate project failure, academia and practitioners have proposed cures and remedies, including combinations of the following:

- (a) Refining the Processes and Procedures (e.g., Project Methodologies);
- (b) Improving the Tools and Techniques (e.g., PM Information System);
- (c) Developing Competencies and Culture (e.g., Skills and Mind-set); and
- (d) Defining Reporting and Responsibilities (e.g., Project Structures, Roles)

These four elements are derived from the “Three legs of SE Capabilities” that *“... are the major determinants of cost, schedule, and quality: the people in the organization, the technologies/tools that they use, and the processes and practices that are established. This metaphor is useful here as we consider the ways that an organization can improve its systems engineering capability.”* (SE for ITS, 2007, p. 104) – “people” and “structure” are set apart here to discern individual dynamics from group dynamics; structure being *“the sum total of the ways in which the organisation divides its labour into distinct tasks and then achieves coordination among them.”* (Mintzberg, 1979, p. 66)

While the application of these knowledge, skills, tools, and techniques to project activities have led to a degree of standardisation of the profession and a great deal of project successes, the same could not be reached regarding successful delivery of Large Infrastructure Projects (LIPs); many such projects have failed to the dismay of project managers and sponsors.

In terms of processes, a noticeable step in the right direction was in the parting with the *“rush to get the substance of the project under way”* (Meredith, 2009, p. 558) and the adoption of lifecycle-based project delivery methodologies. LIPs industry has experienced a marked increase in the level of awareness of the benefits and of practice of the lifecycle model. Again, this isolated advance has produced very little overall enhancement. (Hoehne, Dec. 2010)

However, the prevailing marginal “overall improvements” would suggest that such interventions, though workable and useful, are not comprehensive to prove effective. It has already been argued that something *more structural* is

being missed – A more systematic approach might be needed to effectively and substantially address delivery issues that are still leading to project failures. *“The importance of the early stages of the systems engineering process is emphasized in most books on systems engineering; it is in taking a holistic view of the project and developing an optimal framework for its execution before any discipline-specific work is carried out that systems engineering makes its major contribution.”* (INCOSE-TP-2010-007-01, p. 53)

It is actually a known fact (as confirmed in “Systems Engineering for Intelligent Transportation Systems”, 2007, p. 12) that *“late changes drive project costs. There is no such thing as a mistake-free project development. In the transportation industry, experienced construction managers will tell you that every project has change orders. The problem is that change orders during construction are more expensive to the project. A mistake or missed system feature that is not recognized until after project closeout will be even more expensive to address. Studies of software development projects have shown that this ‘latency cost’ can increase the cost of fixing a mistake dramatically.”*

Legac et al. (2014) provide a few examples (including the Channel-Canal) and a Mott McDonald Review to arrive at the following conclusion:

“Cost overruns and an extension of time may be avoided ... cost overruns that occur due to poor project management, incorrect planning or errors in design are harmful problems that could have been avoided because they are supposed to predict and try to reasonably prevent.” (p. 23)

Of particular attention is the mention of *“due to poor project management”* and *“harmful problems that could have been avoided”* (above) – which indeed suggests that cost and/or schedule overruns or failures are not beyond cure. Large Infrastructure Projects (LIPs), due to their high complexity, suffer from an *inadequate* project management methodology that allows such missteps. Inserts from the Eurotunnel Report and Mott McDonald confirm the above verdict – Traditional project management is failing to predict and reasonably prevent *adverse system behaviours* that are costly to fix, particularly in LIPs, as they translate into (i) “poor planning” and (ii) “inaccurate business case”:

- (i) The Eurotunnel Channel (Legac et al., 2014, p. 2):
“Estimations of total investment cost amounted to 2.6 billion £ (in 1985 prices). After completion in 1994, actual cost amounted to 4.65 billion £, or 80% more than the forecasted amount ... partly due to the increased traffic security and environmental protection requirements. Financing costs turned out to 140% higher than forecast. The total traffic volume of passenger traffic in peak was 18.4 million in 1998, and then fell to 14.9 million in the 2003. Since then traffic volume rose again to 17.0 million in the 2010. At the time of the decision to build the tunnel, projected number of passengers for the Eurostar trains were 15.9 million passengers in the year of the opening of the tunnel to traffic. In 1995, first full year after the commissioning, actual number of passengers amounted to slightly more than 2.9 million, with an increase to 7.1 million in 2000.”
- (ii) The Mott MacDonald Review (Legac et al., 2014, p. 10):
“Based on the results of the research for the UK Ministry of Finance defined the areas of project risks that will most likely cause overruns if not used in some of the strategies to mitigate risk. In descending order are listed first eleven project risks that are recorded according to the maximum average percentage of contributions by type of project.
- (1) Inaccuracy of business case (58%)*
 - (2) Environmental Impact (19%)*
 - (3) Disputes and Claims (16%)*
 - (4) Economic (13%)*
 - (5) Late contractor involvement in design (12%)*
 - (6) Complexity of the contract structure (11%)*
 - (7) Legislation (7%)*
 - (8) Degree of innovation (7%)*
 - (9) Poor contractor capabilities (6%)*
 - (10) Project management team (4%)*
 - (11) Poor project intelligence (4%) ...”*

Traditional project management is based on “Analytical Thinking”, which is *deficient* in dealing with complexity in Large Infrastructure Projects. Wood and Ashton (2010, p. 1) contend, “*Although a number of systems exists to evaluate construction projects such as risk assessment methods, no system designed specifically to measure and evaluate the complexity of a project at the pre-construction stage exists.*” – This assertion could be quite significant as it might provide a clue concerning the missing system.

They further argue that “*Being able to measure the complexity at an early stage in a project will lead to a better understanding of the project and therefore could be of great benefit in successfully managing projects and reducing the risks associated with complexity.*” (Wood & Aston, 2010, p. 1)

For instance, Mike Stubbs and Alan Knott, who worked on the East London Line Project (ELLP) in the United Kingdom, have had this to say about applying Systems Engineering in delivering complex, large-scale projects: “*The East London Line Project (ELLP) is now well into detailed design and construction stages and the tools and techniques of system engineering have shown their benefits in defining clear responsibilities and the ability to control the Project effectively, particularly in the areas of requirements and change management ... The systems engineering approach adopted on the ELLP is essential for a project of such technical and organisational complexity. The systems engineering and, in particular, the progressive assurance approach engage internal and external stakeholders early in the lifecycle and thereby mitigate the risk of rejection of the product of the Project, the ELL System.*” (Stubbs & Knott, 2008, p. 6)

This leads to the examining of complexity as a cause of project failure, particularly for construction projects (e.g., Large Infrastructure Projects). Since those are large, complex projects, many problems encountered are such that arise in complex systems in general. (INCOSE-TP-2010-007-01)

2.5. Increasing Complexity of Infrastructure Projects

Increased complexity, more than anything else, has contributed to LIPs failure. Maqsood *et al.* (2001, p. 1) concur, *“Construction projects are faced with a challenge that must not be underestimated. These projects are increasingly becoming highly competitive, more complex, and difficult to manage. They become problems that are difficult to solve using traditional approaches.”*

The inherent complexity of LIPs arises from their emergent behaviour. *“A fundamental reason for the difficulties with modern large engineering projects is their inherent complexity. Complexity is generally a characteristic of large engineering projects today. Complexity implies that different parts of the system are interdependent so that changes in one part may have effects on other parts of the systems. Complexity may cause unanticipated effects that lead to failures of the system, and in terms of emergent collective behaviours of the system as a whole. Such behaviors are generally difficult to anticipate and understand.”* (Bar-Yam, 2014, p. 2)

Furthermore, the complexity of a system is usually determined by the number of parts or activities, the degree of differentiation between the parts, and the structure of their connections. Complex systems have multiple interacting components whose collective behaviour cannot be simply inferred from the behaviour of the individual components. (Gould, 1996)

Modern “man-made” systems, and system of systems (SoS), continually increase in complexity. These systems are developed, and increasingly so, by partnerships involving multiple suppliers and developers and, very often, geographically dispersed teams, involving several key stakeholders with conflicting concerns and interests.

Infrastructure projects are complex adaptive systems, which consist of a large number of parts or activities that interact with each other in numerous and various ways – they are *adaptive* since their activities adjust or react to the events of the environment. Successful adaptive systems adjust in a way that facilitates or allows the system or project to achieve its purpose.

In a paper discussing the application of SE to building design, Yahiaoui writes, *“A more focused use of applying systems engineering approach to the building design support is presented in response to the ever-increasing complexity of buildings. In particular, this paper addresses all issues of interrelated dynamic optimisation, as local optimisations do not give a global optimisation. The paradigm used here is to extend and particularly to adapt the work carried out in military and space systems to modern building services by taking into account the semantics of buildings in terms of different engineering fields and architecture issues.”* (Yahiaoui et al., 2006, p. 1)

Having acknowledged that construction projects have become inherently complex and that traditional approaches are no longer suitable to manage them, a number of organisations have looked elsewhere for instruments that could still assist in effectively and successfully managing large and complex infrastructure projects and Systems Engineering has had a lot to offer. (SE for PWW, 2008, p. 7)

Systems Engineering (SE) is an interdisciplinary approach and means to enable the realisation of successful systems – It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, schedule and cost, performance, training and support, test, manufacturing, and disposal. (INCOSE SEH v3)

According to the NASA *Systems Engineering Handbook* (2007), Systems Engineering is *“A disciplined approach for the definition, implementation, integration and operation of a system (product or service) with the emphasis on the satisfaction of stakeholders functional, physical and operational performance requirements in the intended use environment over its planned life cycle within cost and schedule constraints.”* (p. 3)

This provides a departure from traditional project management, which put emphasis on the “construction of a physical asset” as opposed to a “system”

satisfying stakeholders' functional, physical and operational performance requirements in the intended use-environment. Blanchard (2012) further comments that these techniques provide fully integrated solutions for the management of complex projects by capturing the functional requirements and effectively managing them through the project lifecycle.

The INCOSE Infrastructure Working Group has published a Guide for the Application of Systems Engineering in Large Infrastructure Projects in 2012. It seeks to reposition the traditional SE practices, as it has been successfully developed and applied in the military, aerospace, manufacturing and telecommunications industries, into the context of the construction industry and thereby provide professionals engaged in LIPs a convenient and comprehensive access to the relevant parts of the system engineer's toolkit.

The emphasis is, *again*, on using SE *"to better perform the construction stage of a project. The focus is on the realisation of the designed (or engineered) solution during construction and the transition into service of the resulting built product, and as a consequence, the application of SE practices is concentrated more on the construction process than on the design of the product or on the continuing operation and maintenance stage"* (Ibidem, p. 8)

This stance is prompted by the view that in construction projects (e.g., involving highways, railways, electricity generation and distribution, water collection, storage, and distribution, and waste water collection and transfer) the bulk of the capital is spent during "construction" of the unique product. Notwithstanding this logic, the same rationale should also be extended to "design and development" of the same product, where "value" is actually created, although very little capital is generally spent at that Study Stage – This will then suggest that SE should apply to both, to the whole lifecycle. (Morrow, 2011, pp. 4-5)

The application of SE practices throughout the entire lifecycle, to both "design and development" and "construction" is in line with the works of INCOSE Transportation Working Group through the publication of *Systems*

Engineering in Transportation Projects – A Library of Case Studies (2013). The compilation of case studies on Systems Engineering Applications to transportation projects (i.e. Large Infrastructure Projects) has confirmed the benefits of using SE principles and practices, among others, in managing project requirements, risks, and stakeholders throughout the project lifecycle.

Moreover, the INCOSE SE Handbook (INCOSE SEH v3) clearly states, *“Complexity can lead to unexpected and unpredictable behaviour of systems, hence, one of the objectives is to minimise undesirable consequences. This can be accomplished through the inclusion of and contributions from experts across relevant disciplines coordinated by the systems engineer.”* (p. 2.1) – It adds, *“As can be readily inferred from the nature of the earliest projects, the systems engineering discipline emerged as an effective way to manage complexity and change. Both complexity and change have escalated in our products, services, and society.”* (p. 2.5)

2.6. Systems Engineering Contributions to LIPs

In “Science, objective knowledge, and the theory of project management”, Morris (2004) boldly submits that *“Of all the approaches that have consciously sought to bring the rigour of the scientific method to management, that of ‘systems thinking’ has probably been the widest and arguably the most influential. Its impact on project management has been enormous, and illustrates both the possibilities and the limitations of the scientific method.”*

In contrast, *“The South Africa approach to construction industry development (South Africa, Ministry of Public Works 1998: 1-70) has much more emphasis on the basic resources of materials, plant, finance, institutional infrastructure, and human resource education & training. At the same time there is much less regard paid to a culture of thinking the best and behaving the best, together with a learning culture.”* (Fox & Skitmore, 2002, p. 11)

How much of this “paradigm” has changed over the last twenty years or so? If nothing, then improving the South African construction industry will require a *change in thinking* (about LIPs, in particular) on the part of key players for

“... the complexity of construction can no longer be ignored and that the basis for our PM paradigms should thus be redefined.” (Bertelsen, 2003, p. 12)

2.6.1. Systems Thinking and Project Management

Peter Senge (2006, p. 68-69) would concur with Bertelsen (2003) as follows:

"Systems Thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static 'snapshots' ... Today Systems Thinking is needed more than ever because we are becoming overwhelmed by complexity. Perhaps for the first time in history, humankind has the capacity to create far more information than anyone can absorb, to foster far greater interdependency than anyone can manage, and to accelerate change far faster than anyone's ability to keep pace."

The notion of Systems Thinking (ST) relies on the concept of “system”, which is introduced here below by way of definition and scope of application. What is a system and how shall any set of connected systems be treated?

The INCOSE Systems Engineering Handbook (SEH v3, Appendix 8) defines *System* as “A combination of interacting elements organised to achieve one or more stated purposes.” Putting it more simply, a system is interpreted as “A set of related components that contribute to a joint goal in an organised way” – A system can be part of yet another system; thus, the notion of “Systems-of-Systems”.

Systems-of-Systems (SoS) are defined as an “... *interoperating collection of component systems that produce results unachievable by individual systems alone*”. (Krygiel, 1999, p. 33) – The Guide to the Systems Engineering Body of Knowledge (SEBoK, 19 Sep. 2011, p. 697) cautions on SoS as follows: “*While SE is a fairly established field, SoSE represents a challenge for the present systems engineers on a global level. In general, SoSE requires considerations beyond those usually associated with engineering to include socio-technical and sometimes socio-economic phenomena.*”

INCOSE defines the technical processes to invoke throughout the lifecycle stages of a system and to use in establishing requirements for the system as the basis for the efforts to create an effective product or service; to sustain the system through its useful life; and to support retirement of the system. (ISO 15288, the International Standard for Systems and Software Engineering — System life cycle processes, 2015)

ISO 15288 (2015, p. 11) therefore considers “*systems that are man-made, created and utilised to provide products and/or services in defined environment for the benefits of users and other stakeholders. These systems may be configured with one or more of the following systems elements: hardware, software, data, humans, processes (e.g., processes for providing services to others), procedures (e.g., operator instructions), facilities, materials and naturally occurring entities. In practice, they are thought of as products or services.*”

Morris (2004, cited above) has explained that Systems Thinking stems from several routes. Two particularly strong ones are from the following:

- (i) Study of complex organisational entities (systems), as in biology, economics, sociology and organisation theory where new and important characteristics emerge the higher the level of analysis – so called emergence and hierarchy; and,
- (ii) Engineering, in particular from the work related to control and communication (i.e. cybernetics).

Morris (2004) goes on to state that it is the *understanding* of the way systems behave – particularly ‘open’ ones, those that purposefully interact with their ‘environment’ as opposed to ‘closed’ ones, those that do not – which has led to several revealing insights into the way systems organise and manage themselves. For instance, the importance of feedback (as discussed by Ashby, 1956 and Beer, 1972), differentiation (as discussed by Katz & Kahn, 1966), and boundary management (as discussed by Miller & Rice, 1967).

In Morris's view, the impact of Systems Thinking on project management can already be seen, both in 'hard' systems engineering and decision analysis ways (Systems Engineering and Systems Analysis), and in 'softer' areas of organisation development and organisational learning. The 'hard systems' approach is essentially an engineering one about how to perceive, design, evaluate and implement a system to meet a defined need (as discussed by Hall, 1962) and that it is highly congruent with the 'execution' view of project management – or the 'closed' project world of Apollo.

Morris (1997) believes that its influence on the formulation of modern project management terms, practices and approaches has been seminal, as seen earlier, not just because of what NASA, the USAF and USN did with it, but in that it was then so heavily promoted by the Department of Defence (DoD). By the mid-60s, the (hard and decision support) systems approach had given rise to almost the entire vocabulary of modern project management.

Referring to "transformation", increasingly decentralised, and fluid context of the organisation (as discussed by Banner and Gagné, 1995) within which projects are conceived and delivered, Morris (2005) realises an interesting point. The 'execution' view of project management, as indeed witnessed, is being increasingly recognised as not being the full view, and not always even the appropriate view, of the discipline. At the front end of project definition (i.e. Front-End-Loading), for example, we often have quite messy, poorly structured situations, where objectives are not clear, where different constituencies have conflicting aims, and where the way forward requires vision and leadership as well as hard analysis and design.

It would appear that rushing into building the physical asset, particularly under such messy, poorly structured situations might prove disastrous. Incidentally, for such situations was Soft Systems Methodology (SSM) developed. The Soft Systems Methodology actually grew out of the frustration of trying to model the management of the Concorde project within the shifting political context of De Gaulle and Britain's application to join the Common Market. (Checkland, 1999)

In “Soft Systems Methodology – An Introduction” (1994), J. Simonson writes, “SSM was developed in the 1970s by Peter Checkland and others at Department of Systems, University of Lancaster.

Checkland (1999) distinguishes between 'hard' and 'soft' systems thinking within the attempt to use system concepts to solve problems. Hard systems thinking is identified within Systems Engineering (SE), as the totality of an engineering project in the broadest sense of that term; Systems Analysis (SA) is a type of appraisal relevant both to the decision-making which ought to proceed the setting up of any engineering project and to the early stages of such a project once it is started.” (p. 1)

Thus, argues Simonson (1994, pp. 1-2), SE defines the 'need', or the objective to attain, and Systems Analysis (SA) provides an ordered way of selecting the best among the alternative systems that could fulfil that need. Nonetheless, Checkland refers to hard systems thinking as the 'optimization paradigm' while referring to soft systems thinking as the 'learning paradigm'. (Checkland, 1981, p. 258)

Soft Systems Thinking, Simonson (1994) would further argue, has its starting point in 'unstructured' problems within social activity systems in which there is felt to be an ill-defined problem situation. It is concerned not with problems as such but with problem situations in which there are felt to be unstructured problems, ones in which the designation of objectives is itself problematic – This phenomenon is also referred to as “Wicked Problems”.

Green (1999) identifies wicked problems in the building and construction industries {including LIPs} and suggests that the potential of SSM lies in the early stages of a project to assist stakeholders to achieve a “common understanding” of the problem situation. Indeed, Cushman *et al.* (2002, p. 3) observe that “*Construction is ultimately a very complex, multi-disciplinary activity and there is a need to integrate the kind of design and management processes in terms of skill and the knowledge that people bring*”. The ‘learning paradigm’ of SSM could assist in addressing LIPs unstructured requirements.

Maqsood et al. (2003), before giving an overview of SSM, define what wicked problems are: *“Wicked problems typically have a dense web of inter-related factors, making it very difficult to understand how one decision will impact decisions in other areas. This class of problem often exists in dynamic and uncertain environments that generate significant risk.”* (p. 313)

Moreover, Becker (2002) observes that conflict arises from wicked problems where there are competing claims, especially where ‘good outcomes’ are traded off against ‘bad outcomes’ within the same value system.

Soft Systems Methodology may be used to analyse any problem or situation, but it is most appropriate where the problem *“cannot be formulated as a search for an efficient means of achieving a defined end; a problem in which ends, goals, purposes are themselves problematic”*. (Checkland, 1999, p. 316)

Soft Systems Methodology, in its idealised form, is described as a logical sequence of seven steps (Checkland, 1999, pp. 162-183).

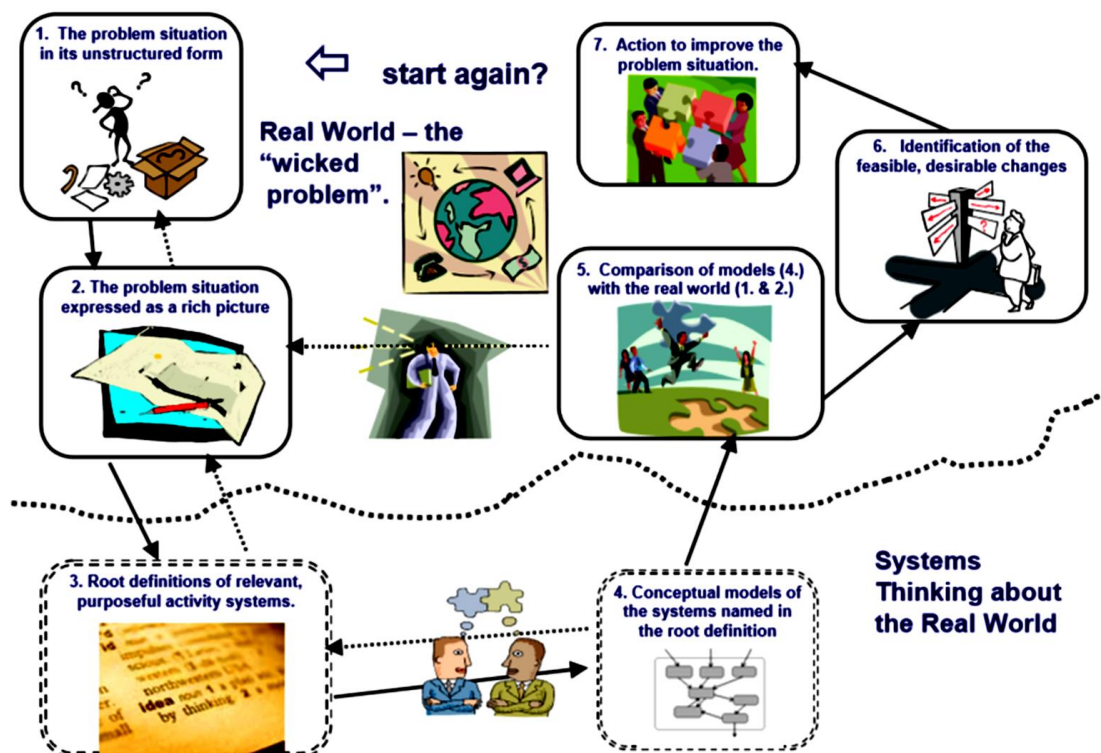


Figure 2.6 – Summary of SSM as a Seven-Stage Process
(Adapted from Checkland, 1999: p. 163, and Checkland & Scholes, 1990: p. 28)

2.6.2. Systems Engineering Concepts and Practices

Flowing from the Systems Thinking (ST) paradigm, Systems Engineering (SE) integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operations to retirement (disposal) of a “system”. Therefore, SE should be viewed as an *extension* to the traditional project development process that is already established. (Ryen, 2008, p. 2)

INCOSE SEH v3 (2008, p. 2.1, citing S. Ramo, “Systems Engineering Manual”, Federal Aviation Agency), argues that Systems Engineering is a discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at a problem in its entirety, taking into account all the facets and variables, and relating the social to the technical.

Thus far, the most comprehensive definition has unsurprisingly come from the International Council on Systems Engineering (INCOSE SEH v3, p. 1.5):

“Systems Engineering is an interdisciplinary approach and means to enable the realisation of successful systems. It focusses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.”

ISO 15288 (International Standard on *Systems and Software Engineering — System Life Cycle Processes*, 2015) identifies four (4) process groups to support Systems Engineering as to its application to the project lifecycle:

(1) Agreement Processes:

Organizations are producers and users of systems. One organization (acting as an Acquirer) can task another (acting as a Supplier) for products or services. The above is achieved using agreements. (ISO 15288)

(2) Organizational Project-Enabling Processes:

The Organizational Project-Enabling Processes are concerned with providing the resources needed to enable the project to meet the needs and expectations of the organization's interested parties. The Organizational Project-Enabling Processes establish the environment in which projects are conducted. The organization establishes the processes and life cycle models to be used by projects. (ISO 15288)

(3) Technical Management Processes:

The Technical Management Processes are concerned with managing the resources and assets allocated by organization management and with applying them to fulfil the agreements into which the organization or organizations enter. The Technical Management Processes relate to the technical effort of projects, in particular to planning in terms of cost, timescales and achievements, to the checking of actions to help ensure that they comply with plans and performance criteria, and to the identification and selection of corrective actions that recover shortfalls in progress and achievement. (ISO 15288)

(4) Technical Processes:

The Technical Processes are concerned with technical actions throughout the life cycle. Technical Processes transform the needs of stakeholders into a product and service. By applying the product or operating the service, technical processes provide sustainable performance, when and where needed, in order to meet the stakeholder requirements and achieve customer satisfaction. The Technical Processes are applied in order to create and use a system, whether it is in the form of a model or is a finished product. The Technical Processes apply at any level in a hierarchy of system structure and at any stage in the life cycle. (ISO 15288)

However, this research will *particularly* focus on “lifecycle” and any other SE “requirement” elements as identified in the ISO 15288:2008 (which are of

most relevance to the objectives of this research) that could be worth incorporating in project lifecycle models for Large Infrastructure Projects.

Firstly, because *SE treats the requirements of the complete lifecycle as core elements* (so as to meet stakeholders' requirements – the *actual* purpose of project management); and secondly, considering as indicated by the [Dutch] Guideline Systems Engineering for Public Works and Water Management (2008) that Systems Engineering has three important aspects as follows:

- (i) Separation of Specification and Design;
- (ii) Verification and Validation; and,
- (iii) The Lifecycle is the starting point.

It shall be noted that both aspects (i) and (ii) are domains of requirements, which leads this research to focussing particularly on those SE elements that govern or relate to project requirements and project lifecycle processes. Figure 2.7 (next page) presents a summary of Systems Lifecycle Processes.

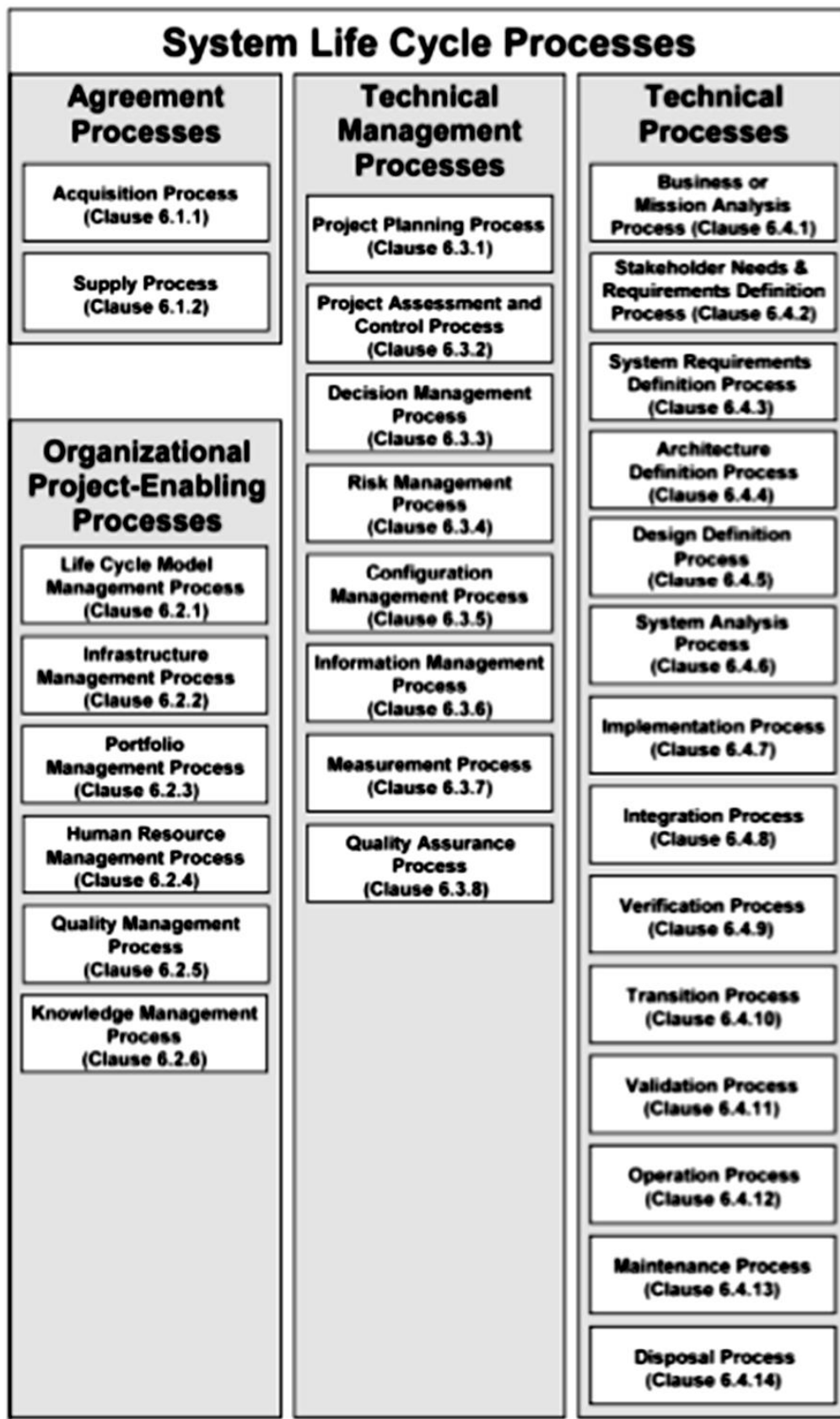


Figure 2.7 – INCOSE System Lifecycle Processes (INCOSE SEH v3)

2.6.3. Project Lifecycle Models

Referring to project lifecycle models, Archibald *et al.* (2012, p. 4) contend: *“A well-documented Project Lifecycle Model enables us to apply Systems Thinking to creating, planning, scheduling, and managing the project through all of its phases, and to evaluating both the success and the value of both the project and results that the project has produced ...”*. Moreover, Archibald *et al.* further maintain that, *“Unless a well-documented, integrated, understandable picture of the overall life cycle process – the model – for each project category/sub-category exists, it will be difficult to achieve the full benefits of modern, systematic project management.”* (Ibidem)

The [Dutch] Guideline Systems Engineering for Public Works and Water Management (2008) suggests that the use of the lifecycle as a starting point is evident in two ways. First, because they apply the systems engineering approach as described to all phases of the lifecycle. Second, this comes to the fore in the way in which lifecycle considerations are included in advance and explicit in the design process as a mandatory element.

Cleland and Ireland (2002) argue that managing a large project (i.e. LIP) is so complex that it is difficult to comprehend all the actions that have to be taken to successfully plan and execute the project. The project needs to be divided into parts in order to grasp the full significance of each part and just where that part fits in the scheme of the project. This requires looking at the project parts, its “work packages”, its logical flow of activities, and the phases that the project goes through in its evolution, growth, and decline – The importance of the project lifecycle in directing the project delivery effort supports the idea of enhancing the lifecycle itself to improve LIPs delivery.

It transpires from the above that the lifecycle model constitutes the basis of any project delivery methodology; therefore, addressing shortcomings and inadequacies in the delivery of LIPs should start by applying enhancements to the project lifecycle itself, as the “racetrack” of the project delivery efforts. This study is thus justified in envisaging an enhanced and SE-based model.

2.6.3.1. Basic Principles of Lifecycle Model

ISO 15288:2008 states: *“A lifecycle model that is composed of stages shall be established. The life cycle model comprises one or more stage models, as needed. It is assembled as a sequence of stages that may overlap and/or iterate, as appropriate for the scope, magnitude, and complexity, changing needs and opportunities.”* (p. 19) – to which the PMBoK agrees as follows:

“The phases are generally sequential, and their names and numbers are determined by the management and control needs of the organization or organizations involved in the project, the nature of the project itself, and its area of application. The phases can be broken down by functional or partial objectives, intermediate results or deliverables, specific milestones within the overall scope of work, or financial availability.” (PMBoK, 5th Ed., p. 38)

PMBoK (Ibidem) further maintains, *“Phases are generally time bounded, with a start and ending or control point. A life cycle can be documented within a methodology. The project life cycle can be determined or shaped by the unique aspects of the organization, industry, or technology employed. While every project has a definite start and a definite end, the specific deliverables and activities that take place in between will vary widely with the project”*.

Cleland and Ireland (2002, p. 44) further argue that using a model of the project’s lifecycle is useful in identifying and understanding the total breadth and longevity of the project and as a means to identify the management functions involved in the lifecycle. A project’s lifecycle contains a series of major steps in the process of conceptualising, designing, developing, and putting in operation the project’s technical performance “deliverables.”

The effectiveness of this argument consists in its referring to “total breadth and longevity of the project” and referring to “putting in operation the project’s technical performance deliverables.” – The above statement suggests that managing projects should extend beyond the *proverbial* handover to operations. The problem with this argument, however, is that many project professionals are still under the impression that the project lifecycle ends at

Closure, where active involvement of the project management team stops, following delivery of the physical *artefact* (e.g., physical asset) to operations.

Citing Wideman (1996, 1999), Bullen (2001) suggests that there should be four sequential time periods through which any project passes, namely, Conception, Definition, Execution and Finishing or Closing. Indeed, Wideman defines a project as “A *novel undertaking or systematic process to create a new product or service that the delivery of which signals completion ...*” (p. 1) Moreover, PMBoK (5th Ed., 2013) states: “A *project life cycle is the series of phases that a project passes through from its initiation to its closure.*” (p. 38)

The below figure (spotted after *project* definition in the PMBoK) might reinforce the wrong perception that projects are all about producing the physical artefact.

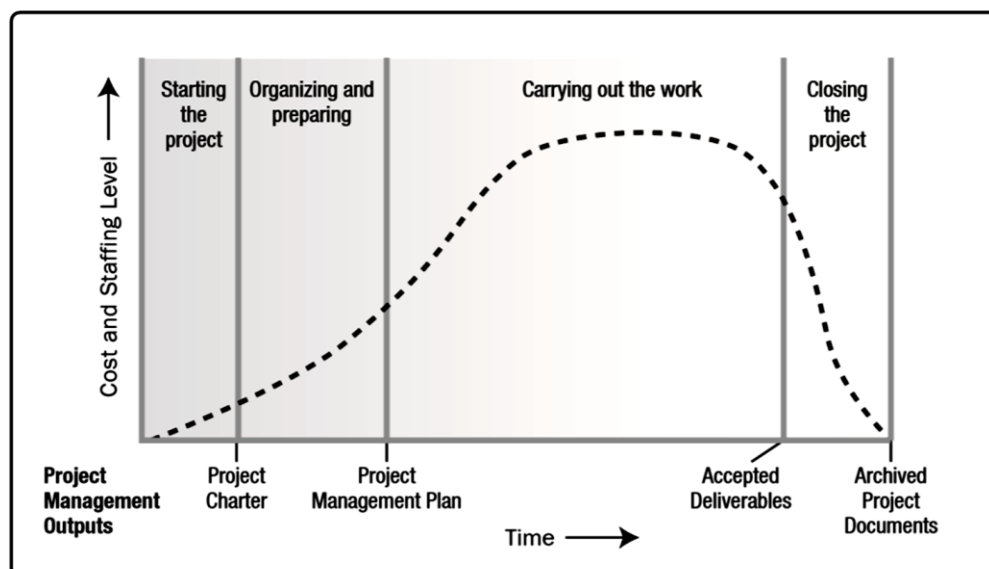


Figure 2.8 – Generic Project Lifecycle Structure (PMBok Ver. 5)

However, PMBoK has taken care to dispel any misunderstanding by adding: “The *project life cycle is independent from the life cycle of the product produced by or modified by the project. However, the project should take the current life-cycle phase of the product into consideration.*” – Operations of the “product” should be considered in the project lifecycle, which dispels any perceived *misalignment* between PMBoK and the SE view of the lifecycle. Indeed, a project ideally stops at the delivery of the new product or service; however, nothing in these definitions precludes from considering operations.

2.6.3.2. Alternative Lifecycle Models

As per ISO/IEC TR 24748-1, the typical system life cycle stages include concept, development, production, utilization, support, and retirement.

LIFE-CYCLE STAGES	PURPOSE	DECISION GATES
<i>EXPLORATORY RESEARCH</i>	<i>Identify stakeholders' needs Explore ideas and technologies</i>	<i>Decision Options</i> – Proceed with next stage – Proceed and respond to action items – Continue this stage – Return to preceding stage – Put a hold on project activity – Terminate project.
<i>CONCEPT</i>	<i>Refine stakeholders' needs Explore feasible concepts Propose viable solutions</i>	
<i>DEVELOPMENT</i>	<i>Refine system requirements Create solution description Build system Verify and validate system</i>	
<i>PRODUCTION</i>	<i>Produce systems Inspect and verify</i>	
<i>UTILIZATION</i>	<i>Operate system to satisfy users' needs</i>	
<i>SUPPORT</i>	<i>Provide sustained system capability</i>	
<i>RETIREMENT</i>	<i>Store, archive, or dispose of the system</i>	

Table 2.1 – Generic Life-cycle Stages, Purposes, and Decision Gate Options (INCOSE-TP-2003-002-03.2.2, 2011)

ISO 15288 (2008) further states that lifecycles vary according to the nature, purpose, use, and prevailing circumstances of the system. Each stage has a distinct purpose and contribution to the whole life cycle and is considered when planning and executing the system lifecycle.

The stages represent the major lifecycle periods associated with a system and they relate to the state of the system description or the system itself. The stages describe the major progress and achievement milestones of the system through its lifecycle. (ISO 15288, 2008)

They give rise to the primary decision gates (refer to 2.6.7) of the lifecycle. These decision gates are used by organizations to understand and manage the inherent uncertainties and risks associated with costs, schedule and functionality when creating or utilising a system. The stages thus provide organizations with a framework within which organization management has high-level visibility and control of project and technical processes. (Ibidem)

The Independent Project Analysts (IPA), a global firm, has been reviewing typically 40 to 60 megaprojects in the course of each year. They arrange their data collection largely in accordance to a staged and gated project work process (i.e. project lifecycle). The “Three-Phase” Front-End-Loading (FEL) arrangement, which is the most common, is shown in the figure below along with the various names widely used by different parts of the industry.

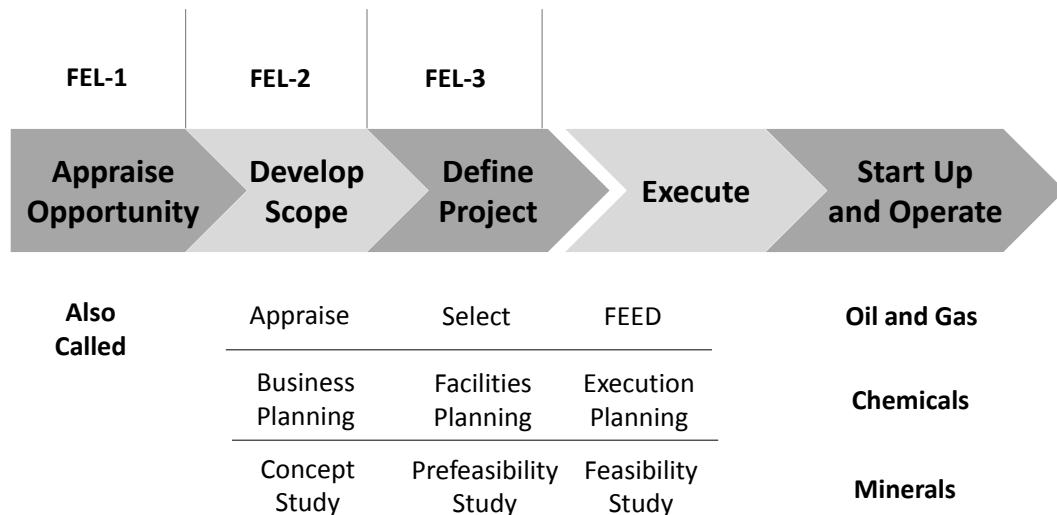


Figure 2.9 – Front-End-Loading Phases (Adapted from Merrow, 2011, p. 24)

The Main Purpose of the various phases of the IPA Lifecycle Model as generally used in the delivery of LIPs could be summarised as follows:

Lifecycle Phase	Main Purpose
FEL-1	Business Case & Capital Feasibility & Options Exploration
FEL-2	Scope (and Option) Selection & Development
FEL-3	Advanced Engineering & Advanced Execution Planning
EXECUTE	Carry-out Planned Works
START UP and OPERATE	Commissioning & Transition to Operations

Figure 2.10 – Front-End-Loading Phases (Inspired: Merrow, 2011, pp. 23-26)

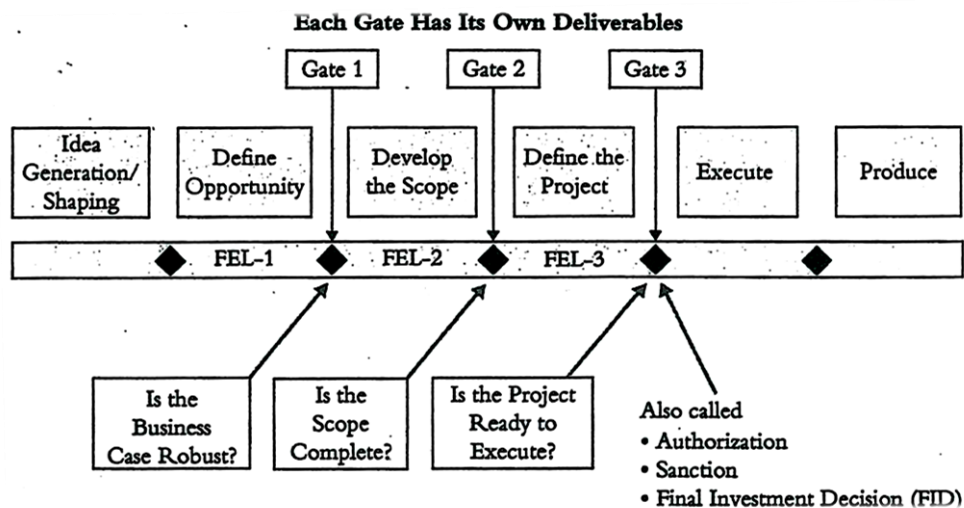


Figure 2.11 – Lifecycle Gateway and Issues (Morrow, 2011, p. 203)

The IPA model, widely used in the large-scale industrial and infrastructure projects scope, could be reconciled with the ISO 15288 Model as follows:

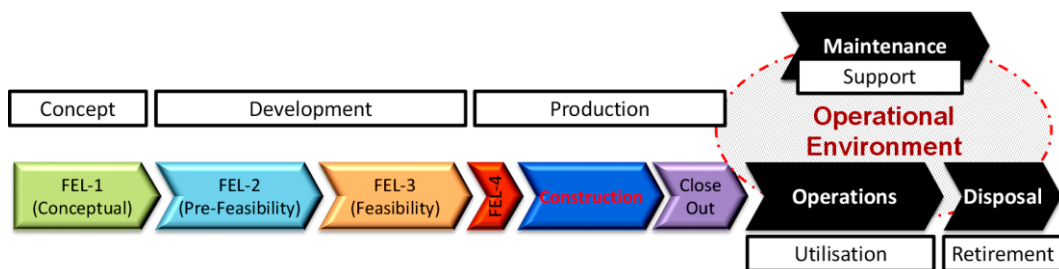


Figure 2.12 – SE-Based Project Lifecycle Model (Adapted from IPA & ISO 15288)

This Model does consider matters pertaining to the operational environment. Indeed, showing a project lifecycle model that closes at "close-out" has led many inexperienced project management practitioners and researchers to believe *whatever happens after close-out and hand-over should not concern them; "By the time the end-item has been delivered and installed, many members of the project team will have lost enthusiasm and be anxious to move on to something new."* (Nicholas & Steyn, 4th Ed., 2011, p. 468) – This has disastrous implications in terms of realising effective systems (e.g., LIPs that add value).

Various lifecycle models such as the waterfall (i.e. the IPA type), spiral, Vee, and Agile development models are useful in defining the start, stop, and activities appropriate to lifecycle stages as per the ISO 15288 requirements.

INCOSE SEH v3 states that using the Vee-Model help visualise the system engineering focus, particularly during the concept and development stages. The Vee highlights the need to define verification plans during requirements development, the need for continuous validation with the stakeholders, and the importance of continuous risk (i.e. threat and opportunity) assessment.

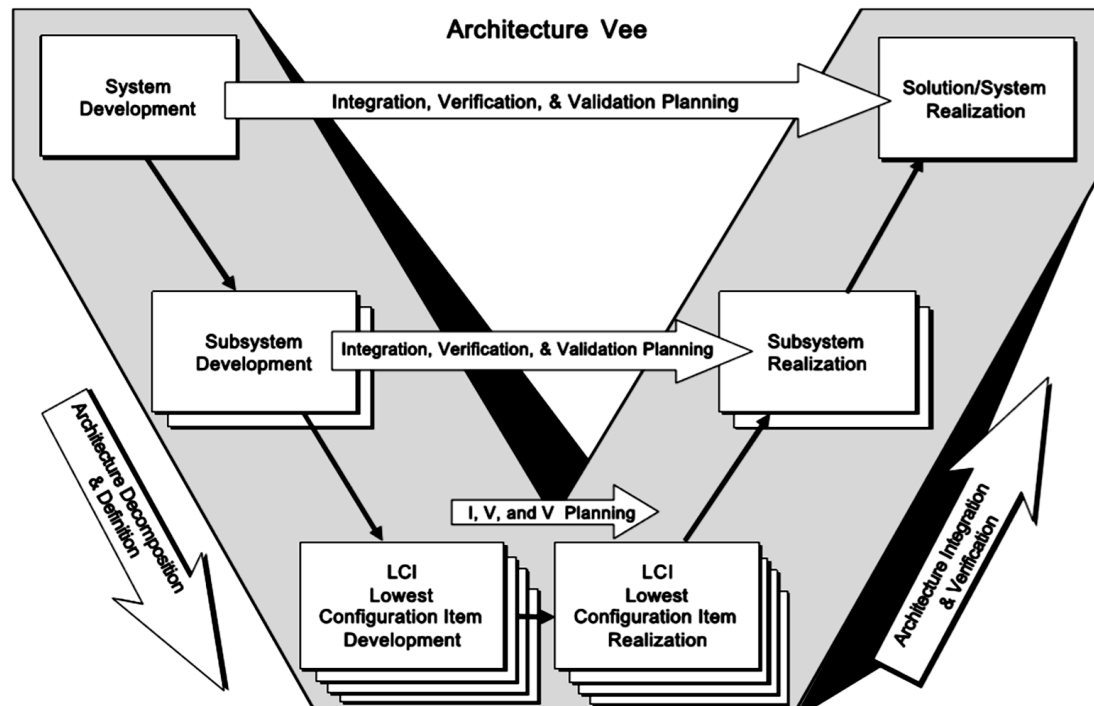


Figure 2.13 – The Vee-Model Structure (Forsberg *et al*, 2005, p. 109)

INCOSE (SEBoK, 2011) further maintains that the Vee Model (where time and system maturity proceed from the left to the right) provides a useful illustration of the Systems Engineering activities during the lifecycle stages. With the Vee Model, project requirements are managed throughout the entire project lifecycle, from elicitation to their incorporation into the new product.

The core of the Vee depicts the evolving baseline from user requirements agreement to identification of a system concept to definition of systems components that will comprise the final product. With time moving to the right and with the system maturity shown vertically, the evolving baseline defines the left side of the core of the Vee. As entities are being constructed, verified and integrated, the right side of the core of the Vee ("V") is being executed. (INCOSE SEH v3) – Hence, the Vee Model can reconcile with the IPA Model.

A common model, which leverages on the Vee Model and was adapted by the Dutch Ministry of Public Works (“Guideline System Engineering for Public Works and Water management”, 2008, p. 62), is increasingly being adopted within the Large Infrastructure Projects industry. It is depicted here as follows:

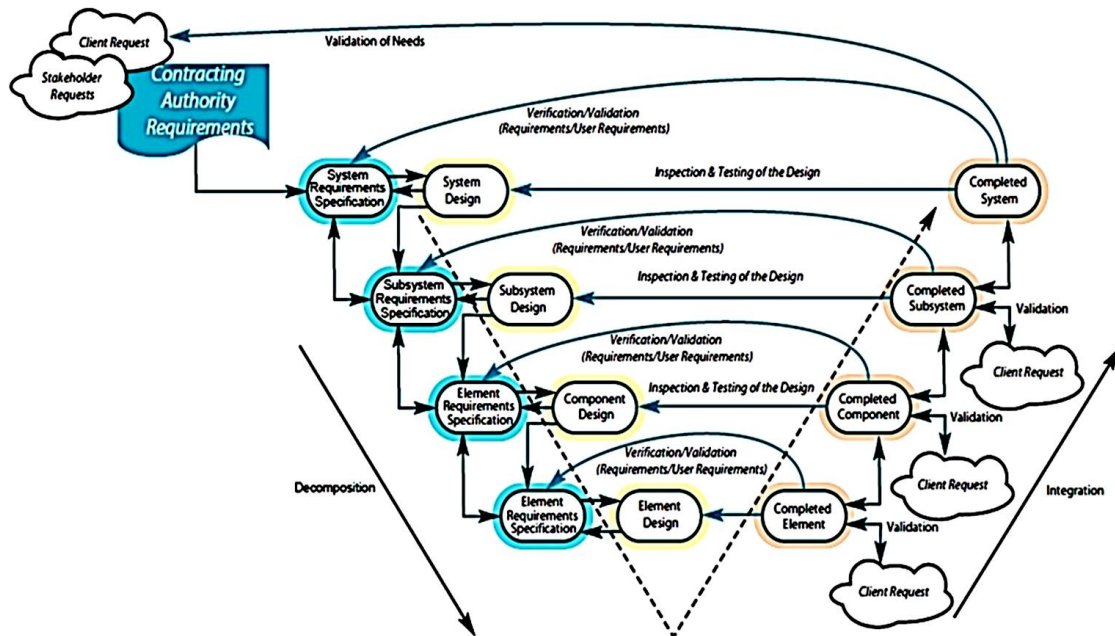


Figure 2.14 – Integrated Vee-Model (Adapted from PWW, 2008, p. 62)

Bersson *et al.* (“Journal of Green Building”, 2012, Vol. 7, No 3, p. 177) observe, “The Vee model has applicability to complex projects that may require technology insertion, concurrent engineering, and incremental development. The steps flowing down the Vee are User Requirements, Functional requirements, Configuration and Technical Specification, and Detailed Design. The bottom of the Vee is System Development and/or Configuration”.

Moreover, the Manual on Systems Engineering for Intelligent Transportation Systems (SE for ITS, US Department of Transportation, 2007) maintains that many different process models have been developed over the years that specify a series of steps that make up the Systems Engineering approach. Among these models, the “V” model is emerging as the de facto standard way to represent systems engineering for Intelligent Transportation Systems (ITS) projects. (SE for ITS, 2007)

Wings have been recently added to the “V” as part of its adaptation for ITS to show how project development fits within the broader ITS project life cycle. The wings are a key addition to the model since it is important to consider the entire life cycle during project development. The left wing shows the regional ITS architecture, feasibility studies, and concept exploration that support initial identification and scoping of an ITS project based on regional needs. The right wing shows the operations and maintenance, changes and upgrades, and ultimate retirement (Disposal) of the system. (SE for ITS, 2007)

With the wings added, the Vee Model now reflects the *holistic* lifecycle for the system being developed, although it does not fully reconcile to the waterfall type to suit Large Infrastructure Projects. (DOE G 413.3-1, 2008, pp. 22-23) However, as shown in the “V”, the Systems Engineering approach defines project requirements before technology choices are made and the system is implemented. On the left side of the “V”, the system definition progresses from a general user view of the system to a detailed specification of the system design. (SE for ITS, 2007)

The following steps in the “V” are for a specific ITS project. The central core of the “V” shows the project definition, implementation, and verification processes. The system is decomposed into subsystems, and the subsystems are decomposed into components – a large system may be broken into smaller and smaller pieces through many layers of decomposition. As the system is decomposed, the requirements are also decomposed into more specific requirements that are allocated to the system components. (SE for ITS, 2007)

Projects have been managed for years using Gantt charts that identify tasks, key activities, and major milestones (Steyn *et al.*, 4th Ed., 2016, p. 107). Thus, the next task should not start until the previous supporting tasks have been completed and passed the intervening milestone. The “V” diagram, likewise, is punctuated by a series of major milestones (labelled in figure 2.15 below as Document/Approval) where the output of the previous step is reviewed and the customer and project team determine whether the project is ready to move to the next step in the process. (SE for ITS, 2007)

The project moves forward only if the criteria for the decision point have been satisfied. Decision points (i.e. Gate Reviews) are important milestones that provide visibility into the project development and allow for issue identification and course correction during development. (SE for ITS, 2007)

An overview of the Vee Model as proposed for the ITS is depicted here below:

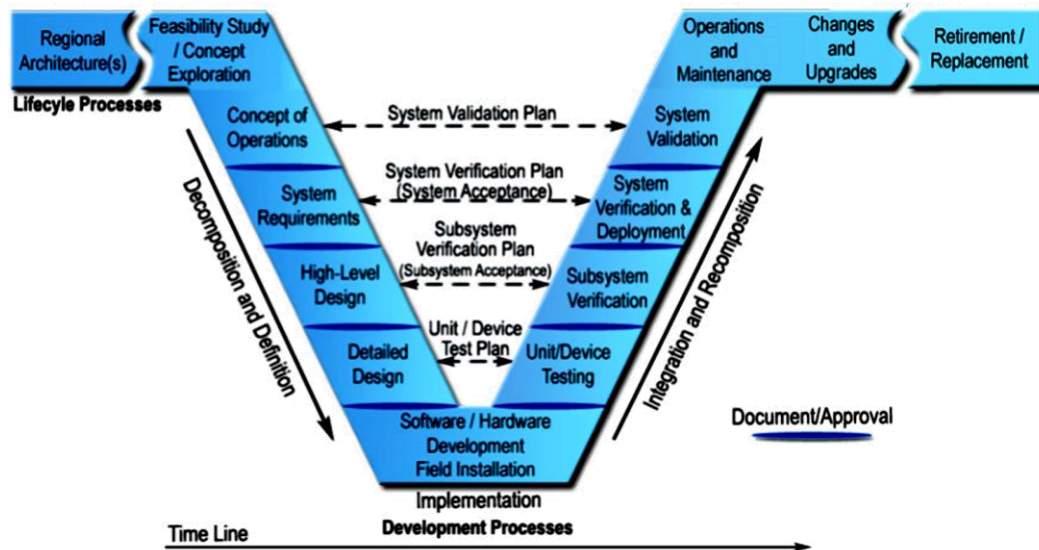


Figure 2.15 – Vee Model Representation (SE for ITS, 2007, p. 11)

2.6.4. Four Domains of Systems Engineering

Zane Scott, in seminal webinar titled “Engineers Behaving Badly” (26 February 2014), is using the Gutenberg Press as an example to introduce the notion of SE Domain and explains that an *effective system* should be developed according to the four Systems Engineering Domains:

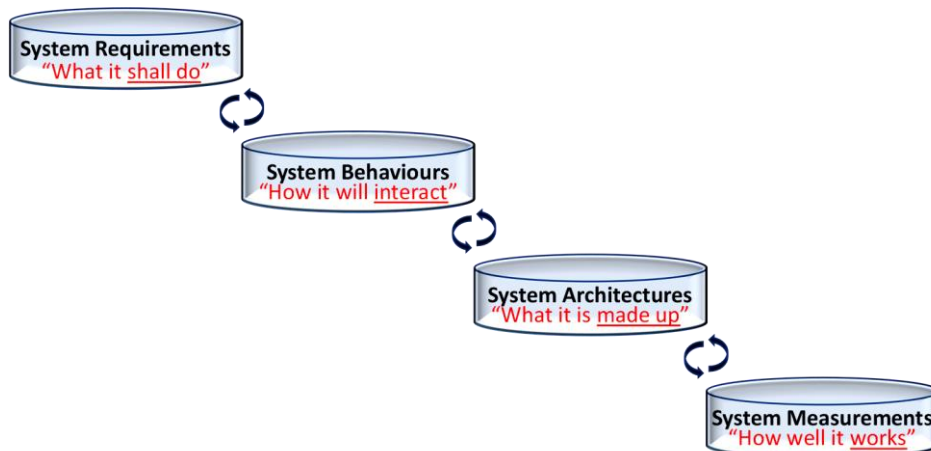


Figure 2.16 – Systems Engineering Domains (Adapted from Scott, 2014)

(1) Requirements – *What the system shall do:*

A requirement is a collection of capabilities originating from users (and stakeholders) that all must be met by the solution to solve the problem or achieve the objectives. The purpose of Requirements Engineering, a discipline at the heart of SE, is to maximise the likelihood that a developed or bought solution or maintenance initiative will deliver solutions that function as desired. (Marnewick, A. *et al.*, 2014)

(2) Behaviours – *How the system shall interact:*

Functional Behaviours allows the synergy (from combinations of such behaviours) that satisfies the needs of the Customer(s). Allocating requirements directly to components will constrain choices and forfeit opportunities of developing innovative, smart behaviours. Therefore, Zane Scott observes that many systems are *behaving badly* because a critical domain of Systems Engineering, the Behaviour Domain, is often neglected or ignored. (Scott, 2014 & 2012, p. 12)

(3) Architecture – *What the system shall consist of:*

Architecture is a collection of fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution. (ISO/IEC 42010:2011)
– Architecture is rather a way in which the behaviours are allocated.

(4) Measurements – *How well the system shall perform:*

Measurements, as a domain, are managed through the SE processes of Verification and Validation discussed under 2.6.6. (Hoehne, 2010 & Estefan, 2008, p. 36)

2.6.5. Systems of Interest (Sol) in Large Infrastructure Projects

According to ISO 15288 (2008, p. 6), a System-of-Interest (Sol) is a “*system whose life cycle is under consideration in the context of this International Standard.*” – The same ISO 15288 Standard (2008, p. 7) further states:

“The perception and definition of a particular system, its architecture and its system elements depend on a stakeholder's interests and responsibilities. One stakeholder's system-of-interest can be viewed as a system element in

another stakeholder's system-of-interest. Furthermore, a system-of-interest can be viewed as being part of the environment for another stakeholder's system-of-interest.”

Accordingly, the characteristics of the Systems-of-Interest (Sol) would be:

- (a) Defined boundaries encapsulate meaningful needs and practical solutions;
- (b) A hierarchical or other relationship between system elements;
- (c) An entity at any level in the system-of-interest can be viewed as a system;
- (d) A system comprises an integrated, defined set of subordinate system elements;
- (e) Humans can be viewed as both users external to a system and as system elements (i.e., operators) within a system; and lastly,
- (f) A system can be viewed in isolation as an entity, i.e., a product; or as a collection of functions capable of interacting with its surrounding environment, i.e., a set of services.

Whatever the *boundaries* chosen to define the system, the concepts in the ISO 15288 International Standard are generic and permit a practitioner to correlate or adapt individual instances of life cycles to its system principles.

All parties in the sector approach projects as a system in itself. This means that they take into account the complete system, as part of a larger system, its lifespan, and all parties involved in the chain. (SE in CES, 2013)

In a Systems Engineering White Paper titled “9 Laws of Effective Systems Engineering” Zane Scott (2012, pp. 11-12) states as Law No 9 – Systems Come in 3s: *“Every system design involves three systems: The system being designed (i.e. Solution-System), the system it will “live” in (i.e. Context-System), and the system used by the team to design it (i.e. Realisation-System).”*

Hence, the complexity of a project could stem from “inherent complexity” of the *Solution-System*, of the *Context-System*, or of the *Realisation-System*.

Scott (2012) gives the example of designing a subway train, right in the middle of the sketch; to the right of the train is the subway system in which it will operate, and to the left is the process chart depicting the design process.

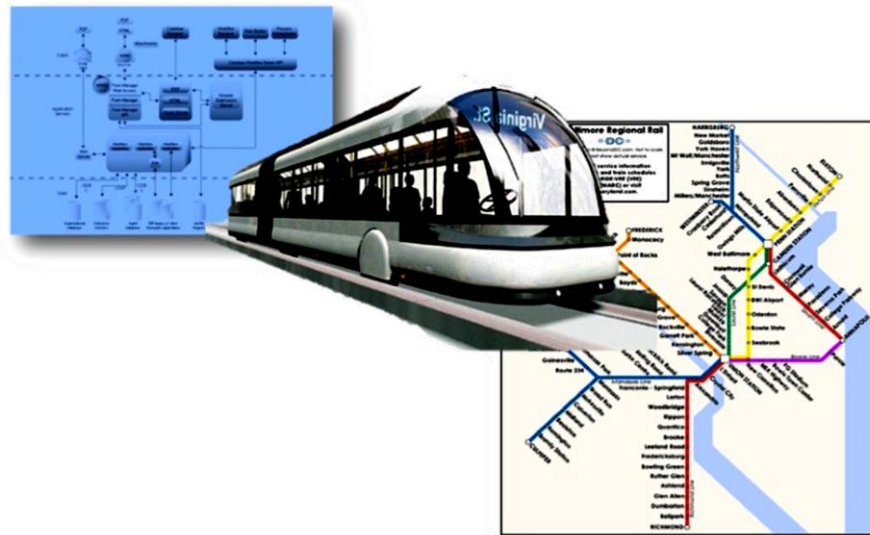


Figure 2.17 – Systems come in 3's – Realisation-, Solution-, Context-Systems
(Adapted from Scott, 2012, p. 11)

While project teams understand that the Solution-System is the purpose of their assignment and efforts, many fail to adequately consider the Context-System (e.g., the requirements of the operational environment), and worse still, most teams do not intentionally factor in the Realisation-Systems. In this specific case, the System-of-Interest to the project team should have consisted of all three systems – a Complex-Adaptive-Systems-of-Systems. *“Complex systems have multiple interacting components whose collective behaviors cannot be simply inferred from the behaviour of the individual component ... The nature of complex adaptive systems can be probed by investigating the impact of change in one activity and the effect on other activities and the behaviour of the whole.”* (Wiley et al., 2012, Chap. 2.4)

James N. Martin has taken this notion further in his seminal paper titled, “The Seven Samurai of Systems Engineering: Dealing with the Complexity of 7 Interrelated Systems”, which he presented at the 2004 INCOSE Symposium. He suggests that the Intervention-System (also referred to as Solution-

System) could actually “morph” into a Deployed-System once installed in the Context-System, which might itself become a Modified-System, and have to deal with a Collaborating-System, and have to contend with a Sustaining-System as well as with a Competing-System.

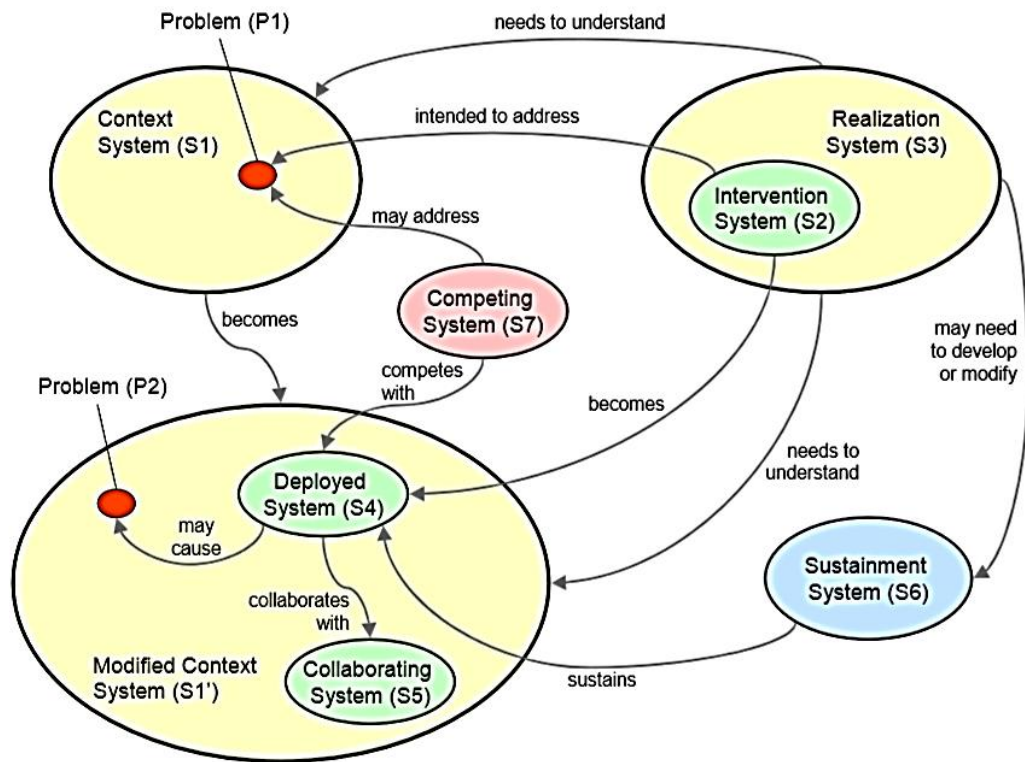


Figure 2.18 – Systems-of-Interest covering Seven Systems (Martin, 2004, p. 11)

The seven System’s constitute a Systems-of-Interest to consider when solving Problem 1 – which in some instances could even create Problem 2. Having explicitly acknowledged and understood the various systems that need addressing when engineering a solution for a complex adaptive situation (e.g., Large Infrastructure Projects), it should be applied in practice. *“Since SE involves the development of new systems and understanding and modelling of its operations, the lessons learnt from applying systems concepts need to be translated to LIPs.”* (INCOSE-TP-2010-007-01, p. 37)

Of equally great importance is his suggestion by Martin (2014) that the Realisation-System (which is required for *delivering* the Solution-System) should encompass the following technical and organisational components:

(1) People & Organisations; (2) Facilities & Equipment; (3) Materials & Supplies; (4) Services & Utilities; (5) Processes & Methods; (6) Tools & Techniques; (7) Policies & Procedures; (8) Data & Information; and (9) Knowledge & Wisdom – yet many an organisation frown upon the latter.

Moreover, a “balanced, strategy-aligned combination” of the above elements will constitute a sound Delivery Infrastructure. (Philips & Gully, 2013, p. 472) Moreover, *“All project delivery systems have three basic domains within which they operate: the project organisation, the project’s ‘operating system’, and the commercial terms binding the project participants. In order for the delivery system to be coherent, the structure in each of these domains must be aligned or in balance”*, especially in construction projects. (Thomsen et al., 2009, p. 11)

2.6.6. Validation and Verification

In the foreword to the Guideline Systems Engineering for Public Works and Water Management, Keijts et al., (2008, p. 5) defined the purpose of the guidelines: *“The trends in the industry require new procedures to structure the activities of all parties. A method to identify what the involved parties can expect from one another and when. A method that furthermore does justice to the criteria that serve as a basis for judging the performance of ProRail and Rijkswaterstaat: products that lend themselves to verification and validation.”*

A key tenet of Systems Engineering, as a part of managing requirements throughout the lifecycle, is Verification and Validation (V&V) processes; the focus being respectively on meeting of requirements and user concurrence. INCOSE (SEH v3) puts the purpose of the Verification Process as follows: *“To confirm that all requirements are fulfilled by the system elements and eventual system-of-interest, i.e. that the system has been built right.”* (p. 4.13)

The Verification Process confirms (using methods such as test, inspection, analysis, and demonstration) that all elements of the system-of-interest perform their intended functions and meet the performance requirements allocated to them – and shall be scheduled, confirmed, with verification enabling systems installed on time. (SEBoK, 2015)

INCOSE (SEH v3) states the purpose of the Validation Process as follows: *“To confirm that the realised system complies with the stakeholders requirements, i.e. that the right system has been built.”* (p. 4.16)

System Validation is subject to approval by the project authority and key stakeholders and the process performs a comparative assessment as a means to determine *to what extent* stakeholders' requirements and defined measure of effectiveness have been duly, correctly translated into technical design specifications and measures of performance.

Verification activities and Validations criteria are determined/selected based on perceived risks, safety, and criticality of the elements under consideration. Therefore, INCOSE (Guide for the Application of Systems Engineering in Large Infrastructure Projects, 2012) recommends that the criteria for validating requirements are specified early in the project lifecycle and, where practical, at the same time as the requirements themselves are defined.

The [Dutch] Guideline Systems Engineering for Public Works and Water Management (2008) provides practical guidance as to how the V&V process should be conducted in the context of Large Infrastructure Projects:

“A system design is prepared on the basis of the specified requirements. After this, the design is verified to determine whether it meets these requirements. In addition, it is validated to determine if it meets the client's requests. The sub-system is assembled from the components and the total system is ultimately constructed. This also involves validation (does the produced system also meet the client's requests) and verification (does the produced system respect the design) ... inspection and testing are the commonly used terms ... carried out on the basis of the design, while the requirements must ultimately be clarified.” (p. 20)

The Guideline for Systems Engineering within the Civil Engineering Sector (SE in CES) advocates commencing V&V processes at the concept phase: *“During the iterative specification process, verification and validation are performed at every level of detail and in all phases of the lifecycle ... It is*

important here to start both verifying and validating as early as possible during the system development. Even before a contract has been signed ... For both verification and validation there is an assessor, a performance method and a criterion ... Such criterion may, for example, consists of a minimum measured value.” (2013, p. 46)

The foregoing, thus, motivates for the inclusion of verification and validation clauses in project delivery contracts to prevent the usual and frustrating contestation resulting from the mismatch of expectations between the contractor/consultant and the project sponsor (or his project manager).

This could assist in instances where the project manager might not be in a position to confirm whether project requirements (as vague as they were) are met – since they were not even incorporated in the actual contract, no legal recourse was sustained, to the dismay of the project sponsor. Integration and verification are iterative processes in which the software and hardware components that make up the system are progressively combined into subsystems and verified against the requirements. This process continues until the entire system is integrated and verified against all of its requirements. This is the opposite of the decomposition that was performed during the Requirements and Design steps, which is reflected in the symmetry between the left and right sides of the “V” in the Vee Model – Components that are identified and defined on the left side of the “V” are integrated and verified on the right. (SE for ITS, 2007)

The same ITS Manual further advises on the validation process as follows: *“Validation really can’t be completed until the system is in its operational environment and is being used by the real users. For example, validation of a new signal control system can’t really be completed until the new system is in place and we can see how effectively it controls traffic. Of course, the last thing we want to find is that we’ve built the wrong system just as it is becoming operational. This is why the systems engineering approach seeks to validate the products that lead up to the final operational system to maximize the chances of a successful system validation at the end of the project.” (p. 71)*

The figures below (adopted from Forsberg *et al.*, 2005) and INCOSE-TP-2010-007-01 depict V&V done throughout the lifecycle as per the V-model.

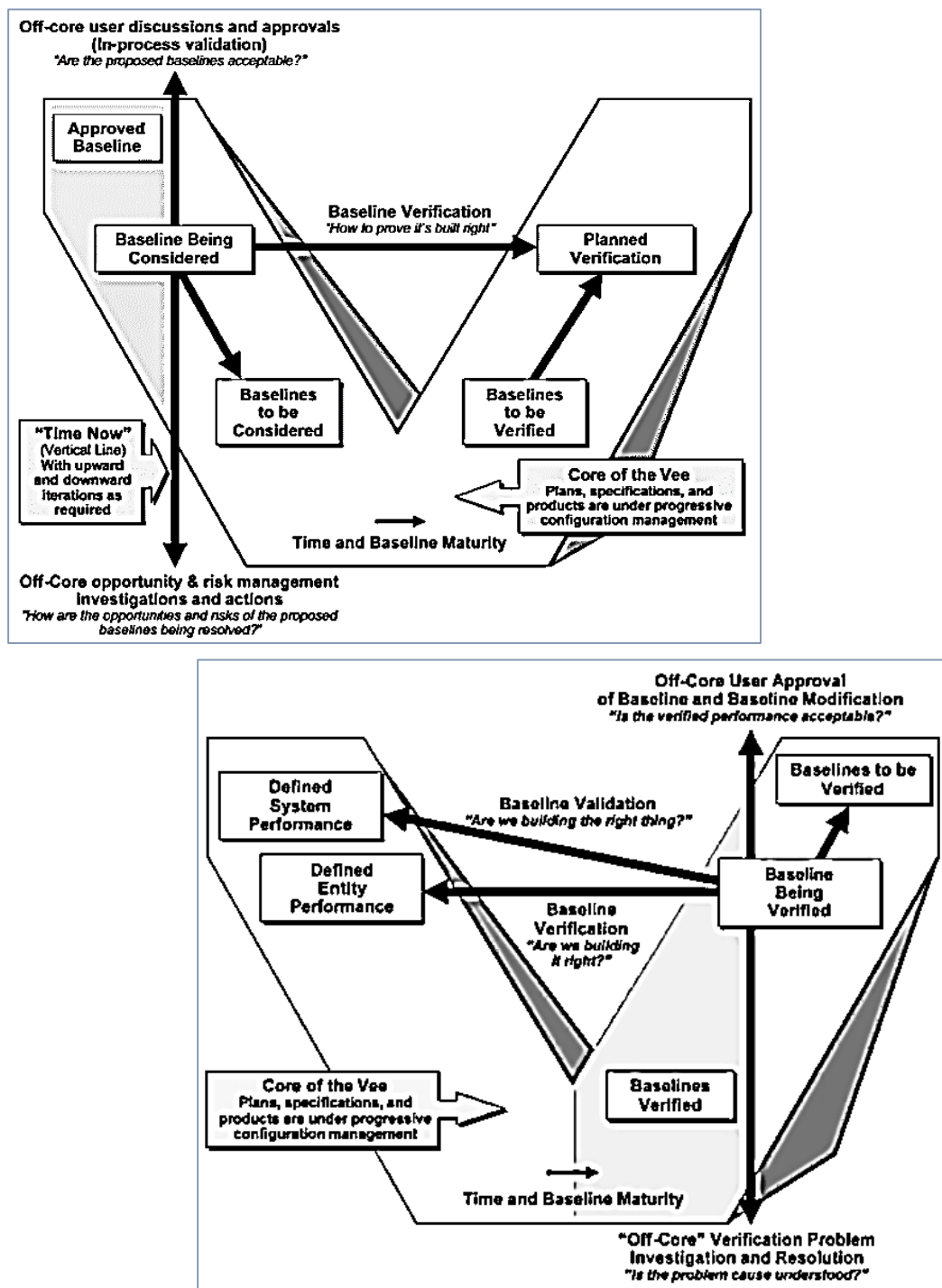


Figure 2.19 – Verification & Validation as per V-Model (Forsberg, 2005)

Hence, the [Dutch] Guideline Systems Engineering for Public Works and Water Management (2008, p. 49) depicts V&V during the Production Process:

The Production Process

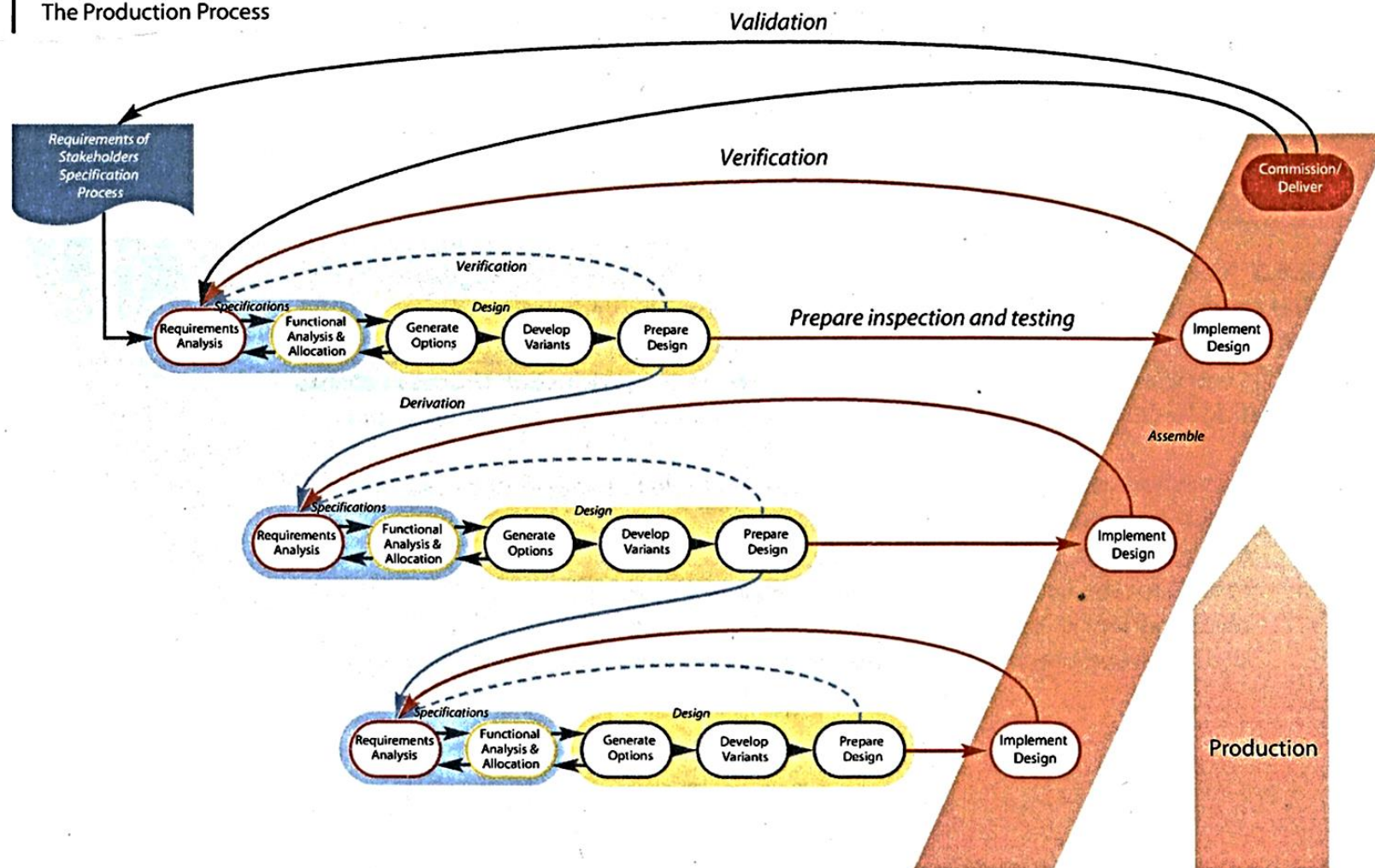


Figure 2.20 – Verification & Validation during Production Process (SE for PWW, 2008, p. 49)

Furthermore, Bahill and Henderson (2004) thus caution against confusing the terms verification and validation as applicable to requirements and systems; they articulate distinct meanings for requirements and systems respectively:

(a) Verifying requirements:

Proving that each requirement has been satisfied. Verification can be done by logical argument, inspection, modelling, simulation, analysis, expert review, test or demonstration.

(b) Validating requirements:

Ensuring that (1) the set of requirements is correct, complete, and consistent, (2) a model can be created that satisfies the requirements, and (3) a real-world solution can be built and tested to prove that it satisfies the requirements. For instance, the project should be stopped if Systems Engineering discovers the customer has requested a perpetual-motion machine (i.e. impossibility).

(c) Verifying a system:

Building the system right: ensuring that the system complies with the system requirements and conforms to its design.

(d) Validating a system:

Building the right system: making sure that the system does what it is supposed to do in its intended environment.

Bahill and Henderson (2004) provide infamous examples of V&V failures:

(i) *“The Tacoma Narrows Bridge was a scale-up of an old design. But the strait where they built it had strong winds: The bridge became unstable in these crosswinds and it collapsed. The film of its collapse is available on the Web: It is well worth watching [Tacoma-1 and Tacoma-2]. The design engineers reused the requirements for an existing bridge, so these requirements were up to the standards of the day. The bridge was built well, so verification was OK. But it was the wrong bridge for that environment, a validation error.”*

- (ii) *“The requirements for the Space Shuttle Challenger seem to be OK. But the design, manufacturing, testing, and operation were faulty. Therefore, verification was bad. Bahill thinks that validation was also bad, because putting schoolteachers and Indian art objects in space does not profit the U.S. taxpayer. Low temperatures caused the o-rings to leak, which led to the explosion of Challenger. The air temperature was below the design expectations, and no shuttle had ever been launched in such cold weather. The political decision was to launch in an environment for which the system was not designed, a validation mistake.”*

In closing, having acknowledged that Verification and Validation (V&V) failures could ultimately lead to systems failure, it is worth noting that assurance that the processes are being followed (which is verification), and that the intention of each stage has been achieved in the subsequent stage of the lifecycle (which is validation) is important. In many project delivery organisations, this is done by way of lifecycle-embedded Gate Reviews.

2.6.7. Gate Review Process

According to INCOSE (SEH v3, 2008), a Gate Review (or decision gate) is an approval event (often associated with a review meeting). Entry and exit criteria are duly established for each decision gate; continuation beyond the decision gate is contingent on the agreement of the decision-makers.

Gate Reviews (GR) are major project reviews and shall be treated as such. *“Project reviews provide a structured and organized approach to reviewing project products to determine if they are fit for their intended use. These reviews are a primary method of communicating progress, monitoring risk, and transferring products and knowledge between project team members. The reviews often occur at the completion of a “V” process step and ITS Project {i.e. Large Infrastructure Projects} Processes represent decision points that must be passed successfully before moving to the next step in the process.”* (SE for ITS, 2007, pp. 85-86)

In keeping with the Project Lifecycle adopted in a particular organisation, an effective Project Governance will entail including specific gates or decision points (e.g., Gate Reviews) that operate in conjunction with governance structures (e.g., capital investment committee) as established in the executive and aligned to the “decision-rights” allocated to such. (Murray, 2011)

Accordingly, projects that no longer contribute value to an organisation should be changed or terminated in a way that conserves the maximum value and the resources reallocated through the portfolio management process to more valuable endeavours – Thus, Project Governance shall link strategy to project portfolio to project planning and delivery to Gate Reviews to existent governing bodies. (Murray, 2010)

Forsberg *et al.* (2005) states that a Decision Gate is a baseline-approval event *embedded* in the project lifecycle, sufficiently important to be defined and included in the schedule by project managers and other stakeholders. Gate Reviews ensure that new activities are not pursued until the previously scheduled activities are *adequately* completed.

Forsberg (2005) defines the primary objectives of Gate Reviews as follows:

- (i) Ensure that the elaboration of the business and technical baselines are acceptable and will lead to satisfactory Verification and Validation;
- (ii) Ensure that the next phase team is prepared, that resources are available, and that the risk of proceeding is acceptable; and
- (iii) Continue to foster “Collaborative Governance” among the project sponsor, the project manager, the Project Management Office.

Forsberg *et al.* (2005) contend that Gate Reviews are *business reviews* (not just technical) and should address the following questions regarding the project under consideration:

- (1) Does it still satisfy the Business Case?
- (2) Is it affordable (e.g., budget to build it, tariff affordable to users)?
- (3) Can it be delivered when needed?
- (4) Will the business be ready to take over and operate it?

Gate Review records from a certain organisation involved in a multi-billion Rand infrastructure programme revealed that despite widespread adoption of a project lifecycle methodology, Large Infrastructure Projects were still underperforming. Analytics conducted on Gate Review outcomes over a 5-year period on a sample of 53 Large Infrastructure Projects totalling R 150+ billion has revealed shocking statistics, which talks to the inadequacy of the adopted methodology to deal with complexity both in projects and in the organisation itself. (Gate Review Analytics, 2014)

In fact, the objectives of the Gate Review (GR) Analytics were to determine:

- (1) Possible reason(s) why so many projects underperform at GRs;
- (2) What project domain(s) are generally underperforming at GRs; and
- (3) What could be done to improve project performance?

The outcome was that for a number of issues ranging from project sponsor rushing over, skipping the execution of FEL-1 and FEL-2 phases to the belief that good Engineering Design at FEL-3 is largely sufficient to ensure

a successful “execution” to critical execution planning elements not being given proper attention crippled performance. Results are summarised here.

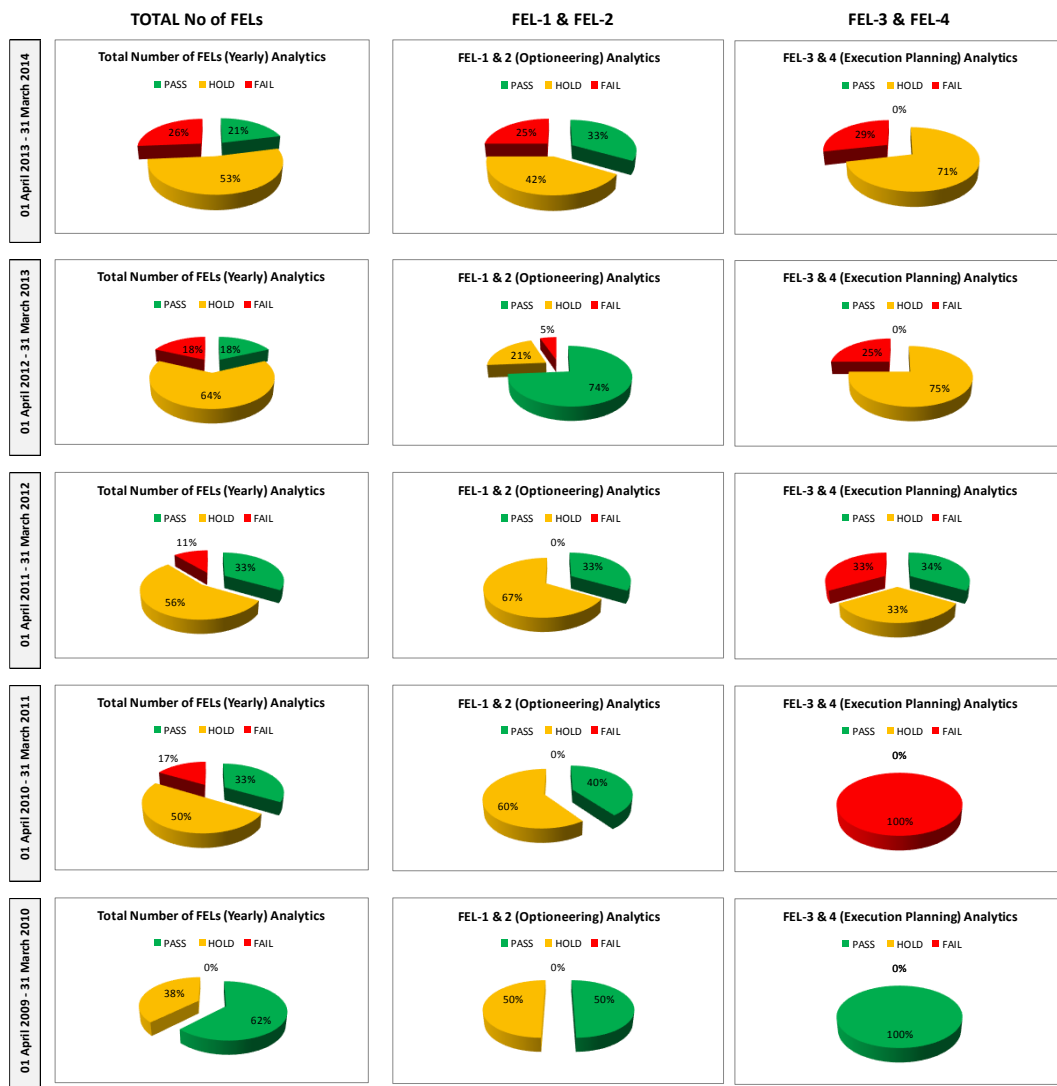


Figure 2.21 – Extract of GR Analytics (Gate Review Analytics @ 2014, showing how very few projects are passing GRs first time [1])

Moreover, a closer look suggests that the focus was more on the “what to build, i.e. design it right”, as opposed to “why should we build it, i.e. building the right system”, or to “how shall we build it, i.e. build it right”. Considering, sadly as it may appear, that the surveyed sample represented almost half of the capital portfolio in terms of Rand value, these results could be inferred across the organisation to suggest that very few projects ($\pm 20\%$) are passing GRs first time ([1] Green Outcome. (Gate Review Analytics, 2014)

In fact no-single project from the sample passed a FEL-3 GR first-time over the last two (2) financial years reviewed; most projects having to re-submit before eventually passing a Gate Review. Addressing shortcomings *after* Gate Reviews entails committing further resources (e.g., time, money and teams) that could have been available to deliver other projects – and adds to the usual costs and schedule overruns. (Gate Review Analytics, 2014)

This kind of situation generally arises from a lack of System Thinking in the organisation and/or from a lack/poor application of Systems Engineering in managing large-scale and complex projects (or in a complex environment). Be it as it may, the consequences to the capital portfolio remain disastrous:

- (i) Delivering projects that may not deliver any value to the organisation, even if they were to be well executed; and
- (ii) Committing sizable additional (capital) resources in correcting project domains that failed to satisfy GR criteria first time.

Once again, this raises the issue of capital loss, negative equity, forfeited business opportunities, commercial liabilities and lawsuits, or reputational damages on the part of the project owner, i.e. the sponsoring organisation. *“Capital investment decisions may be irreversible once production and assembly of the product begins ... Allowing the project definition team more time to expand the solution set with adequate verification and testing of concepts typically lowers the technological, financial, social and political risks.”* (Whelton & Ballard, 2002, p. 6) – A good advice for project sponsors.

The answer to the purposive question of the Gate Review Analysis as to “What could be done to improve project performance?” is therefore quite straightforward: Adopt a System Thinking paradigm (including and starting at the executive level) and adopt a SE-based Project Lifecycle Methodology. The essence of this research shall seek to confirm the wisdom of this advice.

Those who have done so would agree: *“In view of the changing context and the positive experience with systems engineering, the expectation is that the application of this method of work will continue to expand. It is not*

inconceivable that systems engineering in few years time will become the method of choice for delivering projects.” (SE for PWW, 2008, p. 7)

Thus far this insert has proved that Gate Reviews can be used to practically pinpoint the causes of systemic performance deficits due to flawed project methodologies. A full set of “anonymised records” is included in Annexure A.

2.6.8. Risk Management

The Project Management Institute (PMI) in the PMBoK 5th Edition states: *“Project Risk Management includes the processes of conducting risk management planning, identification, analysis, response planning, and controlling risk on a project. The objectives of project risk management are to increase the likelihood and impact of positive events, and decrease the likelihood and impact of negative events in the project.”* (p. 309)

While there is a substantial and growing body of knowledge pertaining to the management of project risks, including in Large Infrastructure Projects, current experience suggests that the widespread misperception as to ultimate aim of a project consisting in the production of its physical artefacts seems to have also misplaced the focus of risk management to construction risks. This flawed view is reflected in many books; for instance, K. Visser wrote: *“The ultimate goal of project risk management is to improve project performance, i.e. to supply the correct deliverables on time and within budget.”* (Steyn et al., 2016, p. 375) – Thus, delivery organisations got the wrong cue.

Risk and opportunity management is a disciplined approach to dealing with *uncertainty* that is present through the entire lifecycle. (INCOSE, 2006, p. 5.9) In fact, risk being the *effect of uncertainty on objectives* (ISO 31000 Standard), contemplating the wrong objective (e.g. ultimate goal of Risk Management) as K. Visser (and many others) did might have rendered futile the whole exercise.

Extracts (summarised in the table below) from a major local company (say, MaxCoal – real name concealed for confidentiality reasons) involved in delivery of large infrastructure projects indeed reflect similar inadequacies.

PROJECT LIFECYCLE GUIDELINES					
DELIVERABLES STATUS					
	DELIVERABLE	FEL-1 CONCEPT STUDY	FEL-2 PRE- FEASIBILITY STUDY	FEL-3 FEASIBILITY STUDY (Includes Basic Engineering)	FEL-4 IMPLEMENTATI ON (Includes Detailed Engineering)
RISK MANAGEMENT					
	Project Risk Management Plan (PRMP)	Not Started Formal risk management plan not required at this stage.	FEL-2 - PRMP Includes risk management activities, deliverables, resourcing an responsibilities for the FEL-2	FEL-3-PRMP Implementation PRMP typically upgraded from FEL-2 – includes both overall project risk and technical risk management for the project.	FEL-4-PRMP
	Schedule Risk Profile (SRA = Schedule Risk analysis completed using Pertmaster)	Not Started Not typically required at this stage.	FEL-2 Schedule Risk Profile Use either 1) Schedule risk profile form a SRA or 2) Best, most likely and worst case schedules to assess schedule contingency	FEL-3 Schedule Risk Profile Thorough SRA to assess schedule contingency and treatment plans to control schedule risk.	N/A
	Capital Cost Risk Profile	Not Started Not typically required at this stage	FEL-2 Capital Risk Profile Quantitative risk profile of capex based on estimate uncertainty and potential discrete risk events to get P10, P50 and P90 as input to contingency	FEL-3 Capital Risk Profile Quantitative risk profile on capex based on estimate uncertainty and potential discrete risk events to get mean, P10,P50 and P90 as inputs to contingency and target budget.	

Figure 2.22 – Lifecycle Risk Management Requirements at “MaxCoal”
(showing key Risk Management elements as “Not Started” at Concept Study)

The above extract from a local project delivery organisation involved in LIPs reflects crucial and strategic project risk aspects (such as project risk management plan, schedule risk, capital cost risk) as “Not Started” or “Not typically required at this stage” at the concept stage, where such matters should precisely be discussed to inform the shaping of the project. (This could be expressed in terms of operational risks that inform the Concept Study.)

Even so, the INCOSE (SEH v3, 2008) refers to such issues as *Programmatic Risk*, meaning, such that are produced by events that are *beyond* the control of the project manager. These events often are produced by decisions made by executive-authority personnel (e.g., changes in enterprise or national objectives, in project priority, approval delays, reduced/delayed funding).

Then again, the NETLIPSE Report (2008) recommends (under Findings 6.6.7) that Risk Management should be made part of regular management routines, stating, *“Risk analysis should not be an abstract tool, but instead should be seen as a main-stream management task. The research has shown that a systematic approach, right from the start of a project, gives insight into causes and effects of events and allows for more effective control ... The management promotes risk management in order to create the necessary ‘risk awareness’ and attitude.”*

The mention of *“systematic approach”*, *“right from the start of a project”*, and *“in order to create the necessary ‘risk awareness’ and attitude”* shall indeed be noted; all these phrases are calling for a Risk Management emphasis right from the start of the project – Why would project managers still frown upon it?

In fact, the current PMBoK definition of Risk Management (above) is in itself problematic as it conspicuously fails to mention any “effecting” of the Risk Response. This has led to situations where risks are identified and analysed, but the “planned response” is never effected, integrated into core project tasks. Numerous instances of a “laminated” Risk Register (thus, its mitigating actions could not be updated, executed or followed up) may testify to this poor practice. Risk Response activities must be executed with same rigor as any other tasks.

Hence, Merrow (2011, p. 322) states, as an admonition to many project teams: *“Exercises that sensitise team members to potential problems down the road must surely be worthwhile. But we all must remember that the very basis of risk management is sound basic practice around things such as business objectives, team staffing and integration, and thorough FEL. In the absence of those things, layering on risk management practices is a futile exercise.”*

Therefore, since these issues could actually generate technical, cost and schedule risks, project managers are encouraged to consider such topics. Accordingly, after having noted that “Identify Operational Risks” (red-circled in figure 2.23) occurs at early stages, the aligning of Risk Management practices on Large Infrastructure Projects with SE could rely on a Vee-Model as follows:

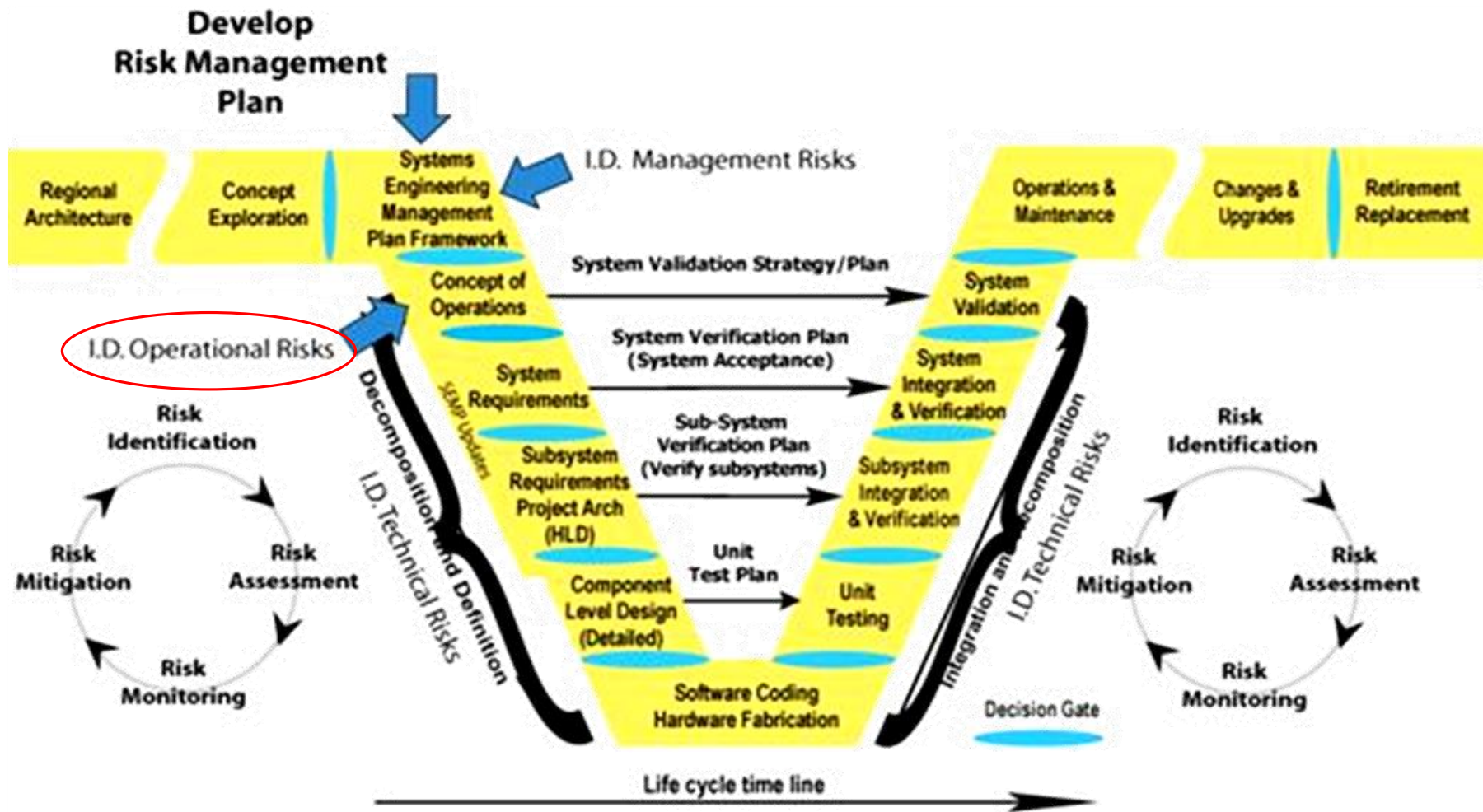


Figure 2.23 – Risk Management Process as per Vee Model (FHWA, p. 3.9.4)

Marcel Hertogh, the NETLIPSE Project Manager, asserts that as important as implementing a risk management that focusses on threats may be, it is not sufficient. Risk management should also focus on opportunities, which are the result of interacting with relevant stakeholders. (NETLIPSE, 2008)

In fact, Project management is all about pursuing an opportunity to solve a problem or fulfill a need. Opportunities enable creativity in resolving concepts, architectures, designs, strategic and tactical approaches, as well as the many administrative issues within the project. It is the selection and pursuit of these strategic and tactical opportunities that determine just how successful the project will be. (Forsberg, 2005)

Furthermore, having acknowledged the implications and benefits of considering the whole Systems-of-Interest (refer to 2.6.5), it will certainly prove useful applying Risk Management processes and activities not only throughout the lifecycle, but across the Systems-of-Interest as well.

2.6.9. Stakeholder Management

A stakeholder is any entity (individual or organisation) with the legitimate interest in the system. Typical stakeholders include operators, enterprise decision-makers, parties to the agreement, regulatory bodies and society-at-large. (INCOSE SEH v3, 2008)

The NETLIPSE Report remarks, *“It is clear that stakeholders should be seen as very important by project delivery organisations, not least because of the adverse impact that stakeholders can have on the timescales for achieving the consents and approvals for work to commence.”* – However, *“... only in limited cases from the projects researched was stakeholder management seen to be a pro-active and longer term priority.”* (pp. 44-45)

The construction industry has largely not adopted Stakeholder Management (SM) in its arsenal. *“Construction projects are traditionally viewed as highly mechanistic, deterministic endeavours. Successful construction practice revolves around tightly controlled labor, materials, equipment, and processes*

... there is ample evidence that LIPs struggle with the increase in complexity due to such factors as ... complex relationships between numerous project participants, community concerns ...” (INCOSE-TP-2010-007-01, p. 35)

This could have arisen from a number of “Stakeholder Management Myths”, as often witnessed by project personnel involved in project delivery:

- (1) SM is covered as part of Environmental Impact Assessment process;
- (2) SM is done through the Communication Plan, as per a usual template;
- (3) Stakeholders are, and behave in the same manner, in most projects;
- (4) Stakeholders are essentially external to the project environment;
- (5) SM is an add-on task (done by a 3rd party), not part of core delivery;
- (6) SM is required in view of, and during construction activities; hence,
- (7) SM is primarily the responsibility of the Contractor.

Many in the industry have reduced SM to a mere communication scheme. Owing to the above *misplaced* practices, Stakeholder Management is hardly seen as a vehicle for gathering project input (i.e. stakeholder requirements) and consensus-building among various stakeholders across the Systems-of-Interest, and across the entire project lifecycle – and as a support process to Risk Management in *identifying opportunities* and in *reducing risk of project rejection* through continued engagement with relevant stakeholders.

“Successful projects involve the customer, users, operators, and other stakeholders in the project development ... The systems engineering process includes stakeholders through all stages of the project, from initial needs definition through system verification and acceptance ... with an opportunity to contribute to the steps in the process where their input is needed.” (Ryen, 2008, p. 3)

“One of the first things that a project manager should therefore do is to identify all the stakeholders, determine their needs as well as their expectations, and resolve conflicts. If this is not done, a large number of disruptive changes could be expected at a later stage.” (Steyn et al., 2016, p. 65)

2.6.9.1. Stakeholder Management for a Systems-of-Interest (Sol)

The effective and successful execution of the Stakeholder Management process is a major component of any construction project and the handling of the numerous elements and their interactions as a system rather than individually offers significant advantages. (INCOSE-TP-2010-007-01)

Such interactions are considered not only in and around the Product-System, but should equally (or more importantly) be addressed in any other system(s) that may affect the performance of the Solution-System. (Fryer, 2016)

Hence, the SEBoK Portal states: *“Stakeholders of a Sol may vary throughout the lifecycle. Thus, in order to get a complete set of needs and subsequent requirements, it is important to consider all stages of the lifecycle when identifying the stakeholders or classes of stakeholders.”*

Merrow (2011) gives the example of a serious illness for the local population that was not identified and mitigated to explain how *“the failure to identify a set of stakeholders can have tragic implications”*. (pp. 84-85). Indeed, history suggests that the first real attempt to build the Panama Canal was by the French (1880), led by Ferdinand de Lesseps using the experience from the Suez Canal (i.e. successfully completed in 1869). The attempt, however, was cancelled in 1893 due to high death rate due to Yellow Fever and Malaria among workers, resulting in huge losses for the private and public investors.

2.6.9.2. Stakeholder Management and Requirement Formulation

It would transpire from NETLIPSE (2008), Ryen (2008), and Steyn (2016) that Stakeholder Management has two-fold, somewhat intertwined purposes:

- (1) Securing relevant input (and validation) into project delivery processes;
- (2) Securing support for a winning coalition on the part of various role-players within the project environment.

Both purposes contribute to creating a sound, solid project for most people (i.e. project stakeholders) would only support what they have helped create.

The purpose of the Stakeholder Needs and Requirements Definition activity is to elicit as set of needs related to a new or changed mission {project} for an enterprise, and to transform these stakeholder needs into clear, concise, consistent, and verifiable stakeholder requirements. (SEBoK: 2015)

The set of stakeholders' needs, desires, and expectations may contain vague, ambitious, and qualitative *user-oriented* needs statements that are difficult to use for SE activities. These statements (of needs) may need to be further clarified and translated into more *engineering-oriented* language to enable architecture definition and requirement activities. (SEBoK: 2015)

The Owner's Requirements Specification is a vehicle for the Owner(s) – and key stakeholders, as identified – to provide a complete, clear, unambiguous statement of the Owner(s) requirements in measurable terms, and a key source document in setting the project context and the required commercial outcomes. (SE in CES, p. 13)

The ORS should be “updated” after each FEL, and shall serve as a *frozen* input to the next FEL Phase, reflecting both System Requirements (WHAT is required) and Process Requirements (HOW it is required) items, if necessary. Hence, stakeholders play a major role in System Validation. (SE for ITS)

Requirement Formulation entails three activities (Marnewick, A. *et al.*, 2014):

- (1) Transforming unclear needs into a complete system specification;
- (2) Transforming informal knowledge into formal representation;
- (3) Securing a common agreement on the specification (i.e. from the various personal views, emanating from relevant stakeholders).

Unfortunately, industry itself is still facing many challenges in practice with Requirement Formulation processes during the delivery of a solution. Industry reports, surveys and research are continuously alluding to poor requirement as the main contributor to failed projects (Schwaber, 2006), along with the cost and rework implications of requirements errors (Marnewick, A. *et al.*, 2014); Requirements Elicitation is an iterative activity and benefits from continuous communication and validation with relevant

stakeholders. Techniques for Requirements Elicitation include interviews, Focus Group, Delphi Technique, and Soft Systems Methodology (SSM), according to INCOSE (SEH v3, 2008).

2.6.9.3. Use of Soft System Methodology (SSM)

In many situations, the complexity of business operations is intensified by the complexity of capital projects; defining requirements for such complex projects may prove difficult as management might not be able to understand requirements until some kind of solution has been developed.

“Where decision problems are more complex and cannot be easily defined by decision-makers, rational methods are more difficult to apply. Such problems involve solving a set of interlocking issues and constraints by multiple stakeholders. A set of auxiliary management tools are required by groups engaged in project definition to help manage such complexity.” (Whelton et al., 2002, p. 2)

This situation refers to a *wicked problem*, which was presented as a SE concept under Section 2.6.1 – “Green (1999) identifies wicked problems in the building and construction industries {including LIPs} and suggests that the potential of SSM lies in the early stages of a project to assist stakeholders to achieve a common understanding of the problem situation”. The concept is reintroduced here in the context of Stakeholder Management.

Wicked problems are systematic problems that are typified by multiple stakeholders involved in complex and unpredictable interactions, where both the problem and the solution to it are unknown until a kind of “solution” is first proposed, and where understanding of motivations, viewpoints and interactions and addressing both qualitative and quantitative dimensions of the situation are required. (William & van’t Hof, 2014)

Wicked problems can take many forms and exist in a wide variety of settings. Gustafsson (2002) describes *the design and management of the*

physical setting for organisational change as a complex process that is a wicked problem.

Citing Simon (1984) and Rowe (1987), Whelton defines a wicked problem as *“A problem whose structure lacks definition in some respect. The problem has unknown associated with the ends (set of project goals) and means (set of process actions and decisions rules) of solution, at the outset of the problem solving process.”*; whereas, he argues, *“Well defined problems are those for which the end or goal is already prescribed or apparent, and their solution requires the provision of appropriate means.”* (Whelton *et al.*, 2002, p. 3)

The response to wicked problems, as suggested by Gustafsson (2002), is to adopt a holistic open systems approach that recognises that all the parts are inter-related and can affect each other. Lang (2001 a) recommends that wicked problems should be addressed through a process of discussion, debate and deliberation among team members, leading to compromise and the reconciliation of different viewpoints and perspectives – the ‘learning paradigm’. Hence, Bryson *et al.* (2002) recommend that Stakeholder Analysis is particularly useful for turning wicked problems into problems that can be solved, and are worth solving.

The concept of wicked problems originated in the work of Rittel and Webber (1984) that examined the societal problems that planners face. Becker (2002) defines problems as being wicked in the sense that they are very difficult to solve. Wicked problems typically have a dense web of inter-related factors, making it very difficult to understand how one decision will affect decisions in other areas. This class of problem often exists in dynamic and uncertain environments that generate significant risk.

Furthermore, Becker (2002) observes that conflict arises from wicked problems where there are competing claims, especially where ‘good outcomes’ are traded off against ‘bad outcomes’ within the same value system.

Figure 2.24 below provides an overview of the nature of wicked problems.

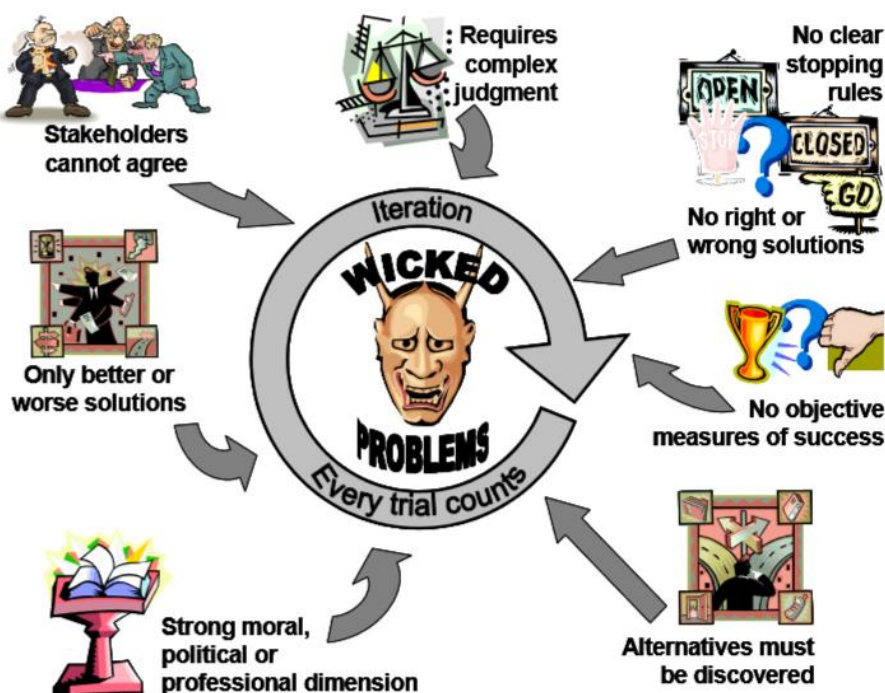


Figure 2.24 – Essence of Wicked Problems
(Adapted from Rittel & Webber, 1984)

A further complication about wicked problem arises in the fact that solutions to such problems are not true-or-false, but better-or-worse and that there is no immediate or ultimate test of a solution. The bottom line is that you cannot solve wicked problem; you can only dissolve such problems; and traditional forecasting and planning processes, though sophisticated, are based on analysis and therefore not suitable for addressing wicked problems. (Rittel & Webber, 1973; Whelton & Ballard, 2002, p. 2)

A different approach such as the Soft Systems Methodology (SSM) that compares the world “as it is” and some models of the world “as it might be” could prove suitable in dealing with increased complexity in defining requirements for complex projects. Soft Systems Methodology (SSM) offers a framework to involve all the stakeholders in a continual learning cycle. It particularly offers an empirically based theoretical foundation for thinking about, analysing, and responding to wicked problems. (Maqsood *et al.*, 2003)

Soft systems strive to learn from the different perceptions that exist in the minds of the different people involved in a project situation. (Andrews, 2000) Attempts by Checkland (1999), and Checkland and Scholes (1990) to transform these ideas from systems theory into a practical methodology have eventually resulted in what is called Soft Systems Methodology (SSM). Checkland's premise is that systems analysts need to apply their craft to problems of complexity that are not well defined, and that SSM attempts to understand the wicked and fuzzy world of complex organisations. This is achieved with the core paradigm of learning. (Checkland, 1999, p. 258)

INCOSE has recognised Soft Systems Methodologies (SSM) as a suitable technique for Requirements Elicitation. Moreover, Barry and Fourie McIntosh (2001) suggest that SSM, which incorporates Systems Thinking and systems concepts, is an approach that provides the opportunity for incremental improvement that is needed to address wicked problems.

In the seminal "The Concept of the CLIOS Process" (Dodder, 2005), a *wicked problem* is captured in the case study on Mexico City, one of the world's largest megacities, which is attempting to improve its air quality under the pressures of a growing population and economy, and the concomitant expansion of demand for goods and services, housing, transportation, and energy. Then again, urban sprawl is related to important environmental issues including to overexploitation of local and regional water supplies, deforestation, and soil erosion. (Molina & Molina, 2001)

As land use patterns become less dense and not well planned, the efficacy of public transit systems deteriorates, trip lengths increase and the costs of service provision escalate. Thus, this phenomenon is tightly interconnected with air quality through operation of the surface transportation system. (Dodder, 2005)

As one of the major contributors of emissions, the transportation system is also subject to substantial congestion, which not only exacerbates the air quality issues in the Mexico City Metropolitan Area (MCMA), but also impacts

the quality of life of residents through lost travel time, and poses a constraint to the efficient operation of industries transporting their goods in and out of the metropolitan area. While in Mexico City the environmental authorities and transportation planners would clearly be included, so would stakeholders such as bus companies, taxi associations and non-governmental organizations, the case study further mentions. (Dodder, 2005)

Because of the many subsystems involved, the uncertainty in the behavior of the subsystems and their interactions, and the degree of human agency involved, the emergent behavior of the MCMA-system is difficult to predict and often counterintuitive. This holds true even when subsystem behavior is readily predictable – this is a good example of a *wicked system* that is not straightforward to resolve, due to some of the reasons mentioned above. (Dodder, 2005)

In discussing incidence of wicked problems in project definition, Whelton notes: *“Recognition, formulation and resolution of wicked problems require auxiliary group management skills to complement systematic processes ... during early phases of project definition ... In order to generate greater value for customers and stakeholders, groups need to think critically and collectively on project issues, and gain a greater understanding of how stakeholder organizations operate, and how their value sets are developed.”* (Whelton et al., 2002, p. 11)

From the foregoing discussions, it follows that SSM should prove extremely useful in situations where requirements are to be elicited to develop, for instance, an Owner Requirements Specification (ORS) for a messy, *systematic problems that are typified by multiple stakeholders involved in complex and unpredictable interactions* like the Mexico City problematic illustrated above. Indeed, its iterative process suits the progressive elaboration of ORS Elicitation; it is a *“holistic open systems approach that recognises that all the parts are inter-related and can affect each other”* and requires a *“process of discussion, debate and deliberation among team members, leading to compromise and the reconciliation of different viewpoints and perspectives”*. (Gustafsson (2002), cited above)

2.6.10. Value of Systems Engineering

A seemingly pertinent question could arise as to why additional efforts shall be expended in introducing and applying Systems Engineering onto project management at this point since, despite all their *usual* challenges, most projects (even complex and large-scale ones) are *eventually* completed? It is not as if every large project will turn into a disaster, someone may argue.

Section 2.2 (above) made the point that *odds are generally against project success*; it is argued that nearly 70% of projects are likely to fail and waste resources. One infamous failure, for instance, is the “Unsinkable” Titanic (i.e. largest and most complex ship afloat) that sank on its maiden voyage on 14 April 1912 – 2,228 people died including 885 crew, according to official records.

On the ground of near-irreversibility of the consequences of project failure, it might make sense considering a slight increase in the level of effort if such may result in better chances of effectively, successfully delivering projects. For this very reason was Systems Engineering introduced in LIPs delivery; *“The primary drivers for introducing SE are to improve cost-effectiveness, maximise quality and minimise rework ...”* (INCOSE-TP-2010-007-01, p. 37)

Moreover, the guide on Systems Engineering for Intelligent Transportation Systems suggests that requirements errors (which proper application of Systems Engineering will prevent) may cause exorbitant “Cost to Correct” down the lifecycle. (SE for ITS, 2007)

As shown in Figure 2.25 below, a bad requirement will be relatively cheap to fix while you are still in the requirements phase (1x) but increasingly expensive to fix later in project development. This is because not only the bad requirement has to be fixed later in the project, but one also has to fix the design and implementation problems that were caused by the bad requirement. The problems compound themselves *if left uncorrected*. In Systems Engineering (SE), verification and validation (V&V) of the evolving project elaboration (and documentation) is performed early and often to

maximize the chances of identifying defects as early in the project development cycle as possible. (SE for ITS, 2007)

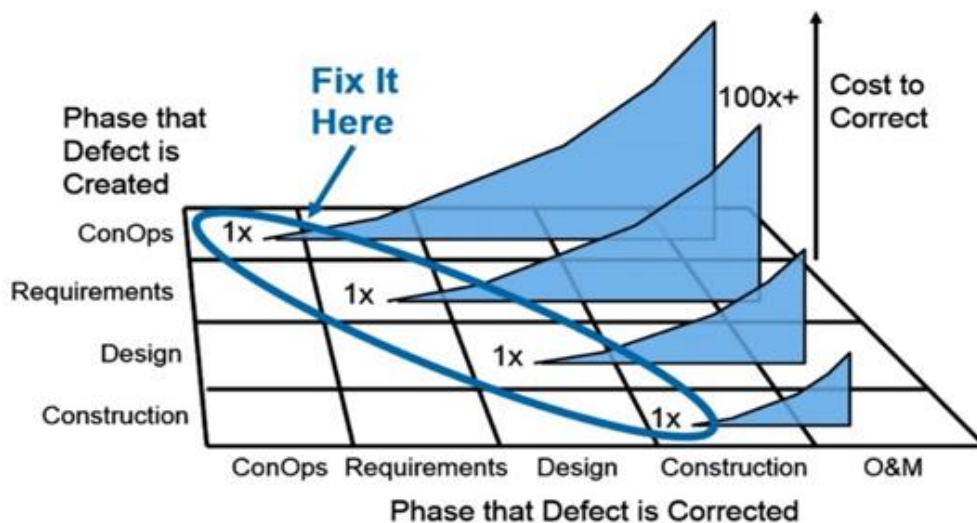


Figure 2.25 – Late Change Drive Project Costs (SE for ITS, 2007)

However, the cost of implementing SE processes must be added to the overall project costs; thus, SE cost should be small compared to the resulting savings and the value of the improved effectiveness. (INCOSE-TP-2010-007)

INCOSE (SEH v3) under the section “Value of Systems Engineering” reads: *“A study researching the return on investment from using SE was conducted by the INCOSE Systems Engineering Center of Excellence (SECoE) at the beginning in 2001. The results uncovered an inverse correlation between cost and schedule overruns and the amount of SE effort applied to a project or development activity.”* (2008, p. 2.7)

According to the above-cited research, the following effects are apparent:

- (i) Cost variances and overruns lessens with increasing SE efforts, and overruns appear to flatten at something greater than 10% SE efforts;
- (ii) Schedule variances and overruns lessen with increasing SE efforts, and overruns appear to level at roughly around than 10% of SE efforts.

Figure 2.27 below illustrates both points (i) and (ii), confirming the positive outcome (i.e. overruns and accuracies) of the Systems Engineering efforts.

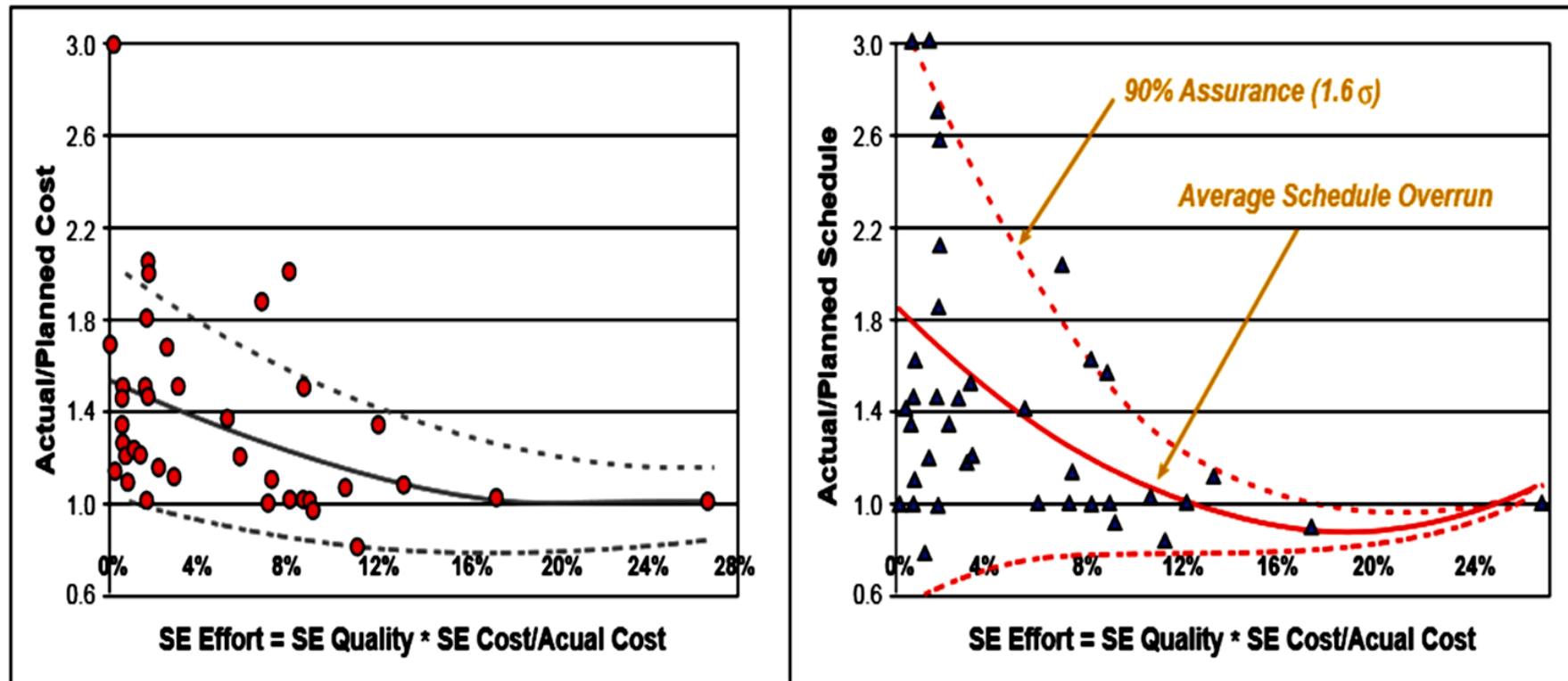


Figure 2.27 – SE Effort to Cost Overruns by Honour (2004) and Gruhl (1992)

These graphs show SE effort as a factor positively controlling schedule and cost overruns and variances, reducing the uncertainty of project outcomes. Recent research work conducted by Honour (2013) has also revealed that:

- (i) There is a quantifiable relationship between Systems Engineering effort levels and program {project} success (i.e. meeting the program {project} schedule and within budget), as shown in the graphs below;
- (ii) Systems Engineering has a significant and quantifiable Return on Investment, achieving, optimally, a ROI of 3.5:1; and,
- (iii) There is an *optimum* amount of Systems Engineering for best success, representing an “investment” of 14.4% of the total program cost on Systems Engineering activities.

A similar research by Werner Gruhl (who worked in the Comptroller Office at NASA) reviewed 26 space projects and stated that 15% SE effort is ideal for success – which is a fairly low *premium* to pay (due to applying of SE over the FEL phases) and prevent 50% to 500% overruns, if not total failure. A small cost compared to savings and value added (INCOSE-TP-2010, p. 36)

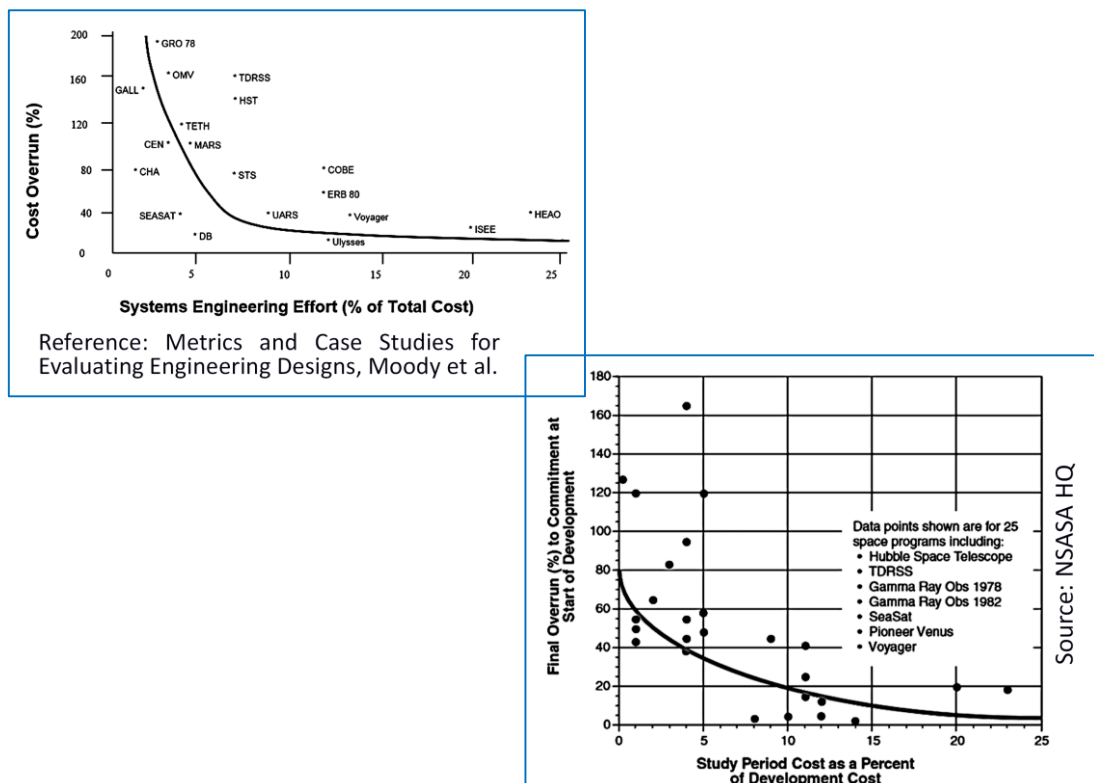


Figure 2.27 – SE Effort to Cost Overruns by Honour (2004) and Gruhl (1992)

Notwithstanding the above findings, indications are that SE efforts might cost even less on Large Infrastructure Projects. On industrial megaprojects, Merrow (2011) submits, “In general, the costs to the end of FEL-2 are no more than about 0.5 to 1.5 percent of eventual total costs”. He further says, “... to go from the end of FEL-2 to a ready-to-sanction project is considerably more expensive: another 2 percent to as much as 4 percent of eventual total capital cost may be required to complete FEL-3” (p. 214) – Totaling $\pm 7\%$ during the FEL phases, though based on a *partial* SE regime. (Refer to 2.7.3)

2.6.11. Construction as a Complex System

Bertelsen (2003, p. 1) aptly submits in his abstract, *“The paper argues that construction should also be understood as a complex, dynamic phenomenon. It analyses the construction process, the production system and the industry, as well as the social systems formed by humans involved in the project execution from a complexity perspective using a number of general characteristics of complex systems. It finds all these characteristics present in the construction system. The paper concludes that the complexity view should thus be more in focus when discussing new project management paradigms.”*

A salient outcome of this study is the realisation, as Bertelsen (2003, p. 12) submits, *“Even though analysis of the construction process’ complexity may be an interesting exercise in its own right, the important conclusion is that the complexity of construction can no longer be ignored and that the basis for our project management paradigms should thus be redefined. Our managing projects in practice must then be changed accordingly. This is the real challenge!”* – A challenge this study is set out to explore and address in LIPs.

Citing Baccarini (1996), Bertelsen (2003) recommends, *“Complexity be operationalized in terms of differentiation and interdependency and applied to dimensions relevant to the project management process, such as organisation, technology, environment, information, decision-making and systems.”* (p. 2) (E.g., assessment of *environment* is the foundation of a sound execution plan.)

2.6.12. Pertinent SE Concepts from the Literature Review

This section seeks to provide a synopsis of the pertinent SE concepts and practices that transpired from this Literature Review, which should be further explored in this research, starting with a comparative analysis of the extent of adoption of such SE concepts in widespread project lifecycle methodologies.

As a modern discipline, project management has offered tremendous benefits, including efficiency of resource utilisation and better scheduling leading to greater certainty of meeting deadlines. However, traditional project management approaches are proving increasingly inadequate in the face of escalating complexity, particularly in large, complex projects (e.g., transportation, energy, industrial, water infrastructure projects) as mounting cost and schedule overruns in Large Infrastructure Projects could testify.

Large construction projects (which are LIPs) are complex systems and should be treated as such. *“The motivation for introducing SE {in LIPs} is therefore the same as in aerospace and defence industries, it is only that the sources of the complexity are partly different ...”* – Indeed, it seeks *“... to reposition traditional SE practices, as it has been successfully developed and applied in the defence, aerospace, manufacturing and telecommunications industries, into the context of the construction industry and thereby provide professionals engaged on LIPs a convenient and comprehensive access to the relevant parts of the system engineer’s toolkit.”* (INCOSE-TP-2010-007-01, pp. 36, 8)

Of particular importance is the consideration of operational requirements early in the lifecycle, shifting the focus away from building of physical deliverables to developing a system that improves the operational environment. (Scott, 2012)

The judicious application of Systems Engineering as an *extension* (not as a substitute) to traditional project management tools and techniques seeks to improve project delivery performance and outcomes. In fact, early application of SE principles and concepts has already produced practical and substantial improvements to particular project delivery areas/aspects. (NETLIPSE, 2008) SE concepts and practices such as Project Lifecycle Models, SE Domains,

Systems-of-Interest, Verification & Validation, Gate Review Process, and enhancements to Risk and Stakeholder Management (and the application of Soft Systems Methodology for Requirement Elicitation) have been explored.

2.7. Analysis of Project Life-Cycle Models and SE Concepts

Systems Engineering (SE) is undergoing major developments as part of infrastructure projects. The approach is widely recognised and project entities are gradually adopting it; yet, a comprehensive framework that meaningfully encapsulates Project Management and Systems Engineering principles, concepts, and practices is not readily available yet. (SE for PWW, 2008)

This point guides the second purpose (*enhancement* question) of this study:

- (b) *To develop a theoretical Project Lifecycle Management Model (for Large Infrastructure Projects) based on Systems Engineering principles.*

In this section, by way of high-level comparisons, an attempt is made to establish the extent to which SE elements (as identified above) are readily available in methodologies commonly used in Large Infrastructure Projects. The following project delivery methodologies are selected for comparison:

- (i) PMBoK (PMI) – the most widely adopted project management standard;
- (ii) [Dutch] SE PWW – the most advanced application of SE in LIPs delivery;
- (iii) IPA Model – the most widely adopted methodology for LIPs delivery.

Lastly, a summary of the NETLIPSE Report (2008) is presented to exhibit not only the application of SE concepts in LIPs, but their *tangible* benefits as well.

2.7.1. Comparison with the PMBoK

A comparison of the overview of System Lifecycle Processes (above) and the Project Management Body of Knowledge, 5th Edition (PMI, 2013) could reveal a number of SE concepts and practices yet to be included in PMBoK.

From Table 2.2 below, PMBoK appears to lack in the following aspects:

- (a) While procurement of goods and services is covered, the Supply side (e.g., bid by project teams) to the market is not explored nor addressed;
- (b) Management of the infrastructure (as engineered by project teams) is not addressed – for it is assumed operations personnel will manage it;
- (c) Management of knowledge, insights, experience and lessons learned generated during delivery of infrastructure projects is not addressed;
- (d) Systems Design (e.g., System Architecture definition), Integration and Verification are not covered – it is probably the reserve of the engineer;
- (e) Only Validation of scope is addressed, not of requirements or system;
- (f) Maintenance and Disposal matters and processes are not addressed.

The above inadequacies of the PMBoK with regards to inherent complexity of Large Infrastructure Projects could provide a clue as to why project professionals trained under the PMI's PMBoK are usually prone to focussing on the delivery of the "physical asset" (even when *wrongly* conceived or designed). They generally give very little attention to effectively "realising the right system" that will prove successful in its operational environment.

Table 2.2 – Comparison between SE Elements and PMBoK 5th Ed. (2013)

SE Lifecycle Element and ISO 15288 Reference		PMBoK 5 Reference	Comment
Acquisition Process	6.1.1	12.1	
Supply Process	6.1.2		Not covered
Lifecycle Model Management	6.2.1	2.1.4	
Infrastructure Management Process	6.2.2		Not covered
Portfolio Management Process	6.2.3	1.4	
Human Resource Management Process	6.2.4	9.1	
Quality Management Process	6.2.5	8.1	
Knowledge Management Process	6.2.6		Not covered
Project Planning Process	6.3.1	3.2	
Project Assessment & Control Process	6.3.2	3.6	
Decision Management Process	6.3.3		Not covered
Risk Management Process	6.3.4	11.1	
Configuration Management Process	6.3.5	4.5	
Information Management	6.3.6	10.2	
Measurement Process	6.3.7	7.4	In part only
Quality Assurance Process	6.3.8	8.2	
Business & Mission Analysis Process	6.4.1	1.6	
Stakeholder Needs & Requirements Process	6.4.2	5.2	
System Requirements Definition Process	6.4.3	5.3	
Architecture Definition Process	6.4.4		Not covered
Design Definition Process	6.4.5		Not covered
System Analysis Process	6.4.6		Not covered
Implementation Process	6.4.7	4.3	
Integration Process	6.4.8		Not covered
Verification Process	6.4.9		Not covered
Transition Process	6.4.10	4.6	
Validation Process	6.4.11	5.5	In part only
Operation Process	6.4.12	1.5	
Maintenance Process	6.4.13		Not covered
Disposal Process	6.4.14		Not covered

Process Legend:

 Agreement Process	 Project-Enabling Process	 Technical Management Process	 Technical Process
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2.7.2. Comparison with the [Dutch] PWW Model

A comparison of the overview of System Lifecycle Processes (above) and the “[Dutch] Public Works and Water” Model could reveal a number of SE concepts and practices yet to be included in the [Dutch] PWW Model.

From Table 2.3 below, [Dutch] PWW appears to lack in the following aspects:

- (a) While the PWW Model aligns to ISO 15288 Standard, it is of concern, essentially in terms of implementation, that the model fails to address organisational processes (e.g., project enablers) such as Infrastructure Management, Human Resources Management, Portfolio Management;
- (b) Furthermore, Knowledge Management (a Lessons-Learned enabler), is conspicuous in its absence. This shortcoming will affect the project entity in gathering experiential learning needed in “taming” complexity;
- (c) In the same vein, the model fails to address (or expressly discuss) Risk Management as a process, and as a vital component of LIPs delivery. In LIPs, *“there will always be residual project risk.”* (Forsberg, 2005);
- (d) By not addressing Business and Mission Analysis, the model assumes the project delivery entity (as an implementation agent) is not required to play any meaningful role in the planning phase, nor in ensuring that business benefits are realised – rather than just producing an asset;
- (e) The above supposition (d) could also explain the evident omission of Transition Process (which deals with realisation of business benefits even beyond handover) – thus, failing to appreciate the critical importance of effective ramp up in successfully delivering LIPs; and,
- (f) Considering that the model omits Project Planning altogether, it could again be deducted that the [Dutch] PWW Model assumes (or would perhaps recommends?) that the decision to create the “system” should rest outside the ambit of the project entity, as the implementing agent.

Apart from these few (and yet major in impact) shortcomings, it would appear that the [Dutch] PWW Model is sufficiently comprehensive and is the most advanced Project Lifecycle Model (as applicable to LIPs) explored thus far.

Table 2.3 – Comparison between SE Elements and the [Dutch] PWW Model

SE Lifecycle Element and ISO 15288 Reference		PWW Model	Comment
Acquisition Process	6.1.1	3.3	
Supply Process	6.1.2	3.3	
Lifecycle Model Management	6.2.1	2.7	
Infrastructure Management Process	6.2.2		Not covered
Portfolio Management Process	6.2.3		Not covered
Human Resource Management Process	6.2.4		Not covered
Quality Management Process	6.2.5	3.1	
Knowledge Management Process	6.2.6		Not covered
Project Planning Process	6.3.1		Not covered
Project Assessment & Control Process	6.3.2	3.4	
Decision Management Process	6.3.3	2.4.2	
Risk Management Process	6.3.4	--	Incidentally
Configuration Management Process	6.3.5	3.4	
Information Management	6.3.6	3.4	
Measurement Process	6.3.7	2.5.5	
Quality Assurance Process	6.3.8	3.1	
Business & Mission Analysis Process	6.4.1		Not covered
Stakeholder Needs & Requirements Process	6.4.2	2.3.1 / 2.5.3	
System Requirements Definition Process	6.4.3	2.3.3	
Architecture Definition Process	6.4.4	2.8	
Design Definition Process	6.4.5	2.3.4 / 2.4	
System Analysis Process	6.4.6	2.8.3	
Implementation Process	6.4.7	2.6	
Integration Process	6.4.8	2.5.4	
Verification Process	6.4.9	2.3.1 / 2.6.3	
Transition Process	6.4.10		Not covered
Validation Process	6.4.11	2.6.4	
Operation Process	6.4.12	2.7	
Maintenance Process	6.4.13	2.7	
Disposal Process	6.4.14	2.7	

Process Legend:

 Agreement Process	 Project-Enabling Process	 Technical Management Process	 Technical Process
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2.7.3. Comparison with the IPA Model

Based on Best-Practices found in “Industrial Megaproject”. (Morrow, 2011)

A comparison of the overview of System Lifecycle Processes (above) and the “Independent Project Analysts, IPA” Model could reveal a number of SE concepts and practices yet to be included in the IPA Model.

From Table 2.4 below, IPA Model appears to lack in the following aspects:

- (a) The IPA Model extensively reviews the project lifecycle concept, rightly putting a very strong emphasis on the notion of Front End Loading (FEL), and thus making a welcomed departure from the “*jump-straight-into-execution*” tendencies that typified the traditional school of delivery;
- (b) The IPA Model, however, falls short of addressing project organisational aspects, said to be project enablers (e.g., Infrastructure Management, Portfolio Management), affecting the deployment of project systems;
- (c) The IPA Model fails to discuss critical technical management processes such as Configuration Management (i.e. crucial for scope integrity in LIPs); Quality Management (i.e. ensures consistency of processes; and Information Management (i.e. a Lessons-Learned enabler);
- (d) As if to exacerbate the above, the model is conspicuously silent on vital SE practices such as Systems Requirement Definition, Architecture Definition, Integration, Verification, Transition (i.e. apart from ramp-up), Validation, Maintenance, Disposal, and Operations (e.g., it only raises some operational readiness and Post-Implementation-Review issues).

The IPA Model reflects serious weaknesses from a Systems Engineering perspective; while it *persuasively* articulates the essence and practical benefits of Front End Loading (FEL), it appears to do so with an undue focus on the ensuing Execution Phase (i.e. constructability), not necessarily on meeting the requirements arising from the operational environment (e.g., improving value, throughput) . Therefore, projects delivery under the IPA Model might fall short of meeting operational requirements (even when the physical asset is well delivered), except when consultants/contractors specifically address such.

Table 2.4 – Comparison between SE Elements and the IPA Model

SE Lifecycle Element and ISO 15288 Reference		IPA Model	Comment
Acquisition Process	6.1.1	Chap 11	
Supply Process	6.1.2	Chap 11	Partial cover
Lifecycle Model Management	6.2.1	Chap 5	
Infrastructure Management Process	6.2.2		Not covered
Portfolio Management Process	6.2.3		Not covered
Human Resource Management Process	6.2.4	Chap 8, 9	
Quality Management Process	6.2.5	Chap 12	Partial cover
Knowledge Management Process	6.2.6	Chap 7	
Project Planning Process	6.3.1	Chap 4, 10	
Project Assessment & Control Process	6.3.2	Chap 10, 12	
Decision Management Process	6.3.3	Chap 4, 7	
Risk Management Process	6.3.4	Chap 6, 12	
Configuration Management Process	6.3.5		Not covered
Information Management	6.3.6		Not covered
Measurement Process	6.3.7	Chap 10, 12	
Quality Assurance Process	6.3.8		Not covered
Business & Mission Analysis Process	6.4.1	Chap 4	
Stakeholder Needs & Requirements Process	6.4.2	Chap 4, 5	
System Requirements Definition Process	6.4.3		Not covered
Architecture Definition Process	6.4.4		Not covered
Design Definition Process	6.4.5		Not covered
System Analysis Process	6.4.6	Chap 10	
Implementation Process	6.4.7	Chap 8, 12	
Integration Process	6.4.8		Not covered
Verification Process	6.4.9		Not covered
Transition Process	6.4.10		Not covered
Validation Process	6.4.11		Not covered
Operation Process	6.4.12		Not covered
Maintenance Process	6.4.13		Not covered
Disposal Process	6.4.14		Not covered

Process Legend:

 Agreement Process	 Project-Enabling Process	 Technical Management Process	 Technical Process
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2.7.4. Findings of the NETLIPSE Report

Notwithstanding the above, a recent report (2008) from the NETwork for the dissemination of knowledge on the management and organisation of Large Infrastructure ProjectS in Europe, NETLIPSE, researched Best-Practices and Lessons Learned from a review of fifteen LIPs across Europe and made practical recommendations for Managing Large Infrastructure Projects. While the initiative was not specifically about Systems Engineering practices, the committee proceeded mentioning a number of SE concepts and practices in their main findings [*Italics added for emphasis*] as follows:

- (a) One of the most important findings is that *LIPs must be conceived, managed and operated as an integrated whole*, focussing not only on the completion of a physical project as an end in itself, but also on stakeholders involved. LIPs are an important link for European {could also apply to South Africa} transport and on a higher level contribute to economic and social sustainable growth of our society;
- (b) *Open culture within and between project delivery organisations and with external parties and stakeholders is critical* to the smooth progression of a scheme. The communication between the client or sponsor and the project delivery organisation is of paramount importance, both on a formal and on an informal basis;
- (c) The *project objectives should clearly translate into a functional output specification*. The functional specification should be translated to required technical outputs, scope of work, work packages and milestones;
- (d) It is important not just to *assess risk systematically but also to identify opportunities that may arise or be achieved within a project*. These may not be simply the opposite of risks. For example, the opportunity to re-use or sell spoil material brought significant financial gains to several of the projects studied. Risks and opportunities should both be recorded on a risk and opportunities database, which should be kept continually updated;

- (e) *Project management is more than a technical construction process. It is also a process of sense-making and a process of creating, managing and maintaining interfaces between all the elements and actors in the delivery process. Interface management is a key part of mature project management;*
- (f) *Stakeholder management in a project is critical. It is important to categorise stakeholders according to their impact to the project; and*
- (g) *It is vital that the client/sponsor takes into full account the whole life requirements of a project, especially in terms of maintenance so that the durability of the asset is an integrated part of the design.*

The published findings of the NETLIPSE Report (2008) indeed confirmed that lack or poor application of Systems Engineering concepts and practices on Large Scale Projects across Europe has caused major challenges to their effective implementation and threatened their successful outcome – conversely, judicious applications of such SE elements throughout projects have consistently enhanced both the performance and outcome those LIPs. Two short examples do substantiate and validate this conclusion as follows:

Example 1 – Functional and technical specifications on the BetuRoute:

Managing scope {i.e. requirements} means a balance between rigidity and flexibility. An identified success factor is to assess the impact of proposed scope changes on the entire project. A method for scope control is configuration management {of requirements}. By separating technical and functional demands, scope changes can be processed quicker and decisions on scope changes can be taken at the proper level.

“At the beginning of the project, functional and technical issues were not separated in discussions on scope change. This made discussions on scope changes diffuse. The authorities and responsibilities of the parties involved were unclear. Proposed scope changes were referred upwards, often to the highest levels. This slowed down the decision making process. By splitting functional and technical demands, these earlier problems have now been resolved. The project delivery organisation has been allowed to change

technical specifications; however functional specifications can only be changed with the authority of the Minister of Transport.” (NETLIPSE, 2008, p. 69)

Example 2 – Involving railway operators in the West Coast Main Line:

A cross-industry, open approach to a project can yield many benefits. Rail safety systems and standards are complex. This is especially true when the interactions between infrastructure and rolling stock are taken into account – a number of interfaces have to be managed adequately. This is one reason to involve them in early project phases. A second reason to involve train operators is that they have a clearer view on current and future customer needs. Involving the industry enables a better and clearer specification, resulting in additional benefits, reduced costs, a more robust design and a more effective implementation. Here is how it manifested on the project:

“After half a decade of a project at an apparent standstill with railway traffic rapidly increasing, operators had become extremely frustrated at the lack of progress. There had been no consensus either between the train operators and Railtrack, or indeed within Railtrack itself. The Strategic Rail Authority (SRA) decided to obtain an open, cross-industry approach. They wanted to inform the entire railway industry about their strategy for the West Coast Main Line and to achieve a consensus. In October 2002 a new consultation document was published. Under the leadership of the SRA (now DfT) different parties of the railway industry became actively involved in developing the consultation document and eventually signed up to it. The document included revised franchise specifications for the train operating companies.” (NETLIPSE, 2008, p. 74)

In Table 2.5 (attached as Annexure C), NETLIPSE findings are mapped against the applicable clause in ISO 15288:2008 – and clearly indicates that NETLIPSE’s SE scope of is *broader* than in ISO 15288, probably owing to:

- (a) ISO 15288 assumes that projects are carried out within an enterprise; in these LIPs each project is an enterprise. That is, many of the enterprise processes become project processes;
- (b) The study highlights the importance of the contracting strategy and its influence on almost all the other processes in the project; this is completely missing from ISO 15288;
- (c) The study and the findings focus on cost and schedule issues (risks) arising from causes within the environment (political, economic, societal) of the project; this important aspect is only indirectly (and vaguely) addressed in ISO 15288; and,
- (d) The legal aspects, and their influence on the project in the form of obtaining consents, are highlighted in the study, but are ignored in ISO 15288;
- (e) The study also emphasizes the importance of developing and managing knowledge within the project; again, this is not addressed by ISO 15288.

The NETLIPSE findings match the requirements of ISO 15288:2008 and specifically apply to Large Infrastructure Projects (LIPs) – in addition, they provide *real-life* empirical corroboration on the application of SE to LIPs. However, the NETLIPSE Report still does not meet the objectives of this research in as much as it did not (which incidentally was not their intended purpose) develop a SE-based Project Lifecycle Model that might serve as a basis for LIP’s project delivery methodologies – which is indeed the crux of this research.

NETLIPSE rather seeks to develop and Infrastructure Maturity Tool that may assist the European Commission (EC) in providing insight into the likely success of the project to be funded in terms of finance, planning and scope.

2.8. Key Theoretical Concepts for Further Investigations

This section indicates key theoretical concepts for further investigation (by way of industry survey and interviews) in the course of this research such as:

- (1) **Project Life Cycle Methodology** – to determine the adequacy of the lifecycle model in use in the project delivery entity, in comparison to ISO 15288 Model encompassing from Concept to Disposal phases;
E.g., Are Delivery Organisations using a project lifecycle methodology?
Does such a project methodology have distinct phases/stages?
Does its planning phase(s) also considers Operations matters?
- (2) **Principles & Concepts of the Methodology** – to determine the extent of SE principles and concepts incorporation in the methodology;
E.g., Is a multi-disciplinary approach encouraged on projects?
Are stakeholders consulted in defining the requirements?
Are outcomes of project phases tested against requirements?
- (3) **Project Delivery Process** – to determine the extent of application of SE practices and the overall project performance outcome, as a result;
E.g., Are Risk Management activities considered as core to project delivery?
Are most projects (+90%) completed on time and on budget?
Is Post-Implementation-Review of projects considered mandatory?
- (4) **Readiness to Improve Project Delivery** – will establish the readiness and willingness of the organisation to adopt/improve SE application;
E.g., Are project personnel consistently using the adopted methodology?
Will management support the improvement of adopted methodology?
Are project Lessons-Learned captured and shared in the organisation?

These key theoretical concepts (and others as might be deemed relevant) will be elaborated through the content of the surveys and interviews as the requirements of the research methodology will demand.

Chapter 3: Research Methodology

The topic of this dissertation seeks to contribute to the Project Lifecycle Methodology by suggesting practical SE applications and paving the way for further research in the field of project management. Since it intends to address issues of effective project management with relevance to current practices, procedures, and policies pertaining to successful delivery of Large Infrastructure Projects (LIPs), the research method employed shall lean toward Applied Research, according to Leedy and Ormrod (2013).

Applied Research is “*intended to address issues that have immediate relevance to current practices, procedures, and policies; intended to human decision making about practical problems; occasionally address questions in one’s immediate work environment (action research).*” (Ibidem, p. 2-29)

3.1 Research Framework

In seeking to answer the Research Question, this study will follow a Data Analysis Framework (Figure 3.1) adapted from “Investigational Methods” manual. (B. Sunjka, 2015)

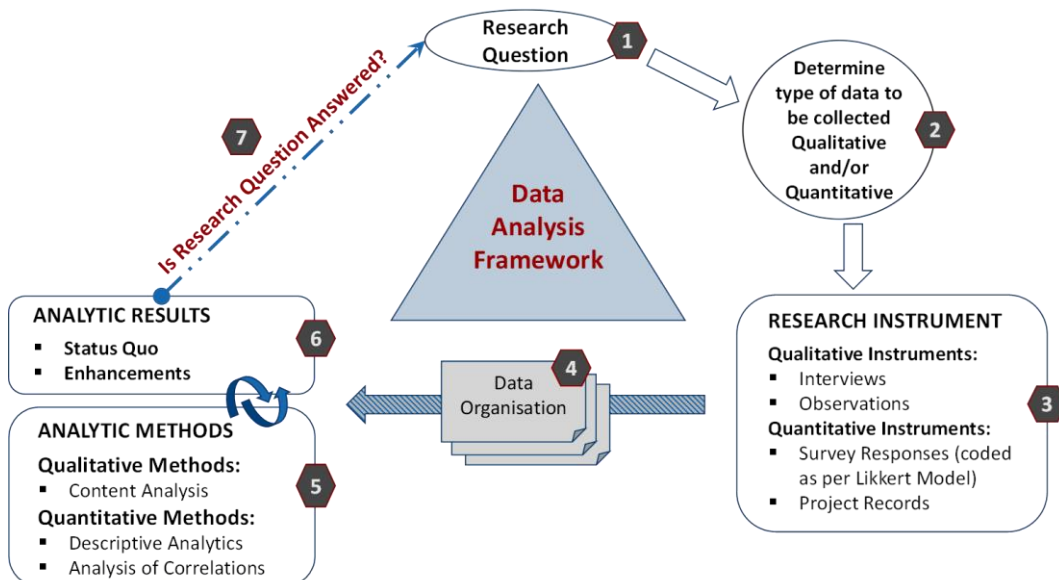


Figure 3.1 – Data Analysis Framework (Adapted from B. Sunjka, 2015)

This framework runs in full cycle, from and back to the Research Question.

The application of SE concepts to Large Infrastructure Projects is such a novel domain that the number of appropriate research methodologies is limited. This research will adopt the PLD Model (Ellis & Levy, 2009), which is conducive to proving reliability and validity, and follows the following steps:

[P] – Develop a research-worthy problem (i.e. Research Question);

[L] – Conduct a valid quality peer-reviewed literature (i.e. Literature Review);

[D] – Data Analysis.

This model relies on the interactions among the three common drivers for selection of study type. *“The research-worthy problem [P] serves as the input to the process of selecting the appropriate type of research to conduct. The valid peer-reviewed literature [L] is the key funnel that limits the range of applicable research approaches, based on the body of knowledge. The data [D] available to the researcher serves as the final filter used to identify the specific study type.”* (Ellis & Levis, 2009, p. 324)

In fact, Chapters 1, 2, and 3 form the Model Investigation part of this study (*Figure 1.1 – Dissertation Structure - Three Main Parts*) in line with PLD Model as they include Research Question, Literature Review, and Research Methodology (i.e. approach to data collection and selection of instruments).

Data available to the researcher determines the study type, as *“Every solid research study must use data in order to validate the proposed theory ... researcher should understand the centrality of access to data ... Without access to data, it is impossible for a researcher to make any meaningful conclusions on the phenomena.”* (Ellis & Levy, 2009, p. 324)

3.2 Research Question

The Research Question (Section 1.3), further expanded into Research Objectives, is the driver of this research effort as data collection, analysis and interpretation must contribute to the crux of this investigation:

“Can Systems Engineering (SE) concepts and principles be applied to project management methodologies (for Large Infrastructure Projects, LIPs)

in order to enable Project managers to more effectively and successfully attain the desired outcome of a planned Project?”

3.3 Collection of Qualitative and Quantitative Data

Project information (i.e. quantitative and qualitative data) will be gathered through the review of available records, industry surveys, and interviews. In particular, qualitative data will be subjected to an analysis (as appropriate) to answer the critical question as to whether the meaning found in qualitative data are trustworthy and “right” by minimising bias, testing and confirming findings and ensuring the quality of the conclusions. (Miles *et al.*, 2014) – This shall then provide assurance as to the validity of the outcomes and conclusions of this study.

An Analysis of Correlations will identify interfaces and links that govern overall performance (Scott, 2012, p. 7). Therefore, Content and Statistical Analysis with correlation measures will ensure reliability of the research. Besides, taking a cue from Patton (1990) and since Large Infrastructure Projects (LIPs) are an extremely peculiar case of project delivery, Structured Interviews will rely of a “Purposive Sampling” method that seeks to targets Subject-Matter-Experts (SMEs) and other suitably selected high-calibre professionals involved in the delivery of LIPs. This will bring a variety of perspectives, backgrounds, and areas of expertise to reduce theoretical biases (Leedy & Ormrod, 2013).

Lastly, since Structured Interviews seek to collect data from a selected panel of experts (i.e. professionals immersed and imbedded in the topic of interest and can provide real-time and real-world knowledge), the Delphi Technique is suitable as a method for consensus-building by using a series of questionnaires delivered using multiple iterations. (Hsu, 2007)

Hence, follow up questionnaires will be delivered to the selected panel up until a reasonable consensus on the proposed SE-based PM model is reached among panel members – augmenting the previous validation by literature.

3.3.1 Research Instrument

Any research endeavour is essentially about the data and their selection, collection, and treatment – which govern the validity of their interpretations, even the outcome of the investigation.

Citing Isaac and Michael (1981), Ellis and Levy (2009) argue, *“Different research approaches are appropriate for quantitative data – precise, numeric data derived from a reduced variable – than for qualitative data – complex, multidimensional data derived from a natural setting. Of equal importance is the nature of the problem being addressed by the research”*. (p. 325)

In the case of this study, which seeks to answer the Research Question, *“Qualitative researchers are more typically interested in the generation and rectification of theoretical concepts ... Where, as in all theory-building, model-building research, the theory is emergent from the research, then we have a reverse process upward, the ‘upward inferring’ of theorizations and even of theoretical concepts on the basis of examined evidence.”* (Wengraf, 2001, p. 56)

Moreover, Ellis and Levy (2009) suggest a developmental approach will apply in a research situation where finding an adequate solution for testing the efficacy in addressing the problem at hand (i.e. an approach to building a solution that can be tested) proves problematic. Such an approach will consist of quantitative and qualitative data (mixed method) used to describe the phenomenon under consideration for the revising of the current framework, which is the case for this research.

3.3.2 Research Data

Data *“permit scientists to test theories and hypotheses about phenomena around them, to estimate models that might be used to predict the behaviour of various phenomena ... to develop ways of simulating the real world in a laboratory or controlled conditions, and so forth.”* (Stopher, 2012, p. 64)

This study will rely both on Project Management and Systems Engineering literature and on data pertaining to project methodologies and delivery performance (on Large Infrastructure Projects) to answer the Research Question. The investigation shall therefore determine:

- (1) *Status Quo* Question – whether the inadequacies observed in the application of traditional approaches will warrant proposing any enhancements to the current project lifecycle models; and
- (2) *Enhancement* Question – what specific Systems Engineering principles, concepts, and practices could lead to such enhancements.

Primary data (i.e. original data) as well as secondary data (i.e. obtaining and reuse of existing, previously collected data) will underpin this investigation. (Section 3.3.4 discusses appropriate instruments for collecting such data.)

3.3.2.1 Primary Data

The primary data to be collected for this research is in the form of,

- (i) Responses to surveys, including to project demographics questions;
- (ii) Outcomes of interviews (as per records and transcripts).

Considering the current maturity of the LIP industry in Southern Africa (e.g., limited awareness of Systems Engineering concepts and practices), primary data will primarily serve as a basis for determining the *status quo* as opposed to generating feasible *enhancements* – except for a Delphi Panel.

3.3.2.2 Secondary Data

The secondary data to be collected for this research is in the form of,

- (i) Research papers, industry publications (i.e. best-practice, handbook);
- (ii) Literature relating to research methods;
- (iii) Project records, company project delivery documentation (if available);

Considering the reluctance to disclose details of (unfavourable) project outcomes, and issues of confidentiality (e.g., project methodology treated as Intellectual Property), secondary data should mostly serve as a basis for generating *enhancements*, but still contribute to determining the *status quo*.

3.3.3 Selection of Research Instruments

The literature review pertaining to Project Management and Systems Engineering (Chapter 2) was used to develop questionnaire and interview questions in order to collect data relevant to this investigation.

Surveys are appropriate for measuring the impact of {social and psychological} phenomena; therefore, a questionnaire will be used to gather information by asking a range of individuals the same questions related to their characteristics, attributes, practices, or opinions. (O’Leary, 2004) – *“In the practice of good survey research, you design a questionnaire with the intention of gathering meaningful information”*. (Berenson *et al.*, 2013, p. 224)

Interviews, however, are a more formalised, systematic and extended version of a conversation aimed at finding rich, descriptive data. (Salkin, 2011) According to Levine *et al.* (2008), they are prone to the “halo effect” when the respondent feels obligated to please the interviewer. Hence, it is crucial for the interviewer to rely on effective facilitation skills to minimise this effect. Poor facilitation skills during the interview may create problems as follows:

- (1) A survey sponsor chooses leading questions that guide the responses in a particular direction;
- (2) An interviewer, through mannerisms and tone, purposely creates a halo effect or otherwise guides the responses in a particular direction;
- (3) A respondent wilfully provides false information.

The personal interview and the telephone interview usually produce a higher response rate than does the mail (i.e. posted) survey but at a higher cost. For this reason, mail execution was excluded and one-on-one interviews were chosen and conducted in a location or venue convenient to the respondents, apart from “follow up” questions to be electronically mailed to selected participants. (Levine *et al.*, 2008)

3.3.4 Questionnaire and Interview Design

The preliminary planning and definition of a questionnaire involves four key, interlinked aspects. (Sapsford, 2007) – The design of both questionnaire and interview forms are based on a framework as depicted in Figure 3.2 below:

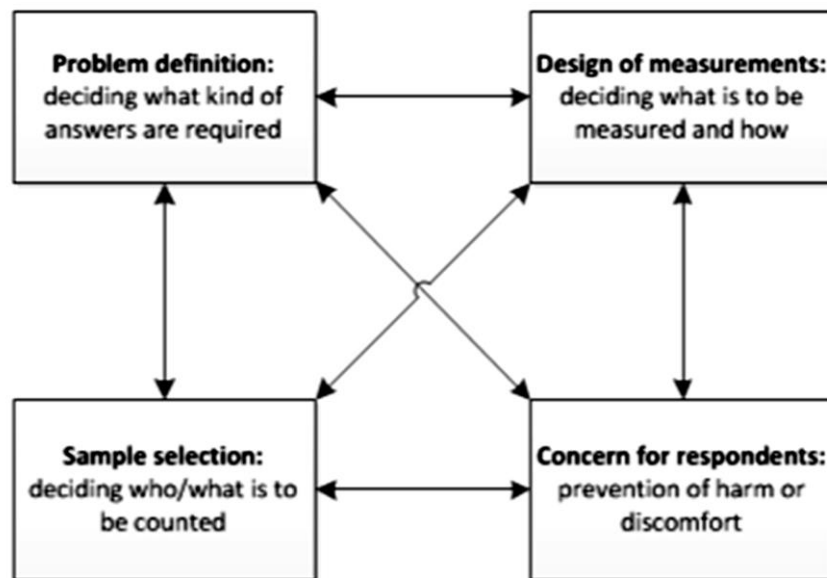


Figure 3.2 – Overall Design of a Survey Project (Sapsford, 2007)

A discussion of the four aspects in the context of this study reads as follows:

- (i) **Problem Definition** – Section 1.3 discusses the Problem Statement, which shall inform the data items (i.e. content and format of questions);
- (ii) **Research Measurements** – Two subsequent sections discuss data items based on insights gathered throughout the literature survey. Section 3.5.2, in particular, discussed the treatment of collected data;
- (iii) **Concern for Respondents** – Section 1.7 (on Ethics Clearance) discussed the approach and practical steps taken in pre-empting and addressing concerns of respondents to questionnaires and interviews;
- (iv) **Sample Selection** – Sections 3.3.2.1 and 3.3.2.2 specify the type of primary and secondary data required in terms of this study in order to answer the Research Question satisfactorily.

3.3.4.1 Sample Selection

INCOSE support the view that Large Infrastructure Projects (LIPs) are an extremely peculiar type of project delivery. (INCOSE-TP-2010-007, pp. 9-11) To gather meaningful responses for the primary data needed in the development of feasible *enhancements* (to current practices), professionals (immersed and imbedded in the topic of interest and can provide real-time and real-world knowledge) will be targeted for interviews and Delphi Panel. Selection criteria may include knowledge/expertise in Systems Engineering, exposure/experience in delivery of Large Infrastructure Projects (LIPs).

Online questionnaires, however, shall target as many project practitioners as possible, including project personnel, consultants, and academia. The researcher will thus rely on available networks (e.g., fellow project managers, colleagues, database entries) to reach potential respondents for the survey.

Patton (1990) specifies that in case of deviant cases, that are perceived as unusual or rare, a purposive sampling approach is the most commonly used in qualitative studies – It is a non-probability sampling method that is characterised by a deliberate effort to gain representative samples by including groups or typical areas in a sample.

The investigation should target those rare project personnel with knowledge and/or experience in Large Infrastructure Projects (in Southern Africa) and/or in Systems Engineering; therefore, the primary data (for the elicitation of enhancement propositions) needs to be obtained from a very specific group of respondents (e.g., representatives of LIPs industry and SMEs who can contribute to the study. Purposive sampling, in the case of this study, is a good way to recruit the members of the rare or much sought after LIPs group.

Patton (1990) argues that the results of purposive sampling are usually more representative of target population compared to other sampling methods. However, *“Research which is considered for model-building and model-rectifying {the case of this study} very frequently changes its sampling strategy as the research proceeds; it puts forward theories not originally*

envisaged at the start of the research; it accounts itself particularly successful and important if it manages to contribute to a better conceptual framework than the one with which it started off.” (Wengraf, 2001, p. 55)

Regarding the issue of “sampling size”, this investigation will align itself to Erickson *et al.* (1982, cited by Patton, 1990, p. 185) who suggest that *“The validity, meaningfulness, and insights generated from qualitative inquiry have more to do with the information-richness of the cases selected and the observational/analytical capabilities of the researcher than with sample size”*.

Therefore, given the limited access to LIPs delivery entities and the unwillingness to share any details on poor performance of LIPs, this investigation will target around 30 “entities” (i.e. owner-organisations or consultants involved in the delivery of LIPs in Southern Africa) as far as industry survey is concerned.

According to a recent PwC Africa Infrastructure Report (2014), South Africa’s infrastructure spending reflects an investment of US\$ 22 billion ($\pm$ R 300 billion) per annum; therefore, this survey will aim at a sampling of entities that will collectively spend close to R 900 billion over the next 3 to 5 years. Should the sampling of entities achieve this goal, around 10 SMEs from such entities will be selected for the Structured Interview (and the Delphi Panel).

3.3.4.2 Questionnaire Design

According to Maxwell’s Model, *“A ‘well-designed’ {research} object is an object whose component parts have been designed to be able to work together and in sequence such that the functions, or purposes, for which the object was designed are most likely to be served.” (Wengraf, 2001, p. 56)*

From the Literature Review and the Research Question, specific theoretical concepts (ultimately linking the essence of project management to Systems Engineering) that are foundational to this study have emerged as follows:

- (1) **General Information** – to classify respondents into groups as per the entity’s project characteristics for demographics analysis purposes. This

refers to aspects such as entity's business sector, industry, size and granularity of its portfolio (i.e. Questions Q₀₁ to Q₁₀ of the questionnaire).

- (2) **Project Life Cycle Methodology** – to determine the adequacy of the lifecycle model in use in the project delivery entity, in comparison to ISO 15288 Model encompassing from Concept to Disposal phases;
- (3) **Principles & Concepts of the Methodology** – to determine the extent of SE principles and concepts incorporation in the methodology;
- (4) **Project Delivery Process** – to determine the extent of application of SE practices and the overall project performance outcome, as a result;
- (5) **Readiness to Improve Project Delivery** – will establish the readiness and willingness of the organisation to adopt/improve SE applications.

Since this research seeks to investigate the application of SE concepts in project delivery organisations, the term “entity” will be *interchangeably* used to mean a “project delivery organisation, e.g., owner” or a “consulting entity, e.g., EPCM Provider” that delivers a project on behalf of an owner-organisation. Therefore, the questionnaire shall ask questions that seek to determine the *prevalence* of these theoretical concepts in the different entities to be surveyed.

The General Information section collects information to establish the project management profile of the entity will rely on “quantitative data” from a range of pre-set discriminatory values, informed by the size and nature of LIPs in the Southern African environment.

The other sections [from (2) to (5)] being of a *qualitative* nature and dealing with *insubstantial measurements* (i.e. concepts, ideas, opinions, or other intangible entities) will have a code in line with the 5-Scale Likert as follows:

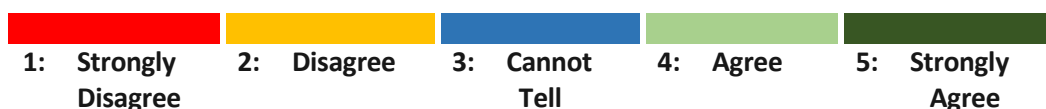


Figure 3.3 – Proposed Five (5) Scale Likert Continuum

Boone et al., (2012) indicate, “*Likert ... developed a procedure for measuring attitudinal {to a particular question or statement} scales*”. (p. 1) – Boone also

warns against attempting to combine responses from individual items into a composite scale (which might lack any meaning) while dealing with multiple questions in a research instrument – which definitively applies to this study.

The Likert Scale is a “simple to construct”, “likely to produce a highly reliable scale”, and “easy to read and complete” kind of tool, despite its “central tendency bias”, and a possible “halo effect” not prevalent in questionnaires.

The design of the questionnaire has given careful attention to its structure, section ordering, appearance (e.g., visual appeal), and most importantly interpretability of statements – which is key to the Likert Method applied. *“Our concern in selecting scales for questionnaires is with the quality of the measurement obtained. A scientific study must always address these two issues, reliability and validity. When these issues are properly addressed, measurement error is reduced. Measurement error occurs when the values obtained in a survey (observed values) are not the same as the true value”,* warn Hair et al. (2015, p. 233)

For that purpose, a Cronbach’s Alpha Coefficient will serve as an “ex-post” test (i.e. after data collection) to confirm the reliability of the Liker-coded questionnaire – an Alpha score of 0.8 or higher will indicate good reliability. In principle, the Cronbach’s Alpha Coefficient serves to pilot-test the reliability of a questionnaire before its broader distribution. (Radhakrishna et al., 2003) However, given the selective population of the LIPs industry in the region, and to avoid further reducing the ensuing purposive sample, this investigation has proceeded onto the industry survey and only applied the Cronbach’s Alpha test thereafter to verify its reliability on an *after-the-fact* basis. (Refer to Chapter 4) Thus, a Cronbach’s Alpha score of below 0.8 will entail discarding the survey.

After posting the questionnaire on a portal for easy access, a survey tool (i.e. Survey Monkey) was used to forward an online link to participants via email, with the convenience of automatic gathering and archiving of data.

Annexure D shows a sample survey questionnaire and a copy of the online version, both containing 52 “lifecycle” and “requirements” question-items.

3.3.4.3 Interviews Design

Interviews, unlike questionnaires, are prone to the “halo effect”, which occurs if respondents feel obligated to please the interviewer. (Levine *et al.*, 2008) Besides, an open discussion on such a complex matter (i.e. the application of SE principles, concepts, and practices to Large Infrastructure Projects) could turn into a dissipative effort. *“It is unlikely that the meaning of any utterance as ‘decoded’ by the recipient will be identical to that ‘encoded’ by the questioner ... It is the characteristic of the naïve communicator that he or she can only recognize very obvious cases of breakdown ...”* (Wengraf, 2001, p. 39)

Therefore, given the important contribution of the Structured Interview to the formulation of the *enhancement* propositions (e.g., Structured Interview is used for model-building and/or model-testing), this investigation shall guard against the above traps. The following considerations could assist as follows:

- (i) Isolating respondent’s history from the interview proceedings;
“History as a dimension includes feared and desired and expected ‘future’ which may be affected by the interview interaction in the present ...”
(Wengraf, 2001, p. 44)
- (ii) Balancing power-knowledge relationship;
“The question of the politics interview interaction and the conditions and outcomes of interviews have been raised ... sometimes simply inspired by the exploitation of interviewees in a weak power position {or secrecy on LIPs outcomes} ... power is a dimension of interview interaction dangerously likely to be overlooked or ignored or denied by the well-intentioned and good-natured interviewer.” (Ibidem, p. 45-46)
- (iii) Avoiding discrepancy of referent;
“The question of the ‘referent’ is a crucial one. People may imagine that the topic (or referent, that is being referred to) is commonly understood by both parties, but in fact there may be a greater or lesser degree of unperceived discrepancy between the imagined referent ... There may be more than one referent, of which only one is explicit.” (Ibidem, p. 46)

To help focus the discussions, the Structured Interview was adopted, with a few “open-ended” questions that are of relevance and pertinence to the topic. Since this Structured Interview will constitute a “continuation” to the Online Questionnaire, the structured interviews posed the following systems-related questions to open and guide the discussions with the identified SMEs:

- 1° *Would you support the notion of a project lifecycle that consider Operations, Maintenance and Disposal matters during the study or planning phase? If “Yes”, what benefits and risks would you foresee?*
- 2° *Since downstream (i.e. construction/operations) troubles are from upstream (i.e. planning) neglects, should planning phases consider “operations” issues?*
- 3° *Do you find it difficult to formulate Owner’s Requirements at the beginning of the project? If “Yes”, do you think allowing stakeholders’ input will help?*
- 4° *Would you find it useful to confirm that specified requirements are met in the “product” being designed and developed? Or that requirements for an explicit intended use have been satisfied?*
- 5° *Would you agree that projects only derive their full value if all the essential parts of the final “product”, all their interfaces of such parts with one another and with the “environment” are adequately addressed through the lifecycle?*

Specific templates will assist in the recording and scripting of the interview proceedings, in accordance with the requirements of the Ethics Clearance. To maintain the anonymity of the interviewees, no personal or company information will appear except what may serve as “discriminant” in analysis. A copy of the Structured Interview Template is included in Annexure D.

The Structured Interview consists of five (5) open-ended items, which are questions or statements that allow the respondent to give any response in his or her own word, without restriction or undue hints from the interviewer. This type of questions is convenient for use in qualitative research and it generally leads to Content and/or Thematic Analysis of qualitative data.

3.3.4.4 Delphi Panel

“The Delphi technique is a widely used and accepted method for gathering data from respondents within their domain of expertise ... The Delphi technique is well suited as a method for consensus-building by using a series of questionnaires delivered using multiple iterations to collect data from a panel of selected subjects.” (Hsu, 2007, p. 1)

Furthermore, the Delphi process provides the following benefits (Hsu, 2007):

- (i) Anonymity of respondents (in line with Ethical Clearance, Section 1.7);
- (ii) Controlled feedback process; and,
- (iii) Suitability of a variety of statistical analysis techniques to interpret data.

Following the Structured Interviews (seeking to address *“What Lifecycle Model should be”*) with the SMEs, a series of Delphi iterations will ensue until a reasonable consensus concerning the proposed lifecycle elements is attained among the SMEs (who are selected to constitute a Delphi Panel).

Hsu (2007), citing Custer *et al.* (1999), points out that three iterations are often sufficient to collect the needed information and to reach consensus in most cases. Since there may still be a significant spread in individual opinions at the end of the exercise, this study will rather seek a reasonable consensus. Moreover, since the structured interviews will include open-ended questions and the same SMEs will be selected for both the Delphi Panel and the preceding Structured Interviews, it will be acceptable, for practical purposes, to consider such interviews as *Round 1* for the Delphi. (Custer *et al.*, 1999) Therefore, *Round 2* and *Round 3* will respectively address the “rating of items” (arising from *Round 1*) and “reasons for remaining outside the consensus”.

In order to present the information concerning the collective judgment of respondents, measures of central tendency (i.e. median) and of dispersion (i.e. standard deviation) will be applied to Delphi Panel responses. (Hsu, 2007)

3.4 Data Organisation

The table below provides a summary of the utility and purpose of data collected in keeping with the adopted Problem-Literature-Data (PLD) Model.

Data Source	Data Type	Data Utility	Purpose of Data
Project Management Documentation	- Industry Publications - Project Records - Methodology Documentation	- Provided indication of success/failure on LIPs delivery; hence, the research question - Provided historical and contextual information on LIPs delivery - Verified relevance of data collected from other sources	Assisted in determining shortcomings of common methodologies and possible areas of improvements.
Industry Survey	Participant Assessment, Opinion	- Assessment of LIPs delivery across major organisation in Southern African - Verification of data collected from other sources	Assisted in determining current extent of SE concepts application in common methodologies and possible areas of improvements.
Structured Interviews	- Participant Assessment, Opinion - Historical and Contextual information	- Provided historical and contextual information on LIPs delivery - Provided input into enhancement propositions - Provided indication of convergence of opinions	- Provided input to formulation of SE enhancement propositions - Assisted in confirming convergence of opinions around SE enhancement propositions
Delphi Panel	Participant opinion on proposed SE-based enhancement propositions	Provided a proxy of industry agreement regarding proposed enhancement propositions	Measured extent of industry consensus regarding proposed enhancement propositions

Table 3.1 – Summary of Data Collection

3.5 Analytical Methods

Data collected with selected instruments (e.g., survey, interview, Delphi) will be analysed for description or inference purposes. (Leedy & Ormrod, 2013) In line with Golafshani (2003), Quantitative Analysis will address the general nature of the data obtained, e.g., central tendency and degree of dispersion (seeking primarily to answer the *status quo* question), whereas Qualitative Analysis will seek illumination, understanding, and extrapolation to similar situations (seeking primarily to answer the *enhancement* question).

3.5.1 Analysis of Quantitative Data

The survey relied on an online questionnaire containing 52 “lifecycle” and “requirements” question-items to provide Likert-coded responses, which will be analysed in terms of *frequency* (e.g., percentage of respondents having “strongly agreed”, or “agreed”, or both) to establish the extent of agreement (across the industry) with various lifecycle and requirements statements. Ultimately, responses will be interpreted to answer the *status quo* question. Although questions are clustered into delivery aspects, data will not be combined to provide an overall indicator, as such is statistically meaningless.

In addition, Maqsood *et al.* (2003, p. 313) suggest a project delivery machinery “... typically has a dense web of inter-related factors, making it very difficult to understand how one decision will impact decisions in other areas”. Hence, conducting a Correlation Analysis (i.e. Coefficient of Correlation) between the responses of various respondents to the same set of Likert-coded “lifecycle” and “requirements” statements will further the understanding of the “overall behaviour” of the project lifecycle methodology, a system in its own right.

Hass would concur with the systems view of the project delivery as follows: “From all these interactions patterns emerge which informs the behaviour of the agents within the system and the behaviour of the system itself”. She adds, “The ways in which the agents in a system connect and relate to one another is critical to the survival of the system, because it is from these connections that the patterns are formed and the feedback disseminated.” (p. 23)

3.5.2 Analysis of Qualitative Data

Data collected via the Structured Interview are open-ended responses, in a non-numerical form. Two most popular approaches to analysing such data are Content Analysis and Thematic Analysis, the latter employing a more flexible and reflective process, which captures the richness and in-depth nature of qualitative data – e.g., from discussions with SMEs. (Braun & Clarke, 2006) Unlike Content Analysis, Thematic Analysis “*pays greater attention to the qualitative aspects of the material analysed.*” (Marks & Yardley, 2004, p. 56)

In Thematic Analysis, indeed, “*patterns and themes are noted; themes are counted to discern whether a theme is common or more rare; a plausible story is extracted from the data that can be related to the literature review ... disconfirming as well as confirming evidence is examined. In line with a loose definition of ‘testing’ a research question, one looks at whether the original hunch can be satisfied or not, and whether it needs modifying, as well at the direction in which further research might go.*” (Ibidem, p. 63-64)

This kind of subtle and intuitive epistemological inquiry will serve the purpose of this investigation in seeking to address the *enhancement* question for “*The whole interview is not only greater than the sum of its parts, but by ‘immersion’ in the whole one gains understanding of the parts ...*” (Ibidem, p. 66)

3.5.2.1 Analysis of Documents and Records

Marks and Yardley (2004) suggest that the main aim of Thematic Analysis is to understand the latent meaning of the manifest themes observable within the data, which requires interpretation. It also permits, they argue, the researcher to combine analysis of the frequency of codes with the analysis of their meaning *in context*, thus adding the advantage of the subtlety and complexity of a truly qualitative analysis – allowing this study to draw eloquent deductions out of data arising from reviews of project records and other documentation. For this specific reason, a Thematic Analysis is henceforth recommended for the analysis of documents and records as part of this study.

3.5.2.2 Analysis of Interviews

Analysis of Structured Interview could lend itself to either kind of analysis. *“However, on a small sample size only the descriptive use of the thematic coding is advisable, since it is meaningless to assign numbers to a data set that is too small to meet the usual minimum requirements for statistical analysis ... as this would seem to imply that the frequency of occurrence in the sample was in some way representative of the likely frequency of occurrence in the wider population.”* (Marks & Yardley, 2004, p. 66)

To abstract from the immense detail and complexity of data those features that are most salient for the study’s purposes, a “conceptual tool” (e.g., existing model to be replicated, extended or enhanced) is needed to classify and understand the phenomenon under study. Therefore, “deductive” Thematic Analysis (i.e. themes drawn from existing theoretical ideas) is distinguished from “inductive” Thematic Analysis – i.e. themes draw from raw data. (Ibidem)

The content of the Structured Interview (i.e. existing theories drive both the questions and one’s understanding of the answers) and a “model-testing” mind-set dictate that *“inductive themes, drawn from the data, are often useful in the new areas of research”* (Ibidem, p. 58) and shall supplement the primary “deductive” inquiry. Thus, both approaches will apply to the Interview Analysis.

3.5.3 Analysis of Delphi Responses

Delphi responses will be analysed in accordance with their nature, which is largely informed by the sequencing of Delphi rounds (Hsu, 2007) as follows:

Delphi	Response Type	Proposed Analysis
Round 1	Open Questions [i.e. Structured Interview]	<i>Thematic Analysis to establish themes, patterns, and engender understanding ...</i>
Round 2	Rating of Items	<i>Statistical central tendency (i.e. Mean) and dispersion (i.e. Standard Deviation) to establish the level of consensus, augmented by Thematic Analysis ...</i>
Round 3	Reasons for variances	<i>Thematic Analysis to establish reasons for variances of opinions and offer revisions ...</i>

Table 3.2 – Qualitative Analysis as per Delphi Round

The analysis of Delphi responses will therefore entail both Quantitative and Qualitative (i.e. Statistical and Thematic Analysis) depending on the Delphi round reached at a particular point in time (i.e. Delphi rounds).

3.5.4 Validity and Reliability in Qualitative Data

While the industry survey (i.e. online questionnaire) will serve as the basis for a Quantitative Analysis to answer the *status quo* question, data gathered through the Structured Interview shall form the basis of a Qualitative Analysis seeking to answer the *enhancement* question.

To test and demonstrate the credibility of this portion of the investigation, helping the industry “*understand a situation that would otherwise be enigmatic or confusing*” (Eisner, 1991, p. 58) as well as “*establish confidence in the findings*” (Golafshani, 2003, p. 602), a triangulation method will be used to establish the validity and reliability of the research.

“The principle of ‘triangulation’ has been put forward which suggests that you should consider looking for at least three empirical indicators for any particular moderately complex theoretical concept.” (Wengraf, 2001, p. 54)

Citing Patton (2001), Golafshani (2003) discusses triangulation and submits, “*Triangulation strengthens a study by combining methods. This can mean using several kinds of methods or data, including using both quantitative and qualitative approaches*”, and further suggests, “*... exceptions in qualitative research are dealt to modify the theories and are fruitful.*” (p. 603)

Triangulation, as Creswell and Miller (2000) suggest, is considered a validity procedure where researchers search for convergence among multiple and different sources of information to form themes in a study.

Therefore, any “understanding”, insights, or interpretations emerging from the Thematic Analysis (TA) of responses (from the Structured Interview as well as from the survey) will be subjected to two (2) steps to establish validity by triangulation as follows:

- (1) Delphi rounds to establish the extent of convergence (i.e. consensus) of SMEs' opinions about a set of proposed *enhancement* propositions;
- (2) Analytical comparisons against project management literature in order to establish relevance of a set of proposed *enhancement* propositions by way of inclusion in an existing methodology and/or by way of their applicability in addressing current shortcomings. (Sections 6.1 and 6.2)

3.6 Analytic Results

This step is discussed in “Chapter 4: Data Analysis and Results” (below).

3.7 Research Question Conclusion

This step is discussed in “Chapter 7: Research Discussions” (below).

3.8 Outline of Way Forward

The foregoing Sections 3.2 to 3.7 have reflected the seven (7) steps of the Data Analysis Framework (Section 3.1) guiding this research methodology. Moreover, Chapters 1, 2, and 3 specifically followed the PLD Model whereby Chapter 1 elicited the research-worthy problem (i.e. a research question), which informed the approach and scope of Chapter 2 (i.e. a valid quality peer-reviewed literature survey), which in turn informed the applicable research approaches covered in Chapter 3 – and the data available to the researcher.

The subsequent Chapters 4, 5, and 6 will constitute the Model Development part of this study (*Figure 1.1 – Dissertation Structure - Three Main Parts*) and will respectively address the analysis of data (as collected through various instruments and using the selected tools), the building of the SE-based model, and the validation of such a model.

Finally, the third part of this study will therefore address Model Application, meaning, discussions regarding the extent to which this study has satisfactorily answered the Research Question (Chapter 7), future developments, and areas of further research (Chapter 8), and recommendations to industry (Chapter 9).

Chapter 4: Data Analysis and Results

This chapter relies on Thematic Analysis, Descriptive Analytics, and Analysis of Correlations to analyse survey responses (as coded per the Likert Model), project records, outcomes of interviews, and Delphi Panel (i.e. outcome thereof) to address the two most salient points of this investigation as follows:

- (1) The *status quo* question – whether the inadequacies observed in the application of traditional approaches warrant enhancements thereto;
- (2) The *enhancement* question – what specific SE principles, concepts, and practices could serve as such enhancements.

Accordingly, the diagram below outlines the sequential steps of the analysis:

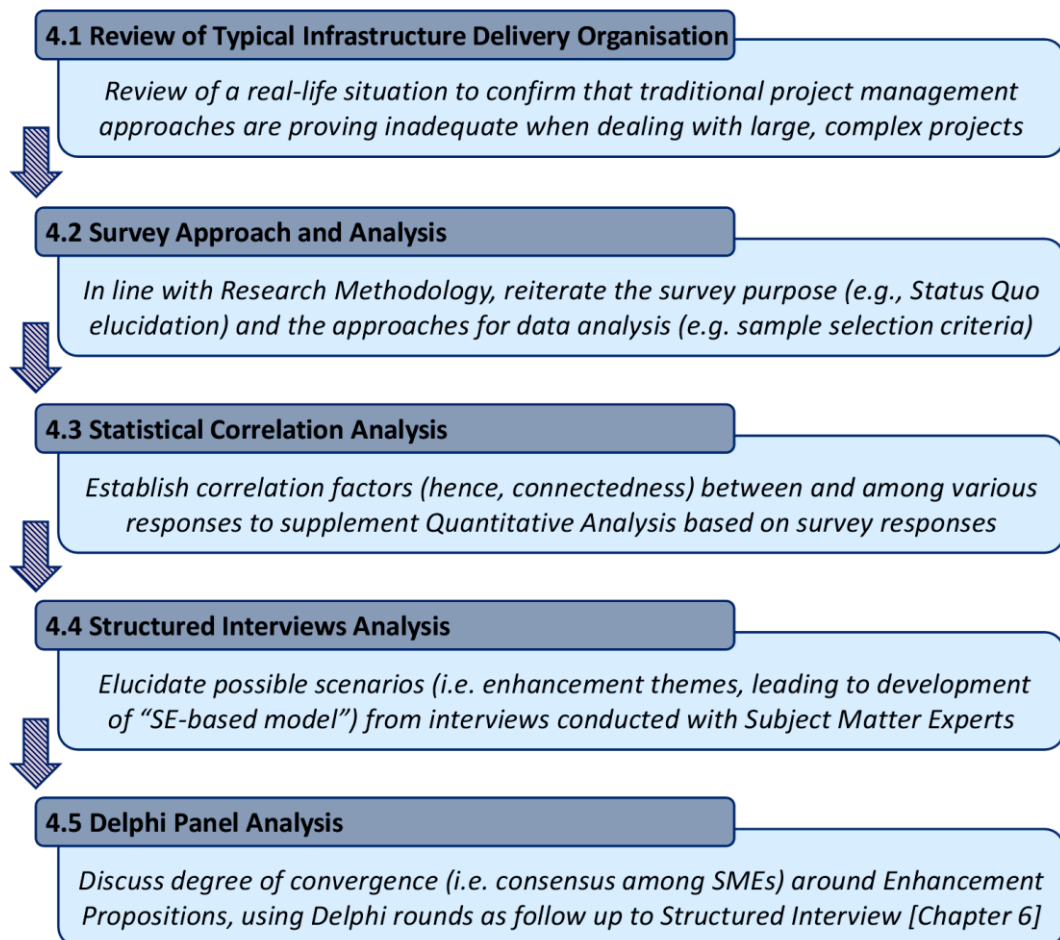


Figure 4.1 – Data and Result Analysis: Chapter Outline

4.1. Review of a Typical Infrastructure Delivery Organisation

Section 2.4 above has dealt with the inadequacies of traditional project management approaches; such inadequacies still manifest themselves despite good efforts to implement “best-practices” lifecycle methodologies. Reviewing a typical infrastructure delivery organisation to ascertain, by way of example, that the *status quo* question is indeed pertinent, and that the inadequacies of traditional approaches actually pertain in the Southern African environment could support this investigation.

Project performance in a certain South African organisation (say, LogisTop – real name concealed for confidentiality reasons) was reviewed. LogisTop is a nation-wide logistics company that regularly embarks on multi-billion Rand programmes to expand, upgrade and/or maintain its infrastructure, utilising internal resources and/or global firms.

It came to light that despite a widespread adoption of a lifecycle methodology with “best-practice” project processes and procedures, “world-class” project controls tools and techniques, and “professionally trained” project personnel working in “fully-projectised” structures and with documented roles and responsibilities, overall performance still leaves a lot to be desired – in meeting both *stakeholder requirements* and *cost and schedule targets*. (Kerzner, 2013)

Project Type	Project Funding/Stream	YTD Approved Budget	YTD Forecast Value	YTD Actuals	Variance YTD Budget vs YTD Actual	Variance YTD Forecast vs YTD Actual	%Accuracy of Budget	% Accuracy of Forecast
Current	- CAPEX	2 715 189 515	3 228 285 674	3 242 754 776	527 565 261	14 469 102	119%	100%
	Names Concealed	427 603 940	232 137 369	281 209 493	-146 394 447	49 072 124	66%	121%
		157 171 147	187 555 728	187 957 584	30 786 437	401 855	120%	100%
		1 111 639 414	1 683 846 554	1 635 736 160	524 096 746	-48 110 394	147%	97%
		204 391 908	123 387 647	102 389 293	-102 002 615	-20 998 354	50%	83%
		195 756 886	256 936 902	276 283 893	80 527 007	19 346 991	141%	108%
		312 488 439	417 860 830	431 535 092	119 046 653	13 674 262	138%	103%
		105 086 321	113 543 239	109 930 490	4 844 169	-3 612 750	105%	97%
		201 051 460	213 017 405	217 712 771	16 661 311	4 695 367	108%	102%
	- OPEX	105 910 966	60 257 441	58 039 701	-47 871 265	-2 217 740	55%	96%
	Names Concealed	58 380 044	25 498 119	23 631 843	-34 748 202	-1 866 276	40%	93%
		1 890 122	1 000 000	1 000 000	-890 122	0	53%	100%
		5 230 824	4 654 589	5 433 737	202 913	779 148	104%	117%
		5 932 934	3 078 570	2 737 488	-3 195 446	-341 081	46%	89%
		2 587 848	1 597 476	1 727 690	-860 158	130 214	67%	108%
		31 889 193	24 428 688	23 508 942	-8 380 251	-919 745	74%	96%
Current Total		2 821 100 481	3 288 543 115	3 300 794 477	479 693 996	12 251 362	117%	100%
Future		174 797 200	0	0	-174 797 200	0	0%	N/A
Grand Total		2 995 897 681	3 288 543 115	3 300 794 477	304 896 796	12 251 362	110%	100%

Figure 4.2 – Mid-Year Records showing Budget and Forecast Accuracy at “LogisTop”
(Extracted from actual Quarterly Reports page submitted to the project committee ...)

The above actual project records (obtained as part of the review itself, with project names concealed for confidentiality sake) illustrate unacceptable patterns of erratic cost and/or schedule over/underruns. These project records reflect YTD Approved Budget, YTD Forecast Value, and YTD Actual figures as recorded between 1st April and 30th September of the same 2013/14 financial year. Both “% Budget Accuracy” and “% Forecast Accuracy” are out of range, even reflecting some massive variances – The delivery system is already “out-of-control”, just six months into the year, and it is likely that this set of projects at LogisTop will not be completed as planned.

This situation, which could relate to many a project delivery organisation, is indicative of *systematic* problems beyond the control of project managers. They found themselves in a predicament in spite of having done a good job; the inadequate project delivery “system” in place has still failed them (due to the complexity inherent to a particular project, if not the whole portfolio).

4.2. Survey Approach and Analysis

Survey responses collected via online questionnaires constitute a primary data and will serve in understanding, responding to the *status quo* question. This section will present the approaches as well as the outcomes of the Data Analysis pertaining to the industry survey done via an online questionnaire.

4.2.1. Survey Validity and Reliability

Considering that the survey questionnaire was not pilot-tested to confirm its reliability as an instrument (Section 3.3.4.2), the first step in Data Analysis section shall entail applying the set of responses collected to a Conbach’s Alpha Test to ascertain the reliability of the data, before any analysis thereof.

While the questionnaire included 52 “lifecycle element” questions, the optional ones (from Q₄₈ to Q₅₂) have been left out of the Conbach’s Alpha Coefficient calculation (details included in Annexure D) – which yields an Alpha of 0.92425. With the Conbach’s Alpha Coefficient close to 0.95, the survey questionnaire is deemed valid, its results highly reliable, and could be used for Data Analysis.

4.2.2. Survey Respondent Profile

The survey relied on a questionnaire targeting as many project practitioners as possible, including project personnel, consultants, experts, and academia. Section 3.3 referred to the peculiarity of LIPs and suggested a sampling tactic that targets around 30 LIPs delivery entities (i.e. organisation actually delivering, or organisations and persons assisting others in delivering LIPs).

The General Information section collects information to establish the project management profile of the entity. Responses to General Information questions (Q₀₁ to Q₁₀ and Q₄₇) indicate that a 63.3% response rate (19 out of 30 entities targeted) was attained from the small LIPs community of Southern Africa – A minimum of 50% was actually required to minimise bias. (Baruch, 1999; Baruch & Holtom, 2008)

In total, 22 respondents (from 19 different entities) participated as follows: (Annexure D has more graphical representation of responses and statistics)

- (i) In terms of industry classification, almost half (40.9%) of entities surveyed are involved in Infrastructure projects, while ICT & Related and Minerals & Mining represent 27.3% and 13.8% respectively;

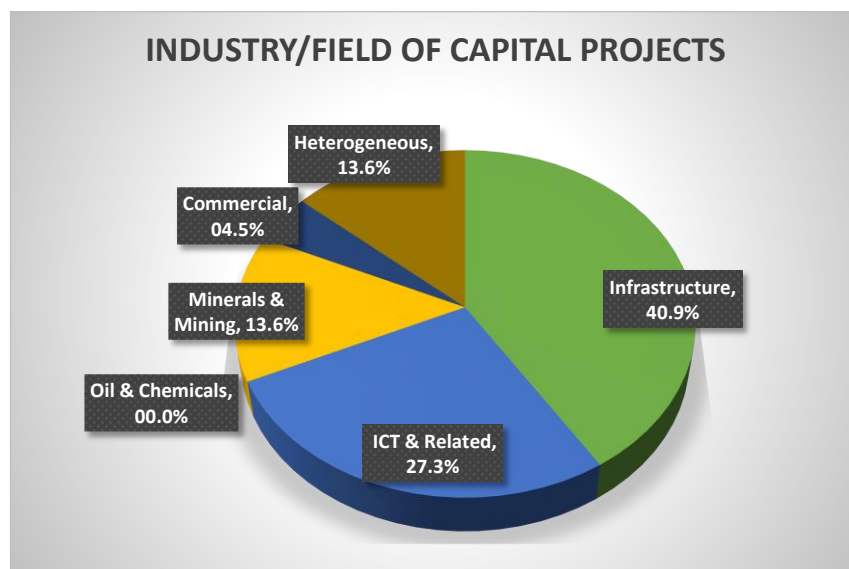


Figure 4.3 – Pie Chart: Industry of Capital Projects

- (ii) 63.6% of respondents are from In-House PM Team, while 9.1% are from a Procurer of PM, 09.1% from a Supplier of PM, and 18.2% are from a PM Contractor – thus, the data collected reflects a wide spread of the LIPs industry and could inform the applicability of the recommendations;

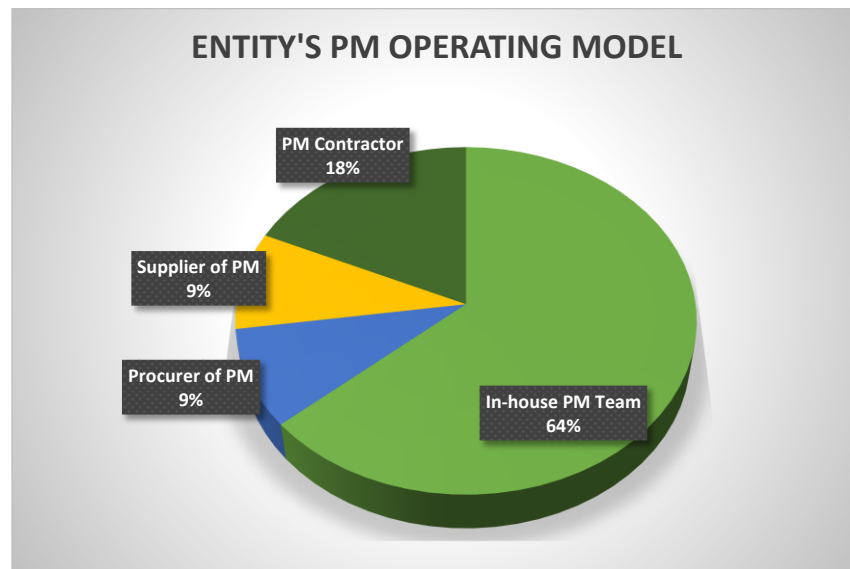


Figure 4.4 – Pie Chart: Entity's PM Operating Model

- (iii) 27% of entities surveyed manage their capital portfolio at a project division level, whereas 23% manage it at department level, and a third (36%) do so at multiple levels across the organisation;

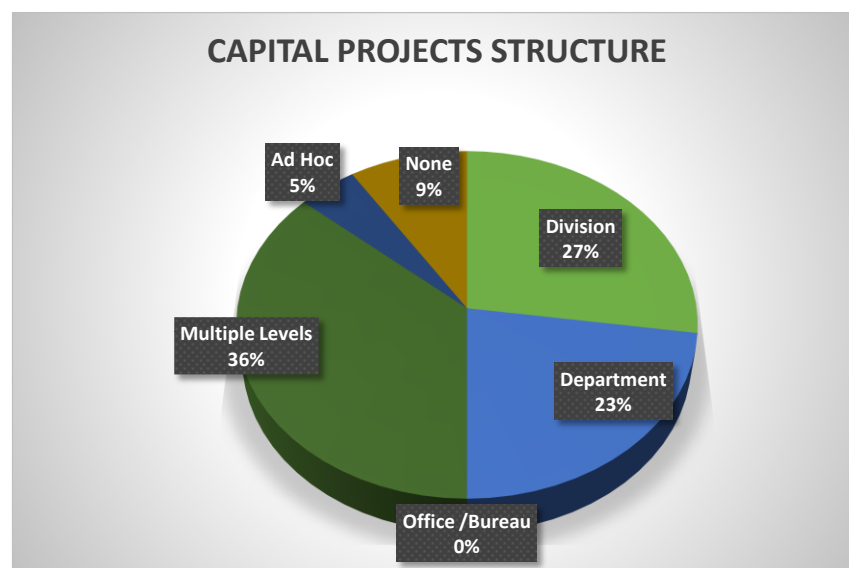


Figure 4.5 – Pie Chart: Capital Delivery Structure

- (iv) Only 31.8% of the entities surveyed do manage capital projects of above R 10 billion; hence, could qualify as Mega-Project (Morrow, 2011, p. 15);

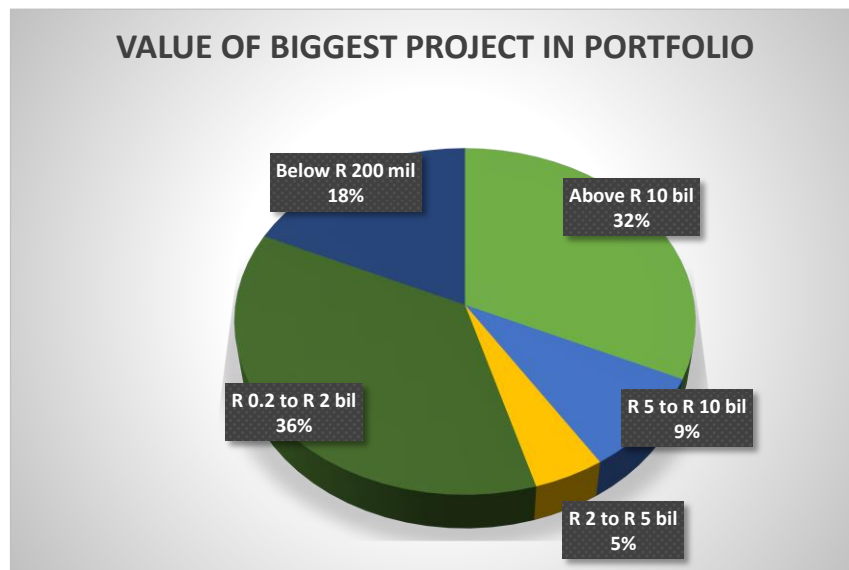


Figure 4.6 – Pie Chart: Value of Biggest Project in Portfolio

- (v) Up to 36.4% of entities surveyed will deliver less than 50 projects over the next three (3) to five (5) years, but 22.7% will deliver between 50 and 150 projects over the same period.

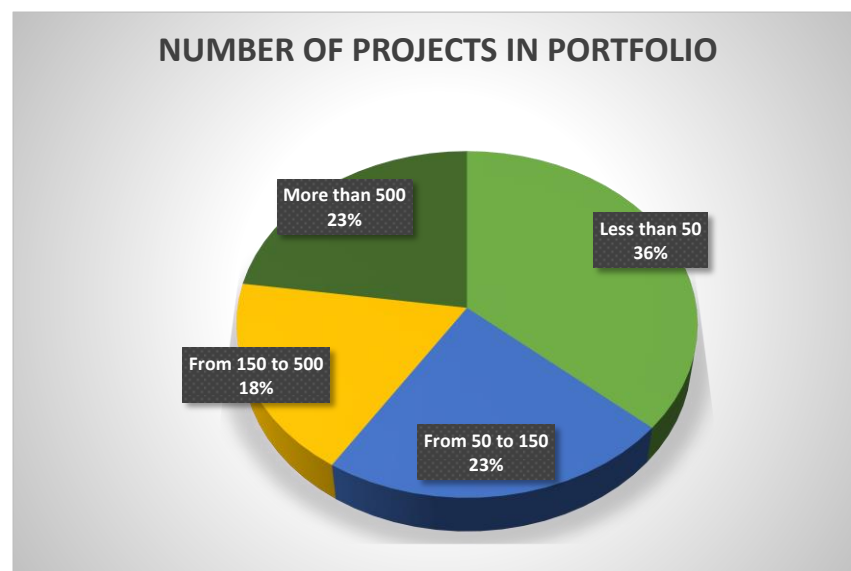


Figure 4.7 – Pie Chart: Number of Projects in Portfolio

Moreover, by allocating responses to question Q₀₄ (Portfolio of Capital Projects, Value over Next 5 Years) to the 19 entities identified (as not every respondent disclosed his/her entity), it is estimated that together these entities

have allocated more than R 800 billion (around US \$ 50 billion) on capital projects for the next 3 to 5 years. This constitutes a fair representation of the general population spending R 900 billion (As per Section 3.3.4.1).

4.2.3. Survey Analysis

The survey results produced Likert-coded responses, providing a quantitative datum as a proxy to a specific qualitative theme – i.e. degree of agreement to “lifecycle” and “requirement” statements. Therefore, a Statistical Analysis was applied to determine the *frequency* (e.g., percentage of respondents having “strongly agreed”, or “agreed”, or both) to establish the extent of agreement (across the industry) with lifecycle and requirements statements. E.g., whenever 5 out of 22 respondents say “Strongly Agree” to question Q₁₄, then it could be said that 22.7% “Strongly Agree”.

The difficulty of interpreting such a confused notion as “*average of Strongly Agree and Agree*” made the measuring of “average” and “standard deviation” inappropriate for this particular exercise. (J. Susan, 2004, pp. 1217-1218)

However, Thematic Analysis was conducted on the survey responses, which “*pays greater attention to the qualitative aspects of the material analysed ... patterns and themes are noted; themes are counted to discern whether a theme is common or more rare; a plausible story is extracted from the data that can be related to literature review*”. (Marks & Yardley, 2004, pp. 56, 63) Such “*inductive themes, drawn from the data, are often useful in the new areas of research*”. (Ibidem, p. 58) – and provided insight and interpretation of data. All responses were ultimately interpreted to answer the *status quo* question.

Furthermore, a Statistical Correlation Analysis was conducted (Section 4.3) to determine the “mutual” Coefficient of Correlations between any two set of responses, which provides an indication of their interactions.

4.2.4. Survey Results Synopsis

A statistical analysis was conducted on data provided by an online-survey (i.e. covering 52 “lifecycle” and “requirements” related questions as per 2.6.3). The statistical analysis was applied to the Likert-coded responses of the survey to determine the frequency pertaining to a specific question. In some cases, the distribution of “Strongly Agree” and “Agree” are combined to indicate the extent of general agreement – e.g., to question Q₁₄ “*Its planning phase(s) also considers Maintenance matters*”, 50% say “Agree” and 22.7% say “Strongly Agree”; hence, 72.7% of respondents “generally agree” (and, conversely, $\pm$ 30% would generally disagree).

4.2.4.1. Survey Results per Segment

Section 3.3.4.2 (Questionnaire Design) identified five segments the survey questionnaire should include. The General Information segment informed the above Survey Respondent Profile (Section 4.2.2); this section will present the survey results in terms of the remaining questionnaire’s segments as follows: (Shades of green  and  on the bar charts reflect a general agreement.)

(1) Segment A – Project Lifecycle Methodology (Items A₀₁ to A₀₉):

The “Lifecycle Methodology” bar chart indicates that most respondents largely agree with most of the survey statements, particularly to the question “Your organisation uses a project lifecycle methodology” (A₀₁). However, they appear to agree less regarding the inclusion of Disposal matters (A₀₅) and full understanding of such methodology (A₀₉).

(2) Segment B – Principles and Concepts of the Methodology (B₀₁-B₀₉):

The “Principles and Concepts of Methodology” bar chart indicates that most respondents largely agree with most survey statements, no respondent “Strongly Disagree”, except to the question “Project personnel are exposed to Systems Thinking” (B₀₉). However, they also appear to agree less regarding discussing linkages between projects at the outset (B₀₂) and testing outcomes of phases against requirements (B₀₈)

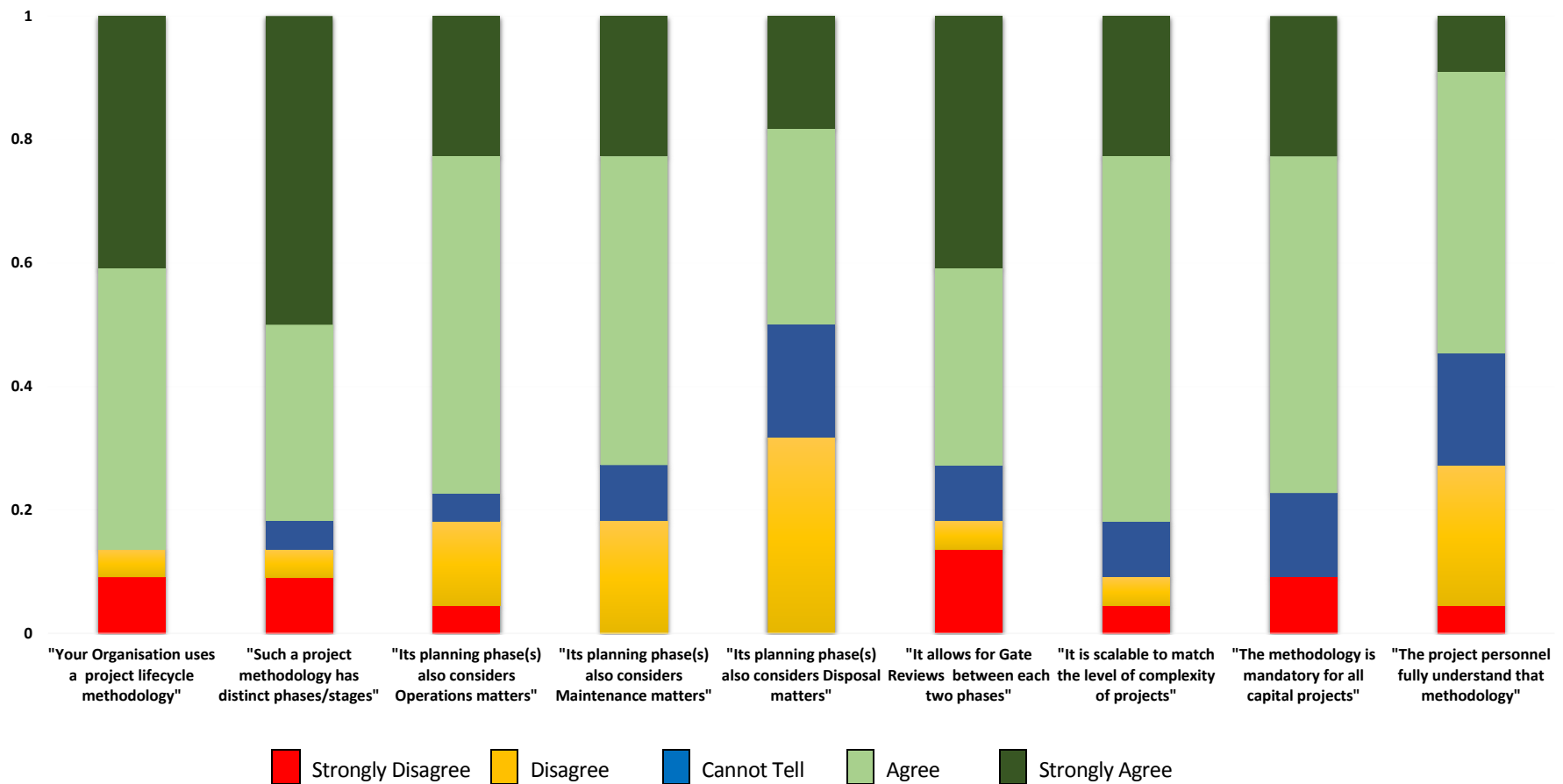


Figure 4.8 – Bar Chart: Lifecycle Methodology

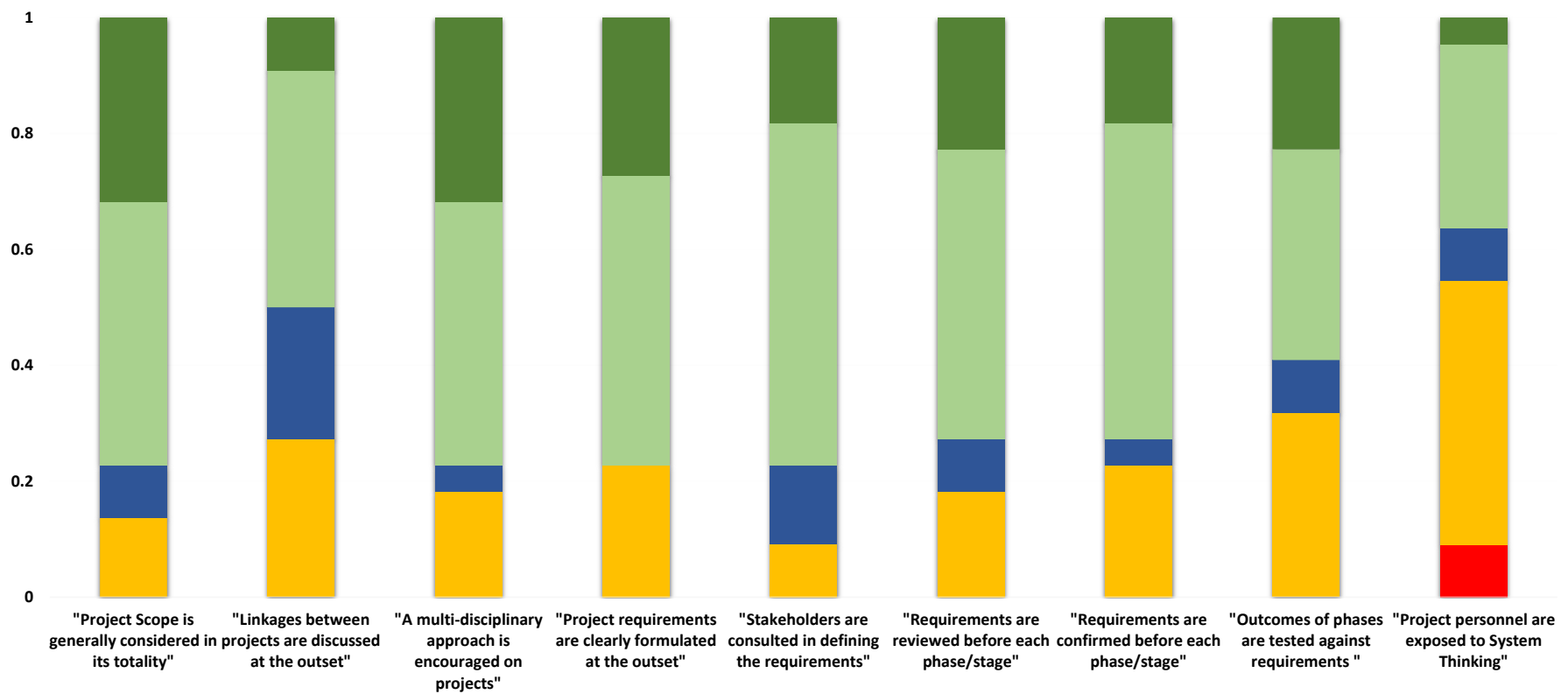


Figure 4.9 – Bar Chart: Principles & Concepts of Methodology

(3) Segment C – Project Delivery Process (C₀₁-C₀₉):

The “Project Delivery Process” bar chart indicates that respondents largely agree on treating Stakeholder Management and Risk Management as core activities (C₀₂ and C₀₃) and to a lesser extent that the outcome of most of their projects meet business objectives and are completed to specifications (C₀₆ and C₀₇). Still, they appear to disagree with the remainder of the statements, particularly on completing projects “on time, on budget” (C₀₈).

(4) Segment D – Readiness to Improve Project Delivery (D₀₁-D₀₉):

The “Readiness to Improve Project Delivery” bar chart indicates that most respondents largely agree with most survey statements, particularly to questions “Project personnel agree that projects do support strategy” (D₀₁) and “Management regularly discuss project performance” (D₀₆). However, they appear to agree less regarding the remainder of the statements. The item on statement (D₀₃) reflects a particularly strong disagreement to a negative assertion, namely, “Project personnel are NOT satisfied with methodology” – which actually indicates an affirmative outcome, a positive stance.

Annexure D provides a tabular representation of all the Online Survey results.

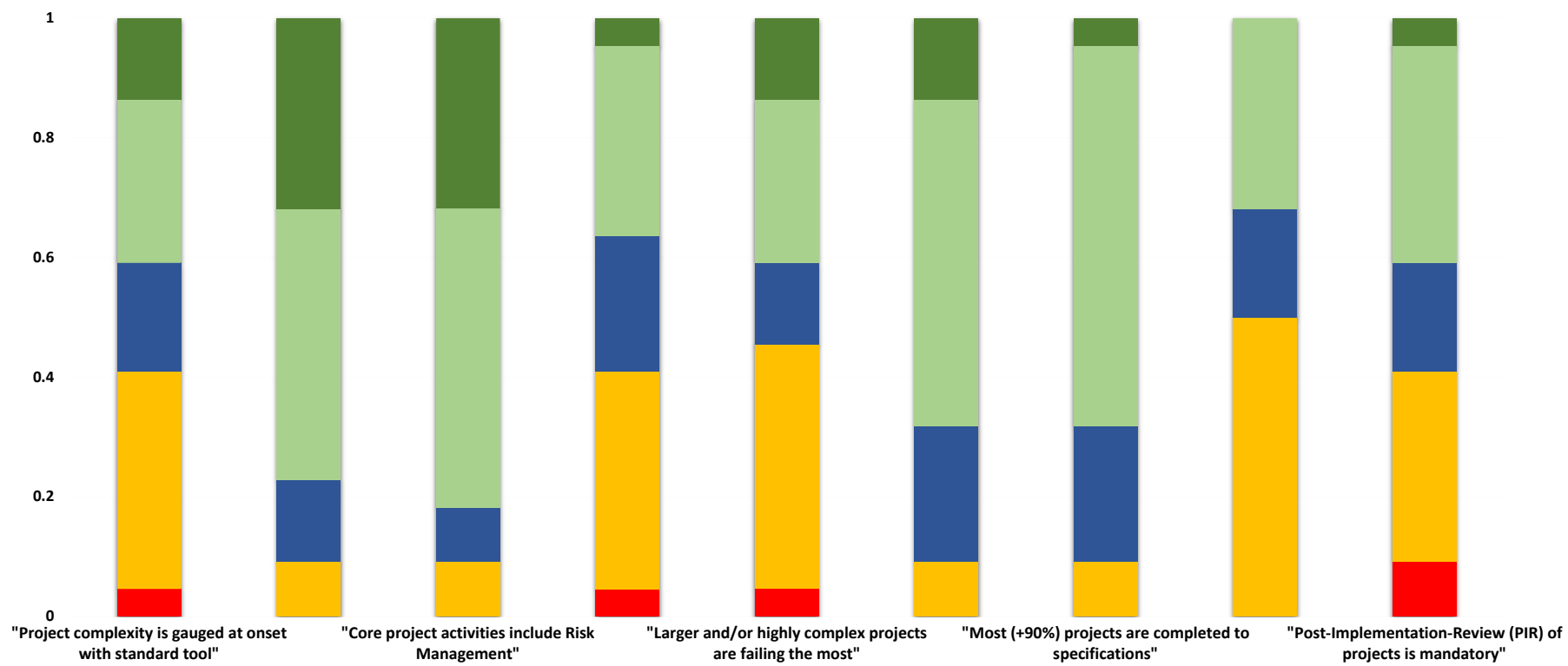


Figure 4.10 – Bar Chart: Project Delivery Process

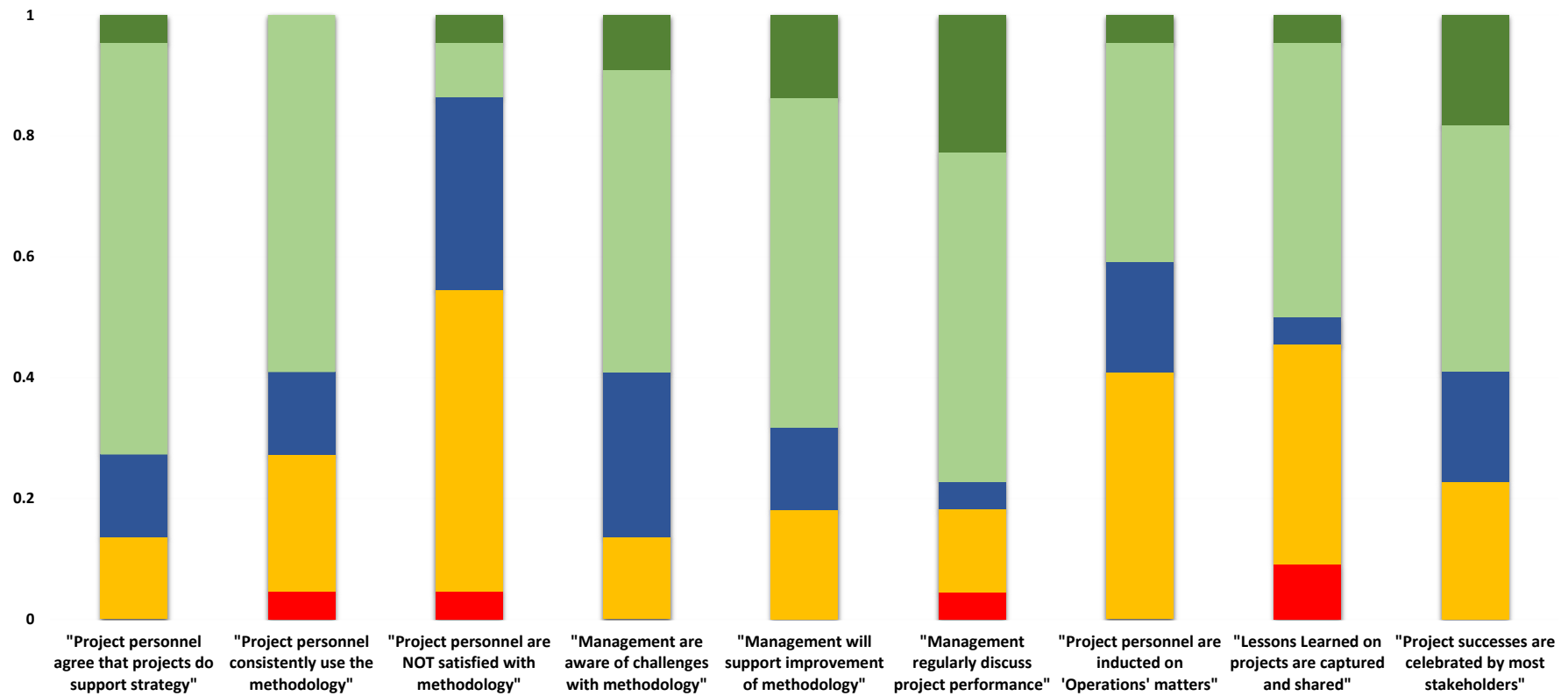


Figure 4.11 – Bar Chart: Readiness to Improve Project Delivery

4.2.4.2. Survey Results per Questions

In this section, a number of questions were selected (around specific themes) for detail analysis. Such an analysis has revealed further insights as follows:

- (1) The respondents answered most “lifecycle” questions *spreading* across the whole Likert scale (e.g., from “strongly disagree to strongly agree”), which reflects the discriminative nature of parameters conveyed in those questions – otherwise most respondents would have picked a fail-safe option such as “Cannot Tell” to most questions. Further to Section 4.2.1, this finding confirms the validity of the Survey Questionnaire;
- (2) Questions Q₀₉ (“*Your Organisation has clear, documented strategic ‘goals’ and most projects are specifically linked to such*”) and Q₃₈ (“*Project personnel agree that projects do support strategy*”) – Most entities surveyed (77%) have a clear, documented organisational strategy and projects are specifically linked to its goals; a majority (73%) are also aware that their projects are meant to support strategy implementation;
- (3) Question Q₀₃ (“*Capital projects are managed at ...*”) – There seems to be many instances (36%) where infrastructure projects are managed a “multiple levels” of the entity, meaning that various spheres within the same organisation are allowed (and perhaps set up) to deliver capital projects. “Capital Division” or “Capital Department” structures that focusses on delivery of capital projects, manage only 27% and 23% of such Infrastructure projects respectively;
- (4) Questions Q₀₇ (“*Granularity of projects in Portfolio*”) and Q₁₁ (“*Your Organisation uses a project lifecycle methodology*”) – Most entities surveyed (86%) use a lifecycle methodology and since the majority (77%) manage a Capital Portfolio including “Big and Small” projects, there is a need to establish a scalability process and/or tool;

It may seem, thus, that tailoring (e.g. scaling the methodology up or down) of a lifecycle methodology to suit the profile of any particular project will prevent any detrimental mismatch between lifecycle requirements and the profile of the project under consideration.

- (5) Questions Q₁₁ ("Your Organisation uses a project lifecycle methodology"), Q₁₂ ("Such a project methodology has distinct phases/stages"), Q₁₆ ("It allows for Gate Reviews between each two phases"), and Q₁₇ ("It is scalable to match the level of complexity of projects") – It is further shows that most entities (64%) using a Project Lifecycle Methodology have adopted a lifecycle model that accommodates distinct stages/phases, with Gate Reviews between each two study phase, and have implemented a scalability tool. Indeed, the Responses Sheet indicates that 63.64% of respondents largely agree to assertions in questions Q₁₁, Q₁₂, Q₁₆, and Q₁₇ concomitantly;

Considering Questions Q₁₈ ("The methodology is mandatory for all capital projects") and Q₁₉ ("The project personnel fully understand that methodology") – 14% of entities surveyed cannot really tell whether the lifecycle methodology is mandatory or not; and a half (45%) have personnel who do not *fully* understand their own project methodology.

- (6) Questions Q₁₃ ("Its planning phase(s) also considers Operations matters"), Q₁₄ ("Its planning phase(s) also considers Maintenance matters"), Q₁₅ ("Its planning phase(s) also considers Disposal matters") and Q₄₄ ("Project personnel are inducted on 'Operations' matters") – 25% of entities surveyed do not consider "operational" matters during the planning or study phases. Moreover, 30% do not consider "maintenance" matters and half (50%) do not consider/incorporate "disposal" requirements – with half (50%) of respondents admitting that their project personnel are not inducted on operational matters;
- (7) Questions Q₂₂ ("A multi-disciplinary approach is encouraged on projects"), Q₂₁ ("Linkages between projects are discussed at the

outset"), and Q₂₀ ("*Project Scope is generally considered in its totality*") – The majority of entities surveyed (76%) are encouraging a "multi-disciplinary approach" on projects, and 73% "consider linkages between various projects at the outset" and consider "the totality of scope" (i.e. full extent of the problem to be solved in context). However, 50% do not do so and some 10% cannot tell whether they do so or not;

(8) Questions Q₂₃ ("*Project requirements are clearly formulated at the outset*"), Q₂₄ ("*Stakeholders are consulted in defining the requirements*"), Q₂₅ ("*Requirements are reviewed before each phase/stage*"), and Q₂₇ ("*Outcomes of phases are tested against requirements*") – The majority (77%) of entities surveyed formulate project requirements at the outset, and most (80%) seem to consult their stakeholders in formulation project requirements (at project outset). However, a third ($\frac{1}{3}$) of the entities surveyed would not review nor confirm such requirements between each two phases, while half of the entities ($\frac{1}{2}$) do not even verify phase outputs/outcomes against agreed requirements to confirm compliance and validity;

(9) Question Q₂₉ ("*Project complexity is gauged at onset with standard tool*") – The majority (just below 60%) of the entities surveyed do not gauge project complexity (i.e. using a standardised tool) at the onset;

(10) Questions Q₃₃ ("*Larger and/or highly complex projects are failing the most*") and Q₃₂ ("*Project failure is clearly defined in a policy/framework*") – Half (50%) of the respondents agree that risk of failure seems to increase with project complexity, more so when some entities would not consider Risk Management and Stakeholder Management as a core project-delivery activity (around 20% of entities surveyed). They might not even have an "official definition" of project failure and would not be able to declare failure even when:

(i) Question Q₃₄ ("*Most projects meet their business objectives*") – projects are not meeting their objectives (23%, almost a quarter of respondent cannot tell whether such had pertained); or

- (ii) Questions Q₃₅ ("*Most projects are completed to specifications*")
 - projects are producing “products” (or systems) that fail to meet agreed specifications (again, 23% of respondent cannot even tell).

A mere third (32%) of entities could boast of completing their projects “on time, on budget” – which concurs with Sections 1.5 and 2.2 above; insight-item (10) confirms project management is facing challenges.

- (11) Question Q₃₇ ("*Post-Implementation-Review of projects is mandatory*")
 - Lack of Post Implementation Review (PIR) practice in many entities further exacerbates point (10) above. Less than a half (41%) of entities surveyed would agree that PIR is actually taking place, whereas a fifth (18%) cannot even tell whether a PIR process/framework is in place.

Management theories suggest people behave according to what they are measured on: “*Tell me how you measure me and I will tell you how I will behave. If you measure me in an illogical way... do not complain about illogical behavior.*” – Eli Goldratt (1990). This could then explain:

- (i) Why adopted lifecycle methodology is not being used consistently;
- (ii) Project personnel are not satisfied with the adopted methodology;
- (iii) Lessons-learned are not shared – as almost half ($\frac{1}{2}$) would admit; to the Question Q₄₅ ("*Lessons Learned on projects are captured and shared*") 45% of respondents disagree, a further 5% cannot tell.

- (12) Questions Q₄₈ to Q₅₂: The entities surveyed had of late experienced project delivery challenges in terms of the following critical aspects:
 - (i) Business Case development – difficulties in establishing business rationale for projects and/or proceeding without such rationale;
 - (ii) Technical Feasibility and Design – although it reflects as the least prevalent, poor technical design or design documentation leading to shortcomings/inadequacies will entail “variation orders and/or compensation events” for fixes during construction or operations;
 - (iii) Execution Planning – poorly developed construction methodology, inadequate cost/schedule estimates during planning phase; and

(iv) Ramp-up to Operations – instances of good design and/or plans but poorly executed, lack of operational readiness by the Owner.

It is thus posited that most organisations seem to suffer less with defining the WHAT (e.g., Engineering Solution), but rather with the WHY (e.g., Business Case, Rationale) and more with the HOW (e.g., Planning of Execution) of projects. (Gate Review Analytics, 2014)

(13) Questions Q₄₁ ("Management are aware of challenges with methodology") and Q₄₃ ("Management regularly discuss project performance") – When executive management of the entity is generally aware of the challenges with the adopted project methodology, they would probably support its improvement (as the majority would believe). However, when they do not regularly discuss project performance – as almost a third ($\frac{1}{3}$) would admit, there is a risk to the organisation and the capital delivery structure (e.g., project teams) that management will impose unsuitable and ill-advised solutions to such project challenges.

The above discourse not only summarises the participants' responses, but also provides some insights into the *status quo* and areas of project methodology that might need enhancements through application of Systems Engineering (SE) concepts in the delivery of Large Scale Projects (LIPs). It is already clear, particularly from item (7), that even when delivery entities decree what ought to be done, many project personnel still fail to comply – "50% do not do so and some 10% cannot tell whether they do so or not".

This attitude vindicates the inclusion of a discussion on implementation issues (e.g., risks, barriers, and opposition to successful implementation) during the interviews with project practitioners and industry experts (SMEs). Section 1.8 previously submitted that a particular attention should be given to practical deployment issues (e.g., implementing risks, benefits, and challenges; SE roles on projects, integration) throughout the numerous reviews, discussions, and articulations leading to the development of an enhanced project lifecycle model applicable to Large Infrastructure Projects.

In fact, one of the recommendations for the introduction of SE is as follows: *“Involvement and belief in SE by management are essential for the successful incorporation of this working method in the organisation. Put SE on the management agenda and make sure that employees see that the managers also support the working method. This is not just about the kick-off; the implementation of SE must remain on the agenda for a prolonged period of time.”* (SE in CES, 2013, p. 22) – A sound SE implementation should start at the top, with senior executive, as opposed to the project community.

4.3. Statistical Correlation Analysis

A Correlation Analysis between and among the various responses has supplemented the above Statistical Analysis based on participants' answers to individual (survey) questions. It determined to what extent some answers with strong reciprocal correlation could provide insight as to any “linkages” between elements of a generic lifecycle (captured in the various questions) – Linkages determines overall behaviours of SoS. (SE Guide for SoS, p. 36)

Therefore, a Coefficient of Correlation Table was developed on spreadsheet (Annexure D4) between every two set of responses to establish their degree of correlation; any sets with strong correlation factors (equal or above 0.7 in absolute value) were identified as significantly correlated. Subsequently, a Thematic Analysis was conducted in line with Section 3.5.2.

The following *systemic patterns* were perceived, which both current industry experience and literature survey would substantiate, corroborate as follows: (More details on the ensuing survey insights are contained in Annexure E.)

- (1) Correlation between Questions Q₀₄ and Q₀₅ could suggest that in Rand value, the biggest individual project probably pertains to the biggest portfolio – *thus, the bigger the portfolio (in Rand value), the more rigour ought to apply to the management of projects through a lifecycle model;*
- (2) Correlations between Q₀₆, Q₀₅, and Q₀₄ could suggest that the biggest portfolio (in Rand value) might not be the biggest in terms of number of

individual projects – *a portfolio could consist of a small number of large individual projects. The number of individual projects in a portfolio would not necessarily add to its project complexity, but certainly to the complexity arising in managing the portfolio itself;*

- (3) Correlation between Q₁₂ and Q₁₁ could suggest that most Project Lifecycle Methodologies do include distinct stages and/or phases – *acceptance and practice of the lifecycle methodologies are now widely established in the capital or infrastructure delivery industry;*
- (4) Correlations between Q₁₅, Q₁₄ and Q₁₃ suggests that methodologies that do not accommodate Operational considerations also fail to include Maintenance and Disposal matters – *this then confirms the current mind-set of focussing on the production of a “physical asset” as an end in itself;*
- (5) Correlations between Q₁₈, Q₁₇, Q₁₆ and Q₀₈ could suggest that where the methodology is made mandatory, the same will generally include a scalability framework and a Gate Review process – *hence, to effectively decree a lifecycle methodology as mandatory will entail making it scalable (i.e. so it may suit all types/sizes) and propping it with a governance mechanism such as the Gate Review process;*
- (6) Correlation between Q₁₉ and Q₁₈ suggests that where the Methodology is mandatory, project personnel are prone to understand it better, even fully – *they have to learn it or else face the penalties. Project personnel would not necessarily comply to any methodology deemed optional;*
- (7) Correlation between Q₁₉ and Q₀₈ could suggest that entities where project personnel understand the methodology also tend to reach higher levels of PM maturity – *consistent application of an integrated, multi-disciplinary lifecycle methodology yields higher PM maturity.*
- (8) Correlation between Q₂₃ and Q₂₀ suggests that entities that endeavour to clearly formulate project requirements at the outset also tend to consider the project scope in its totality – *exploring project requirements*

at the outset provides opportunities to identify commonalities and externalities of the particular project with other initiatives. The same prevailing “systems mind-set” leads to understanding the context of the problem first, before even attempting to find any solution;

- (9) Correlations between Q₂₅, Q₁₈, Q₁₇ and Q₀₈ could suggest that in entities where requirements are reviewed before each phase (e.g., at Gate Reviews), project personnel also tend to fully understand the methodology; they consider operational and disposal matters during planning and may reach higher levels of PM maturity. *Project Lifecycle Methodology is all about managing requirements (both business and technical) throughout the entire lifecycle. Once this is understood, not only the focus will be rightly placed on the “improvement of operational environment”, but such will also be verified prior to starting each phase;*
- (10) Correlations between Q₂₆, Q₂₅ and Q₁₈ could suggest that where the Methodology is mandatory, project personnel would tend to review and confirm project requirements before each lifecycle phase –*Verification and Validation (V&) could be part of a Gate Review process;*
- (11) Correlations between Q₂₇, Q₂₁ and Q₂₀ could suggest that considering project scope in its totality will lead to discussing linkages between projects at the outset and to testing outcomes against requirements (as clearly formulated at the outset) – *this reinforces the need for a systems view and for a Verification & Validation of the system being developed;*
- (12) Correlations between Q₂₉, Q₂₈, Q₂₅, Q₁₈ and Q₀₈ could suggest that in entities where a Systems Thinking mind-set prevails, their project Lifecycle Methodology is generally mandatory; moreover, complexity is gauged (at the outset with a standard tool), requirements are revised before each phase, and their PM maturity may also reach high levels – *Systems Thinking enables project management to handle complexity;*
- (13) Correlations between Q₃₀, Q₂₄, Q₂₃ and Q₀₉ suggest that entities with a documented strategy (and projects are linked thereto) also tend to

regard Stakeholder Management as core activity of project delivery, and tend to involve stakeholders in formulating requirements at the outset – *for those entities understand that Stakeholder Management is vital to strategic success, whether through business as usual or projects;*

- (14) Correlations between Q₃₁, Q₃₀ and Q₂₂ suggest that entities that regard Risk Management as core to delivery also tend to treat Stakeholder Management as core, even encouraging a multi-disciplinary approach on complex projects – *understanding the project as a system brings a comprehensive approach to Risk Management, e.g., managing risk across all boundaries and disciplines of the project as a set of systems;*
- (15) Correlations between Q₃₂, Q₂₅ and Q₂₁ could suggest that entities that explicitly define “project success/failure” will tend to consider linkages between various projects at the outset. They will generally confirm project requirements before each phase – *project personnel that are aware of the impacts of project failure will understand how such failure may have “ripple effects” on other, interrelated projects and operations, and will consider taking steps to bring success, be it so at each phase;*
- (16) Correlations between Q₃₂, Q₂₅ and Q₂₁ could suggest that entities that generally complete their projects to specifications will tend to meet their business objectives – *for business objectives translate in requirements that projects shall meet to the owners’ satisfaction. “Developing and translating into action any corporate strategies can also be understood as project or better a network of projects ... Project Management can itself be a strategic factor ...” (Reschke & Schelle, 2012, p. 85);*
- (17) Correlation between Q₃₇ and Q₂₁ could suggest that those entities that treat Post-Implementation-Review (PIR) as mandatory generally seek to formulate clear project requirements at the outset – *formulating clear, correct requirements in the first place will prevent wrong, unrealistic expectations (and unnecessary arguments) at PIR;*

- (18) Correlations between Q₃₉, Q₁₉, Q₁₀ and Q₀₈ could suggest that in entities where the methodology is fully understood, their project personnel also tend to comply and use it consistently, which will eventually lead to increased PM Maturity – *understanding and consistently using the methodology eventually could lead to an increased in PM Maturity*;
- (19) Correlation between Q₄₀ and Q₁₉ could suggest that in entities where the methodology is fully understood project personnel tend to be satisfied with such, which also leads to increased PM Maturity – *should project personnel be satisfied with the methodology (as they also understand it well), they will tend to use it more consistently, which eventually leads to an increased PM Maturity {as stated above in (18)}*;
- (20) Correlations between Q₄₂, Q₃₀ and Q₂₈ could suggest that in entities where Systems Thinking prevails project personnel tend to treat Stakeholder Management as a core project delivery activity, and their management will tend to support improvement of methodology – *for a Systems mind-set regards stakeholders as part of the system and leads management to appreciate the methodology as a system-integrator*;
- (21) Correlations between Q₄₃, Q₄₂ and Q₄₀ could suggest that in entities where management discuss project performance, their personnel tend to be satisfied with the methodology – *for management that discusses project performance would attend to, address project challenges*;
- (22) Correlations between Q₄₆, Q₄₁, Q₃₀ and Q₂₄ could suggest that in entities that treat Stakeholder Management as core, stakeholders are involved in formulating project requirements. Moreover, their management will be aware of any methodology challenges and most stakeholders will celebrate project success – *the success or failure of any project depend on the support (or otherwise) received from stakeholders; they are part of the project and shall be treated as such throughout its lifecycle*.

This concludes the listing of insight-items that emerged from the Correlation Analysis of the survey responses, as augmented by a Thematic Analysis.

Furthermore, Figure 4.11 below indicates that while most respondents represented (or worked for) project entities that are evenly spread between the Public (40.9%) and the Private sectors (54.5%), the Correlation Table has reflected quite low correlations factors (± 0.4) between Q₀₁ (Organisation Industry Sector) and any other survey questions.

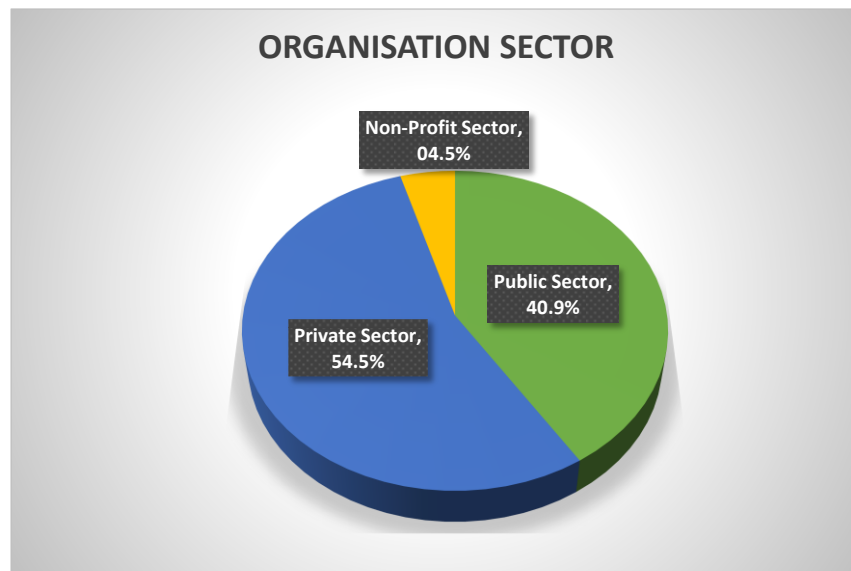


Figure 4.12 – Pie Chart: Organisation Sector

It could therefore mean that industry sector (whether public or private) has little bearing on the overall outcome of the survey and shall be treated as a non-discriminant factor in this study. Therefore, outcomes, findings, and other recommendations emerging from this study should equally apply to both public and private sectors LIPs delivery entities.

Figure 4.13 below maps out those insights – from insight-items (1) to (22) – to reflect the various lifecycle items, taking into account the interactions and dependencies between critical “lifecycle” and/or “requirements” elements as identified throughout the foregoing literature review and industry survey.

An A3 Format of Project Lifecycle Model – Correlation Map is in Annexure F.

Project Lifecycle Model — Correlation Map

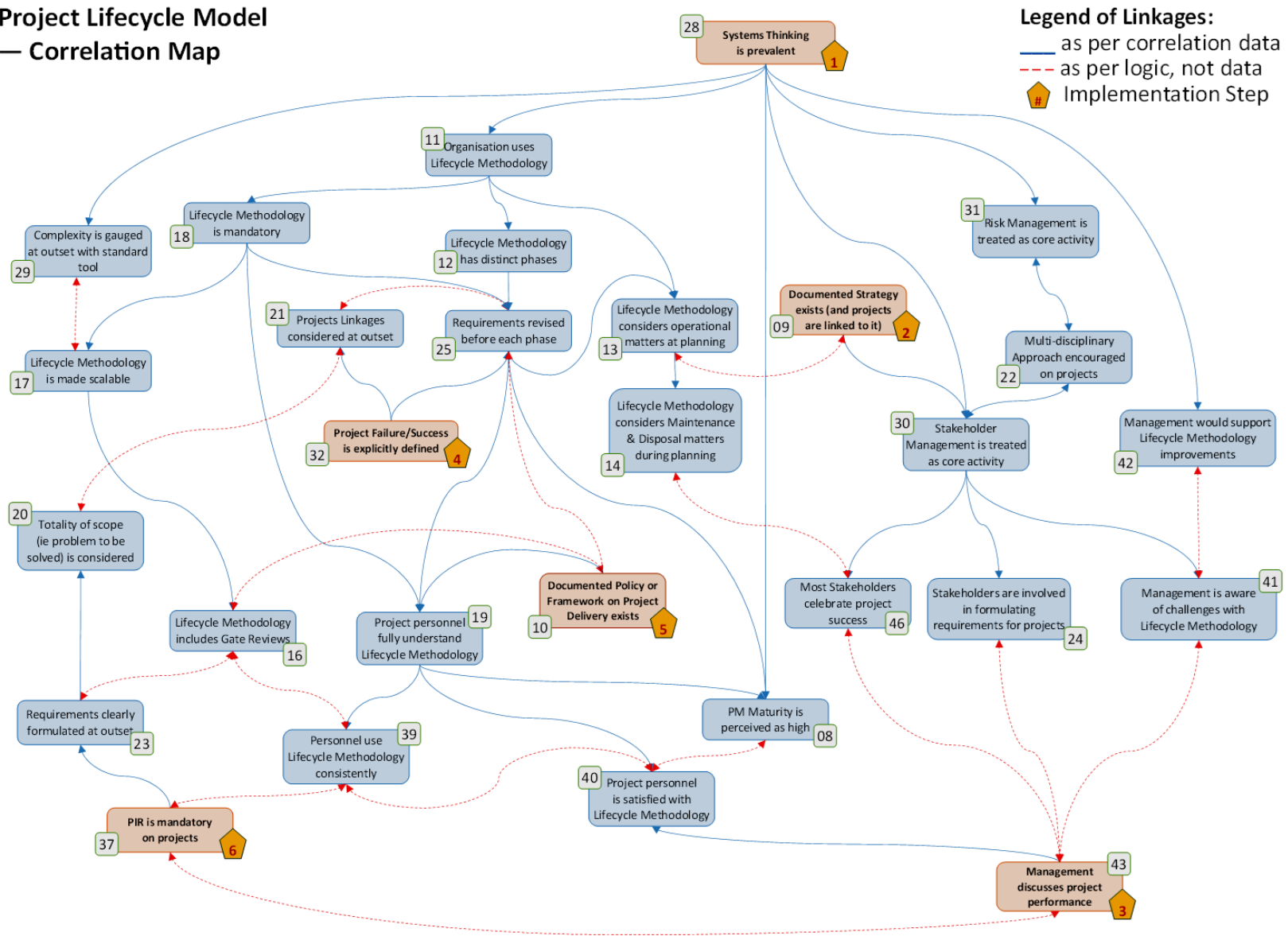


Figure 4.13 – Project Lifecycle Correlation Map (by the author)

The Correlation Map was constructed by drawing connections between critical “lifecycle elements” (as reflected in the survey questionnaire) that show a strong Coefficient of Correlation (i.e. above +0.69 and below -0.69 for positive and negative correlations respectively). According to Levine *et al.* (2008), a strong correlation indicates the *tendencies* present in the data, not necessarily a causality relationship (which, when appropriate, arose from a logical interpretation of lifecycle elements arising from the literature review).

The coefficient of correlation indicates a relationship or association, between two numerical variables. Sets of numerical variables arise from (Likert coded) responses to the same set of (survey) questions. Relationships among variables are displayed by cross-tabulation and correlations. (Simon, 2011)

When the coefficient of correlation gets closer to +1 or -1, the relationship between the two variables is stronger and vice-versa. (Levine *et al.*, 2008) Salkin (2011) argues ± 0.6 is a strong factor; this study sets a ± 0.69 threshold.

These correlations reflect how the agents (e.g., lifecycle elements) in the delivery system interact in apparently random ways, yet from all such interactions patterns might emerge which inform the behaviour of the agents within the system and the behaviour of the overall delivery system itself.

Therefore, the “overall behaviour” of the project lifecycle methodology (a system in its own right) could be interpreted from sets of mutual relationships among its many elements, which are determined by way of coefficient of correlations – hence, the mapping thereof constitutes the Correlation Map. Such a map could evolve into a standardised tool for measuring the “systems-completeness” (i.e. adequacy) of SE-based project lifecycle methodologies.

The Correlation Map reflects two types of “nodes” (i.e. Lifecycle Elements) that are color-coded as “Blue Node”  and “Red Node”  – For the “Blue Node” represents any ordinary node that connects two or more “lifecycle elements”, whereas a “Red Node” (or precursor element) will embody a specific node from which linkages will originate; as such, these nodes constitute starting blocks. It would follow that any errors, inadequacies, and flaws pertaining to the scope,

design, or implementation of any such precursor elements could have a major impact on the overall behaviour of the Project Lifecycle Model (i.e. a Complex Adaptive System, CAS) – these *leverage-points* are to be given strict attention.

“Complex adaptive systems (CAS) exhibits coherence under change, interacting and exchanging information with the changing environment, not necessarily with a central coordination, having leverage points, where a low quantity of input may lead to significant changes”. (Eduardo et al., 2004, p. 1)

The Project Lifecycle Infrastructure (i.e. contains most of the 22 project lifecycle elements) is indeed considered a Complex-Adaptive-System (CAS) as follows: *“As a response to this changing world, the project based organization (PBO) is emerging as a feasible option to companies and organizations in general in order to cope with the complexities and uncertainties of the environment. In this approach, the project as an autonomous agent and the project portfolio as a complex adaptive system (CAS), not the static company or organization, are put at the core of the system.”* (Ibidem)

The Project Lifecycle Model – Correlation Map has identified “Precursor Nodes” that drive Project Lifecycle Infrastructure deployment of as follows:

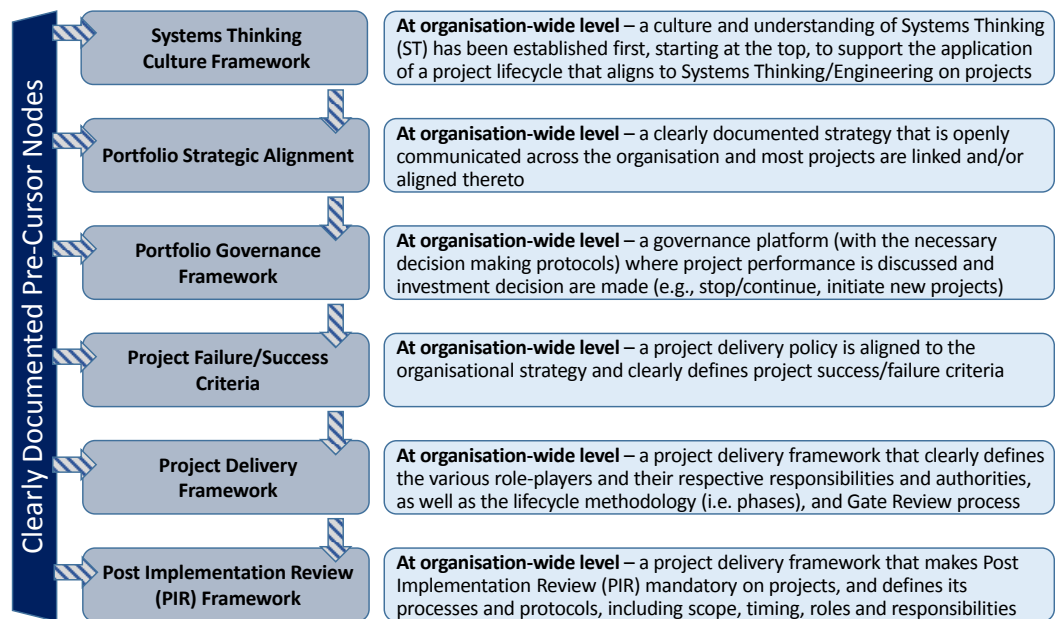


Figure 4.14 – The Six Precursor Nodes of Infrastructure Project Lifecycle (by the author)

It would transpire from the foregoing that the first six (6) critical steps towards deploying an effective Project Lifecycle Infrastructure will consist of strategic interventions at organisational level – as opposed to *starting* at project level. Many organisations expend futile efforts in rushing into hiring reputable project managers, providing them with powerful tools, and expecting them to thrive in delivering capital projects; it must start at the organisational level.

It is however discouraging to realise from the industry survey that, for instance, many of the entities surveyed do not, or if they do, poorly practise most of the above-mentioned “vital” lifecycle elements as the below table seems to indicate:

Lifecycle Element	Brief Description	Comment
09	Clear strategic 'goals' and projects are linked to such	20% do not ...
10	Clear Framework / Policy on Project Delivery	30% do not ...
28	Project personnel are exposed to Systems Thinking	70% do not ...
32	Project success/failure is clearly defined in a policy/framework	60% do not ...
37	Post-Implementation-Review (PIR) of projects is mandatory	60% do not ...
43	Management regularly discuss project performance	20% do not ...

Table 4.1 – Survey Scoring on Precursor Elements of Lifecycle Infrastructure

4.4. Structured Interviews Analysis

Subsequent to the online survey aimed at establishing the *status quo* in the industry as far as capital project delivery is concerned, a series of structured interviews were conducted with Subject Matter Experts (SMEs) identified from the capital projects space (i.e. mostly operating in the infrastructure sector) to discuss possible scenarios (plausible “Should Be” models).

Subject Matter Experts (SMEs) were duly selected from among the initial respondents (who indicated their willingness to participate) based on their knowledge and/or experience in the area of Large Infrastructure Projects (LIPs) and/or in Systems Engineering (SE). Hence, out of a total of 22 initial respondents (to the online survey), only 8 individuals qualified for the subsequent Structured Interview and Delphi Panel – The investigator relied

on his own professional experience in LIPs industry and the outcome of the Literature Survey to select SMEs after an informal discussion to that effect.

The foregoing analysis has clarified plausible elements required for the development (and sound deployment) of an effective and SE-based project lifecycle model. The enhanced model, if suitably and adequately applied, will address most of the shortcomings identified through the literature survey and reliably confirmed through both experience and questionnaire surveys. Hence, the next step consisted of discussing, further corroborating feasible *enhancement* proposals with appropriately selected Subject-Matter-Experts.

To open and guide the discussions with identified SMEs, the Structured Interview posed five (5) project lifecycle-related questions (refer also to Section 3.1.3.3). To prevent a halo effect, no “systems engineering jargon” was accommodated, reflected in the “open ended” questions as follows:

- 1° Would you support the notion of a project lifecycle that consider Operations, Maintenance and Disposal matters during the study or planning phase? If “Yes”, what benefits and risks would you foresee?*
- 2° Since downstream (i.e. construction/operations) troubles are from upstream (i.e. planning) neglects, should planning phases consider “operations” issues?*
- 3° Do you find it difficult to formulate Owner’s Requirements at the beginning of the project? If “Yes”, do you think allowing stakeholders’ input will help?*
- 4° Would you find it useful to confirm that specified requirements are met in the “product” being designed and developed? Or that requirements for an explicit intended use have been satisfied?*
- 5° Would you agree that projects only derive their full value if all the essential parts of the final “product”, all their interfaces of such parts with one another and with the “environment” are adequately addressed through the lifecycle?*

4.4.1. Structured Interview Respondents

A Panel of Subject-Matter-Experts included project professionals as follows:

Panellist	Project Lifecycle Background	Comments
<i>For anonymity sake, the eight panel members were given pseudonyms by colour ...</i>		
Panellist 1	“Red” is currently a consultant in the field of project and operations management; he has worked in the consultancy industry for the last 15 to 18 years, including in construction and other industries and disciplines ...	This participant shall be able to provide industry perspectives on SE in construction
Panellist 2	“Orange” is has worked on projects for the last 15 years or so; and has been involved in all types of projects, ranging from simple ones to highly complex, multi-level, multi-disciplinary, one-of-a-kind, recovery projects.	This participant is conversant with SE and could be able to provide “thinking”, “feasible” solutions
Panellist 3	“Yellow” works as a specialist (in a critical project delivery area) in a large corporation involved in the delivery of large infrastructure projects. He is highly qualified, although he has only 4 years of practical experience.	This participant will provide a real-life perspective as to project lifecycle implementation
Panellist 4	“Blue” is close to retirement; he was originally trained in electronics and worked on computer and military systems. Over the last 8 years, has worked on large infrastructure projects and project lifecycle.	This participant will provide a real-life perspective as to project lifecycle on systems and LIPs
Panellist 5	“Green” is a Risk Management Consultant, having worked for a large state-owned company for 7 years in the project delivery environment and has assisted in rolling out Risk Management in that organisation.	This participant will provide a real-life perspective as to project lifecycle on LIPs
Panellist 6	“Indigo” has 10 years of experience in the railway signalling industry; he has mostly worked for a state-owned-company, as part of the in house project delivery team.	This participant shall be able to provide industry perspectives on SE in rail projects.
Panellist 7	“Violet” is the current Project Management Office manager in a large corporation involved in large infrastructure projects and is very conversant with lifecycle methodologies; has 6 years’ experience, currently completing a PhD in sustainability of projects ...	This participant will provide a real-life perspective as to project lifecycle on LIPs
Panellist 8	“Black” has been a project manager for the last 35 years (10 in the construction industry in the UK, and 25 more as a management consultant in the area of capital projects); he has worked in various industries, and has accumulated experience and best practices.	This participant shall be able to provide industry perspectives on SE in construction

Table 4.2 – Interview and Delphi Panel Members and Professional Background

Table 4.2 reflects the calibre of the selected Subject Matter Experts (SMEs) who participated in structured interviews (and subsequent Delphi Panel) and indicates the nature and intensity of their respective contributions in terms of Systems Engineering and Large Infrastructure Projects – collectively, these SMEs have earned almost a hundred (100) years of experience in the industry.

4.4.2. Thematic Analysis of Interviews

In keeping with the requirements of a Thematic Analysis, responses (e.g., views, opinions, personal experiences) arising from the structured interviews with selected SMEs prompted an intuitive epistemological inquiry in seeking to enrich the understanding of the *status quo*. Insights, interpretations, and understanding reflecting the current situation pertaining to SE application and LIPs delivery were actually teased out of interview proceedings for “*The whole interview is not only greater than the sum of its parts, but by ‘immersion’ in the whole one gains understanding of the parts ...*” (Marks & Yardley, 2004, p. 66)

The current project lifecycle model (i.e. the phenomenon under study) served as a “conceptual tool” (e.g., existing model to be replicated, extended or enhanced) to abstract from the immense detail and complexity of data those features that are most salient for the study’s purposes. This kept *grounded* both the interviews proceedings and their subsequent thematic interpretations – existing theories drove both questions and understanding of answers thereto.

While structured interviews with SMEs were conducted with a “model-testing” mind-set (i.e. seeking primarily to answer the *status quo* question), opinions arising from structured interview responses also constituted “inductive themes” and provided further insights into feasible *enhancement* propositions. For this reason, the outcomes of these structured interviews were incorporated into the building of the new model (i.e. incorporating *enhancement* elements).

Having combined indicators and insights from the literature as well as *increased understanding* from interpretations of interview outcomes, a number of project lifecycle aspects suggested areas requiring SE articulation in order

to develop and propose enhancements to the traditional Project Lifecycle Model.

The following themes informed the Structured Interviews and the Delphi Panel – and subsequent Sections 4.4.3.1 to 4.4.3.5 will expand on the same themes:

- (i) Project Lifecycle Span – *to determine what elements of the asset lifecycle are pertinent and should be incorporated into the project lifecycle Model;*
- (ii) Operational Input into Front End Planning – *to clarify the rationale and scope (e.g., content) of operational input required in effective planning;*
- (iii) Stakeholder Input into Requirement Formulation – *to establish the rationale and scope (e.g., content, timing) of stakeholder input into the formulation (and possibly the validation) of project requirements;*
- (iv) Verification and Validation of Requirements – *to clarify the rationale, scope, and effective approaches to both Verification and Validation;*
- (v) Treating Projects as Systems – *to expand on the rationale, benefits, and practical implications of treating complex projects as systems.*

These five (5) project lifecycle concepts recurrently emerged from the surveys (as plausible enhancements to current project methodologies) and informed the structured interviews; expanding on those will provide the building material for the development of the anticipated SE-Based Project Lifecycle Model.

The ensuing elaborations (pertaining to those five concepts) further reflect the distillation of the practical knowledge, insights, and elucidations that transpired throughout the course of this investigation, particularly from the discussions with the Subject-Matter-Experts (including LIP practitioners and the academia).

Annexure D contains copies of full transcripts of the Structured Interviews. The following significant points consistently transpired from the discussions with the Subject Matter Experts (SMEs) in the capital-project delivery space.

4.4.3. Structured Interview Outcomes

This section attempts to capture, structure, and articulate the essence of discussions with various SMEs around the five themes as identified above; references are provided when appropriate to support/refute their opinions. (Participants are referred by their pseudonyms when quoted in this section.)

4.4.3.1. Project Lifecycle Span

INCOSE SEH v3 differentiates between the asset lifecycle (which reflects the phases, processes, activities, and status of the asset from its inception to its eventual disposal) and the project lifecycle (which reflects the phases, processes, activities, and deliverables of the asset from Concept Design to its Handover to Operations – having a definitive start and finish).

In fact, some respondents have suggested that business teams should focus on the asset lifecycle (including asset lifecycle costs) whereas project teams should focus on project lifecycle, and various organisational functions (e.g., finance, legal, human resources, marketing, procurement) shall each play their role as per the relevant lifecycle.

“Functions that are to deliver the physical asset, those that are to maintain and dispose of it, and those that are to operate and commercialise it shall all work in an integrated fashion. It is inappropriate that project managers will develop and execute asset without understanding, involving operations personnel in the early phases.” (“Red”, Project and Operations Consultant)

It is essential to attain this three-fold demand for projects to produce business benefits, as physical assets are but one element of the business; thus, the focus is on delivering a business solution, not merely a physical asset.

Indeed, both theory and actual experience suggest that a comprehensive exploration of the operational environment may prompt a set of operational improvement-solutions that are possibly far more practical and acceptable than any capital investment solution. Section 4.4.2 further drives this point.

Yet many project lifecycle methodologies neglect or leave out the Close-out phase; this is problematic as the Close-out Phase is very critical in ensuring that the works of the projects are duly, adequately closed out. Indeed, most respondents are aware of difficulties in considering certain phases (e.g., Disposal, Closeout, or Maintenance), but would not support their exclusion:

“The timing of Disposal (e.g., up to 40 years after Closeout) makes predicting or incorporating its imperatives and demands seem impractical ... Lifecycle that neglects or leaves out the closeout phase is problematic”. (“Green”, Risk Manager)

“In the signalling industry, the maintenance portion of an asset lifecycle entails a bigger share of its lifecycle costs than the earlier phases of development or execution; for this reason alone, it ought not to be ignored.” (“Indigo”, Signalling Practitioner)

Proper application of project lifecycle methodologies entails the consideration of all lifecycle aspects and requirements. Moreover, Concurrent Engineering requires that the various “domains” (e.g., engineering disciplines, operations) that play a major role along the asset lifecycle should integrate their demands (e.g., design, construction, operations, maintenance, and disposal) in the Front-End planning stages. (DOE O 413.3A, 2008, p. 27)

In Mining projects, for instance, project methodologies tend to incorporate maintenance and disposal requirements according to applicable legislations. Hence, *“... reviews were conducted, focusing on water quality, environmental legacy issues and tailings disposal facilities.”* (AngloAmerican, 2013, p. 43) – though some fear it could turn the business case unattractive. (Ibidem)

A respondent argues that project teams that are appointed for the producing of a physical asset to be (literally) handed over to operations fall into the usual trap of disregarding operations, maintenance, and disposal considerations – Thus making such matters the exclusive concern of operations personnel.

“Project teams are not measured on operability and maintainability, the emphasis is only on building the physical asset, especially in Africa where maintenance is often not considered.” (“Black”, Infrastructure Project Manager)

Unconfirmed accounts in the industry would suggest that a misplaced focus on producing physical assets has led contractors into delivery “whatever is in scope”, caring less as to the purpose it may serve in the operational setting.

“Contractor will provide ‘whatever’ is asked for {by the client}, even if it is not right.”
(“Black”, Infrastructure Project Manager)

All respondents support the notion of a project lifecycle that includes all the phases of the asset lifecycle, from concept to disposal and maintenance. Indeed, allowing for operational, maintenance and disposal imperatives (e.g., risks, timing, and cost) will optimise asset investment processes and produce *right projects done right first time*. (INCOSE 2012)

In conclusion, while a project lifecycle distinct from the asset lifecycle is being promoted, project personnel should rather adopt a “cradle to grave” (“womb to tomb”, in colloquial speech) approach to lifecycle that starts with proper formulation of the owner’s and other stakeholders’ requirements.

4.4.3.2. Operational Input to Front End Planning

Most respondents have proposed that project personnel (i.e. deliverers of capital assets) should actively engage, not antagonise the community of users (e.g., operations and maintenance) to secure the critical operational input.

“Failure to do so might lead to the delivering of a new asset, but not necessarily a workable business solution”. (“Indigo”, Signalling Practitioner)

Furthermore, this stance may lead to inappropriate and/or inadequate design developments (e.g., disastrous effects on Construction and/or Operations such as faulty interfaces, delayed commissioning, strenuous maintenance, and hazardous disposal) due to a lack of operational input during the planning and development phases. (Kossiakoff *et al.*, 2011, p. 160)

“There is a need to think strategically about operations, maintenance and disposal right from the beginning and propose system-solutions accordingly.” (“Violet”, Project Management Office manager)

“We need to consider managing lessons learned on ‘operability’. Hence, ‘operability input’ could be secured right from FEL-1, if not earlier.” (“Blue”, Senior Project Management Consultant)

Therefore, operations, maintenance, and disposal personnel have to be included/represented in project teams throughout the entire project lifecycle to provide relevant and critical operational inputs. In particular, they must not discard the crucial Lessons Learned on “operability and maintainability” – such lessons are an *engine* driving up maturity on a steep learning curve.

Furthermore, both programme and portfolio management levels shall give attention to considerations of operational issues and requirements, which could provide trade-off opportunities between capital-investment solutions and operation-improvement solutions. As it is currently, project teams are often too eager to inject capital even in situations where inexpensive and practical operation-improvement schemes could have helped.

For example, a particular port project was reviewed at Richards Bay harbour (RSA); at the Pre-Feasibility Phase (i.e. where the most viable is selected), operational staffs proposed *obvious* operational improvement initiatives that could yield nearly twice the project throughput for barely a portion of the capital outlay, saving nearly 20 months on the delivery time. Some respondents agree:

“Simulations conducted during the Study Phase should not merely govern the design (e.g., what parameter to use in the {new} design), but rather in anticipating operational performance (i.e. throughput, suitability, cost, and constraints).”
 (“Yellow”, Infrastructure Planning Specialist)

It is quite a paradox that business executives who should be first to realise that a business solution is actually required to achieve strategic objectives would not always appreciate the necessity of providing input in terms of operations, maintenance and disposal aspects to project planning and design, as they lose sight of the bigger picture – and lack a systems view. They join the *chorus of engineers* in pushing for “building the damn thing” within time, cost, and quality parameters, even questioning the value of any

Front End Loading (FEL) exercise – and not many would think of operations (and its risks and imperatives) until the physical asset is close to completion.

Downstream troubles, however, are symptoms of upstream shortcomings; indeed, Oehmen (2012, p. 70) maintains, “*Upstream activities must be held responsible for issues they cause in downstream activities*”. Construction and operations problems might need a recourse upstream, back to planning and development (in order for such to be addressed in an integrated manner). Attempting to quick-fix a *seemingly isolated* faulty element of the system may have negative impact on other elements, not necessarily in close proximity of time or space (Senge, 2006, pp. 57-63) – at times making the problem worse.

Therefore, fixing problems that emerge down the asset lifecycle (e.g., during construction and/or operations, maintenance and disposal) is always more expensive than *designing them out* during Front End planning (i.e. at FELs). In keeping with the V-Model, before proposing any “quick, practical fixes” to problems and glitches arising during construction and/or operations, there should be an attempt to rethink it in context, and then proceed to some Verification and Validation (V&V) before agreeing to implement those fixes.

“If the upfront study was done properly (and environment has not changed), fixes during construction/operations shall follow a normal change management process. If however the upfront study was poor/flawed, the project should stop and get into a “re-design or recovery” mode (e.g., rethink the system) before proceeding any further ...” (“Orange”, Senior Project Management Consultant)

In practice, fixing of major problems during construction/operations should revert to a “re-design or recovery” mode (i.e. rethink the operational system) before proceeding any further – any single *V-right leg* work must have its compensating *V-left leg* design activity that considers the overall systems in its context (including how other items might change). For a major problem entails a change to the baseline, a significant impact, and/or requires retrofit.

4.4.3.3. Stakeholder Involvement in Requirement Formulation

Key aspects of project requirements such as the Owner's Requirements Specifications (ORS) are derived from the owner(s) and key stakeholders; it is critical to involve relevant stakeholders in Requirement Formulation.

"At this stage, it is commonly done in military and aerospace, but hardly in infrastructure)". ("Black", Infrastructure Project Manager)

There is no alternative to eliciting business and technical requirements, even though most clients would not appreciate the risks, costs, and time involved in adequately formulating requirements – worse still, they resent project staffs imposing what such should be. For instance, a Business Case (which is so close to the client) determines the business viability and informs the investment decision; it should follow from the Owner's (and Stakeholders') Requirements Specification (ORS). A proper ORS effectively incorporates requirements from both the owner(s) and any other relevant stakeholders. Many respondents support this collaborative approach to the ORS Elicitation:

"Deliverers of capital assets must actively engage the community of operations and maintenance to secure the critical operational input." ("Black", Infrastructure Project Manager)

The owner must be conversant with operational, maintenance, and disposal matters to provide any meaningful contribution to Requirement Formulation. Further, formulating Owner's Requirements for Large Infrastructure Projects entails wicket problem(s) owing to conflicting perspectives of the various stakeholders involved as well as their divergent impacts on the socio-political-economic realms around the project environment. (Whelton & Ballard, 2002)

The "SE for Intelligent Transportation System" Manual (January 2007, p. 71) refers to stakeholder involvement in Requirement Formulation and in Validation processes as follows:

"... validation was performed on an ongoing basis throughout the process:

- *The business case for the project was documented and validated by senior decision-makers during the initial feasibility study.*
- *User needs were documented and validated by the stakeholders (i.e., “Are these the right needs?”) during the Concept of Operations development.*
- *Stakeholder and system requirements were developed and validated by the stakeholders (i.e., “Do these requirements accurately reflect your needs?”).*

According to some respondents, a close collaboration between Requirement Formulation and Stakeholder Management will provide a structured process conducive to reconciling and prioritising differing requirements. Therefore Stakeholder Management shall evolve from the practice of *informing* stakeholders on progress to *securing their input* (e.g., requirements, concerns) at first, particularly for Large Scale Projects (LIPs); hence, the effective Identification (i.e. who are they?) and Analysis (i.e. who matters?) of project stakeholders become vital. (Bourne, 2010)

Therefore, Requirement Formulation needs to integrate with Stakeholder Management, especially for Large Infrastructure Projects. This integration would reconcile conflicting stakeholder requirements early in the process.

Most participants agree that involving stakeholders in the Requirement Formulation process will assist in securing their input (e.g., needs, desires, concerns) and/or buy-in (i.e. a supporting ingredient to project success). However, they have raised concerns regarding its practical implementation:

“Long timelines involved in creating capital assets and likely changes of project-context and in its environment might not support the freezing of project requirements from the early phases of the lifecycle ... In ICT, it is practically impossible to define all requirements at the outset.” (“Black”, Infrastructure Project Manager)

“Technology obsolescence in fast-paced technology-dependent industries like railway signalling will force the Owner Requirements Specifications to remain open to changes throughout the project lifecycle.” (“Indigo”, Signalling Practitioner)

In large organisations, relevant project stakeholders originate from different divisions or departments, external entities, and other regulatory bodies; this gives rise to daunting issues of reconciling, prioritising conflicting demands. Requirement formulation ought not to open up to corporate politics, and stakeholder engagement should commence timely, not during construction.

In light of the above difficulties, Requirement Formulation will require a structured, evolutionary, and incremental process; a suitably open process, structured engagement philosophy will probably assist in collecting relevant input and providing appropriate feedback to important project stakeholders.

Owner's input is essential, together with input from other stakeholders; their requirements are to be included in the planning and development phases of the projects. At times, formulating requirements at the outset proves difficult as owner often abdicates that responsibility to the EPCM (Engineering Procurement and Construction Management) or project team; stakeholder engagement is even more critical at the earlier phases of the lifecycle – Again, a well-structured process is needed to avoid chaotic engagement.

Indeed, such a structured approach will gather and reconcile conflicting requirements arising from differing, but still relevant, stakeholders – some prioritisation mechanism will also be required to prevent chaos. Not only are these requirements hard to figure out in the outset of the projects, but they may also turn into “wicked problems” (i.e., systematic problems that are characterised by multiplicity of stakeholders involved in complex and unpredictable interactions), particularly in situations of high complexity in the environment and/or the project. (Williams & van't Hof, 2014)

ISO 29148 Standard provides a robust framework for formulating requirements at the project outset; it even allows for stakeholder requirements identification and analysis, reconciling and prioritising conflicting requirements (from various stakeholders) before proceeding to actual systems requirement formulation.

However, when project complexity turns requirement formulation into a wicked problem, it will be rather advisable to rely of a Soft Systems approach such as

the Soft Systems Methodology (SSM) or the CLIOS Process. Sussman (2007, 2009) refers to “Complex, Large-Scale, Interconnected, Open, Sociotechnical” as CLIOS, a class of engineering systems with a wide-ranging social and environmental impacts due to “nested complexity”, which results when a physical domain is nested within and interacts with an institutional sphere, where both are complex.

4.4.3.4. Verification and Validation of Requirements

In innumerable instances, the client or project owner(s) had to find out the hard way that the deployed system, after hand-over to operational users, would not deliver the intended business benefits. Most respondents agree to the necessity of confirming that project requirements are correct from the start:

“Most project failures have something to do with poor, inadequate requirements in the first place.” (“Red”, Project and Operations Consultant)

Rectifying elements to correct a dysfunctional system is always an onerous exercise, but many organisations leave it to the end of the project (or major phases) before confirming whether the system being developed will meet all specified requirements and/or satisfy the needs of the owner and user(s). *“It is suggested that, the transition from execution into operations is where high value leakage occurs, and in certain case studies has destroyed in the region of 30% of the initial study value.”* (Deloitte & Touche, 2012, p. 6)

It therefore follows that the quality of project requirements could serve as indicator of project outcomes. Such requirements should filter down to the component level. Multiple tools (e.g., simulation modelling, performance analysis, and testing of prototype or similar system) could be used as a basis for the confirmation process – the right performance criteria are confirmed to ascertain that the right system is been built right. Requirement validation is done against operational needs, on a “fit-for-purpose” basis.

Confirmation/review of requirements (through Verification and Validation) should take place throughout the lifecycle. An effective project lifecycle model should thus make accommodation for Verification (i.e. system is

being built right) and Validation (i.e. right system is being built) to happen at several interim points, not just at project completion.

The project context is the reference point – for the project context changes (i.e. pace of change is increasing) along the lifecycle, affecting the relevance of project objectives; a review and confirmation of project requirements becomes necessary at every phase (i.e. have project requirements changed or need to be changed?).

To prevent unnecessary arguments and conflict at later stages, project teams should specify and agreed on the measurements for Verification and Validation (V&V) right from the beginning of the lifecycle. Defining Validation Criteria and/or Measurements at the outset will prevent wasting efforts in adding futile features and/or components to the system under consideration – Validation ought to be against the requirements of relevant stakeholders, including on business requirements such as the return on investment:

“Verifying Net Present Value (NPV) on ongoing basis to advise the client as to the projected value to the business from a project could be a good idea.” (“Blue”, Senior Project Management Consultant)

“Another good application of validation is in confirming that locomotive design caters for features that newly introduced female loco-drivers might require or enjoy.” (“Yellow”, Infrastructure Planning Specialist)

Confirming compliance with and validity of requirements both at interim and final stages will assist in controlling design teams’ tendency of designing from within their own “comfort zone” (e.g., “Design by Habit”, based on what one knows or does well, with no regards as to what stakeholders might need). ISO 9001 Standard “Quality management systems – Requirements” requires Verification and Validation to be planned and carried out and records kept. (Design and development verification and validation [clauses: 7.3.5 & 7.3.6])

It is crucial for project success to ensure that project requirements remain current (e.g., clear, complete, correct, consistent, and in context) throughout the lifecycle to permit a coherent Verification and Validation (V&V) process.

Confirmation is needed that the product is being designed to conform to and meet owner's requirements and needs. It occurs at every phase (probably at Gate Reviews) and at interim points. Interim Verification and Validation (V&V) is critical, and so is the Post Implementation Review (PIR) process.

An asset in operations ought to be assessed to establish whether and to what extent it is fulfilling its intended purposes, which highlights the crucial importance of an effective, robust Post Implementation Review (PIR) process. Nevertheless, the V&V process is more practical for physical systems and components thereof, but may prove challenging in ICT (and related sectors) where interim V&V activities are contingent to a full module being available.

4.4.3.5. Treating Projects as Systems

In a seminal article cited in Section 2.6.5 ("9 Laws of Effective Systems Engineering", 2012), Z. Scott refers to "*the system used by the team to design it (Realisation System)*" to argue that the workings of the project delivery (not only the product or service being delivered) is a "system" in its own right.

Projects are systems and ought to be treated as such; moreover, they are dynamic in their context. Project teams should consider the project context, especially because it changes (over time) and affects project objectives.

Embracing a systems view (i.e. Systems Thinking) is crucial to successfully delivering complex projects; however, delivering the *right project* is even more critical than delivering any project *right* – from a business perspective.

In keeping with this systems view, all project delivery disciplines (e.g., engineering, risk management, cost management, procurement, schedule management, Health and Safety) are valued for their respective contribution to the development of the project-system. At least one respondent agrees:

"There is also a need to ensure that all delivery components (e.g., project disciplines) are valued for their respective contribution to the development of the project-system." ("Yellow", Infrastructure Planning Specialist)

The Systems Theory suggests that a functional system should rely on all its essential elements (i.e. the entirety of the system) being in place and on adequately addressing all the interfaces (i.e. amongst its own elements and between those elements and the environment) throughout its lifecycle.

Projects are systems (of Realisation) for creating systems (as Solutions). In processing the responses and comments inferred during the interviews, practical considerations among many respondents furthermore suggest:

- (i) This criterion (i.e. projects should be treated as systems) is certainly a necessary but not sufficient condition, since a well-designed system (i.e. fulfilling the above conditions) could still end up operating sub-optimally due to other factors (e.g., poor workmanship, white noise). For instance, defining the system's components (i.e. architecture) is actually easier to address than identifying, addressing the interactions (i.e. interfaces) between its components and with the environment;
- (ii) A less-than-perfectly-designed system can operate at near-optimum level, provided reasonable tolerances are accommodated that could be adjusted to suit operational needs. In this regard, the availability of some amount of redundancy could help prevent the system's overall performance from deteriorating due to some *localised* imperfections;
- (iii) Due to challenges experienced in designing and deploying a functional and purposeful system, relevant opportunities should be provided for optimising the project at a later stage. The design of a new/upgraded system may always cater for a phased deployment. It might not always prove practical (nor necessary) to achieve full system functionality *first time* – some (minor) issues such as missing components, ineffective interfaces may be tolerated provided that the whole still performs satisfactorily, until an opportunity will arise to scale up the system and make the facility more sustainable in an evolutionary fashion; and lastly,
- (iv) It is critical to understand the “sensitivities” in both project environment and context, and address such in the design of the project's product

as a system. The project context based on which the project's product (as a solution-system) will be operating has to be considered. Systems relationships and interfaces, and systems boundaries are context-dependent; their interpretation changes with the context.

In light of the above, it is proposed that the notion of project lifecycle models should go beyond the classic concepts of Systems Theory to more relevant concepts of Purposive Systems, expressively considering the structures, processes, and functions managed in a way that secure purposive output.

“Mutual interference between the parts requires that we analyse the system in a holistic way, as it usually shows emergent or higher level functions ... The emergence and self-organization relates to the presence in the system of dynamical attractors. Each attractor will occupy a relatively small area of overall state space. The system will thus be expected to contain multiple alternative attractors, giving several different possible behaviours for the same system.” (Bertelsen, 2003, p. 5) – A Systems Thinking Approach to LIPs delivery is indeed needed, as most respondents would agree as follows:

“Most project management methodologies still apply a 'linear thinking' in seeking solutions to the chaotic problems arising from increased complexity of projects. The mind-set should shift from the 'linear' to a more 'causal loop' that takes into account the fast changes in the environment that feedback and escalate the extent and impact of complexity in and around the project.” (“Orange”, Senior Project Management Consultant)

Many respondents also raised a number of concerns around current project management methodologies during the structured interviews as follows:

- (i) Despite consistent advances in project management processes and methodologies, many projects (i.e. Large Infrastructure Projects, LIPs) continue to fail;
- (ii) Rigid project lifecycle methodologies could become a constraint rather than an “enabler”. However, allowing flexibility will require knowledge and competence on the part of the user-community;

- (iii) Human elements should also be considered as part of the “system” – and will need to undergo a structured change process; thus, Change Management (across the organisation) is crucial to achieving optimum performance of any “system”. The critical impact or influence of human elements (e.g., human factor such as willingness to use it) to overall systems behaviours, which governs performance should be noted;
- (iv) Lifecycle methodologies tend to neglect the importance and benefits of research throughout the project lifecycle; intellectual capital (e.g., historical data, lessons learned) are generally not valued as an asset to be capitalised across the organisation or in industry; and, lastly,
- (v) Verification and Validation (V&V) of design assumptions and historical data should also take place at the Post Implementation Review (PIR) and any data collection (that depicts the project context) should match the complexity of the situation. A set of data that is so simplistic that it fails to capture the complexity of the context would not effectively support the kind of elaborate design that complex systems entail.

The foregoing interpretation of the outcome of structured interviews indicates the wealth of information and practical knowledge on the part of the respondents. Their contributions will feature in the development of an alternative model for LIPs delivery and in the proposed future developments arising from this study.

4.5. Delphi Panel

The Delphi Technique is suitable as a method for consensus-building through a series of questionnaires delivered using multiple iterations. (Hsu, 2007) Moreover, since the structured interviews included open-ended questions and the same SMEs were selected for both the Delphi Panel and the preceding structured interviews, it was agreed for practical purposes to consider such interviews as the first iteration (*Round 1*) for the Delphi. (Custer *et al.*, 1999) Therefore, *Round 2* and *Round 3* respectively addressed the “rating of items” (arising from *Round 1*) and “reasons for remaining outside the consensus”.

Furthermore, in keeping with the adopted research methodology, a double-triangulation (validation both against literature and Delphi Panel) is required to validate the findings – For this reason, Data Analysis pertaining to the outcomes of the Delphi Technique are fully discussed under Section 6.2 that deals with “Model Validation by Delphi Technique”.

Chapter 5: Model Development

Miles (2014) states, “A *conceptual framework* explains, either graphically or in a narrative form, the main things to be studied – the key factors, variables, or constructs – and the presumed interrelationships among them. Frameworks can be simple or elaborate, commonsensical or theory driven, descriptive or causal”. (p. 20)

Traditional project management methods are characterised by an undue focus on the producing of the physical asset. (NETLIPSE, p. 14 and C.L. Roe, 1996) Departing from these approaches, this study recommends a Systems Engineering (SE) approach that reflects a project’s outcome as a solution-system. This entails the development of an enhanced, SE-Based Project Lifecycle Model that incorporates Systems Engineering concepts.

It intends to address issues of effective project management that have relevance to current practices, procedures, and policies with regards to successful delivery of Large Infrastructure Projects – According to Leedy and Ormond (2013), this is about “*improving an existing lifecycle model.*”

5.1. Essential Elements of a SE-based Lifecycle Model

As a version of the researcher’s map of the topic studied, “A *conceptual framework* forces you to be selective – to decide which variables are most important, which relationships are ... most meaningful, and ... what information should be collected and analysed – at least at the outset.” (Miles, 2014, p. 20)

The foregoing literature review, industry surveys, review of actual project documentation and the insights revealed through the “Project Lifecycle Model – Correlation Map” have established essential items that should feature in the modelling of any Systems Engineering-based Project Lifecycle Model:

- [1] While the asset lifecycle (i.e. from need formulation to asset disposal) is essentially different from the project lifecycle (i.e. from concept to close-out, and concerning itself primarily with the production of the “project product”), an effective project lifecycle model should accommodate the

- relevant input emanating from the “operational environment”, such as *operability*, *maintainability* and *disposability* requirements at the concept and feasibility phases of the project lifecycle, commonly known as FELs;
- [2] The nature and scale of infrastructure projects would generally lends itself to a “waterfall” type of project lifecycle (DOE G 413.3-1, 2008, pp. 22-23), as outcomes of their phases are difficult to reverse. “*Capital investment decisions may be irreversible once production and assembly of the product begins*” – like in the case of LIPs. (Whelton & Ballard, 2002, p. 2) However, opportunities should be sought within each lifecycle phase to accommodate alternative lifecycle models such as the spiral (Agile) model or the V-Model as project context, complexity, and the need for flexibility may dictate; moreover, such lifecycle models should also cater for scalability to suit the situation;
 - [3] Owner’s requirements should be determined right at the outset of the project and incorporate other stakeholders’ requirements as well. A structured, evolving, integrative and incremental process shall apply throughout the lifecycle to leverage on Requirement Formulation and Stakeholder Management. Both are needed in gathering and reconciling differing requirements from stakeholders – and an suitable Soft Systems Methodology (SSM) could prove appropriate in formulating appropriate requirements, should such be construed as “wicked problems”;
 - [4] The project lifecycle model should have distinct phases (i.e. defined phases, activities, deliverables, and gates reviews – which are further discussed in ISO 15288 Standard – and roles and responsibilities). Particularly for LIPs, project requirements (including operational input) should be reviewed, updated, and confirmed between each two project phases preceding “construction” because of “*irreversibility of outcomes once production and assembly of the product begins*” (cited above);
 - [5] Outputs/Outcomes of interim stage and/or final phases should be subjected to a Verification and Validation (V&V) process against project lifecycle requirements, giving assurance that *the right system is being built right* – thus assuring project delivery effectiveness and efficiency;

- [6] Control and Governance points (e.g., Gate Reviews) shall be embedded onto the project lifecycle where a Go/No-Go decision is made based on:
- (i) The extent of compliance to the requirements of previous phase(s);
 - (ii) Whether its outcomes satisfactorily meet a set of viability criteria; and
 - (iii) The readiness to proceed to ensuing phase(s).
- [7] Risk Management, supported by an effective Stakeholder Management and a multi-disciplinary approach based on Systems Thinking, should be treated as a core delivery activity throughout the entire lifecycle.

It would also transpire from the Lifecycle Correlation Map that *precursory* interventions should target the executive realm, as opposed to the tactical sphere of project management, by firstly addressing the following issues:

- [8] Ensure that a Systems Thinking (ST) mind-set is pervasively instituted at all spheres of the organisation, indeed starting at the executive level;
- [9] Ensure that a corporate strategy is clearly documented, and that most projects are *explicitly* linked to it – Thus, successful delivery will move the organisation towards fulfilling its strategic goals and objectives;
- [10] Ensure that executive management creates and maintain a platform (and structures) where project performance is regularly discussed;
- [11] Adopt a Project Delivery Framework/Policy aligned to strategy that specifically defines what project success/failure means in the context of the organisation (i.e. what good/bad project outcomes look like);
- [12] Adopt a Project Delivery Framework that clearly defines the delivery model (e.g., in-house versus outsourced or blended teams), contractual approaches (e.g., EPC versus EPCM), the various roles players and their respective responsibilities and authorities; and
- [13] Embed a *mandatory* Post Implementation Review (PIR) process over the asset lifecycle (e.g., three year or so after ramp up to operations) to validate project performance against the original Business Case.

Once the above executive interventions are adequately addressed, the focus should move to addressing the tactical issues of project delivery such as

providing lifecycle training to project personnel – otherwise, making the project lifecycle methodology mandatory could prove counterproductive.

It is important that project personnel gains the appreciation that not only projects (which are Intervention Systems for solving a problem) should be managed throughout their lifecycle, but the same care should also be adequately extended to every Systems of Interest (Sol). The latter could include the Context System, the Realisation System, the Intervention System, the Deployed System, the Collaborating System(s), the Sustaining System(s), and the Competing System(s) – as established in Section 2.6.5

Considering the above seven Systems of Interest (Sols) in approaching Risk Management, Stakeholder Management, and Operational Readiness pertaining to large and complex infrastructure projects is a clear departure from the traditional focus on the delivery of physical assets as an end in itself, and will entail broadening of the project environment. Thus, the profile, skill-set, and competency of project personnel should align to these demands.

Figure 5.1 below reflects a synopsis of the model building process followed:

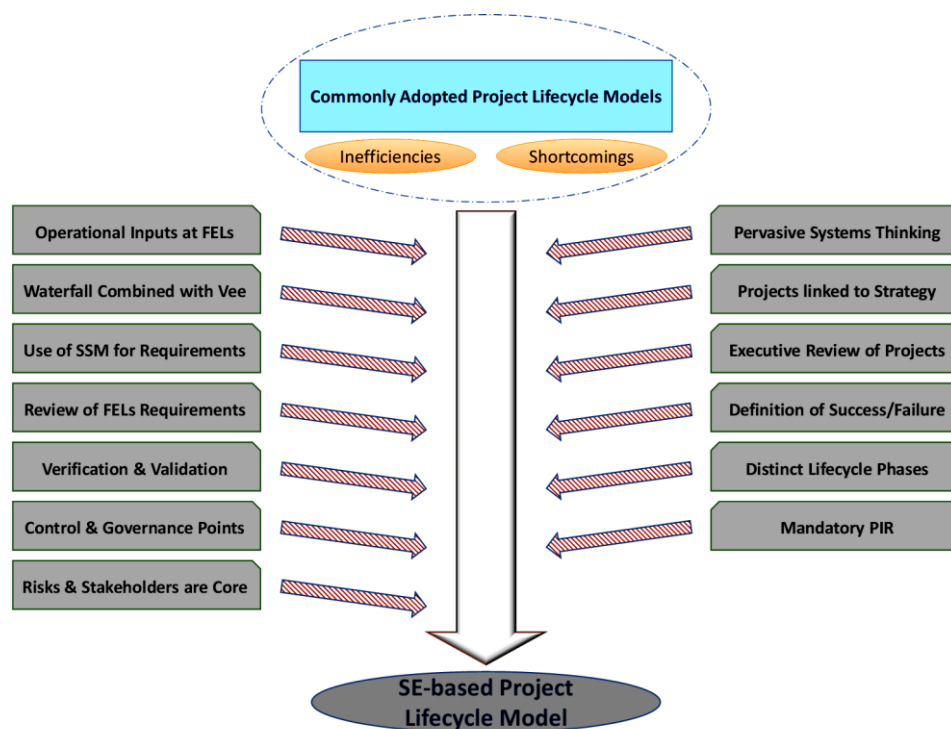


Figure 5.1 – SE-based Project Lifecycle Model Building Process (By the author)

5.2. Project Lifecycle Model Building

Four themes (on project lifecycle model) have emerged from the foregoing discussions and considerations, which will inform the building of a model, namely Project-System Boundaries, Project Lifecycle Span, Requirement Management, and Project Lifecycle Methodology Deployment as follows:

5.2.1. Project-System Boundaries:

Infrastructure projects will largely rely on a Realisation System (e.g., project processes, skills, tools, and structures) to deliver the Project-Systems (i.e. products of the project) which in turn will be deployed in a Context-System (where Collaborative-, Sustaining-, Competing-Systems will also manifest); therefore, the previously mentioned three/seven (refers to 2.6.5) Systems-of-Interest are relevant in addressing project lifecycle processes/aspects:

(i) System Design:

Linkages and behaviours of sub-systems and components in those three/seven Systems-of-Interest (Sols) should be considered in seeking insight regarding the behaviour and performance of the whole product.

(ii) Stakeholder Management:

Project stakeholders shall be identified and engaged in those systems.

(iii) Operational Readiness:

Operational requirements should consider demands from Competing, Collaborative, and Sustaining (sub) systems within the Context System. It, therefore, follows that Operational Readiness (OR) should apply to the whole Sol, including the Context-, Realisation-, and Product-Systems. Moreover, the Realisation System should be subjected to a rigorous “scalability process” so it could concomitantly match the complexity of the Product System and of the Context Systems.

(iv) Risk Management:

It should include analysing and mitigating risk items and aspects (including threats and opportunities to the project) throughout the lifecycle and across the Context-, Realisation-, and Product-Systems.

5.2.2. Project Lifecycle Span:

An effective project lifecycle model, in addition to the traditional phases including Concept to Closeout, should accommodate the following input:

- (i) Operational, maintenance and disposal considerations to inform Study and Execution phases (i.e. Concept to Close out);
- (ii) A mandatory Post-Implementation Review process to confirm the extent to which the project outcomes are fulfilling their operational purposes;
- (iii) Project teams involvements during subsequent upgrades, mid-life refurbishments, and even disposal of the asset, which should be managed as projects and accordingly provide opportunities to gather lessons-learned (i.e. operational insight) to inform future projects; and,
- (iv) A long-term Planning Phase that translates strategy into a portfolio of connected project-initiatives should precede project conceptualisation.

5.2.3. Requirements Management:

Project management is all about *meeting stakeholders' requirements*, which should be managed across the entire project lifecycle (INCOSE SEH v3):

- (i) The Owner's Requirements Specification (ORS), which serves as a "frozen" input to each FEL phase should also include the needs, requirements and concerns of other project stakeholders, as relevant;
- (ii) When project complexity makes requirement formulation delicate and onerous (e.g., solution to a wicked problem), a Soft Systems Approach or Methodology (e.g., SSM, CLIOS) approach could apply in eliciting key stakeholders' requirements, particularly at the project's outset;
- (iii) Steps imbedded at specific points in the project lifecycle (including at PIR) should allow for requirements Verification and Validation (V&V). V&V confirms whether and to what extent the design and/or production of the product of the project (i.e. system) complies to the requirements (i.e. Verification, "*Building the system right*") or will meet the intended purpose(s) in its host environment(s) (i.e. Validation, "*Building the right system*") – both *in-process* (i.e. interim) and *final* V&Vs are required.

5.2.4. Project Lifecycle Methodology and Tailoring:

Sussman *et al.* (2009) suggest that a “complex” system that is composed of interrelated components and subsystems for which the degree and nature of the relationships between them is imperfectly known, with varying directionality, magnitude and time-scales of interactions could present various types of complexity as follows:

- (i) Structural Complexity – a type that concerns itself with the Product; *exists when the system consists of a large number of interconnected parts.*
- (ii) Behavioral complexity – a type that concerns itself with the Product; *exists when predictions of system outputs or behaviour is difficult. This is found when their parts interact over time in closely coupled feedback loops.*
- (iii) Nested Complexity – which concerns itself with the Environment; and, *it is a concept that suggests a complex “physical/technical” system embedded within an institutional system.*
- (iv) Evaluative Complexity – which concerns itself with the Environment; *reflects multi-stakeholder environments in which complex systems exist.*

Moreover, complex projects could consist of both small projects (e.g., digital photography) and large projects (e.g., Large Infrastructure Projects, LIPs); complex projects could also consist of new system developments (e.g., new transportation system) or system modifications (e.g., power-grid upgrades).

Hence, “*Organizations with developed project management practices ... and those with high organizational agility all have significantly better project outcomes than their counterparts who are less advanced in their project management practices.*” (PMI, 2013 a, p. 11) – Since Verification (of Product) is measured against System Requirements (as determined by the Realisation System) but Validation (of Product) is measured against Stakeholder Needs (as determined by the Context System), Verification and Validation would not work unless and until the Realisation System matches the Context System.

INCOSE SEH v3 (2008, p. 10.1) suggests that the principle behind tailoring is “*to establish an acceptable amount of process overhead committed to activities not otherwise directly related to the creation of the system*”. This prerequisite is largely attained through the process of Tailoring (also known as Scalability) which scales (i.e. balances) up/down the rigorous application

of the delivery processes in line with the system lifecycle stage (as determined by the Realisation System) to an right level (i.e. balance) based on stakeholders' needs (as formulated from the Context System). This approach gives rise to the "Verification–Tailoring–Validation Triangle" (VTVT) as shown on the proposed (by the author) Project Lifecycle Model illustrated under Section 5.2.6 below.

5.2.5. Project Lifecycle Methodology Deployment:

Effective deployment and rollout of a SE-based Project Lifecycle Model entails an organisation-wide drive, potentially requiring a suitable change management initiative. From the foregoing statistical and thematic analysis of correlations between various lifecycle elements arising from the industry survey six (6) strategic deployment prerequisites are identified:

- 1st – Establishment of a System Thinking culture in the organisation;
- 2nd – Publishing of a clear, well-documented organisational strategy;
- 3rd – Establishment of executive forum/a to discuss project performance;
- 4th – Publishing a Project Delivery Policy, defining "Project Failure";
- 5th – Adopting of a Project Lifecycle Methodology with distinct phases;
- 6th – Adopting a mandatory Post Implementation Review (PIR) process.

It is emphasised that these specific deployment prerequisites fall within the ambit of executive management. Executives should take strategic steps to ensure that such steps are adequately established prior to expending efforts in installing tactical project management elements such as PM processes and procedures, Project Management Offices (PMOs) and resources, and enabling tools. Effective change management initiatives should support this undertaking and align people to processes to culture to structures, or else the *burden of change* will stifle the course of deployment. (Hamilton, 2004)

Furthermore, INCOSE *Deployment Package: Project Management* (2014) suggests that the elements of a typical Deployment Package (DP) are: roles and products, description of processes, activities, tasks, template, checklist,

reference to standards – all these elements should be *appended* to the conceptual model to migrate it into a fully-fledged lifecycle methodology.

5.2.6. Conceptual SE-based Project Lifecycle Model:

From sections 2.6.3, 2.7, and 4.4.1 the ISO 15288 Model constitutes the most comprehensive of all commonly-adopted project lifecycle models, while the IPA Model is found sound in terms of project team's active involvement.

This study has identified the essential lifecycle elements of a valid SE-based Project Lifecycle Model, such as those arising from the following concepts:

- (i) Project lifecycle boundaries;
- (ii) Project lifecycle span;
- (iii) Project requirements management;
- (iv) Project lifecycle tailoring; and
- (v) Project lifecycle methodology deployment.

This study has therefore considered suitably *appending* those lifecycle elements onto the IPA Model, as per the demands of ISO 15288 Standard. The inclusion of the Context-System (Operational Environment) was a major concern. Thus, this SE-based Project Lifecycle Model entails the following:

- (a) In accordance with the “9 Laws of Effective Systems Engineering” by Zane Scott [Law #1 – Begin with the End in Mind], operational matters (e.g., requirements, concerns) should be considered as a *critical input*, particularly during the Concept and Development phases;
- (b) The delivery focus should shift away from “building the physical facility” to rather developing a “successful system” that will effectively improve the *operational environment*; and,
- (c) Although the project team's active involvement may end at Close-Out, their intermittent involvement in *operational environment* (e.g., at Post Implementation Review to allow for Lessons-Learned, fine-tuning of Design, and/or Retrofitting) has proven highly advisable.

This model (i.e. simplified description of a system or process to assist in predictions) together with the above six strategic deployment prerequisites

will constitute a valid project delivery methodology (i.e. a system of broad principles or rules from which specific methods or procedures may be derived to interpret or solve problems in a discipline) for successful delivery of LIPs.

The above elaboration leads to the building of the below SE-based Project Lifecycle Model; the A3 format thereof is attached hereto as Annexure H.

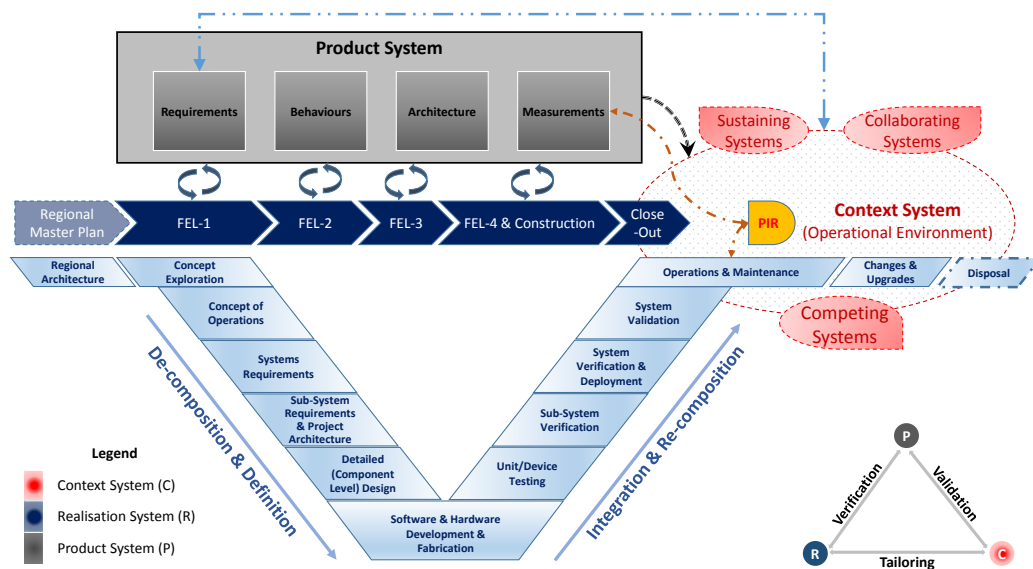


Figure 5.2 – Proposed SE-Based Project Lifecycle Model (By the author)

This holistic lifecycle model follows a “waterfall” development process entailing FELs, Construction and Closeout phases. It uses the IPA Model as its starting point and reflects the “Regional Planning Master Plan”, known as Incubation “*where ... this initial ‘embryonic knowledge and understanding’ about the potential project come from.*” (Archibald *et al.*, 2012, p. 10)

This is the Primary Scheme of the project lifecycle, as shown in dark blue (■).

In discussing the *principles and tactics for mastering complexity*, Forsberg (Forsberg *et al.*, 2005) argues that this Primary Scheme should be repeated (in successive layers) to cater for each entity-level of the System (i.e. system, sub-systems, components) – intersecting the Architecture and Entity Vees.

The Vee Scheme (below it) depicts the System Engineering process that mainly drives the Technical Stream dealing with technical aspects of lifecycle; it is shown in light blue (■) and spans beyond the traditional closeout phase.

The Context System is represented here in light red (■) and encompasses the Operational Environment, as well as the Sustaining, Collaborating, and Competing Systems. While these are outside the authority of the project manager, their requirements will inform the development and implementation of both the Realisation and the Product Systems through a Tailoring Process.

The Product System is represented in grey (■) and reflects the four system domains that govern the development of the “product” as a system; these are namely Requirements, Behaviours, Architecture(s), and Measurements. The Product (Solution) System is developed along the Primary Scheme of the lifecycle, which with the Vee Scheme make up the Realisation System.

This holistic and SE-base Project Lifecycle Model also reflects a Post-Implementation-Review event to take place in the operational environment at an agreed point during Utilisation (i.e. Operations and Maintenance) Stage. Finally, the triangle at the bottom-right corner illustrates the *sine-qua-non* balancing that should be established at all times among the following:

- (a) Tailoring (i.e. what *portions* of the Realisation Systems are required given the complexity of the Product or in the Operational Environment);
- (b) Verification (i.e. to what extent the Product meets the requirements as established by the Realisation System);
- (c) Validation (i.e. to what extent the Product meets the needs and concerns of relevant stakeholders from the Operational Environment).

An expanded version of the System Measurement Triangle is shown below: (i.e. System Measurement Triangle [SMT] or Validation-Tailoring-Verification Triangle [VTVT])

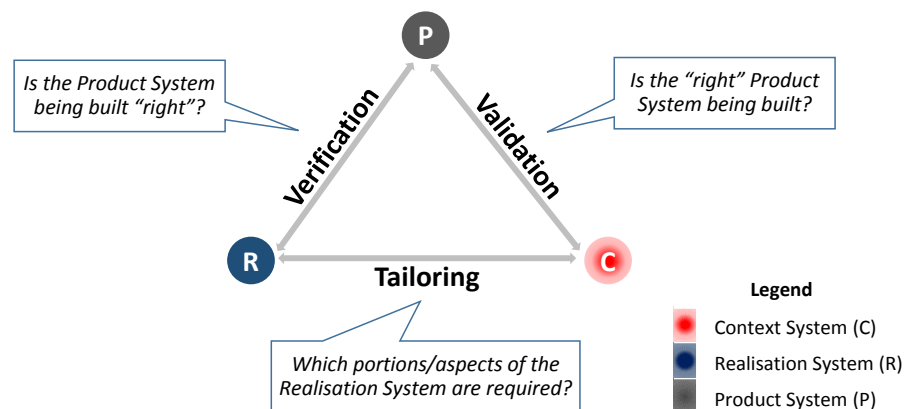


Figure 5.3 – Verification-Tailoring-Validation Triangle [VTVT] (By the author)

However, the challenge of translating the proposed theoretical model into practical frameworks that guide practical application should not be ignored. For instance, having argued that “*proper elicitation and adequate management of requirements*” could prevent cost and schedule overruns, the question arises as to how the Owner’s Requirements Specifications (ORS) will be practically managed, in keeping with the proposed SE-based Project Lifecycle Model.

Figure 5.4 below illustrates the process of evolving the ORS (i.e. business and operational requirements) as elicited from the “Context System” through lifecycle phases, producing domains’ artefacts as per the “Product Scheme”, while systems development activities are being carried out along the “Vee-Scheme”. This portion of the ORS Process Flow culminates in the producing of outputs/outcomes in line with the “Primary Scheme” for each project phase, ensuring that a fit-for-purpose “system/asset” is handed over to operations.

Project Phase	“Product Scheme” Items	“Vee-Scheme” Items	“Primary Scheme” Items
FEL-1	Business/Operations Requirements Approved & Issued as [ORS _{FEL-1}]	System Requirements (<i>for each solution-options</i>) Developed	Option-Solutions Generated
FEL-2	<i>Previous</i> + System Requirements (<i>for each identified options</i>) Approved & Issued as [ORS _{FEL-2}]	- System Behaviours Developed (<i>for each option</i>) - System Architecture Developed (<i>for each option</i>)	Most-viable Option-Solution Selected
FEL-3	<i>Previous</i> + System Behaviour and Architecture (<i>for selected option</i>) Approved & Issued as [ORS _{FEL-3}]	(Sub-) System(s) Designed as per Behaviour & Architecture (<i>for selected option-solution</i>) - Their Performance Measures (i.e. V&V criteria) Developed	- Selected Option-Solution Designed - Selected Option-Solution Planned for “Execution & Operations & Disposal”
FEL-4	<i>Previous</i> + System Measurements Approved & Issued as [ORS _{FEL-4}]	- System Measures (V&V criteria) Incorporated in “Contracts” (Sub-) System(s)/Components Built and Verified & Validated	Construction Readiness Confirmed
Construction	Interim Verification & Validation Reports Approved & Issued	(Sub-) System(s)/Components Built and Verified & Validated	System (i.e. Facility/Asset) Integrated & Realised
Close-Out	Final Verification & Validation Reports Approved & Issued	System (i.e. Facility/Asset) Verified & Validated	System (i.e. Facility/Asset) Handed over to Operations

Note: ORS for any FEL should also reflect high-level requirements for “Domains” pertaining to ensuing FELs (e.g., ORS_{FEL-2} to reflect high-level Behaviours, Architecture & Measures)!

Figure 5.4 – SE-based ORS Process Flow (By the author)

The ORS Process Flow should prevent the current situation whereby project sponsors and personnel are strained at finalising a set of detailed, elaborate systems requirements right at the onset of the lifecycle, at a point where the “problem” itself (e.g., needs, objectives, features) is intrinsically fuzzy as it is the case in LIPs. For precipitate Requirement Management is harmful to LIPs; the Gate Review Analytics Report (p. 4) in Annexure A confirms this finding.

5.2.7. SE-based Project Lifecycle Methodology:

Project delivery organisations should build on the above model to develop a SE-based Project Delivery Methodology that suits their policies and practices, projects complexity, and project management maturity.

As discussed in Section 5.1, the seven (7) Systems Engineering elements will *of necessity* form part of such a SE-based Project Delivery Methodology. It shall combine an “operational system” (i.e. elements of the Project Delivery Infrastructure as per Sections 2.4 and 2.6.5, which shall be deployed as per Section 5.2.5) and a “monitoring and control system”. (Schmidt, 2006, p. 2)

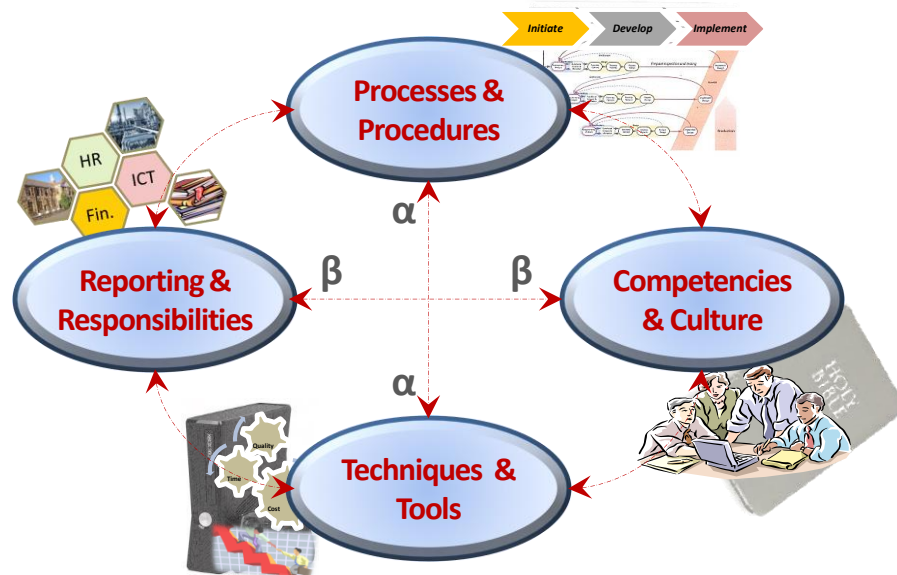


Figure 5.5 – Four (4) Components of Project Delivery Infrastructure
(By author, inspired from Martin, 2012)

Based on participant observation in the role of leading the Project Management Centre of Excellence and as custodian of the delivery methodology for LIPs on an R 300 billion infrastructure programme *patterns* were observed as follows:

- (i) Entities with sound PM Processes prove *consistent* in project delivery;
- (ii) PM Techniques & Tools are needed to *efficiently* gather, process, or distribute projects' inputs and outputs, performance ratios and trends, and progress status and forecast;
- (iii) Specific PM Competencies (e.g., skills and mind-set) are needed to *satisfactorily* carry out complex project activities;

- (iv) Appropriate PM Organisational Structures and Reporting Interfaces enable and/or improve Teamwork and organisational capabilities, leading to an *effective* coordination of project activities.

5.3. Systems Engineering Roles in Project Management

It is thus far acknowledged that project management, contrary to popular belief, is more about the realisation of a system-solution than it is about the delivery of a product – and this perspective is actually heightened with the degree of complexity involved; therefore, it manifests more intensely in LIPs.

It follows that most SE roles such as Systems Engineer, Business Analyst, Systems Analyst, and Systems Engineering Manager will generally apply to the management of Large Infrastructure Projects (LIPs). Accordingly, this study has drawn a particular attention to other lifecycle roles dealing with the management of project requirements along the lifecycle, a critical provision that ensures projects *meet or exceed the expectations of the client or customer(s)*.

Good practice in the industry suggests that project requirements and those activities required for the converting of such into project deliverables (e.g., systems components and their configuration elements) should be managed along the lifecycle according to a number of “streams” or “tracks” as follows:

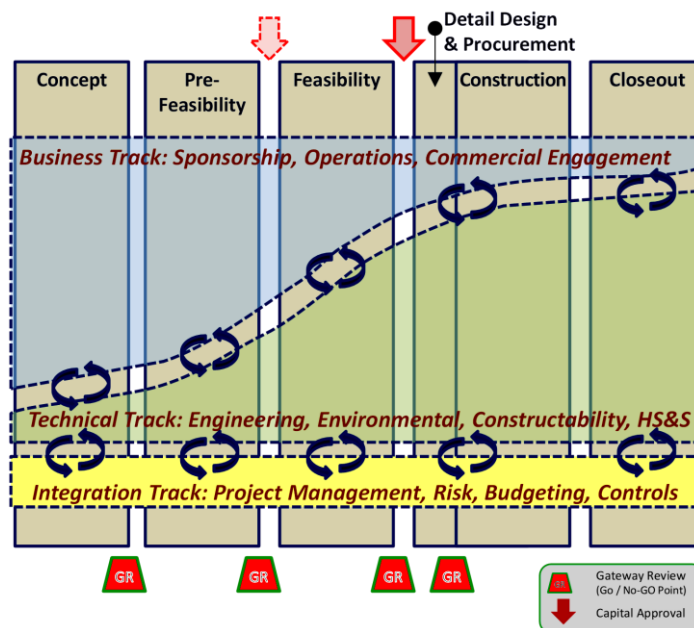


Figure 5.6 – Project Delivery Streams: Business, Technical and Integration
(By the author, inspired from Forsberg, 2005)

- (i) Business Stream:
E.g., sponsorship, business viability, commercial validation, operations;
- (ii) Technical Stream:
E.g., engineering design, Environmental Management, Health & Safety and Security (H&SS), constructability and Construction Management;
- (iii) Integration Stream:
E.g., project management, risk, procurement, planning and costing.

Practical experience confirms that in the early project phases (e.g., Concept) the emphasis should be on “Business” aspects (e.g., commercial validation) as opposed to “Technical” aspects (e.g., Engineering Design) and vice-versa as of FEL-3 to Close-out. Many, however, still proceed the wrong way around.

To maintain each one of these “streams” in line with the Systems Thinking process, it is vital that a Systems Engineering agent lead them. A Soft Systems Engineer (e.g., Business Analyst) should lead the Business Track that deals with socio-political-organisational matters and may rely on tools such as Delphi Process, PESTEL/SWOT Analysis, and Scenario Analysis. The Technical Track should similarly be led by a Hard Systems Engineer to manage project requirements, design, risks, V&V, TQM, and forecasting – both under the headship of a SE-conversant Integration Project Manager.

Track	Typical Project Lifecycle Activities		Skills Needed
Business Track	▪ Recognise opportunity ▪ Develop Business Requirements ▪ Justify “Market” Demand/Appetite ▪ Develop Business Case (i.e. ROI)	▪ Select acquisition approach ▪ In-progress ROI projections ▪ Take System into Business Plan ▪ Confirm ROI (during Operations)	<i>Business Acumen + Systems Engineering (Soft Systems)</i>
Technical Track	▪ Collect Owner/User Requirements ▪ Develop Systems Requirements ▪ Develop System CONOPS ▪ Justify Technical Feasibility	▪ Manage Technical Specifications ▪ Direct ‘Design-to’/‘Build-to’ Specs ▪ Conduct System Integration ▪ Conduct Verification & Validation	<i>Technical Acumen + Systems Engineering (Hard Systems)</i>
Integration Track	▪ Manage project stakeholders ▪ Confirm resource availability ▪ Predict costs and phasing ▪ Deploy available resources ▪ Manage costs & schedule ▪ Select best-value supplier(s)	▪ Manage supplier(s) & contract(s) ▪ Manage and motivate resources ▪ Manage project risk and value ▪ Manage Project Configuration ▪ Manage reviews and approvals ▪ Conduct Project Integration	<i>Project Management + Basic understanding of both above</i>

Table 5.1 – Indicative aspects of SE Roles (Adapted from Forsberg, 2005)

Dennis Van Gemert (2013, p. 6) supports this view of SE Roles, referring to Project Manager, SE (Technical), and SE (Business/commercial) as follows: *“To enhance the success of projects, it is vital to understand the importance of successfully identifying and managing product requirements.*

When the time comes to engineer the front end of the project, during the Planning Phase, a seasoned systems engineer is a critical member of the project leadership team. System engineers are essential in identifying technical risks, managing and deriving requirements, aligning the technical baseline with the project baseline, deriving the system architecture framework, and translating technical issues into actionable business cases that the project manager can use to make critical business decisions. Experienced systems engineers often serve as the project manager’s technical advisor.

On technically complex programs, it is advantageous to appoint a project manager who has a strong technical background; however, partnering with a systems engineer regardless of the technical background of the project manager often adds value to the technical project ... For the project manager to put forth a case for additional resources (time, people, money, or materials) to executive management and the customer, an accurate, complete, and concise definition of the issues and recommendations for rectifying them must be very compelling, which necessitates an in-depth understanding of the technical issues and how their interdependencies on the programmatic are characterized. This requires leveraging the benefits of both project management and systems engineering into a cohesive systems approach to planning and execution.”

These three main Systems Engineering roles are not mutually exclusive and could therefore be efficiently performed by the same competent individual on complex projects of small to medium magnitude (e.g., from 5,000 to 10,000 man-hours). Under such circumstances, a competent Project Manager who is well versed and conversant with both soft and hard Systems Engineering might be able to perform all these roles satisfactorily together.

Chapter 6: Model Validation

The proposed Project Lifecycle Model emanates from insights that emerged from the (online) industry survey and subsequent structured interviews involving SMEs selected across the industry for their knowledge and/or experience in Large Infrastructure Projects (LIPs) or Systems Engineering. In keeping with the adopted research methodology, a double-triangulation is required to validate the findings (i.e. both against the literature and the Delphi Panel).

6.1. Validation by Project Literature

Table 6.1, Table 6.2, and Table 6.3 below indicate the prevalence of the proposed SE Lifecycle Model in commonly adopted project methodologies as well as the correspondence and corroboration between such elements and the causes of project failure, which recent surveys have attributed to current practices. It transpires from these tables that, when appropriately applied, the elements of the proposed SE-based Project Lifecycle Model will address most causes of project failure – at both project team and executive levels.

Of particular significance is the validation against the [Dutch] PWW SE Guideline and the IPA Models, which both seem fairly advanced in terms of incorporating Systems Engineering concepts in the project lifecycle they promote – although IPA would not expressly refer to Systems Engineering, but to practical and empirical evidence (i.e. Best-Practices) to inform their model. Chap 2: Literature Review (Sections 2.7.2. and 2.7.3) has expanded on the Critical lifecycle elements of the [Dutch] PWW and IPA models.

Table 6.1 – Extent of Application of Proposed SE Elements in Lifecycle Management Methodologies.

No	Proposed SE-based Lifecycle Elements	Common PLM	PWW Model ^[a]	IPA Model ^[b]	Comments
[01]	Project lifecycle methodology integrating operational inputs	X	X	√	Enhancement
[02]	LIPs managed in “waterfall” lifecycle supplemented with other models and scalability	X	√	X	Enhancement
[03]	Soft Systems approach could be used to formulate Owner's requirements from outset	X	X	X	Enhancement
[04]	Lifecycle methodology has distinct, purposeful phases	√ (Partial)	√ (Partial)	√	Part Enhancement
[05]	Phase outcomes are subjected to Verification & Validation	X	√	X	Enhancement
[06]	Gate Reviews, Governance points are embedded in lifecycle	√ (Partial)	√	√	Part Enhancement
[07]	Risk Management treated as a core project delivery activity	X	√	X	Enhancement (See Section 2.6.8)
[08]	Systems Thinking is established, starting at executive level; all systems of Interest (Sols) are considered.	X	X	X	Enhancement
[09]	Corporate strategy is known, projects <i>explicitly</i> linked to it	X	X	√	Enhancement
[10]	Executive management has platform(s) for regular review of project performance, not just schedule and cost status.	X	X	X	Enhancement
[11]	Project Delivery Framework defines success/failure	X	X	√	Enhancement
[12]	Project Delivery Framework defines delivery model, contractual approaches, roles players and their responsibilities & authorities	√ (Partial)	X	√	Part Enhancement
[13]	Post Implementation Review (PIR) is mandatory and embedded in asset lifecycle	√ (Partial)	X	√	Part Enhancement

^[a] Guideline Systems Engineering for Public Works and Water Management (2008) and ^[b] E.W. Merrow, Industrial Megaprojects (2011)

Table 6.2 – Lifecycle Elements and Corresponding Causes of Project Failure they Mitigate/Alleviate [Part I]

No	Cause of Project Failure at Executive Level ^[c]	Cause of Project Failure at Project Team Level ^[d]	Proposed Lifecycle Elements [as per section 5.1. above]	Comments
01	Lack of clear links between the project and the organisation's key strategic priorities, including agreed measures of success ^[c]	—	[09] Documented strategy [11] Project Success Defined [13] Mandatory PIR	
02	Lack of clear senior management, ministerial ownership, and leadership ^[c]	—	[10] Executive Project Review	Executives review of project performance brings accountability
03	Lack of effective engagement with stakeholders ^[c]	—	[08] All systems are considered [03] Stakeholders Requirements	Stakeholders of all Sol to be engaged
04	Lack of skills and proven approach to project and risk management ^[c]	<i>Lack of skills and proven approach to project and risk management ^[c]</i>	[12] Project Delivery Framework [07] Lifecycle Risk Management	Risk to be managed at both executive and Tactical levels
05	Too little attention to breaking development and implementation into manageable steps ^[c]	—	[12] Project Delivery Framework [04] Phased Lifecycle Model [02] Scalable Lifecycle Model	
06	Evaluation of proposals driven by initial price rather than long-term value for money (especially securing delivery of business benefits) ^[c]	—	[08] All systems are considered [11] Project Success Defined [01] Operations Issues Included	
07	Lack of understanding of, and contact with the supply industry at senior levels in the organisation ^[c]	—	[08] All systems are considered [10] Executive Project Review [03] Stakeholder Requirements	Soft Systems Methodology (SSM) could apply

^[c] Office of Government Commerce (UK), "Common Causes of Project Failure " (2005) and ^[d] Chaos Report [Standish Group, 1994]

Table 6.3 – Lifecycle Elements and Corresponding Causes of Project Failure they Mitigate/Alleviate [Part II]

No	Cause of Project Failure at Executive Level ^[c]	Cause of Project Failure at Project Team Level ^[d]	Proposed Lifecycle Elements [as per section 5.1. above]	Comments
08	Lack of effective project team integration between clients, the supplier team and supply chain ^[c]	—	[08] All systems are considered [10] Executive Project Review [03] Stakeholder Requirements	Soft Systems Methodology (SSM) could apply
09	—	Lack of User Input ^[d]	[01] Operations Issues Included [03] Stakeholder Requirements	
10	—	Incomplete Requirements ^[d]	[01] Operations Issues Included [03] Stakeholder Requirements	[05] Verification & Validation could apply
11	—	Changing Requirements ^[d]	[05] Verification & Validation [06] Embedded Approval Points	
12	<i>Lack of Executive Support ^[d]</i>	Lack of Executive Support ^[d]	[08] All systems are considered [10] Executive Project Review	Executives interested in business benefits
13	—	Technology Incompetence ^[d]	[01] Operations Issues Included [05] Verification & Validation	Progressive V&V shall reduce technology risk
14	—	Lack of Resources ^[d]	[02] Scalable Lifecycle Model [06] Embedded Approval Points	Next phase starts only if readiness confirmed
15	—	Unrealistic Expectations ^[d]	[01] Operations Issues Included [06] Embedded Approval Points	Projects shall improve “operational” situation
16	—	Unclear Objectives ^[d]	[03] Stakeholder Requirements [05] Verification & Validation	
17	—	Unrealistic Timeframes ^[d]	[07] Lifecycle Risk Management [10] Executive Project Review	Executives appreciate timelines, project risks
18	—	New Technology ^[d]	[07] Lifecycle Risk Management [05] Verification & Validation	Progressive V&V shall reduce technology risk

^[c] Office of Government Commerce (UK), “Common Causes of Project Failure ” (2005) and ^[d] Chaos Report [Standish Group, 1994]

6.2. Validation by Delphi Technique

Common surveys try to identify the “what is”, whereas the Delphi Technique attempts to address “what could/should be” (Miller, 2006, cited by Chia-Chien Hsu, 2007) – and this view concurs with the purpose of this research.

According to the Delphi Research Method, the proposed Project Lifecycle Model, as an outcome the structured interviews with industry SMEs, needed to be captured in another questionnaire and presented in successive rounds to the same SMEs for their inputs and comments. A reasonable consensus among the panel that the proposed model meets their expectations was required in terms of addressing current inadequacies and challenges facing traditional approaches in dealing with complex infrastructure projects (LIPs).

At this stage, a validation round with selected SMEs was arranged by way of a “follow up” questionnaire based on a 0 to 5 “Scale of relevance” to the model. M.B. Miles (2014, p. 309) supports this approach as a logical way of providing a notch of corroboration; *“One of the most logical sources of corroboration is the people you have talked with and watched ... There are also good reasons for conducting feedback after the final analysis. For one thing, you know more. You also know better what you do know – you are less tentative, have more supporting evidence, and can illustrate it. In addition, you can get feedback at a higher level of inference: on main factors, on causal relationships, and on interpretive conclusions.”*

The outcome of the Delphi round is summarised in Table 6.4 below – a copy of the full survey questionnaire is attached herewith as Annexure J, as well as a synopsis of individual responses.

Table 6.4 – Summary of the Delphi Round Testing “Scale of Relevance” of the 13 Identified SE Elements to Proposed Model

No	Elements of Lifecycle Model	Median	S ^{TD} D ^{EV}	Comment
[01]	The Project lifecycle (i.e. from concept to closeout) should integrate relevant input such as operability, maintainability, and disposability from the “operational environment”.	4.5	0.50	
[02]	Infrastructure projects are managed in a “waterfall” lifecycle, which should however accommodate alternative lifecycle models and cater for a suitable degree of scalability.	4	0.97	
[03]	Owner’s (and relevant stakeholders’) requirements are determined from project outset; for projects with complex scope and/or context, a Soft Systems approach could be used.	3	0.93	Relatively low Median rating
[04]	Project lifecycle methodology has distinct and purposeful phases, with clearly defined purpose, critical activities, and main deliverables.	5	0.70	
[05]	Project output/outcomes are subjected to “in-process” and “end-of-phase” Verification and Validation (V&V) exercises.	4	0.48	
[06]	Gate Reviews and other control and governance points are embedded at specific points (e.g., end of phase) of the project lifecycle.	5	0.33	
[07]	Risk Management, supported by Stakeholder Management and a multi-disciplinary approach based on Systems Thinking, is treated as a core delivery activity.	5	0.90	
[08]	Systems Thinking (ST) to be pervasively established across the whole organisation, including and starting at executive level.	3.5	1.54	Fair Median & High S ^{TD} D ^{EV} due to <i>outliner</i> data
[09]	A corporate strategy is clearly documented, and that most projects are <i>explicitly</i> linked to it – in which case, successful project delivery will fulfil strategic goals and objectives.	4.5	0.70	
[10]	Ensure that executive management creates, maintain platforms or structures where project performance is regularly discussed, not just their schedule and cost status.	4.5	0.50	
[11]	A Project Delivery Framework/Policy aligned to strategy that specifically defines what project success/failure means in the context of the organisation’s strategy.	4	0.48	
[12]	A project Delivery Framework/Policy clearly defines the various role-players and their respective responsibilities and authority, and the lifecycle methodology and Gate Review	4.5	0.50	
[13]	A mandatory Post Implementation Review (PIR) process is embedded at a decisive point of the asset lifecycle to validate project performance against the original Business Case.	5	0.43	

The Delphi Panel's responses pertaining to the 13 proposed SE Lifecycle Elements indicate a very strong relevance to the model (around 5 out of 5, with very low standard deviation of less than 1). However, Item [3], "*Soft Systems approach could be used to formulate Owner's requirements from outset*" scored a 3 out of 5 on the same scale and item [8] "*Systems Thinking instituted starting at executive level*" scored a moderate relevance (3.5 out of 5) but both reflect a high standard deviation, which indicates the presence of some "outliner" responses. Table 6.1 in Annexure J confirms that two respondents indeed rated these items on a scale of 1 and 2 respectively. The disparity of ratings, as well as the low score on item [3] and variances on item [8], could be justified by the *newness* and *unfamiliarity* of these two notions within the infrastructure fraternity of South Africa at this point in time.

In practice, the number of Delphi iterations depends largely on the degree of consensus sought by the investigators and can even vary. (Hsu, 2007) – Delphi rounds should stop only once a reasonable consensus has been reached among the Delphi Panel.

The outcome of our *second* Delphi round (refer to Table 6.1 in Annexure J) has indicated that every respondent have rated the whole set of 13 items pertaining to the SE Lifecycle Model at the highest scale of relevance (i.e. both Mode and Median are rated at least at 4 out of 5) and a low Standard Deviation.

One particular respondent (not being identified due to required anonymity), whose responses to the 13 items are fairly high (reflecting a Mode and a median of 4), carries a high Standard Deviation of 1.4 for having allotting, *predictably*, low relevance ratings (1 out of 5) to *peculiar* items [03] and [08].

Every other respondent has tallied a high Median and a Standard Deviation of near/less than 1; on the basis of such reasonable consensus among the Delphi Panel, there was no need for any further rounds – thus the proposed SE-based Project Lifecycle Model was deemed sufficiently validated.

6.3. Concluded Corroboration

Validating the proposed model against the literature has yielded an insightful point. The six (6) strategic steps for the deployment of a SE-based Project Lifecycle Methodology (refer to Sections 4.3 “Statistical Correlations Analysis” and 5.2.4 “Project Lifecycle Methodology Deployment”) have confirmed and expanded on Buttrick’s (2005) observation regarding causes of project failure.

At the organisation level, two (2) items are needed to prevent project failure:

- (i) A clear, documented corporate strategy, from which projects flow; and,
- (ii) A clear, documented company project delivery framework.

Particularly for Large Infrastructure Projects, this study has confirmed that while *necessary*, these two elements are not *sufficient* for deploying an effective project management methodology within the delivery organisation.

Moreover, the Literature Validation Table (Tables 6.2 and 6.3) has established that the proposed Project Lifecycle Model elements contribute *severally* in addressing most of the commonly identified reasons for project failure. Hence, the application of the proposed model will increase the odds of project success.

Most commonly adopted project lifecycle methodologies fail to incorporate the proposed SE elements in a meaningful fashion, except for the [Dutch] PWW and IPA models (the latter albeit implicitly) that strongly recommend incorporating such SE-based lifecycle elements for the effective delivery of Large Infrastructure Projects, LIPs.

Furthermore, the validation by the Delphi Technique has proved insightful as the eight-member panel have not only attributed a strong “relevance” to the proposed 13 items for the development of an effective lifecycle model, but they could reach a reasonable consensus within a single Delphi round.

The foregoing multiple validation is significant as it may suggest that many (if not most) Subject-Matter-Experts in the infrastructure space are aware of the challenges facing commonly adopted lifecycle methodologies and will most probably endorse the proposed SE-based Project Lifecycle Model.

Yet another validation could emerge from the NASA SE Handbook (2007) in its definition of Systems Engineering as, “A *disciplined approach ... with the emphasis on the satisfaction of stakeholders functional, physical and operational performance requirements in the intended use environment over its planned life cycle*”. The emphasis is on “*satisfaction of requirements in the intended use environment*”, the purpose of Project Management. (PMBok v5)

Incidentally, the Chaos Report (Standish Group Report, 2014) has listed ten (10) common reasons for project impairment and failure, which largely apply to both IT and Infrastructure projects (Marnewick, C. *et al.*, 2013) as follows:

Project Impaired Factors	% of Responses
1. Incomplete Requirements	13.1%
2. Lack of User Involvement	12.4%
3. Lack of Resources	10.6%
4. Unrealistic Expectations	9.9%
5. Lack of Executive Support	9.3%
6. Changing Requirements & Specifications	8.7%
7. Lack of Planning	8.1%
8. Didn't Need It Any Longer	7.5%
9. Lack of IT Management	6.2%
10. Technology Illiteracy	4.3%
Other	9.9%

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Figure 6.1 – Reasons for Project Failure (Extracted from Chaos Report, 2014)

At the very least, reasons [1], [2], [4], [6], and [8] (i.e. half of the reasons, which together total 51.5 %; also, half of responses) are somewhat related to “stakeholder requirements”. For instance, “Incomplete requirements” arises from poor or lack of requirement elicitation from various project stakeholders – It follows that a judicious application of Systems Engineering (as advocated herein) with its emphasis on “*satisfying stakeholder requirements over its lifecycle*” will prove effective in eradicating most reasons for project failure.

Chapter 7: Discussions

“In order for the research to be at all meaningful, there has to be an identifiable connection between the answers to the research and the research questions and the research problem inspiring the study.” (Ellis & Levy, 2008, p. 20)

Hence, this chapter will discuss to what extent the Research Question has been adequately answered and Research Objectives sufficiently achieved. It will further elaborate on key SE Roles in Project Management as well as on a number of practical implications arising from the outcomes of this study.

7.1. Achievement of Research Objectives

This study achieved its Research Objectives (Section 1.5) both during the course of the investigation and through its outcomes and findings as follows:

7.1.1. Exploring common methodologies and SE applications to LIPs

Throughout the literature review (e.g., NETLIPSE Report) and an industry survey, common project delivery methodologies were explored to confirm the poor/low extent of SE application in the delivery of large, complex projects.

For instance, the study has found that *“most entities (64%) using a Project Lifecycle Methodology have adopted a lifecycle model that accommodates distinct stages/phases, with Gate Reviews between each two study phase, and have implemented a scalability tool”*. However, it has also found, *“14% of entities surveyed cannot really tell whether the lifecycle methodology is mandatory or not; a half (45%) have personnel who do not fully understand their own project methodology”*, which appear to defeat the purpose.

As a result, *“... a mere third (32%) of entities could boast of completing their projects 'on time, on budget'...”*, and half (50%) of the respondents agree that the risk of failure seems to increase with project complexity, confirming as reflected in literature that traditional project management is facing challenges.

Hence, the above findings have sufficiently answered the *status quo* question, confirming that traditional approaches are proving inadequate for LIPs delivery.

7.1.2. Comparing common methodologies to Project Lifecycle Model

Common lifecycle models (e.g., ISO 15288, IPA, and Dutch PWW models) were compared to each other (to establish the extent of *inadequacies*) and to the SE-based Project Lifecycle Model (to confirm relevance of *enhancements*). While such models are rich in SE-concepts, a more *holistic* model is required.

7.1.3. Developing a theoretical Project Lifecycle Model

The literature review identified the model presented in ISO 15288 Standard as the most advanced model reflecting a deliberate incorporation of SE principles and concepts into a Project Lifecycle Model.

This study, thus, has drawn on the ISO 15288 Model as a basis to develop a SE-based model by way of *appending* suitably identified project lifecycle elements that emerged from the literature and industry surveys, as further supplemented by structured interviews and a Delphi Process. This exercise culminated in a theoretical model that seeks to address (or better, eradicate) the current challenges (e.g., cost and schedule overruns in LIPs delivery).

The model encompasses the three (3) Systems-of-Interest (Sol) involved in the delivery of LIPs, namely, (i) the Realisation System (i.e. waterfall lifecycle and Vee-model), (ii) the Product System (i.e. Requirements, Behaviours, Architectures, and Measurements domains), and (iii) Context System (i.e. Operating Environment) in keeping with Zane Scott's Law Number # 9 of SE. Hence, this portion of the study has addressed the *enhancement* question.

7.2. Systems Engineering Roles in Project Management

Without the support of SE roles, the proposed SE-based Project Lifecycle Model may not yield benefits. This study has identified SE roles (e.g. Systems Engineer, Systems Analyst, and Systems Engineering Manager) that should appropriately apply to the management of Large Infrastructure Projects (LIPs).

Moreover, "*Whereas a systems engineer of a single system implements the 16 SE processes using a waterfall, incremental, or iterative approach, there is*

less structure in timing or sequencing these SoS SE core elements. They may be conducted by members of single or multiple SoS SE teams depending on the size or scope of the SoS.” (SE Guide for SoS, 2008, p. 29)

7.3. Practical Implications

This study made a point (under Section 5.2.1 “Project-System Boundaries”) that incorporating a Systems Engineering approach to the project lifecycle will not only entail a systems approach (e.g., Verification and Validation) to the Design Process, but to other project processes such as Stakeholder Management, Risk Management, and Operational Readiness Management as well. These adjustments could have far-reaching implications in the industry in terms of changes in the related bodies of knowledge, changes in enterprise process-assets, and availability of skills, to name a few issues.

For instance, broadening the scope of Stakeholder Management to cater for a whole range of issues throughout the project lifecycle and across all Systems-of-Interest (Sols) is certainly beneficial to the project endeavour; however, it might put a burden on the capability of project delivery entities. While most Large Infrastructure Projects (LIPs) do need and can afford it, a case could even be made against rigorously applying such a convoluted model on small, simple, and straightforward projects.

The above point reinforces the necessity (as previously raised under sections 4.3 “Statistical Correlation Analysis” and 5.2.4 “Project Lifecycle Methodology Deployment”) of executive actions being *first* taken at the organisational level. This should start with the establishment of a Systems Thinking culture across the organisation and shall apply when high complexity in the project context and/or scope warrants applying a SE-based Project Lifecycle Methodology.

Concerns around cost and timeline implications of applying the proposed SE-based Project Lifecycle Methodology (even when it is required, in LIPs) could be allayed by considering the trade-off between the average cost of applying Systems Engineering (15%, according to Eric Honour and Werner Gruhl) and the cost (and irreversibility) of failure in Large Infrastructure

Projects (LIPs). The study already alluded to this matter in the Introduction. Considering incidences and costs of LIPs failure, the benefits of applying a SE-based Lifecycle Methodology on LIPs certainly outweigh the burden.

Furthermore, traditional approaches to Project Management Training seem to focus on processes and procedures needed for the production of the “product” of the project and, therefore, fail to confer Systems Thinking skills and mind-sets. Project Management Training might need an injection of practical strategies and tools to afford project personnel a better understanding of the necessity and applicability of Project Lifecycle Management and to equip them for complying to such stipulations in order to appropriately apply Systems Thinking, -Engineering, - Approaches and - Methodologies (S-TEAM), leading to effectively managed and successfully delivered projects.

Hence, SE-based Project Management Training and Capacitation initiatives (e.g., lectures, master-classes, seminars and webinars, as appropriate) should include the following important elements:

- (i) An asset view of the lifecycle, making accommodation in the project lifecycle methodology for appropriate consideration during the project planning and development phases of operational considerations (e.g., operational, maintenance and disposal requirements);
- (ii) The necessity and benefits of managing requirements throughout the entire project lifecycle to increase the odds of project success; and,
- (iii) The role of the Systems Engineer (whether soft or hard skilled), which is critical in coordinating development efforts from all project domains.

Besides, an “assessment tool” could be developed that gauges the extent and criticality of any project lifecycle methodology (for large and complex projects) in a particular project delivery organisation against the set of 13 essential elements of an effective Project Lifecycle Model as identified in this study (refer to Section 5.1). Such a tool should not only establish which areas of the *current* methodology might need improvements, but also make an educated *prediction* as to the likely outcomes of projects under delivery.

Chapter 8: Proposed Future Developments

The scope of this study revolved essentially around the development of a project lifecycle model that addresses the shortcomings and inadequacies of most traditional project management methodologies, as they increasingly prove ineffective in managing large and complex infrastructure projects.

The next logical step, thus, should consist of proposing future developments; *“The research problem should advance the frontiers of knowledge by leading to new ways of thinking, suggesting possible applications, or paving the way for further research in the field.”* (Leedy & Ormrod, 2013, p. 2-30)

8.1. Empirical Corroboration

The enhanced, SE-based Project Lifecycle Model has largely emerged from a literature survey (which a review of actual project records supplemented, where available) and a series of structured interviews with Subject Matter Experts selected from respondents to a prior online survey covering mostly big-players in the infrastructure projects delivery industry of Southern Africa.

It will follow that the proposed model, though theoretically validated through a double-triangulation (i.e. validation against relevant project management literature and by a Delphi Panel) might require a further *empirical* validation through its adoption and implementation in the industry – this constitutes a conceivable area for further investigations.

This particular measure is quite important since, as Miles would submit, *“There are often more exceptions or deviant cases than you realise at first; you have to go looking for them. They do not come calling”* – he further says, *“One can always think of exceptions or negative evidence that will force a revision of these propositions.”* (Miles, 2014, p. 305)

Of particular interest will be the empirical corroboration of the suggested “interactions and dependencies” between the proposed lifecycle elements (in Section 4.3.) to rule out any possible “spurious relationships”, meaning relationships incorrectly attributed due to the *limited* availability of data.

8.2. Realisation System (RS) as a Complex System

Secondly, the proposed SE-based Project Lifecycle Model will serve as a basis for the development of various methodologies for effective delivery of infrastructure projects. However, a methodology (i.e. set of processes & procedures) is but one component of the Realisation-System (RS) required for creating, deploying of a Solution-System, the object of a particular project. The RS probably constitutes a type of Complex-Adaptive-System-of-Systems (CASoS), which should be complex-adaptive, purposeful, and viable.

Wiley (Wiley *et al.*, 2012, Chap. 2.4) argues, *“Projects are complex adaptive systems, which consist of a large number of parts or activities that interact with each other in numerous and various ways”*.

Wiley further elaborates as follows: *“The dependence of the project on the activities, the interdependence of the activities, and the specialization of the activities underscore the relationship dependence of project activities. This relationship dependence is a key aspect of complex adaptive systems. The nature of complex adaptive systems can be probed by investigating the impact of change in one activity and the effect on other activities and the behavior of the whole. Activities must be studied and understood as interrelated, connected parts of the whole.”* (Wiley *et al.*, 2012, Chap. 2.4)

Additional elements of the Realisation-System (RS) pertaining to Tools and Techniques, Competencies and Culture, and project Reporting and Roles and Responsibilities might need reviewing in the *emerging* context of LIPs and Systems Thinking – This may constitute another area of future development.

8.3. Realisation System (RS) as a Viable System

Ames & Glass *et al.* (2008) argue that the Realisation-System (i.e. it consists of a System-of-Systems, SoS), just as the LIP Solution-System itself, is actually a Complex Adaptive Systems (i.e. it consists of a large number of mutually interacting and interwoven parts and agents) – which makes it a Complex-Adaptive-System-of-Systems (CASoS) with three characteristics as follows:

- (i) Emergent structure that is complex (i.e. network of networks);
- (ii) Emergent behaviour that is complex (i.e. grow and adapt, contain people);
- (iii) Are interdependent.

As a CASoS, the Realisation-System (which consists of resources necessary for delivering the Solution-System) should operate as an autonomous and viable “system” that is subjected to *recursivity*. Hence, the RS should operate as a complex organisation composed of a series of sub-systems, each having *self-organising* and *self-regulatory* characteristics, making them purposive.

In discussing the concept of “viability”, Espejo and Gill (1997, pp. 1, 3) suggest, *“The Viable System Model (VSM) is not a new idea. Created by Stafford Beer over twenty years ago ... An autonomous unit (or viable system) needs to have five key systems in place if it is to operate effectively in its environment. These are namely: Implementation, Co-ordination, Control, Intelligence, and Policy.”* The “viability” of the Realisation-System is another area of future development.

8.4. SE Supplement to PM Body of Knowledge

Project management associations (e.g., PMI, APM, IPMA) are expending sustained efforts in continuously upgrading their Project Management Body of Knowledge (PMBoK). However, there is little evidence of those associations directing such efforts towards incorporating SE principles and concepts.

Apart from research at leading universities, significant efforts in that direction have emanated from NASA, DoD (USA), International Council on Systems Engineering, and the Dutch Ministry of Public Works and Water Management where SE-based project processes are regularly developed and published.

In light of the above, project-related disciplines including Risk Management, Stakeholder Management, and Operational Readiness, to name a few, may require reformation of their Body of Knowledge (BoK) to better align to (thus more effectively support) the emerging SE-based project lifecycle models. Thus, the “expansion” of the current PM Body of Knowledge to include SE concepts, albeit taxing, may constitute yet another area of further development.

Chapter 9: Conclusions and Recommendations

To conclude this phase of the research pertaining to the application of Systems Engineering as enhancement to the project lifecycle methodology, Section 9.1 will seek to summarise the following aspects of this study:

- (i) Issues that motivated this study in the first place;
- (ii) The approach selected for researching this topic; and,
- (iii) The findings and recommendations regarding future developments and possible changes to current practices in the LIPs delivery industry.

9.1. Study Conclusions

The rise of project management as a means to delivering projects (and thus realising the organisation's strategy) now faces the challenges of rising negative perceptions due to a streak of chronic costs and schedule overruns and an unacceptably high rate of project failure – particularly in large and complex projects, such as Large Infrastructure Projects (LIPs).

Several genuine attempts to address specific “components” of project delivery methodologies (e.g., processes, training content, tools, and role definitions) have delivered very little overall improvement. However, recent developments in the industry indicate that a judicious application of Systems Thinking concepts could bring about the much-needed improvements. *“Understanding and managing complex systems like a project require some systems concepts that have been developed in other disciplines and applied to project management as a tool to make complex projects manageable.”* (CRAM101, “Project Management in a Complex World”, 2009, p. 47)

Early application of Systems Engineering (SE) principles and concepts has indeed produce substantial improvements to specific areas or aspects of project delivery. A research led by Werner Gruhl (who worked in the Comptroller Office at NASA) reviewed 26 space projects and concluded that 15% SE effort is ideal for success – which is a fairly low premium to pay (due to applying of SE over the entire project lifecycle) and prevent 50% to 500% overruns, if not total failure.

Instead of randomly applying SE principles and concepts to some areas of LIPs delivery, this study considered the application of SE elements to the project lifecycle itself, which represent the “racetrack” of any project delivery.

The project lifecycle model is the basis for any project delivery methodology: *“This International Standard provides a common process framework for describing the life cycle of systems created by humans, adopting a Systems Engineering approach ... This life cycle spans the conception of ideas through to the retirement of a system. It provides the processes for acquiring and supplying systems. It helps to improve communication and cooperation among the parties that create, utilize and manage modern systems in order that they can work in an integrated, coherent fashion.”* (ISO 15288, 2008, p. vii)

The Research Question for this study was thus formulated as follows:

“Can Systems Engineering (SE) concepts and principles be applied to project management methodologies (for Large Infrastructure Projects, LIPs) in order to enable Project managers to more effectively and successfully attain the desired outcome of a planned Project?”

The above question was rather answered in a two-step approach as follows:

- (1) Whether the inadequacies observed in the application of traditional approaches will warrant proposing any enhancements to the current project lifecycle models – the *status quo* question; and
- (2) What specific systems engineering principles, concepts, and practices could constitute such enhancements – the *enhancement* question.

Accordingly, this investigation included a literature review and industry survey to establish the *status quo* and to answer the first question (i.e. which inadequacies, if any, are hampering traditional project methodologies?). The outcome was an overwhelming realisation that most current, commonly adopted project management methodologies are based on lifecycle models (and delivery approaches) that have proven inadequate in dealing with the increasing complexity inherent to Large Infrastructure Projects (LIPs).

In light of the above, the second part of the investigation endeavoured to determine what specific SE principles, concepts, and practices should serve as enhancements to the current project lifecycle model. A literature review converged into discussions with SMEs to propose specific elements for incorporation into the lifecycle model. This exercise, mostly supported by thematic analysis and interpretation of statistical results and findings, led to the development of the proposed SE-based Project Lifecycle Model.

This SE-based model reflects a Primary Scheme that follows the “waterfall” development process including FELs, Construction and Closeout phases. An adjacent Vee Scheme depicts the process dealing with the system’s technical aspects; the Product System and Context System represent its “four development domains” and where the system will be deployed respectively.

A salient outcome of this study is the realisation that the basis for our project management paradigms needs redefining. Indeed, the analysis of the construction process has established that the complexity of construction can no longer be ignored, particularly for LIPs. Therefore, traditional project management practices should be changed accordingly (Bertelsen, 2003, p. 12) – This could prove challenging given the current paradigm in Southern Africa.

Whelton and Ballard (2002) suggest that the recognition, formulation, and resolution of wicked problems (i.e. ill-defined problem sets that are too complex to be solved by rational systematic processes) require auxiliary group management skills (e.g., SSM) to complement systematic processes.

This study, along with the proposed future developments and the necessary enhancements to scope and content of current project management training schemes as suggested herein, will inform a better alignment of the Project Management Body of Knowledge to SE-based project lifecycle models.

Furthermore, this study has recommended additional elements that support and translate the lifecycle model into a practical methodology. It proposes a SE-based approach to specific project delivery domains such as Stakeholder Management, Operational Readiness Management, and Risk Management.

9.2. Proposed Future Developments

It has been acknowledged based on the foregoing discussions that systems come in threes, namely the Solution-System, the Context-System, and the Realisation-System (or in sevens, should the Context-System be further separated out into Competing, Sustaining, and Collaborating systems).

The previous chapter further raised that the Realisation-System is actually a Complex-Adaptive-System-of-Systems (CASoS) to be investigated along the perspective of the Viable System Model (VSM). As such, it has to function as an autonomous and viable System-of-Systems that operates effectively in its environment – being sustained by *concomitant* and *interacting* functions pertaining to policy, intelligence, control, co-ordination, and implementation. However, a doctoral study on VSM application to energy projects in Nigeria is already underway at the University of Salford. (Awuzie & McDermott, 2012)

There is also a need for an empirical corroboration of the proposed SE-based Project Lifecycle Model and the ensuing necessity (assuming empirical corroboration be attained) of adjusting and aligning projects domains (such as Risk Management, Stakeholder Management, and Operational Readiness Management) to SE-based models. Incorporating SE concepts into any of these domains will further enhance the delivery process and performance of Large Infrastructure Projects. However, the current misconceptions around the objectives of Risk Management (Section 2.6.8) could provide a greater incentive to prioritise further research in this extremely critical domain of LIPs.

It is clear from Sections 1.5 to 8.1 that for the sake of further corroboration and future developments alluded to above that the project management industry should consider the outcome of this study (i.e. adopt the SE-based Project Lifecycle Model) and embrace a Systems Thinking approach to LIPs delivery. Due to the universality of principles, concepts and practices that contributed to the SE-based model, industry should allow space for any lessons learned from the application of the proposed model to be shared to the PM fraternity, while also applying the same model to other project types.

9.3. Recommendations to the Project Management Industry

Many organisations (e.g., mining and utility companies, state owned firms, government agencies) rely on the delivery of large and complex infrastructure project to realise their strategic plans. (Cleland & Ireland, 2002, pp. 33, 44)

Mark Ally, a consulting leader at PwC South Africa, argues this constitutes a matter of survival in the market place and could even affect shareholder value. *“The pool of available capital is limited and while every dollar invested in infrastructure can potentially have many-fold returns to governments, businesses and citizens, planned shareholder value and stakeholder benefits are rapidly eroded when delays and budget overruns occur due to poorly managed project implementations. Infrastructure projects require an intense focus on transparency and accountability to ensure that they are planned, funded and completed in a timely, cost-effective manner and are efficiently run. There is therefore a need to plan capital projects carefully to ensure that they return maximum value and benefits, while perfectly aligning with strategy.”* (PwC Africa Infrastructure Report, Nov. 2014, p. 61)

AngloAmerican echoed the same sentiment in their 2014 Annual Report, *“Kumba seeks to maximise total shareholder value by enhancing the value of its current operations ... The company captures value across the value chain through its commercial and logistics strategies and by executing its growth projects efficiently, while continuing to deliver on its organisational responsibilities, capabilities and societal obligations.”* (AngloAmerican, p. 55) The firm believes that *value* is captured through *executing projects efficiently*.

The realm of Large Infrastructure Projects is characterised by increasing complexity and this study has demonstrated that traditional approaches to Project Management are proving inadequate to manage complexity, leading to failure. Wood *et al.* (2010) maintains: *“It is a common statement that the construction industry process is one of the most complex and risky businesses undertaken, however it has also been suggested that the construction industry*

has developed great difficulty in coping with the increasing complexity of major construction projects” – Clearly, new approaches to LIPs delivery are needed.

LIPs exhibit extreme complexity due to their structure, behaviour, and impact; *“A project can be said to be complex if it consists of many interdependent parts, each of which can change in ways that are not totally predictable, and which can then have unpredictable impacts on other elements that are themselves capable of change.”* (Cooke-Davies, June 2011, p. 40)

It was shown in this research effort that the SE-based Project Lifecycle Model addresses most inadequacies and shortcomings of the current approaches; it should lead to methodologies that ensure the *right* projects (e.g., meeting owners’ requirements, aligned to strategy) are delivered *right* (e.g., on time, on budget, to quality). It is anticipated that the rate of project delays and costs overruns will be reduced, with a significant positive impact on the realisation of the companies’ strategy, financial performance, and overall business viability.

The Independent Project Analysts (IPA) gives a stern warning to the industry, *“As we look back over the past 23 years at IPA {LIPs} customers that have disappeared, all but one of them grossly overspent for their capital assets.”* (Morrow, 2011, p. 39) – It is a matter of survival to LIPs delivery organisations.

Many organisations involved in delivering Large Infrastructure Projects and that rely on project methodologies for the successful delivery of their portfolio of projects should adopt the proposed SE-based Project Lifecycle Model to reap financial benefits (e.g., in the form of savings) from reduced costs and schedule overruns. However, this adoption shall start at management level.

According to the US DoE Guide (“Managing Design and Construction Using Systems Engineering”, DOE G 413.3-1, 2007), Systems Engineering (SE) is *“A proven, disciplined approach that supports management in clearly defining the mission or problem {LIPs}; managing system functions and requirements; identifying and managing risk; establishing bases for informed decision-making; and verifying products and services meet customer needs”.* (p. 2) – Thus, in the first place, Systems Engineering stands to *support* management.

SE is indeed “a methodology that they can use to ... ensure that design, construction, environmental, safety, security, health, and quality comply with the contract, public law, regulations, and Executive orders”. (Ibidem, p. 1)

Industry should also adopt Systems Engineering roles and responsibilities by including, for instance, Systems Engineers (i.e. soft or hard skilled) as part of the project delivery teams to ensure achievement of project goals – which is really about *meeting the owners and stakeholders requirements*.

In light of the above, it is hereby recommended that the LIPs industry in Southern Africa should embrace the findings of this study and enthusiastically implement the following, as they might see it fit:

- (i) Apply the findings and recommendations of this study not only to their large, complex projects, but also to other projects types as appropriate. This will lead to concurrent advancement of Project Management and Systems Engineering practices, especially in the application of the latter in the particular domain considered in this study (i.e. LIPs);
- (ii) Provide feedback and lessons learned across the industry on results (e.g., success, challenges) emerging from the practical application of the proposed SE-based model (or similar) to LIPs and other projects. This will reinforce the previous recommendation (i) by providing scope and material (i.e. real-life data) for empirical corroboration; and possibly,
- (iii) Provide funding and/or sponsorship in support of further research in this field (and related topics), an investment that will eventually yield returns (i.e. financial and otherwise) in terms of realising effective systems (e.g., major savings from cost/schedule overruns, fit-for-purpose of facilities).

In addition to organisations (whether in the private and public sectors) that are actively involved in the delivery of Large Infrastructure Projects, the above recommendations should equally apply to most organs of government, development agencies, and development banks that initiate, finance, control, own and/or utilise the “product” of such projects as part of their mandates.