Critical success factor model to optimize power plant life cycle management

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DECLARATION

I declare that except where due acknowledgement has been made; the work is that of the author alone. I confirm that to the best of my knowledge, the work has not been submitted previously, in the whole or in part, to qualify for any other academic award; the content of the thesis is the results of work which has been carried out since the official commencement date of the approved research program; and, any editorial work, paid or unpaid, carried out by a third party is acknowledge.

Name: Lalamani Budeli

Date: 04 February 2019

PREFACE

The purpose of this study is to develop an integrated power plant life cycle management model that will perform measurements and analysis of input, process and output data in order to improve the performance of projects, products (projects deliverables) and the organisation (corporate success). The project success life cycle model (PSLCM) constitutes a scoring method that enables organisations to measure success objectively as opposed to common subjective measuring methods. This will make it easy to compare task, activity, projects, product and organisation success levels and to establish a benchmark for future reference in order to continuously improve power plant performance.

The study evaluates project development, which is required to implement business strategy, which in turn, is important for changing organisational performance in different stages of the organisation's life cycle. In order to understand why organisations are not successful in strategy implementation, the project, programme and portfolio management techniques were evaluated. It focussed on the impact of benefit management (BM) practices on success in order to close the gap between planning, execution and operations by ensuring that the right people, within the right process take the right decisions that are effectively implemented, taking the entire life cycle into consideration (to benefit the entire life cycle).

This model analyses the interdependency of related concepts of project success, project product success, and organisational success. It also evaluates the impact of failure factors on those success factors, and then proposes a set of dimensions for defining and measuring project success by measuring input efficiency, process efficiency and output efficiency. A project success life cycle model (PSLCM) is then developed, taking advantage of organisational strength and weaknesses thus evolving a fit for purpose life cycle management system.

ABSTRACT

For power utilities to secure a competitive edge in the energy sector, the efficiency of life cycle management programmes must be improved through successful execution of projects. In today's competitive environment, producing products that are fit for purpose and meet or exceed quality requirements, as well as being cost competitive, are key factors in determining organisational success.

Effective project management practices require a project management system that supports management to achieve its organisational project goals, in order to position the organisation strategically for future performance. However, due to projects being inaccurately monitored resulting in improper management, the project success rate is very low, which has a major economic impact on organisations.

This study proposes a Project Success Life Cycle Model (PSLCM) that is aimed at ensuring that critical factors are considered when the success of power plant life cycle management projects are measured. This model uses data envelopment analysis (DEA) to measure task, activity, process, product or firm input and output, as well as process efficiency at any stage of project, product or business development. It integrates technical performance and financial performance measures so that projects in different industries can be compared objectively and inefficiencies in areas where resource availability is high, can be easily identified.

This paper shows how integrating effective technical and financial performance measures (TFPM), data envelope analysis (DEA) and design of experiments (DOE), as well as the use of standard processes, can dramatically improve plant life cycle management through an integrated life cycle management model. Statistical methods, which include analysis of variance (ANOVA), factorial experiments, T test, relative importance index (RII), and Pearson correlation coefficient where used to evaluate, verify and validate data.

The outcome of the model is a success performance measure which incorporates project, product and corporate performance into a single value. This model will make it easy to compare projects, product and organisational performance in different stages of the power plant life cycle. The paper demonstrates how utilities can achieve sustained performance by identifying how the combination of project management best practices and life cycle management methodologies can recognise process improvement opportunities.

Keywords: Critical success factors, life cycle management, benefits realisation, data envelope analyses and performance measurement.

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ABREVATIONS

Abbreviation	Description
ANOVA	Analysis of variance
BM	Benefit management
DEA	Data envelope analysis
DMU	Decision making units
DOE	Design of experiment
EAF	Energy availability factor
EVM	Earned value method
GO	General overhaul
IBI	Integrated business improvement
IEA	International energy agency
IR	Interim repairs
ISO	International organisation for standardisation
LOPP	Life of a plant plan
LCC	Life cycle cost
LCM	Life cycle model
MPCS	Multidimensional project control system
SAP	System application processes
SPC	Statistical process control
SS	Sum of squares
PM	Project management
PMBoK	Project management body of knowledge
PMS	Project management success
PPS	Project product success
OEM	Original equipment manufacturer
OHS Act	Occupational health and safety act
OS	Organisational success
PCLF	Planned capacity loss factor
PLCM	Plant life cycle management
PDCA	Plan-do-check-act
PSLCM	Project success life cycle model
TOC	Theory of constraint
TPM	Technical performance measure
TQM	Total quality management
QMS	Quality management system
UCLF	Unplanned capacity loss factor

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CHAPTER 1

INTRODUCTION

This chapter introduces the reader to the background of the research problem and discusses the significance of the study, the aims and objective, the research hypotheses and the format of the thesis. The chapter further explains the contribution of this study to the body of knowledge towards both engineering and project management disciplines.

1.1 Introduction to study

"I returned, and saw under the sun, that the race is not to the swift, nor the battle to the strong, neither yet riches to men of understanding, nor yet favour to men of skill; but time and chance happened to them all. (Ecclesiastes 9:11)"

Conti et al. (2016:131) indicate that according to the International Energy Agency (IEA), the development of coal fired power plants started in 1866. The first central power station in New York was built in 1882. Power generating plants require large initial investment and significant further expenditure to continue operations over its intended life cycle. This means that the cost requirements for the continuing operations should be determined in order to sustain the plant output over its intended life cycle. In addition, regular detailed life cycle plans that reflect essential refurbishment and replacement activities of all relevant plant systems, are needed. These plans must reflect modifications, projects and technological improvements that may be required to address any changes in plant conditions, operations, capacity, and legislative requirements, as well as primary energy supply or operational life span.

It is important for utilities to determine standard practice involved in the plant life cycle management process, which include the inputs and expectations of key stakeholders, as well as proposed methods to ensure process effectiveness. It is vitally important that the technical planning process must follow all the critical steps to ensure that an effective and efficient plan is developed. This is achieved by establishing correct planning assumptions and inputs when developing the life cycle management plans. These include the planned operational life of the power plant, economic evaluation parameters, plant maintenance strategies, legislative and statutory requirements, the future production regime, performance targets and primary energy

requirements, as well as quality. Power utilities require these inputs to integrate information systems into a database in which all project proposals, as well as finalised technical plans and life of plant plans are in place to avoid developing technical plans from a zero base every year. Financial targets are applied to sections over the period of the technical plan to optimise the plan within the available funding, while project proposals are prioritised according to approved ranking methodologies.

The power industry landscape continuously experiences disruptions mostly due to existing business models, systems and methods of operation and a blend of players and electricity subsectors. In developing countries, energy efficiency can be realised quickly because the potential for energy efficiency improvement is high. Due to the constraint in which power plants are constructed and operated, it can be expected that there will be differences in efficiency and performance from one plant to another. Real plant design constraints also limit power plant efficiency beyond the control of utilities, which is not necessarily a result of ineffective design or operation. Farfan and Breyer (2017:378) state that various factors are perceived to affect the efficiency of power plants. However, this study will focus on technical efficiency problems due to design and maintenance, which is subdivided into plant design, deterioration, plant maintenance and availability.

MICALI (2014:261) states that the unit capability factor (UCF) monitors progress in attaining high unit and industry energy production availability. This indicator reflects effectiveness of plant programmes and practices in maximising available electrical generation, and provides an overall indication of how well plants are operated and maintained. The unplanned capability loss factor (UCLF) monitors industry progress in minimising outage time and power reductions that result from unplanned equipment failure or other conditions. This indicator reflects the effectiveness of plant programmes and practices in maintaining systems available for safe electrical generation. The planned capacity loss factor (PCLF) is energy that was not produced during the period as a result of planned shutdowns or load reductions due to causes under plant management control. The relationship between UCF, PCLF and UCLF is represented by the equation below:

$$\boldsymbol{UCF + PCLF + UCLF = 100\%} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{1.1})$$

Chanda and Mukhopaddhyay (2016:14) maintain that the objective of power plants' Life of Plant Plan (LOPP) is to ensure sustainability of future energy supply. Pheng (2018:102) holds that every LOPP project starts with a set of user's requirements which are translated into unique technical specifications for a specific environment for implementation purposes. Handzic and Bassi (2017:104) believes that the execution of a LOPP project is subject to numerous

constraints that limit the commencement or progression of field operations, which invariably have a significant negative impact on overall project performance. Cosgrove (2017:144) specifies that by definition, project constraint is any condition that may prevent a project to achieve its goals and objectives. Vanhoucke et al. (2016:14) state that project success relies on effective identification and management of constraint, thorough project planning, scheduling and execution. Alhamid et al. (2016:739) acknowledges that with the above issues in mind, a forward-looking methodology can offer a detailed account of operational constraints. This provides field personnel with operational instructions free of constraints, showing work to be done within a relatively short time frame reflecting actual field condition, thus allowing the project baseline or master schedule, to provide a global view of a project and its execution strategy.

1.2 Background to the problem

According to the international energy agency (IEA), the essential challenge of most power utilities is to maintain or improve the performance of the existing generating plant, specifically considering how to evaluate performance in the context of multiple objectives (Heubaum and Biermann, 2015:231). These include availability, reliability, efficiency, environmental performance, and flexibility (Agency, 2015:48). Ramage and Armstrong (2005:10) point out that the failure of life cycle projects or project delays is a global phenomenon and African power utilities are not an exception in this regard. Vanhoucke et al. (2016:10) indicate that the objective of owners, engineers, consultants, and contractors involved in projects, is to complete the projects successfully within budget and on schedule, with high quality and without safety concessions. Aibinu and Jagboro (2002:595) believe that project stakeholders must work towards a common goal for a project to be successful. Doloi et al. (2012:481) explain that an evaluation of recent literature indicates that life cycle projects and outages are completed with high cost overruns, extended schedules and serious quality concerns.

According to Gadonneix et al. (2010:14), different project management scholars take different factors into account that affect the progress and the overall success of a project. Prabhakar (2009:3) believes that budget compliance and accurate schedules will matter less if the project results do not meet the project goals and expectations. Jugdev and Müller (2005:28) hold that factors that create an environment which ensures that projects are managed in a consistently successful way are critical. Humphrey (2005:27) indicates that critical success factors are those

factors that will significantly improve the chances of project success if addressed appropriately, which requires choosing processes and activities that will address critical factors.

Generally, a successful project will be completed on time, within cost, deliver quality as promised, meet or exceed stakeholder expectations and maintain a win-all situation. Kerzner and Kerzner (2017:207) state that companies increasingly make use of the project management methodology as a management tool to promote organisational change. Daniel and Stewart (2016:166) hold that although numerous effects result from the stakeholders' expectations, aspects that lead to successful projects are part of the strategic perspective. Saynisch (2010:14) states that project management literature has identified some determining factors, such as complexity and uncertainty.

Hu et al. (2013:9) point out that project management has an established approach intended to assist project managers to manage project activities by applying techniques, skills and tools to meet stakeholders' needs through effective project management practices. It is also generally acknowledged that good project management does not necessarily result in project success or that bad project management necessarily leads to project failure. Baškarada et al. (2013:11) point out that the success factors identified in other industries cannot be used as valid factors for power plant life cycle projects, because factors are not universal to all projects.

Leybourne et al. (2014:21) explain that due to projects delivering substandard products, most power utilities today are faced with a short product life cycle, as well as technical products that are highly complex resulting in increased life cycle costs (LCC). Tillmann et al. (2010:407) argue that there are many constraints in realising and executing LOPP-based project work. The key factors involved in the organisational structure in which the project is set, include forming high-performance teams and resolving any conflict that may arise, as well as ensuring effective project managers with the required expertise, the improbability and risks intrinsic in all projects, and a flawless definition of how project success should be measured (Petro and Gardiner, 2015:1722). The table below shows various researchers' views on project, product and organisational performance.

Table 1-1: Project, product and organisational performance: researcher's views

	Survey	**Relevant findings**
Project	Pulse of the Profession (PMI, 2015)	On average, 64% of the projects are successful in meeting their goals.
	Industrial Megaprojects (Marrow,	"65% of all industrial megaprojects

	2011)	failed to meet business objectives."
	KPMG New Zealand Project Management Survey 2010 (KPMG, 2010a)	Over 50% of respondents stated that they do not consistently achieve stated project deliverables.
	2010 Project Management Survey Results (First Line Projects LLP 2010)	Only 24% of respondents could confidently tell a client that a project would be delivered on time.
	PMI®-KPMG Study on Drivers for Success in Infrastructure Projects 2010 (KPMG, 2010b)	41% participants faced cost overruns and 82% witnessed time overruns.
	Adapting to complexity - Global Major Project Owners Survey 2008 (KPMG 2008)	Less than a third of projects are completed on time and less than two-fifths come in on budget.
Product	Cooper (2010)	Product failure rates of 48%
		35% projects product (deliverable) fail to deliver a significant return.
	The Access Group (2018)	Reliability, ease of use, and ease of integration are the top three requirements project managers look for when procuring equipment.
Organisation	PWC global project report (2012)	97% of organisations believe project management is critical to business performance and organisational success.
	Change point (2016)	80% of project management executives don't know how their projects align with their company's business strategy.
	PMI (2018)	High-performing organisations successfully complete 89% of their projects, while low performers complete only 36%.

Due to increasing legislation relating to the environmental and social impacts of power plants on society and the environment, various driving forces are emerging from government, society and employees influencing power utilities to incorporate sustainable development in their business practices by aligning all internal operations and practices. Developing project management methodologies that consider sustainable project life cycle management by effectively addressing social and environmental aspects of sustainable development, will position power plants as energy sources of the future. System engineers have long recognised environmental and social impacts that exist due to interaction of the system and its environment, and the effects it has on the wellbeing of the system throughout the system's life cycle. The functional interactions of a system with its environment include its inputs, outputs and human control interfaces. System engineers design and prioritise the system requirements ensuring that the different system attributes are appropriately weighed when balancing the various technical efforts by deciding which risks are worth undertaking. They also determine whether new approaches to the problem are necessary, whether intense effort will accomplish the purpose, and whether the requirements can be surmounted to relieve the problem.

In recent years, projects have become strategic management tools, resulting in project management becoming a core competency and a necessity for organisational survival. This requires an appropriate methodology and clear understanding of the life cycle phases which has been confirmed through a benchmarking study by Gunduz and Yahya (2015:10). This indicated that companies that are successful in project management, all use a company-specific, simple and well-defined project management framework that defines a staged approach for all projects under all circumstances.

Baccarini (1999:27) maintains that it is important to differentiate between project success criteria and project success factors, because criteria are used to measure success, while factors facilitate the achievement of success. Project success comprises of two distinctive components namely project management success and project product success illustrated by the formula below:

$$\boldsymbol{Project\ success} = \boldsymbol{Project\ management\ success} + \boldsymbol{Project\ product\ success} \ldots\ldots (\mathbf{1.2})$$

Gunduz and Yahya (2015:308) argue that project management success concentrates on the project management process and in specific on the successful achievement of the project regarding cost, time and quality. According to Pinkerton (2003:333), these three dimensions determine the degree of proficiency of project execution. Project product success concentrates on the properties of the project's end-product. Though project product success is unique from

project management success, the successful outcomes of both are inseparably linked. If the project is not a success, neither is the product (Pinkerton, 2003:334). According to Baccarini (1999:23), the imperative to successful project interactions is in understanding that dissimilar stakeholders have dissimilar expectation of the projects and dissimilar definitions of success. Rezvani et al. (2016:1117) argue that project accomplishment and failure is strongly prejudiced by both the expectation and perception of its stakeholders, and the capability and disposition of project managers to manage organisational politics.

Rezvani et al. (2016:127) explain that all projects must have a plan with sufficient details so that all stakeholders are aware of where the project is going, including clear project milestones and deliverables. DuBois et al. (2015:13) point out that the project managers must also keep the project team inspired by involving them throughout the project, and by planning frequent milestones to help them feel that they are making progress; they should never promise or expect what cannot be delivered. Anantatmula and Rad (2018:11) indicate that the objective of every project manager is ensuring that the project team meets or exceeds customer requirements, while balancing this with the other requirements that enable a project manager to take advantage of project opportunities, while ensuring that focus is maintained on key areas of the project.

Identifying all project risks is another area of concern where some risks are only noticed when they have materialised during execution, making it difficult for the project teams and with significant effect on the cost and schedule of the project (Manoliadis, 2018:4). A project system attempts to predict and produce a certain result for a certain cost by a certain time. Hickson (2015:15) alleged that variation exists in projects and processes because predictions are never completely accurate, but understanding variation is essential in making any real system operate.

Martinsuo et al. (2014:738) indicate that although the project management industry has recognised the importance of developing constraint-free and reliable work plans, numerous projects are still plagued by delays, unacceptable deliverables and cost overruns, which can frequently be traced to ineffective identification and treatment of constraints. Subsequent conflicts in the field are unavoidable if project constraints are not properly identified during project identification, planning and scheduling. Due to projects that are becoming technically more complex and logistically challenging, project teams are confronted with even more complex constraints exposing traditional scheduling methods such as bar charts, critical chain project management (CCPM) and critical path method (CPM) widely used for constraint analyses to greatly limit our capability in modelling and resolving constraint.

The concept of sustainable life cycle project management requires that sustainable development becomes an integral part of planning and managing the project over its life cycle. This is due to the impact of social and environmental influences that must be recognised from project inception. Sustainable development aspects must feature in all project activities and deliverables.

1.3 Problem statement

Energy is an asset-intensive industry that requires a vast array of plants and field assets for production, processing and refining. In today's competitive global environment, it is critical to maximise asset return through all the stages from design, building, operations, maintenance and decommissioning. Utilities invest tens of billions of dollars annually through life-cycle management programmes to maximise uptime, ensure safety, and drive cost effective operations to deliver a strong return on investment, which requires assets to run at peak capacity throughout their lifespan. Panos et al. (2015:28) alleges that 32% to 37% of life-cycle projects equivalent to a capital investment of between $22 billion and $28 billion is lost annually by Africa utilities as a result of sub-optimal and unsuccessful project execution. According to Panos et al. (2015:23), many power utilities suffer from poor technical and financial performance, insufficient technical and managerial skills and a lack of proper maintenance.

Eskom, Africa's largest and most efficient utility for the last 40 years, benchmarks power generation performance of its power plants against those of the members of the Vereinigung der Großkesselbesitzer (VGB), a European-based technical association for electricity and heat generation industries (Jaglin and Dubresson, 2016:39). The 2015 benchmark result indicates that:

- The trend in the performance of Eskom's generating plants across all indicators, continues to be below the VGB benchmark.
- The availability of the top performing stations in the VGB benchmark has historically been consistent, but a decline was observed from 2012 through 2013, and the availability of the benchmark stations in the median and worst quartiles has also been declining.
- Eskom units are on a par with the VGB benchmark with respect to planned maintenance in the median and low quartiles, while the PCLF of Eskom's best performing units was significantly better than that of the VGB benchmark units.

- Since 2012, Eskom's UCLF performance showed a significant deterioration compared to the VGB benchmark on all quartiles; this trend is continuing. (Eskom, 2016:13).

The figure below indicates the performance of VGB utilities compared to Eskom performance for a period until 2014.

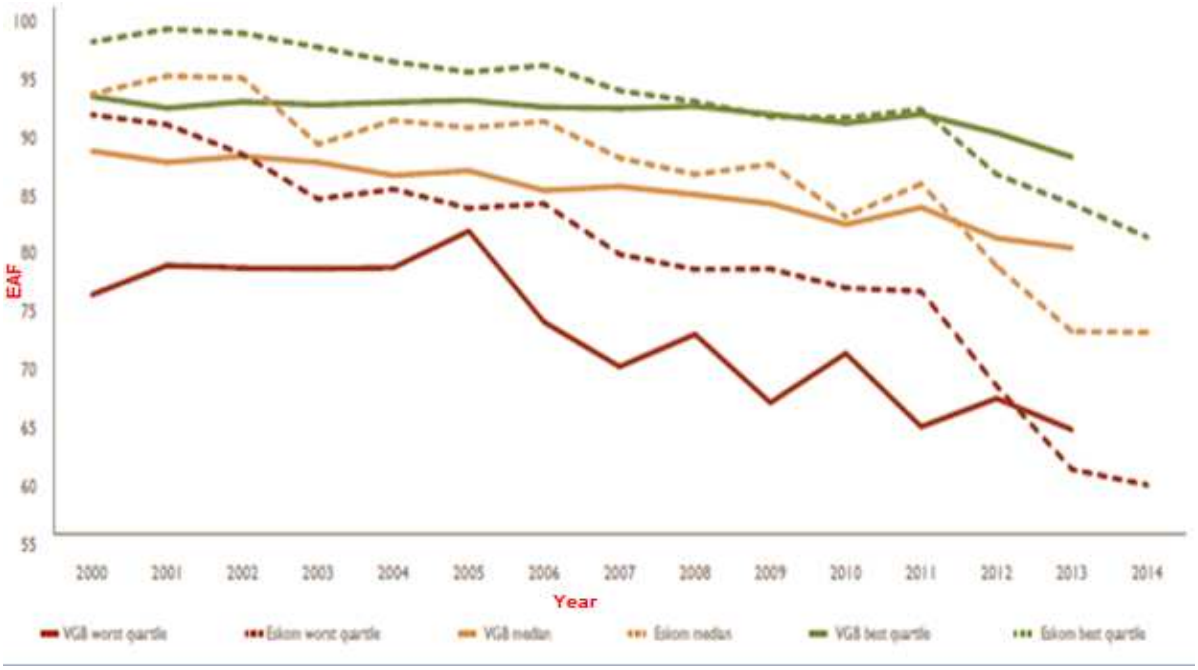


Figure 1-1: EAF benchmark between Eskom VGB (Jaglin and Dubresson, 2016)

Power plants are characterised by large investment and long operational phases presenting costs as a common problem within the industry. The first expense, which is the initial investment, can be clearly determined. The figure below shows the life of plant plan (LOPP) for a fossil power plant.

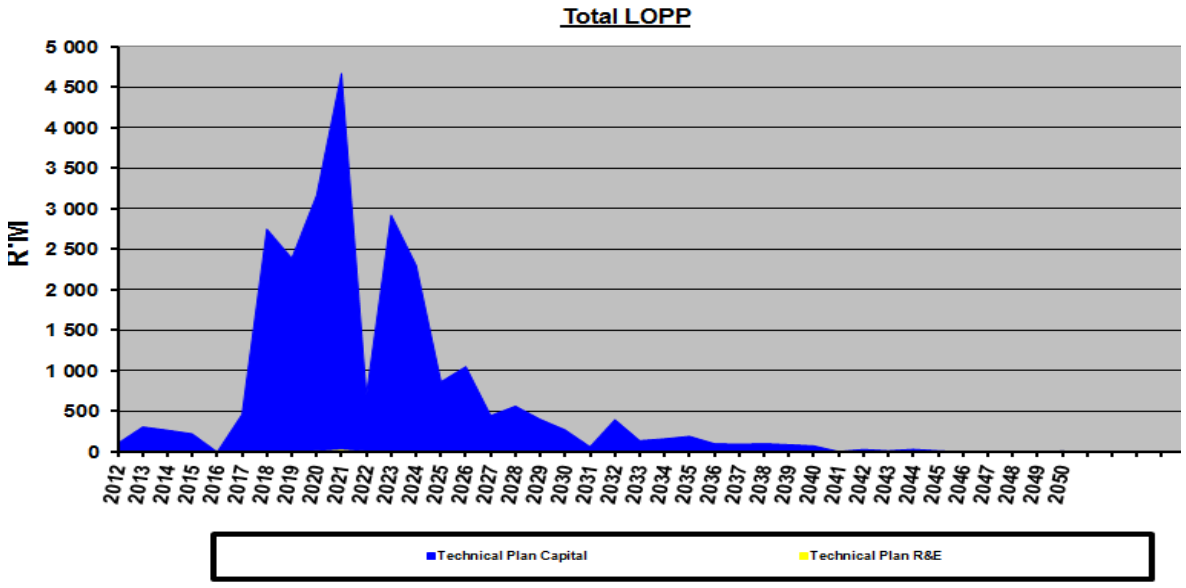


Figure 1-2: Life of plant plan (LOPP) for a fossil power plant (Capital and R&E)- (Bohlmann et al., 2016)

Although the performance of power plants depreciate over time, the capital investment required increases as the assets age. This second expense, which is operational cost over the entire life cycle, is difficult to determine during the early stages. This requires utilities to align projects with strategies, making effective use of limited resources and delivering certain benefits that require processes to bring the operations and project functions together to fulfil those expectations.

Utilities need to take a holistic approach to address infrastructure assets, supporting resources, and business processes, as well as data and supporting technology, to ensure effective investment decision making to achieve sustainable results. This research involves assessing and evaluating the critical success factors of technical life cycle management projects, project deliverables and outcomes for power plants, since projects form a key foundation for power utilities to create and sustain their assets throughout their life cycles. The three distinguishing elements of the desired model are:

- A comprehensive, sustainable project life cycle measurement and monitoring system that should measure project, deliverables and business performance (impact on business) at any stage during its life cycle; including various criteria and indicators enforcing sustainability consequences of the project's future implementation.
- Evaluation methods and tools to assess individual project performance against a developed framework, which will generally compare the project's performance to any other power plant project (current and historical).

- Ensure an efficient and transparent project, product and asset life cycle management methodology that provides easier decision making techniques and easier reporting through integrating financial and technical measures to form a holistic measure.

The research problem is thus that such a model does not exist currently.

1.4 Research hypothesis

The research addressed five hypotheses:

Hypothesis 1

- Null hypothesis: H_0 : There is no significant relationship between project, product (project deliverable) and organisational (corporate) success factors in power plants.
- Alternative hypothesis: H_1 : There is a significant relationship between project, product (project deliverable) and organisational (corporate) success factors in power plants.

Hypothesis 2

- Null hypothesis: H_0 : There is no association between critical success factors and constraints in power plant life cycle management projects.
- Alternative hypothesis: H_1 : There is an association between critical success factors and constraints in power plant life cycle management projects.

Hypothesis 3

- Null hypothesis: H_0 : Critical success factor importance may not be verified and validated through evaluating each factor against PMBoK area across the system life cycle.
- Alternative hypothesis: H_1 : Critical success factor importance may be verified and validated through evaluating each factor against PMBoK area across the system life cycle.

Hypothesis 4

- Null hypothesis: H_0 : There are no best life cycle management practices as a result of theory advancements in modelling which will assist to improve power plant life cycle monitoring, control and management.
- Alternative hypothesis : H_1 : There are best life cycle management practices as a result of theory advancements in modeling which will assist to improve power plant life cycle monitoring, control and management.

Hypothesis 5

- Null hypothesis: H_0 : Good project management practices combined with benefits management will not increase the probability of success in delivering business value.
- Alternative hypothesis: H_1 : Good project management practices combined with benefits management will increase the probability of success in delivering business value.

A response to these questions will allow the development of a model to be used to improve life cycle management performance, which will result in improved power plant performance. This will go a long way towards reducing power plant operational costs.

1.5 Research objectives

The main objective of this research is to develop a plant life cycle model which will identify, classify and resolve project, product and organisational constraints, creating a faultless environment were projects are delivered excellently by reviewing literature and industry practices in relation to constraint analysis and outline a conceptual model for constraint management. This key aims of the study are:

- To provide a comprehensive review of sources and characteristics of critical success factors and constraints typically found in life cycle management models;
- To develop a success factor and constraint classification method for easier constraint identification using a life cycle model;
- To review current industry practices regarding life cycle management and constraint modelling;

- To develop a theoretical method for total constraint management during life cycle management.

The result of this study will be valuable to project management and engineering industry practitioners, as well as related software providers in developing improved preparation and tools for constraint management and for future planning. Objectively comparing project performance throughout the project life cycle will be the main benefit for this model, which is aimed at driving the investigation of failed projects in order to establish why they failed and to subsequently improve overall project delivery.

1.6 Justification of the research

The power industry landscape continuously experiences disturbance, mainly due to existing business models, systems and methods of operation, as well as various players and electricity subsectors. Energy efficiency can be realised rapidly because the prospective for energy efficiency improvement is high. This can be achieved by ensuring that the designed capacity is achieved at all times. Due to the constraints within which power plants are constructed and operated, it can be expected that there will be differences in efficiency and performance. Real plant design constraint also limits power plant efficiency beyond utilities' control, which is not necessarily a result of ineffective design or operation. Many factors are perceived to affect the efficiency of a power plant, but this study will focus on efficiency problems due to design and maintenance. These are subdivided into:

- Plant design – the efficiency of a power plant is largely dependent on the basic plant design and how well it has been maintained. Best practices comparisons are generally confined to this area because other factors such as fuel quality, local ambient conditions and plant operating philosophy, which are largely beyond the control of power plant owners and operators.
- Deterioration – equipment deterioration over the years of operation affect plant efficiency and performance significantly. Deterioration of equipment is also evident in the overall plant performance and overhauls are therefore used to generally restore plant performance. But, while not all deterioration can be recovered by routine maintenance, ensuing efficiency benefits, extent of repairs and refurbishment work are commercial decisions to be taken by utilities.

- Plant maintenance – Comparing actual performance to design is important as equipment distorts, leaks, wears, fouls and corrodes, which result in calibrations drifting and the plant becoming less efficient. A key requirement of maintenance is to improve efficiency and performance, which represents an opportunity to retrofit more modern components with improved performance. Substantial improvements in efficiency can be achieved by the combination of performance restoration and plant modernisation, where plant design improvements are realised from original designs. In practice, any poorly performing equipment or components contribute to the overall deterioration of plant performance over time resulting in deterioration in major components.
- Component availability – non-availability of certain plant components and equipment can affect efficiency which requires cleanliness to be maintained to avoid degradation. Faulty equipment or instrumentation can result in significant loss of efficiency or leave units operating with restricted control facilities and flexibility.

Although factors causing the failure or success of life cycle projects have been studied in other countries, the revisiting of studies undertaken in the context of African utilities, deserves particular attention since the provision of low-cost and reliable electricity supply is critical for the growth and development of African countries. Hartono et al. (2014:408) note that, what is really important is that project stakeholders should be fully satisfied with the results of their projects, but point out that project and product deficiencies continue to be a problem in life cycle projects.

Various international research studies have identified the causes of project failure, while supplementary literature identified a range of success factors. However, no research has been found that illustrates the relationship between success and failure factors in power plant life cycle projects and product, and how more successful life cycle projects can be delivered through knowledge of this interface. This study is the first of its kind to measure life cycle project, product, organisational success and failure factors, and to develop a model that will deliver a successful project considering the existing constraints. The current study was motivated by this gap in research. Appropriate schedules and properly applied budgets will not matter if the final project outcomes do not meet the expectations and goals.

Kerzner (2018:271) defines the critical success factors as those components that are required to establish an environment where projects are managed consistently with excellence. Critical success factors in the area of project management is provided by Osei-Kyei and Chan (2015:1340), who found that strategic and tactical factors influence project performance at various stages of a project's life cycle. Zou et al. (2014:270) augment the range of success factors by considering the specifics of the various stages of project life-cycle. From another

point of view, some scholars prefer not to distinguish between the project success and the success of project management as a whole (Ram and Corkindale, 2014:164). Rather, they consider the project success as part of or even a consequence of the overall managerial success.

While most studies ague that project success is directly linked to product success, the question arises what are these critical success factors that are so noticeably absent in most businesses' new projects and product? Research has uncovered two categories or classes of success factors, namely those that are doing the right projects and those that are doing the projects right. There are no technical risk-free projects because there are an infinite number of factors that can have a negative effect on the project. It is important that project stakeholders understand that risk management is not about eliminating risk, but about identifying, assessing, and managing risk. Studies in risk management practices on more than hundred projects in a variety of industries, suggest that when risk management practices are applied to projects, they appeared to be positively related to the success of the project. This means that it is generally accepted that risk management increases the likelihood of a successful project.

Projects are the vehicles of change, where funding and resources are allocated because they help drive the necessary changes both individually and organisationally, creating value for the organisation. This study can thus be useful for other utilities worldwide as a reference throughout. The literature on project success factors, focussing on best project management principles in different stages of the project, its product and organisational impact will be explored.

Change management practices have been part of project management for many years, ranging from stakeholder management to communications, to human resources management. Project managers and project sponsors are judged more by the value their projects create, which requires managing organisational change and facilitating adoption, than by simply delivering on time, within budget and according to scope. Good change management is not simply about communicating the benefits of the project to the organisation, because no change management plan in the world will save a poorly conceived or executed project. By integrating change management activities into project design and decision making, the quality of the overall initiative will be increased. This will help facilitate the subsequent adoption of project outputs and deliverables.

1.7 Research scope

As part of this research, a comprehensive literature review was undertaken to assist in designing and conducting a survey to gather information about success and failure factors, as well as to obtain the opinions of experts using the Delphi method to rank the most critical factors relating to life cycle management projects. To this end, a general survey was distributed to power utility contractors, consultants, engineers and project owners to establish the most critical success and delay factors. Data was collected and evaluated using statistical methods to identify the most significant factors and to measure the strengths and direction between these factors in order to examine projects, and evaluate project and product delay/success factors, as well as to evaluate the influence of critical success on critical delay/failure factors.

The relative important index (RII) was used to determine the relative importance of the various factors. Analysis of variance (ANOVA) was used to examine how groups evaluated the influence of critical success factors in avoiding or preventing delay factors, and which success factors were perceived as most influential in avoiding or preventing each of the delay factors. Finally, the Delphi method using consensus from an expert panel was employed to evaluate the impact of each factor on the body of knowledge areas. A T-test was performed to further determine the final factors to be explored.

1.8 Knowledge gap to be closed

Most research studies worldwide acknowledge that life cycle projects are high risk. They need proper coordination and matching project requirements, as well as project team experience, which is always a challenge resulting in deliverables that are not always accepted by stakeholders. This study integrates project management processes, as well as project team experience, aligning it with stakeholder's requirements and investigating all factors of success and failure present in power plant life cycle projects in order to make recommendations to improve the overall performance of power plants throughout their life cycle. The project model with a scoring system is developed to objectively measure life cycle project performance through project life, which will ensure that project constraints are easily identified. While this study is specific to power plants, the recommendations can easily be applied at any other plant. The literature that is investigated relates to project management success factors, focussing on

best project management principles at different stages of the project, capable of delivering the project and product acceptable by project stakeholders.

1.9 Contribution to the body of knowledge

Theory generated from this study will help to make sense of the complex relationships that underline project management practice and will elucidate why efforts to improve performance succeed under some circumstances, but not in others. This will be done by analysing the interaction between various factors to understand how knowledge of this interaction may lead to the delivery of more successful projects, as well as measuring and ranking the relationship to help power utilities minimise power plant problems. The study furthermore introduces a model to identify and manage project constraint with a view that this will improve project life cycle success. This gap in research has motivated the current study which will contribute to the engineering and project management body of knowledge.

1.10 Chapter outline

This thesis is organised into eight chapters.

Chapter 1: Introduction to the study. This chapter explains the background to the research by highlighting the research problem, research objectives and justification of the research, and explaining the proposed research methods.

Chapter 2: Literature survey. This chapter presents a thorough review of literature from previous studies relating to project success and failure factors. It examines literature and comparative studies about factors causing delays or failure in projects. Life cycle management models (project, product, organisation and assets) were revisited to provide insight into factors that have a holistic impact on success and failure.

Chapter 3: Research methodology. This chapter describes the methodology used in this study to collect information and data to uncover those critical factors required for project success.

Chapter 4: Data collection and analysis. This chapter outlines the process used to collect data, as well as the data analyses techniques and statistical methods used to identify the causes of success and failure/delays in projects, products and organisation. Statistical analysis methods

were used to determine the correlation between critical delay/failure factors and critical success factors.

Chapter 5: Delphi technique. In this chapter, a three-stage Delphi technique is conducted to determine expert opinions regarding success and failure factors. The various factors are prioritised and will be used to develop an integrated life cycle model, which is discussed in the next chapter.

Chapter 6: Development of the theory of a Project Success Life Cycle Model (PSLCM). This model is developed to deliver the best deliverable taking into consideration all success factors and constraints specified in Chapter Five.

Chapter 7: Project Success Life Cycle Model (PSLM) verifications and validation. This chapter presents a project case study to verify and validate the proposed model results, using the factorial design process.

Chapter 8: Conclusion and recommendations. This chapter provides a conclusion to the study, discusses the research limitations of the research and the contribution to new knowledge. It also provides recommendations and implications for further research.

1.11 Conclusion

It is evident from previous studies that factors which influence the outcome of projects vary considerably; they are contextual and to some extent they are also contradictory. Hence, it is relevant to identify variables based on the needs identified from the basic factors. Project success is a complex and ambiguous concept and it changes over the project and product life cycle. Various driving forces compel globally competitive businesses to incorporate sustainable development issues in their life cycle management. These driving forces originate from both society and government. The progress made in aligning all business activities with the principles of sustainable development, first requires aligning project and life cycle management models to respond to this increasingly important and essential task. This research study is aimed at identifying critical factors and constraints in plant life cycle management models, and to subsequently develop an integrated model incorporating sustainability in project management methodologies. A model equation will finally be derived to mathematically calculate the performance at any stage.

CHAPTER 2

LITERATURE SURVEY

The purpose of this chapter is to review previous research relating to success and failure factors in plant life cycle management, placing more emphasis on efficiency and effectiveness of life cycle projects (meeting and exceeding performance requirements). This study provides a means of understanding important factors that constrain plant performance in order to identify factors that are important for improving the effectiveness of power plant life cycle projects. This is because the concept of project success remains indistinctly defined in the mind of power plant engineering and project management professionals.

2.1 Introduction

According to Meredith and Mantel Jr (2011:7), there is disagreement between project management researchers, project managers and key project stakeholders as to what constitutes project success and how it is to be measured. Jayaraman (2016:1247) indicate that life cycle projects are strategic initiatives by organisations to advance new technology and eliminate current system deficiencies by undertaking new ventures to supplant old, worn-out and obsolete assets with new upgraded relevant technology. These ventures are projects and differ in terms of objectives, deliverable and economic value added to the organisation. Muñoz et al. (2015:13) believe that when a project is pronounced a success, the judgement is usually based on some factual evidence, although not everyone uses the same data. Badewi and Shehab (2016:418) indicate that projects are becoming more and more common in businesses, while expectations are greater in terms of time, cost and quality. It is therefore vital for companies to have a process in place that:

- identifies the correct project to be executed;
- specifies how it should be executed;
- assists the organisation to achieve all deliverables as dictated by its stakeholders; and
- aligns the projects to the organisation’s strategic objectives.

Padgett (2009:168) states that organisations need to have effective project management processes in place - not too light, not to heavy – in order to function optimally. Today, most organisations are still unclear about how to measure project success, since different project stakeholders perceive success or failure factors differently. In addition, it is also difficult to measure project manager performance in most organisations due to the lack of a project success and failure scale that may possibly suggest how a particular project manager is performing at a particular point in time. NcMullen and Newbold (2000:209) indicate that there is common understanding among project stakeholders that there are certain elements of project management associated with project success, and common ills that befall many troubled projects. Although there is certainly a good sense of quality and traits shared by successful projects, it is known that no two projects are ever the same; while every project has its own unique set of challenges, there are common core principles that successful project share.

Dinsmore and Rocha (2014:204) maintain that project delay and cost overrun are essentially a part of most projects. Despite much-acquired knowledge of project management, however, some might contend that this is insignificant. It is widely accepted that physical and economic scale of projects is driven on the basis of profit to the parent organisation. In order to increase the perception of project success, it is important to understand the inevitable delays and cost overrun in most projects, as well as their mitigation methods.

2.2 Integrated life cycle management phases (project, product and organisation)

Steenkamp and Bekker (2018:81) maintain that different project management scholars take different factors into account that affect the progress and the overall success of a project. Todorović et al. (2015:773) believe that budget compliance and accurate schedules will matter less if the project results do not meet the project goals and expectations. According to Kerzner (1998:48), factors that create an environment which ensure that projects are managed in a consistently successful way, are critical. According to Humphrey (2005:149), critical success factors are those factors that will significantly improve the chances of project success if addressed appropriately; this also requires choosing processes and activities that will address critical success factors. Volkov and Kuzina (2016:842) state that generally, a successful project will be completed on time, within cost, deliver quality as promised, meet or exceed stakeholder expectations and maintain a win-all situation.

Beringer et al. (2013:834) state that companies increasingly make use of the project management methodology as a management tool to promote organisational changes. Jugdev et al. (2013:535) hold that although numerous effects result from stakeholders' expectations, factors that lead to successful projects are part of the strategic perspective. Saynisch (2010:18) indicates that project management literature has identified some determining factors, which include complexity and uncertainty. Tan et al. (2018:155) point out that project management has a long-standing approach intended to assist organisations' project managers to manage project activities by applying techniques, skills and tools in order to meet stakeholders' needs using effective project management practices.

Rokooei (2015:92) indicate that it is also generally acknowledged that good project management does not necessarily result in project success or bad project management to project failure. DE PAULA et al. (2017:35) suggest that the success factors identified in other industries cannot be used as valid factors for power plant life cycle projects, because factors are not universal to all projects and industries. Rokooei (2015:94) indicate that the life cycle project management framework integrates the processes of all functions including governance, project management, engineering, finance, commercial, environment, quality, health and safety to effectively deliver a project. According to Beringer et al. (2013:844), the following are the important stages of project life cycle model (PLCM):

2.2.1 Define the need

According to Bérubé and Gauthier (2017:6), the need statement describes the problem area or need that the proposed project will address. Pre-concept review approval (CRA) documentation is prepared and submitted at this stage. Kerzner and Kerzner (2017:235) suggest that at this stage, all required documentation are finalised and required signatures are obtained and authorised to transfer a project from the life of plant plan (LOPP) to the pre-project planning phase of a technical plan (TP). Turner (2016:288) states that project stakeholders are identified and sorted according to their impact on the project and the impact the project will have on them. This includes both internal and external stakeholders. Lock (2017:187) specify that the project's benefits resulting from the execution and completion of its deliverables, which add value as perceived by the stakeholder, are identified with quantified measurements.

2.2.2 Identify alternatives

According to Cole (2017:484), the project business case captures the reasoning for initiating the project. Lukosevicius et al. (2016:458) believe that the logic of the business case is that, whenever resources such as money or effort are consumed, they should be in support of a specific business need which adds value to the business or mitigates a risk to the business. Nicholas and Steyn (2017:15) indicate that the milestone schedule is developed to provide an estimated duration for the life of the project. It includes a list of all gates, major milestones and completion dates for the span of the project. A high-level estimate of total estimated project cost to completion, computed (calculated) on the basis of available information is developed.

Eskerod and Ang (2017:63) maintain that all business risks that have the ability to cause the project not to achieve its desired performance or outcome goals, are identified. Eskerod and Ang (2017:67) recognise that the source of funding (whether budgeted/un-budgeted, internal or external funding, in full or partial) for the total estimated project cost to completion is identified and made available to all stakeholders.

Martens and Carvalho (2016:31) maintain that at this stage, a preliminary contracting and procurement strategy is developed outlining how the project intends to issue contracts and conduct possible procurement. Martens and Carvalho (2016:42) assume that this strategy takes into account the corporate contracting and procurement strategy. Martens and Carvalho (2016:38) furthermore indicate that a list of the recommended alternatives which will satisfy the need statement is developed. The project governance is established, which will be the management framework within which project decisions are made, and by which the project will be governed and controlled. The project is formally initiated on system application products (SAP). Midler et al. (2016:14) assert that the project charter describing the scope of the project and outlining the project objectives, is issued to provide preliminary de-lineation of roles and responsibilities.

2.2.3 Develop alternatives

Midler et al. (2016:138) maintain that the core project functions and roles are identified to enable the successful delivery of the project. Roles and responsibilities are defined and allocated from an existing pool of internal resources or pre-approved professional service

contracts. Nicholas and Steyn (2017:48) assert that stakeholder requirements and how configuration management and change management will be managed by the project, as well as how the management and control of documents will be managed and governed, is defined. Sergeeva (2017:62) states that any changes in the solution affecting the time, cost, and quality, require formal notification through engineering change management (configuration management), which logs and tracks any alterations to the solution.

Sergeeva (2017:59) holds that the project delivery strategy is then developed to determine the way the project will be structured, organised, managed, executed and controlled to best ensure project success. According to Joslin and Müller (2016:1378), competitive analysis of alternatives is performed focusing on the strengths and weaknesses of the identified alternatives and comparing them in order to aid selection of the most suitable alternative for the specific need.

Monteiro et al. (2016:1086) suppose that the high level schedule which includes a list of all the key (major) deliverables, summary work activity and milestones for each alternative, may be one of the competitive advantages. According to Monteiro et al. (2016:1088), cost estimate for each alternative using the high level schedule to provide a detailed cost analysis and cost estimate for each of the identified alternatives that may be one of the competitive advantages, is explored. Justin et al. (2016:211) point out that quantifiable risks specific to each of the identified alternatives and regulatory requirements, must be identified, which will be applicable to the project and require to be managed.

2.2.4 Select single solution

Oke et al. (2017:108) maintain that based on the competitive advantages which were evaluated for each alternative (develop alternatives), the alternative with the best competitive advantage is selected. This should be the alternative that is most suited to achieving the stated project need. Nsour (2016:14) believes that the preferred alternative now becomes the preferred solution. Based on the need statement, business case, and selection of the preferred alternative, a preliminary scope of work must be developed. The scope will be finalised once the concept for the solution has been finalised.

According to Morales et al. (2015:1350),the concept design for the preferred solution is developed and completed to ensure that the preferred solution is achievable from an

engineering/technical perspective. A work breakdown structure which is a deliverable-oriented hierarchical decomposition of the work to be executed is developed to accomplish the project objectives. A stakeholder management matrix and plan are developed based on previously identified stakeholders. Using the stakeholder management plan, a communications management plan is developed. Required design review area (DRA) documentation are finalised and required signatures and authority are obtained to commit resources and funding for the next phase of the project, and the overall project.

2.2.5 Develop solution

Stark (2015:13) claims that the scope for the project based on the concept design for the preferred solution, is finalised in this stage. Prior to commencing the solution definition, the location (site/s) selection should be finalised. The solution definition needs to be developed based on the location/site of the project. The concept is now developed further by dividing the project into its different disciplines and developing each discipline up to the point where the solution has been stabilised, ready for finalising the design. Detailed risk analysis and quantification for the project is compiled and updated on a regular basis; it can be completed in great detail which includes risk owner, probability of risk occurring, cost and time elements and mitigation actions with dates (Morales et al., 2015:1351).

A quality plan specific to this project is generated to specify the quality and quality management requirements, as well how the required quality for the project and project deliverables is to be managed, measured, controlled and reported. The benefits management plan describe how the identified benefits (identified in defined needs) will be managed and measured throughout the lifecycle of the project up to the point where these stated benefits have been realised (Nsour, 2016:12).

2.2.6 Finalise solution

According to Oliveira et al. (2016:103), the stable solution (stage ‘develop solution’) must be detailed further by fully developing the different disciplines within the solution to enable design integration to the lowest level of the design work breakdown structure (WBS), ready for

implementation. Following execution review area (ERA) approval, tenders can be issued, bids received and evaluated, and contracts awarded. Procurement of services, resources and materials for implementation can then commence (Nsour, 2016:15).

2.2.7 Implement solution

According to Stark (2015:17), the site location must be prepared at this stage, ready to commence with project implementation. The solution as per detailed solution definition and scope, according to the project management plan, is then executed. Morales et al. (2015:1352) indicate that project and design integration is managed to ensure efficient integration of project work packages and deliverables in terms of scope, schedule, cost and risk. Quality inspections are conducted on all equipment, products, materials, training, and procedures according to the quality management plan, to ensure the effective management of quality. Project controls to monitor and control project scope, schedule, cost and risks are also established and managed (Oke et al., 2017:107).

2.2.8 Commissioning and handover

Oliveira et al. (2016:98), point out that operational readiness is important at this stage and is a process of ensuring all personnel, resources and supporting infrastructure required for operating and maintaining the product, are fully established and that they will be operationally ready to take over and support, operate and maintain the product. Start-up commissioning of larger sub-systems and assemblies to ensure product is fit for purpose, up to when the product is switched on (start-up) for non-commercial use. Stark (2015:115) states that this could include demonstrations to relevant stakeholders to obtain their approval or authorisation and proving the product is ready to be put into commercial operation/production. Formal handing over the ownership of the product (asset) to the client (or user/maintainer) with the associated operational and maintenance (O&M) manuals, safety procedures, quality/performance checks and maintenance procedures is carried out. All required documentation is finalised and the required signatures and authority to finalise the handover of all project work deliverables are obtained.

2.2.9 Close project

According to Morales et al. (2015:1351), final data and drawings produced for the product of the project must be updated, signed-off and handed over to the owner/operator during a close-out meeting. These include drawings, diagrams, manuals, operating procedures and test certificates defining the as built baseline status. The formal transfer of all obligations (including warrantees/guarantees, contracts, other legal documents etc.) to the client/user are maintained until maturity. All contracts and project accounts are closed out, and project delivery and implementation performance in terms of scope, schedule, cost, quality and performance is evaluated.

2.2.10 System operation

According to Bahr (2014:13), the concept and technical effort during the development stages is focused on achieving the performance objectives of the system by ensuring that the product is affordable and will operate reliably meeting all system operational requirements. Because these factors are influenced by earlier system decision making and implementation, there is a need to consider those requirements from concept throughout the development process.

Buede and Miller (2016:144) hold that new technology at any stage of the system's life offers an opportunity to introduce cheaper elements and higher performance, which can produce numerous engineering change proposals. The advancement of science forcing competition and specialisation by manufacturers exerts pressure to change the design of the system components and subcomponents, which subsequently force changes in the engineering design of a system.

Kapos et al. (2014:535) indicate that transition from concepts to production and design to product, is critical and requires effective engineering, communication and analytical skills from systems engineers and project managers. This is because configuration management processes must continue more intensively during the production process; this is because component interface incompatibilities that have not been previously detected and eliminated will be revealed at this stage and must be addressed. Each incompatibility requires decisions to be taken on whether it can be remedied in parallel with continuing production or whether production should be interrupted.

2.2.11 System maintenance

Routine maintenance

Wienker et al. (2016:412) indicate that after the system is delivered for operation, it requires substantial technical effort and undergoes testing and component replacement during sporadic maintenance periods because the operation of modern complex systems is never without incident. According to Wienker et al. (2016:418), large complex systems are costly to replace completely and are then subjected to major upgrades, introducing new subsystems in place of obsolescent ones, which is a significant role of systems engineering. According to Rastegari and Mobin (2016:3), computerised maintenance management systems are used to:

- Reduce cost (reduce equipment downtime, overtime, repair time, lower repair cost and improve budgeting)
- Inventory and asset management (optimise stock levels, eliminate human error, track upgrades and optimise resources)
- Tracking, reporting and work-flow improvement (improve communication, have all data in one place, keep track of progress, quick priority assignment).

Subsystem and components obsolescence affect the performance of a system as a whole, but presents the opportunity of restoring overall system effectiveness by substituting imperfect critical components in subsystems at a fraction of the cost of replacing the complete system (system upgrade).

Outage management

Schwindt and Zimmermann (2015:640) specify that outages are a period of time during which a power plant shuts down (stops producing power) in order to perform required maintenance replacements and life cycle project implementation. They are periods of intense activity at power plants and the aim is usually to get on line again as quickly as possible. When the unit is switched off for an outage, it stops generating revenue for the owners and start accumulating expenses with dire economic consequences, if poorly planned. The outage extension, poor performance after shutdowns or reworks, drastically reduces the utility's annual returns. Rastegari and Mobin (2016:7) indicate that the four pillars of a good outage management process are:

- Identify – an outage work list is identified from different sources, which are aligned to the outage objectives. The major task is to identify activities and the level of services required and how effectively they were addressed.
- Plan – the planning of the most important outage events takes place well in advance and requires work to be locked down at least six months prior to the start date.
- Execute – this requires plant operators to secure sufficient budget and technical resources to properly oversee the outage. Most organisations prepare to hire an owners' engineer who works with the original equipment manufacturer (OEM); this will assist organisations to avoid problems that can be very costly for the organisation.
- Review –during execution, the right way at the right time is measured and proper communication allows control of activities.

Wienker et al. (2016:414) state that for power utilities to meet their outage planned days and budget, expert support and proper planning is essential. Developing an integrated plan which carters for resources, processes, parts and repairs allows efficient use of available time to perform those activities. Kapos et al. (2014:538) agree that proper power plant outage planning and expert support are essential factors in ensuring that planned dates and budgets are met.

2.2.12 Power plant life of plant schedule for project execution

Justin et al. (2016:198) believe that depending on management models, utilities employ the main categories maintenance or a forced outage. A forced outage can be defined as emergent or unforeseen, based on degradation of safety or key equipment. An emergent shutdown can initiate a forced outage that is administratively based. New industry issues, surveillance or committed corrective actions can also initiate a forced outage. Iyer and Banerjee (2016:13) state that the key to minimising the impacts of a forced outage is to be prepared to execute the required work in the most efficient time possible. This means that outages are regularly spaced and timed to occur at a period of low-energy demand, or perhaps when human and tooling resources are available. Serra and Kunc (2015:54) points out that this strategy has been demonstrated to be effective, but it creates the need for additional maintenance outages, and so does not necessarily result in greater overall availability. To help determine the best maintenance approach, each system, structure or component should first be categorised according to its safety significance. Kapos et al. (2014:539) advise that the judgement should be based on three factors:

- Impact of failure (economic and safety)
- Risk of occurrence, and
- Detectability

Wolken-Möhlmann et al. (2016:20) suppose that the highest priority should be given to safety-related components where the risk of occurrence is high and the failure is not detectable until the component is called on to perform. The ideal maintenance approach thus depends on the ageing-related degradation mechanisms for systems and components. There needs to be a detailed technical evaluation of the maintenance history, both preventative and corrective.

Wolken-Möhlmann et al. (2016:19) maintain that maintenance activities can be performed on equipment that is not usually accessible when the boiler is running or fuelled, or equipment that supports the primary system function during shutdown activities. It also creates opportunities to perform periodic inspections and refurbishments (typically, a period from 14 to 120 days in length and are performed every 12, 18 and 24 months depending on licence requirements and technical specifications). According to the Harvard Business School (2005:65), to analyse plant availability performance, outages should be scrutinised to identify the causes of unplanned or forced energy losses and to reduce the planned energy losses. Reducing planned outages, increase the number of operating hours, decrease the planned energy losses, and therefore increase the energy availability factor (EAF). Reducing unplanned outages leads to a safe and reliable operation, and also reduces energy loss. Technological innovation is one of the key challenges in addressing the greenhouse gas problem, which has several implications:

- First, while most of the current focus has been on applying technology to address high hurdles to meet enormous reduction targets, one should not discount the use of innovation/technology to address lower and more readily attainable hurdles via existing plant performance/emissions improvements.
- Second, technologies to address carbon capture/sequestration will have a significant impact on overall plant efficiency (due to power required in the separation process) and may also significantly alter system reliability (depending on technology's impact on plant reliability and system reserve margins).

Bitten et al. (2018:10) indicate that each power plant develops its strategy for short-term, medium-term and long-term outage planning. Extensive efforts are usually directed towards detailed and comprehensive preplanning to minimise outages, avoid outage extensions, and ensure future safe and reliable plant operation. All these elements are part of the plant outage strategy. Effective outage management plays an important role in the management of the life

cycle of the equipment in power stations. It is mainly concerned with a drastic reduction in outage durations and an increase in the duration between outages. The outage philosophy is based on the equipment manufacturers' recommendations in the operating manual, inspections, test plans, plant history, and statutory recommendations. The figure below shows an example of the 10-year outage schedule with the number of days scheduled for each outage.

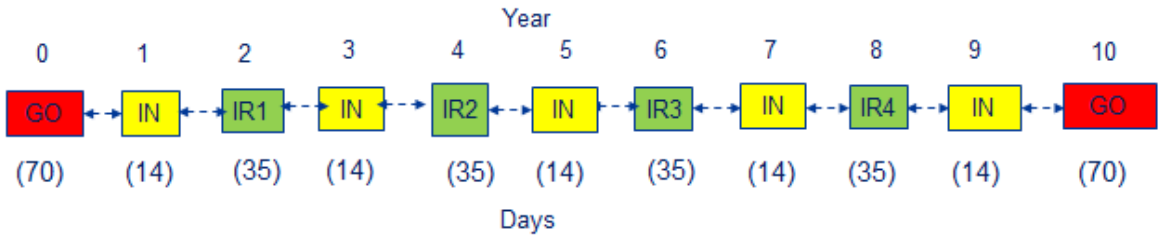


Figure 2-1: 10-year outages schedule with duration estimates (Eskom, 2013)

Tang et al. (2014:26) state that to remain competitive, utilities need to better understand the underlying nature of their plants' operating and maintenance costs, and should take measures to use this knowledge to their advantage. A root cause of this increase in operating and maintenance costs for many fossil units, is unit cycling. Power plant operators and utilities have been forced to cycle aging fossil units that were originally designed for base-load operation. Tang et al. (2014:31)point out that every time a power plant is turned off and on, the boiler, steam lines, turbine, and auxiliary components go through unavoidably large thermal and pressure stresses, which cause damage. This damage is made worse for high temperature components by the phenomenon we call creep-fatigue interaction. While cycling-related increase failure rates may not be noted immediately, critical components will eventually start to fail (Bitten et al., 2018:12). This may result in reduced overall plant life.

2.3 Life cycle management

2.3.1 Project life cycle management

According to Vanhoucke (2014:1186), the execution of a project should be based on a robust project plan that can only be achieved through an effective schedule control methodology. The

development of a suitable project control system is an important part of the project management effort according to Andersen (2016:58). There is wide recognition that a lack of planning and monitoring plays a major role as the cause of project failure. Despite the continuous evolution in the project management field, it appears evident that the traditional approach still lacks utilisation of project controls.

According to de Waal and de Boer (2017:148), project controls are the data gathering, management and analytical processes used to predict, understand and constructively influence the time and cost outcomes of a project or program, communicating information in formats that assist effective management and decision making. Sakka et al. (2016:508) assume that the planning, execution and control of projects in organisations are conducted against control/barriers that include processes, standard practices, and expected behaviour that should either prevent or protect against various errors or hazards, or mitigate the consequences, incidents or performance deviation.

A trending system has been developed and put in place to provide framework and practical understanding of prevention and improvement. Mubarak (2015:158) indicates that project controls encompass the people, processes and tools used to plan, manage and mitigate cost and schedule issues and any risk events that may have an impact on a project. According to Vanhoucke (2014:978), project control is essentially equivalent to the project management process stripped of its facilitating sub-processes for safety, quality, organisational, behavioural, and communications management. Schwindt and Zimmermann (2015:304) state that a project is defined as a temporary endeavor undertaken to produce a unique service or products. Turner (2014:107) supposes that, although the impact of the project on society, environment and economy is minimal, but the product has long-term effects. The project profitability, return on investment (ROI) and net present value (NPV) calculations are performed to determine financial viability at early project stages. According to Schwindt and Zimmermann (2015:164) project life cycle is defined as integrated activities sequenced together and performed in phases to achieve success. Crowder and Friess (2015:45) state that different authors arrived at different conclusion regarding the stages to follow when implementing projects. The difference is mainly due to the industrial sector, management skills, project complexity, flexibility and budget constraints. Project life cycle models integrate the processes emanating from all the functions that are involved to efficiently deliver a project. The table below highlights researchers' findings about phases in project life cycle.

Table 2-1: Phases in project life cycle

Researcher	Number of phases	Phases
(Crowder and Friess, 2015)	4	Conception, selection, planning/scheduling/monitoring/control and evaluation and termination
(Harrison and Lock, 2017)	4	Define, design, deliver, develop a process, future use
(Stark, 2015)	4	Inception, development, execution and finalisation
(Nicholas and Steyn, 2017)	3	Introduction, planning and execution, closeout
(Wegner et al., 2016)	4	Definition, planning, execution and finalisation
(Kyes et al., 2000), (Kerzner and Kerzner, 2017)	4	Introduction, planning, execution, closeout
(Levine, 2005), (Ruhe and Wohlin, 2014)	3	conceptualisation, planning and execution, closeout
(Dinsmore and Rocha, 2014)	6	Needs analysis, concept definition, demonstration and validation, engineering and manufacturing development, production and deployment, operations and support.
(Millson, 2015)	4	Feasibility, planning and design, production, turnover and start-up

2.3.2 Product life cycle management (project deliverable)

According to Stark (2015:3), product life cycle management (PLM) is effectively managing business activities from product inception, across the life cycle until it is retired and disposed of. Chan et al. (2018:34) point out that every product/project deliverable has a life of its own and goes through cycles. The life cycle refers to the period from the product's/deliverable's first launch into the market (start operating) until its final withdrawal; during this period significant changes are made in the way that the product behaves. Komninos et al. (2006:11) hold that

since an increase in profits is the major goal of a company that introduces a product into a market, the product's life cycle management is very important. Millson (2015:23) indicates that for a company to fully understand the above cycle and successfully manages a product's life cycle, strategies and methodologies must be developed. The table below shows researchers' findings about phases in product life cycle.

Table 2-2: Phases in product life cycle

Researcher	**Number of phases**	**Phases**
(Chan et al., 2018)	3	Consumer (need), producer (planning, research, design, construct), consumer (evaluation, logistic support)
(Açıkgöz et al., 2016)	4	Design and develop, production/construction, operations and maintenance, retirement and material disposal
(Cooper, 2018)	3	Feasibility, development and operations
(Petro and Gardiner, 2015)	4	Active, classical, limited and obsolete
(Richards et al., 2016)	4	Acquire, utilise, maintain, dispose
(Galli and Kaviani, 2017)	4	Introduction, growth, maturity and decline
(Holler, 2018)	4	Marked development, growth, maturity and decline
(Komninos et al., 2006) (Boso et al., 2017)	7	Idea generation, screening, concept development and testing, business analyses, beta and market testing, technical implementation, commercialisation
(Komninos, 2002) (Millson, 2015)	5	Conception, creation, production, operation and disposal
(Audretsch et al., 2017)	6	Development, introduction, growth, maturity, saturation and decline

2.3.3 Asset life cycle management

El-Akruti et al. (2015:21) state that asset management is often one of the last options to maximise cost saving in a competitive global economy due to its intrinsic complexity, especially in many developing countries. Asset management in the process industry must consider the commissioning, operational and end-of-life phases of physical assets when commencing a design and implementation project. Lloyd (2010:17) indicates that current asset management models show inefficiencies in terms of addressing life cycle costs comprehensively, as well as other aspects of sustainable development. Sarkar et al. (2015:22) state that an asset life cycle management plan which integrates the concepts of generic project management frameworks and systems engineering with operational reliability in order to address these inefficiencies, is desirable. The following table below show reseachers findings regarding asset life cycle phases:

Table 2-3: Phase in asset/process life cycle

Researcher	Number of phases	Phases
(Bhamidipati et al., 2015)	2	Acquisition and utilisation phase
(Baines et al., 2007) (El-Akruti et al., 2015)	3	Strategy and policy, practical developments, system policies
(Lloyd, 2010)	3	Design, construction, operation
(Ashley et al., 2008) (Sarkar et al., 2015)	4	Acquire, commission, operate and dispose
(Sarkar et al., 2015)	3	Design, construction, operation
(Girsch et al., 2008) (Balzer and Schorn, 2016)	4	Acquire, design, construct and operate

2.3.4 Business life cycle management

According to Whyte et al. (2016:44), a business undergoes business phases over the course of its existence known as the life cycle of a business. Emblemsvag (2017:14) holds that, if a business adapts successfully to the different challenges at each stage of the cycle, it can avoid

the final stage of decline in the cycle. Whyte et al. (2016:7) state that various researchers have conducted studies on business life cycle management phases. The table below highlights some researchers' views on these phases.

Table 2-4: Phase in business life cycle

Researcher	Number of phases	Phases
(Helin et al., 2013) (Ming et al., 2013)	4	Introduction, growth, maturity, decay
(Koelsch, 2016)	4	Intimacy, growth, maturity, decline
(Liu et al., 2014) (Emblemsvag, 2017) (Whyte et al., 2016)	3	Introduction, mature, decline

2.3.5 Life cycle interaction

Serrador and Pinto (2015:1042), Whyte et al. (2016:17) agree that the power plant LOPP identifies projects to be executed through the life cycle of a plant. The asset life cycle results from the project and the product life cycle resulting from the asset has economic, social and environmental consequences, which are in turn associated with an implemented project (Kolodiziev et al., 2017:72). According to Daft (2014:41), organisations like any other living organisms, follow a very predictable path over time; the most common patterns include that they are all born, they also live and they eventually die. The only major difference is that some ・倀卄嗀Ĉ黏 鞦ㄱ 轔Ã쬙 ・・ ˢ・傳ᵍ ・s are very short (less than two years) while others are very long (more than 200 years). This is further explained by the models below:

2.3.5.1 Resources models

According to Negrusa et al. (2017:9), the time when an organisation is founded, establishes a role in its organisational structure (social resource model). Pearson et al. (2015:184) understands this to mean that the social resources of the organisation largely determine the organisational structure and culture. This is evident because most companies formed during the 21st century are more dependent on a high-level skilled workforce as compared to before when

organisations were dependent on a labour-intensive workforce; this means that advancement in technology has had an impact on most traditional manufacturing companies.

Pearson et al. (2015:170) indicate that companies also invest in research and development in order to develop products as required by the market and to continuously improve the product based on the customer's ever increasing demand for products, which provides opportunities to emerging companies to quickly develop their competitive advantage. Roome and Louche (2016:21) specify that resource life cycle analysis (RLCA) uses a form of business modelling to perform strategic planning. The goal of resource analysis is to address the organisational operational as well as the strategic needs required by management. The strategic function focus on resources that essential for the firms survival and information systems are used to plan, develop and deliver.

2.3.5.2 Crisis models

According to Amankwah-Amoah (2016:3392),the situational confrontational model argues that key issues that organisation face, determine the stages at which the organisation is, rather than by size, age, market share or management sophistication, as stated by Negrusa et al. (2017:79). Cooper (2017:130) supposes that the six confrontations that organisations face, are launching the venture by taking a risk and investing to start a business; followed by the survival and sacrifice stage by sacrificing resources to ensure that the venture stays in operation; achieving stability, deciding to formalise business and developing codes of ethics to instil discipline among members; pride and reputation by examining and ensuring the organisation responds to both internal and external threats; and developing uniqueness in creating the organisation's competitive advantage.

2.3.5.3 Decline and inertia models

Previtali (2015:11) maintains that the decline and inertia models focus more on the organisational decline stage and argues that organisation grows through creativity, direction, delegation, coordination and collaboration. According to Daft (2014:39), growth, size and age of the organisation has an impact during the decline stages as all departments, including the better performing ones, that have proven themselves to be efficient and effective, are also affected. Hollow (2014:761) holds that the most common sources of organisational decline are:

- Atrophy as a results of firms failing to adapt to market changes.
- Vulnerability especially in new organisations' exposure to failure.
- Loss of legitimacy when an organisation is not standing for what it was founded for.
- Environmental entropy when an organisation is continuously exposed to increasing disorder.

2.4 Life cycle integration

Wiesner et al. (2015:39) specify that all the stages within the life cycle of a power plant interact and are linked by the results they produce. Arikan and Stulz (2016:152) believe that the asset life cycle results from the project and the product life cycle resulting from the asset has economic, social and environmental consequences, which are in turn associated with an implemented project. The figure below illustrates desired project life cycle interaction.

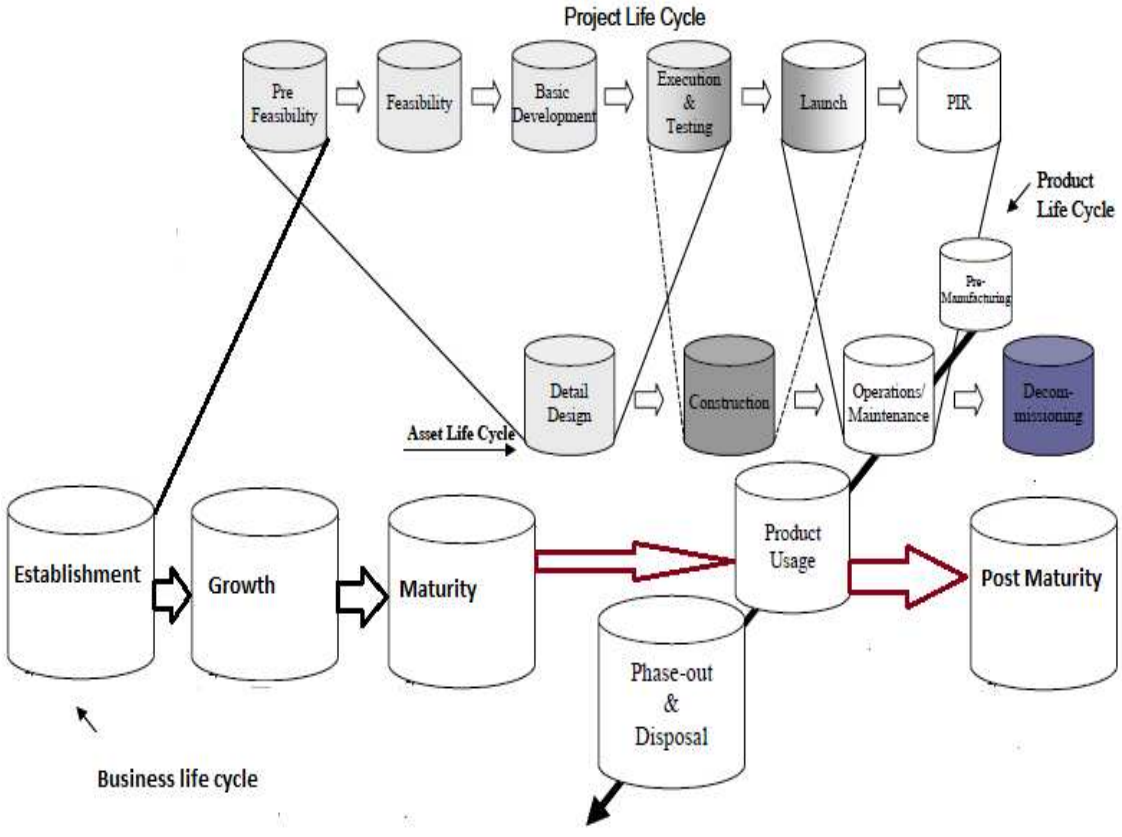


Figure 2-2: Desired life cycle interaction

The table below clarifies integrated life cycle management

Table 2-5: integrated life cycle management

Phase	Stage	Inputs	Process	Outputs
Pre-concept	Define the need	Deficiency, technology advancement	System performance review	Pre-approval concept release documents, stakeholders analysis and benefits
	Identify alternatives	Business risks, cost estimates,	Business case development	Milestones, funding, contracting procurement strategy
Concept	Develop alternatives	Stakeholders requirements, project delivery strategy	Competitive analysis	Each alternative high-level schedule, cost estimate, risk, legal and regulatory requirements.
	Select a single solution	Schedule, cost estimates, risk analysis	Weigh alternatives	Project plan, stakeholders plan
Definition	Initial value proposition	Life cycle Revenue estimation, revenue flow period	Business value	System contribution to business
	Value proposition	Technology innovation, market research data, integration touchpoints	Business value	System contribution to business
	Business case	Revenue model, integration touchpoints	Business value	System contribution to business
	Develop a solution	Detail cost estimate, risk analysis, plans	System development	Master schedule, identification of

				equipment and material
Execution	Finalise a solution	Project sourcing and procurement, execution plan,	Advanced development	Finalise solution details and integration requirements
	Implementation	Site establishment, execute, manage plans, monitoring and reporting, pretesting,	Engineering designs	Project delivery
	Commissioning and handover	Operational readiness, commissioning and start-up.	Integration	Project handover and acceptance
Finalisation	Close project	As built data (drawings, diagrams, manuals, procedures, certificates)	Finalise	Final project performance, obligations transfer
System deployment	System environment	System external conditions, operational environment.	System environment	System physical configuration, Other systems, subsystem impact management
Production support	Operation efficiency	System performance data, system interaction requirement	System efficiency	Availability, reliability, capability and maintainability
Life cycle monitoring	Realise benefits	Operations and maintenance data	System effectiveness	Achieved / unachieved benefits, measure solution performance.

System decline or renew	System capability	System performance data. Power plant operational period requirement	System effectiveness	System retire requirements,

2.5 Success factors

According to Costantino et al. (2015:1745), project success means different things to different people. Nicholas and Steyn (2017:309) point out that the requirements of each stakeholder group differ and their perceptions of what constitutes success vary, but certain factors are more critical to project success than others. Project success is defined by Costantino et al. (2015:1752) as results much better than expected or normally observed in terms of schedule, quality, safety, cost and participant satisfaction. Nicholas and Steyn (2017:321) indicate that this section investigates critical success factors that lead to successful completion of projects within a planned budget, on time, safely and with high quality.

2.5.1 Determinates of construction project success

Joslin and Müller (2015:364) specify that factual evidence is used when a project is pronounced a success but different authors show lack of consensus and objectivity as to what constitute a successful project. Todorović et al. (2015:774) maintain that in order to identify factors that significantly affect construction project success, input from several construction project personnel must be obtained. This will assist in identifying factors which showed average projects and outstanding projects, identifying the principal measure of project success, and identifying factors showing a strong correlation to project outcome.

2.5.2 Critical success factors for construction projects

Wu et al. (2017:852) assume that construction project success factors can be grouped into one of four components, namely:

- Comfort – warranting that leadership determinations are well aligned for the implementation of the project
- Competence – having appropriate technology, experience, and expertise available for the project
- Commitment – ensuring that all parties concerned and all levels of the management hierarchy of each participating organisation are willing to manage, plan, design, construct and operate the facility harmoniously.
- Communication – clarifying and disseminating all necessary project information and status to all internal and external project stakeholders.

Barbalho et al. (2016:87) indicate that project control and monitoring tools are based on expert judgement and parametric tools. Projects are the means by which companies implement their strategies. Nicholas and Steyn (2017:177) hold that some determining factors identified in project management literature, are increasingly becoming evident as projects become more complex, stakeholders play an increasingly important role in project development success, and projects are always surrounded by uncertainty with continuous changes. Nicholas and Steyn (2017:234) suppose that expert judgement as an important tool in project management is limited, because resources are mostly limited. Nicholas and Steyn (2017:198) further hold that high complexity and accuracy make it difficult to apply the expected judgement required in projects.

Cunha et al. (2014:233) believe that applying artificial intelligence algorithms to the prediction of project success, brings to light a wide selection of objectives, which can be divided into predicting project success and identifying critical success factors. Nicholas and Steyn (2017:67) point out that statistical models were used as an initial approach, but were unable to meet project management needs. With artificial intelligence, however, researchers have found tools and algorithms that address complex environments and project uncertainty during normal project development with algorithms addressing specific goals, namely:

- Critical success factors identification - Bayesian model, genetic algorithms, fuzzy cognitive maps and neural networks.

- Project success prediction - adaptive boosting neural networks, bootstrap aggregating neural networks, k-means clustering, fast messy genetic algorithm, support vector machine and evolutionary fuzzy neural inference model.

Norang et al. (2016:762) assume that the main finding deduced from the reviewed theory, is that artificial intelligence tools are more accurate than traditional tools, but are still complementary to traditional tools. Nicholas and Steyn (2017:201) suppose that artificial intelligence tools are really helpful for the project manager to control and monitor the project. According to Nicholas and Steyn (2017:308), models also have weaknesses and limitations, thus requiring project managers to use expert judgement and compare artificial intelligence results with traditional tools before decisions are made; so, they adjust if necessary.

2.5.3 Project success and project efficiency

Serrador and Turner (2015:32) point out that several researchers have suggested that meeting time, cost, and budget goals, also called project efficiencies, are not a compressive measures of project success. Ahmadabadi and Heravi (2018:7) point out that project success is generally determined by primary stakeholders, mostly projects sponsors. Serrador and Pinto (2015:1050) indicate that when the project is delivered, it does not matter to the next stakeholders whether it has met its resource constraint, since the second dimension, namely impact on the customer and customer satisfaction, becomes more relevant. Serrador and Pinto (2015:1044) suggest a model of success based on five dimensions. These are indicated in the table below.

Table 2-6: The five dimensions of project success after Serrador and Pinto (2015)

Success Dimension	Measures
Project efficiency	Meeting schedule goal Meeting budget goal
Team satisfaction	Team morale Skill development Team member growth Team member retention
Impact on the customer	Meeting functional performance Meeting technical specifications Fulfilling customer's needs Solving a customer's problem The customer is using the product Customer satisfaction
Business success	Commercial success Creating a large market share
Preparing for the future	Creating a new market Creating a new product line Developing a new technology

Serrador and Turner (2015:32) point out that a wider literature study focussed on the impact of a project on the business, because while satisfying customer needs has always been a key factor, it is not usually included as a formal measure of success. Project managers must look at their companies' business aspirations to understand the business environment and should view their projects as company strategy in order to achieve a competitive advantage. Joslin and Müller (2015:1383) reiterated this view after finding that a more holistic approach to measuring success was becoming more evident, with researchers increasingly measuring project success by its impact on the organisation rather than just meeting the triple constraint. Serrador and Pinto (2015:1044) points out that it should also be noted that while projects are often delivered on time, on budget and achieve performance requirements, they became complete failures, because they were unsuccessful in producing benefits, adequate revenue and profit for the performing organisation. Joslin and Müller (2015:1381) point out that meeting planning goals, end-user benefits, contractor benefits, and overall project success, imply that projects perceived to be successful must be successful for all their stakeholders.

2.5.4 Project status model (PSM) evaluating project success

Serrador and Pinto (2015:1048) suppose that the project status model (PSM) is used to monitor and show changes in project status through constant updates during the project and at certain points after it ends, thus indicating the project's progress and results to the manager. This model could be used by the project manager as part of a general overview of a project and can be included in project reports and made available to sponsors, other stakeholders and, in some cases, the public. Joslin and Müller (2015:1382) quantify that while a project brings more uncertainty than business as usual, useful benefits are produced. Experimentation and innovation are bound, to a certain extent, to involve failure, which most organisations use for learning to progress the firm to new heights, according to Wang et al. (2014:237)).

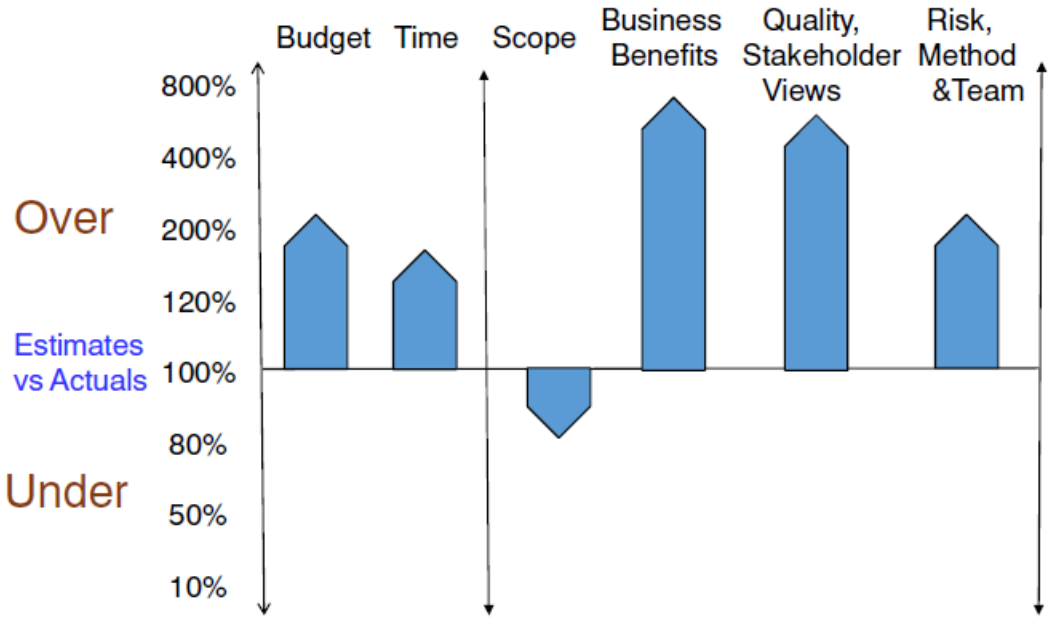


Figure 2-3: Project status model of a project (Atkinson, 1999)

From critical success factors to critical success processes

Wang et al. (2014:239) state that the techniques of planning are diverse, ranging from simulation, buffer management, risk management and iterative planning, depending on project uncertainty, whether it is variation, foreseen uncertainty, unforeseen uncertainty or a chaos project. Project planning specifies a set of decisions concerning the ways that things should be

done in the future to execute the design for a desired product or service. According to Hornstein (2015:293), the project manager is responsible for completing the project to the satisfaction of all relevant stakeholders.

Serra and Kunc (2015:44) point out that the PMBoK identifies 21 planning processes, out of the 44 processes required to manage a project. However, project literature does not clearly identify which of the 21 planning processes are more crucial than the others. Kerzner (2018:244) points out that the output is what project managers, who are short of time and therefore unable to properly perform all planning processes, may choose to perform those processes which are easiest to execute or those mandatory to the start of a project, rather than those that actually contribute the most to the success of the project.

2.5.5 Impact of risk management on project performance

Wu et al. (2017:857) believe that the impact of risk management on a project management study, aims to elucidate the relationship between risk management and project success, considering the contingent effect of project complexity. Nicholas and Steyn (2017:59) point out that the inflexible characteristics of project management in general, and risk management in particular, lead to several problems which include non-acceptance in practice, restricted effectiveness and ambiguous application scenarios.

The relationship between project success and risk management has been studied extensively and most researchers conclude that risk management has a low impact on project performance. Several authors reported that risk management practices are rarely applied in daily routine large, as well as complex projects, characterising a gap that needs to be filled. It is also deduced that a moderate level of risk management planning will suffice to reduce the negative effects of risk on project success. Other authors like Aga et al. (2016:44) support these findings and highlight the importance of identifying risks as having more widespread effects on project success, followed by risk reports.

2.5.6 Forecasting success on project

de Bakker et al. (2012:452) state that projects have an impact that can go well beyond the immediate completion of the project, and that success is perceived not just by the traditional view of completing the work to time, cost, and quality, but also by whether the project delivers the desired outcome, namely to deliver the desired new capabilities and business objectives to the parent organisation. Projects will have a wider range of stakeholders making judgments about whether the project and its output, outcome, and impact achieved its desired objectives, and these stakeholders will make those judgments over the months, years, and even decades following project completion.

According to Williams (2017:7), the perception of success by a project's stakeholders often has little to do with whether the project was completed on time, at cost, and with the desired quality. Eskerod et al. (2015b:9) point out that there are well-known cases of projects that were substantially late and exceeded their budgets, but were later perceived to be very successful (The Sydney Opera House and Thames Barrier are two examples). Haron et al. (2014:54) indicate that on the other hand, some projects have been completed on time and at cost, but have left their investors dissatisfied because they failed to deliver the desired benefits.

What this illustrates is that the golden triangle of project success (time, cost, and quality) is an inadequate indicator of project success, and that success is not only related to completion of the project's scope of work, but also to the achievement of the business objectives. Aga et al. (2016:15) hold that project success is measured not only by completion of the scope of work to time, cost, and quality, but also by performance of the project's outputs, outcomes, and impacts, and thereby the achievement of the desired business objectives, as assessed by different stakeholders over different time scales.

Turner (2014:114) holds that project success may be perceived differently by different stakeholders over different time scales. In this model, the users, consumers, and investors are in one sense swept into one entity, called the customer. Aga et al. (2016:812) believe that project output is the new asset delivered by the project, commissioned at the end of the project. It is sometimes called the 'project deliverable' or 'project objective'. Turner (2014:263) holds that successful achievement will be judged at the end of the project by the project outcome, including the new capabilities that operation of the new asset provides to the investing organisation. These enable the parent organisation to do new things, solve problems, or exploit

opportunities to achieve its business objectives and generate benefit. Its successful achievement can be judged in the months after the project, although it is expected that it will provide benefit for years.

Aga et al. (2016:1075) assume that project impact is the long-term performance improvement that is expected, the new capabilities will enable the parent organisation to achieve. This will enable the parent organisation to attain its strategic goals and its longer-term development objectives.

Turner (2014:758) supposes that the success of the project can only be fully evaluated by the stakeholders in the months and years following completion of the project. However, the project manager and project team have to make judgments during project execution about whether the project will be successful, and inevitably they focus on the immediate goals: whether the work will be completed on time, at cost, and with quality. Haron et al. (2014:58) believe that their major contributions are the recognition of stakeholders as the evaluators of project success, combined with our method of evaluating project success across a range of time frames.

Leading performance indicators can be used by project managers to forecast the way stakeholders will perceive the project in the months and years following project completion. According to Mabood and Maroof (2017:141), it is important that project managers are able to make decisions during project execution that will truly guide the project towards project success. We believe we have initiated the development of such leading performance indicators, but the ones we have developed still have a fairly narrow time horizon. More research is needed to test the ability of these scales to predict long-term project success.

2.5.7 Success factors of research and development projects

According to Durand et al. (2016:14),research and development (R&D) projects, which are classified into basic research, applied research and product development, are being carried out by industries, academia and R&D institutes. Davis (2014:196) state that R&D projects stand apart from other projects in the sense that their outcome may be of longer term. Ultimate benefits may be intangible and/or be more of an information basis for future projects. Research or policy environment may change with new breakthroughs or problems affecting the relevance of the projects. Ika and Donnelly (2017:55) assume that the project is the seed, the organisation and its environment is the soil, and the caretakers are the project leaders and the team associated with the project. They require resources and also collaboration when external

knowledge/facilities are needed. After consolidating the major reasons for time delays and cost escalations of projects, discussions were held with the senior management about the success criteria to complete the projects in time and within budget.

2.5.8 Measuring project success across time

Zacher (2015:13) specifies that, although the iron triangle is still very important, other success criteria are welcomed and the emphasis shifts from project management success to project/product success. It was only in 1995 that concerns began to emerge about discovering links between project success factors and project success criteria. Zacher (2015:22) proposes a compressive model for project success by merging the success dimensions from project management streams and information systems, believing that these would assist project managers to assess the likely success early in the development stages. Four aspects that make the DeLone and McLean model an appropriate incorporation into a project success model are:

- Simplicity
- Acceptability
- Similarity of intensions
- Reusability

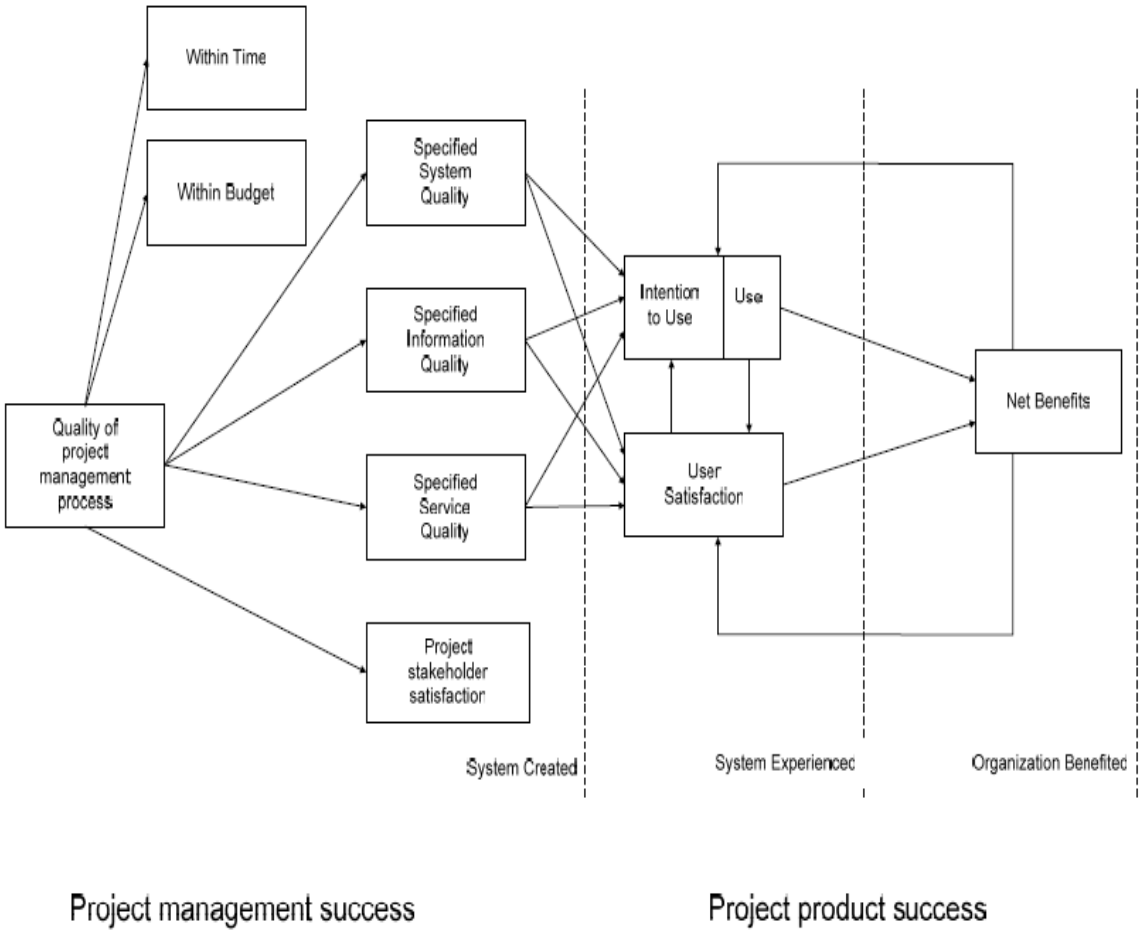


Figure 2-4: Project product successes (DeLone and McLean 2003)

Grand et al. (2017:188) state that in our journey towards a comprehensive understanding of project success, we should not confuse project management success and project success. Semantically, project management success refers to efficiency, an internal concern to the project team, while project success embraces concerns for efficiency and effectiveness; in other words, all concerns, whether internal or external, short-term or long-term (Ismail et al., 2017:40). According to Bardsiri et al. (2014:866), project classification and the factors that contribute to project success, can result in project failure. Bardsiri et al. identify the causes of project failure as mostly planning and estimation failure, as well as implementation and human factors.

Table 2-7: Research focus and success over time (Westerveld, 2003)

Research Focus	Period 1 1960s–1980s	Period 2 1980s–2000s	Period 3 21st Century
Success criteria	"Iron triangle" (time, cost, quality)	Iron triangle Client satisfaction Benefits to organization (org) End-user's satisfaction Benefits to stakeholders Benefits to project personnel	Iron triangle Strategic objective of client organizations and business success End-user's satisfaction Benefits to stakeholders Benefits to project personnel and symbolic and rhetoric evaluations of success and failure
Success factors	Anecdotic lists	CSF lists and frameworks	More inclusive CSF frameworks and symbolic and rhetoric success factors
Emphasis	Project management success	Project/product success	Project/product, portfolio, and program success and narratives of success and failure

2.5.9 Perspective-based understanding of project success

Görög (2016:15) maintains that these studies are grounded in an objectivist tradition, in which it is assumed that a universal, objective set of success criteria exists in practice, to be measured using scientific methods and quantitative techniques. According to Açıkgöz et al. (2016:98), despite the level of research attention that project success has received, the characterisation of project outcomes as successes or failures remains problematic and, in general, the development of project management knowledge has been fragmented and incomplete. Moreover, attempts by the project management research community to remedy any knowledge shortcomings continue to rely almost exclusively on objectivist approaches.

Görög (2016:9) holds that in the project management literature, the outcome of a project is frequently conceived of in terms of success or failure, while identifying just what constitutes these can be problematic. Gemünden (2015:9) alleges that there is a lack of consensus on how to define success, a lack of success and failure, pointing out that despite their frequent use, such terms are perceived to be vague and difficult to measure. Mikkelsen (2018:8) states that projects may be viewed as successful to varying degrees, depending on which success criteria are met. Researchers have progressively widened the scope and constituency of what is meant by project success, recognising that project success is more than project management success, and that it needs to be measured against the overall objectives of the project.

Table 2-8: Perspective-based understanding of project success (Westerveld, 2003)

Expanding dimensions →		
Process Success	**Product Success**	**Organizational Success**
Focus on project management	*Focus on project objectives*	*Focus on organizational objectives*
• On time	• Product use	• Business benefits
• Within budget	• Client satisfaction	• Strategic benefits
• To scope/specifications	• Client benefits	

2.5.10 Project success criteria

According to Gu et al. (2014:1175) the project that may initially be deemed a success can subsequently come to be regarded as a failure, or vice versa. The objectives were to understand how project outcomes are subjectively perceived by different stakeholders and the evaluation criteria that different stakeholders draw on in doing so, influenced their choice of which criteria were perceived to be relevant for evaluating the project's success. Berssaneti and Carvalho (2015:642) purport that overall, there was a degree of convergence around the perceived success of the project among different stakeholders when the scope of the evaluation was focused on the production of a successful solution. Over the time frame of the project, product success was more important to the various stakeholders than the initial failure to achieve the timely delivery of a functioning solution (Morris et al., 2016:67).

Fallanca et al. (2015:55) believe that from a subjectivist perspective, project evaluation is a complex ongoing process of sense making, emerging from observations or experiences before, during, and often after a project. The perspective-based framework for project evaluation has a number of implications. It serves as a useful analytical device for researchers investigating the subjectivity of project evaluation and the role that context plays in this process. Bannerman (2008:2123) assumes that regarding practice, the framework can be used by project managers and other practitioners to recognise and understand that project evaluation is an emergent, multidimensional, situated, and subjective process. According to Bannerman (2008:2125), the possibility of multiple perspectives, and hence multiple evaluative judgments, could be usefully applied by project management practitioners in the planning, management, and conduct of formal evaluations.

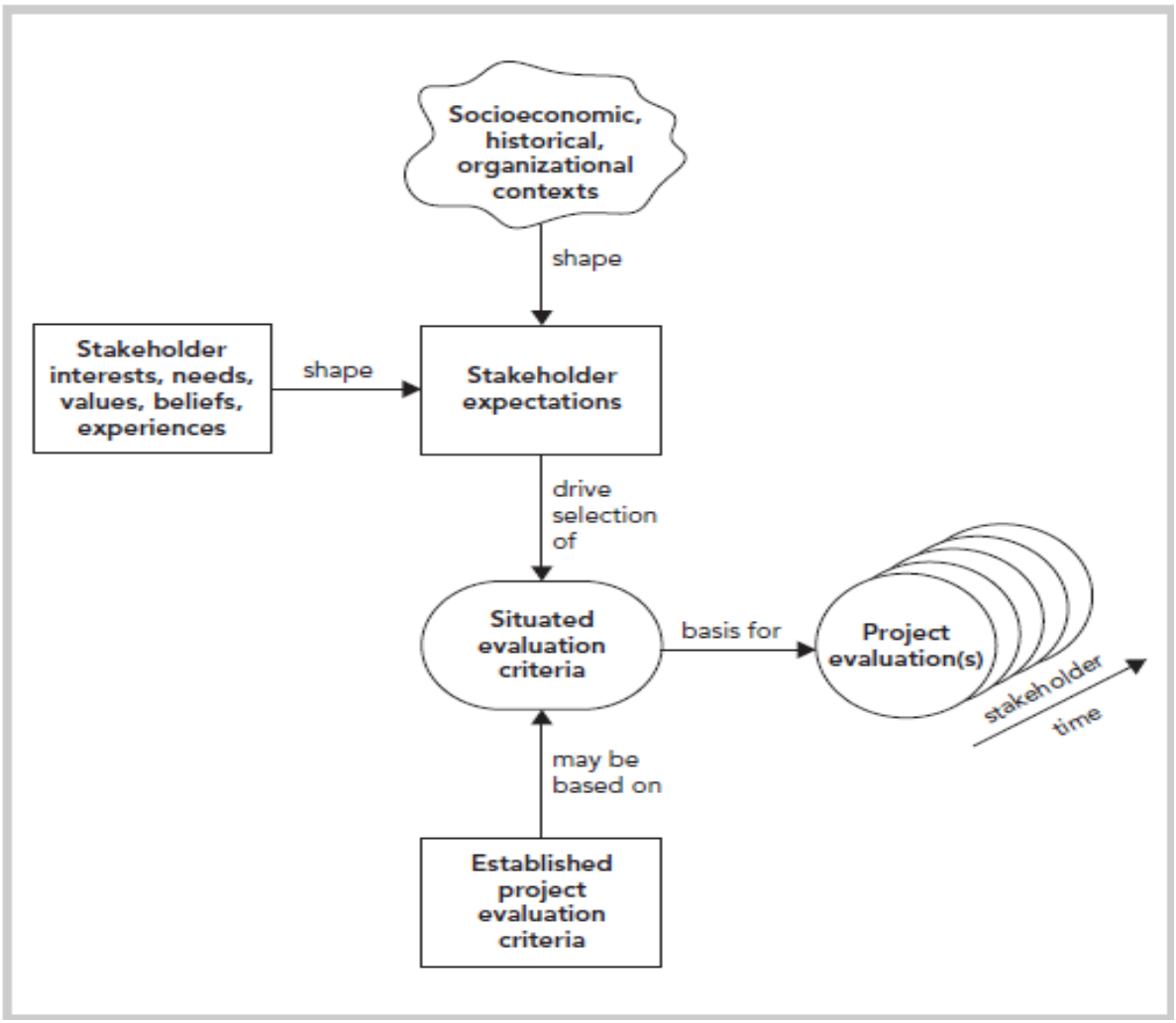


Figure 2-5: A perspective-based framework for evaluating project success (Cao and Hoffman, 2011)

2.5.11 Satisfaction metrics used by project stakeholders

Chih and Zwikael (2015:358) point out that the study "Satisfying metrics used by stakeholders" found that the stakeholders rated the identified satisfaction metrics very high, and fulfilment of (client and technical) requirements was rated the highest. The study also established that there was a significant difference in the perception of stakeholders on the use of fulfilling project requirements as a project satisfaction metric, while these perceptions did not differ on the use of the other identified satisfaction metrics. Eskerod et al. (2015a:47) state that based on these findings, the study concludes that the difficulties experienced with projects, especially large engineering projects, and the high degree of failure, may be traced to the differing views of

stakeholders on the use of fulfilling project requirements. A project satisfaction metric concluded that project stakeholders tend to be more satisfied with projects that are completed within scheduled time and budget. Evidence from literature indicates that it is essential that stakeholders at the commencement of the project ensure that they have a common insight into how project success will be determined and that stakeholders, especially clients, must be satisfied with the overall project performance.

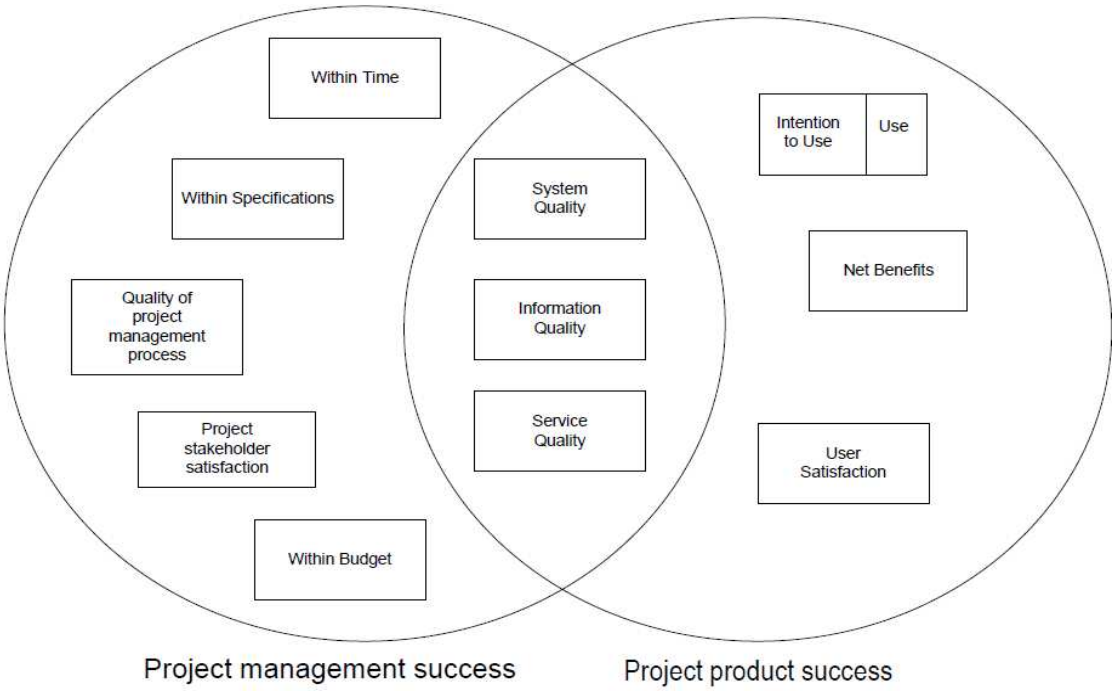


Figure 2-6: Project product success with overlapping dimensions (Delone and McLean, 2003)

2.5.12 Relationship system thinking and project success.

Carvalho and Rabechini Junior (2015:334) state that in recent years, systems engineering and project management bodies of knowledge have been rapidly growing, but about two-thirds of all projects still fail. According to the Standish Group Report (2009:15), 68% of all projects failed, while 44% of the projects were late, had an over-planned budget, and/or had fewer than the required features and functions. In addition, 24% were cancelled prior to completion or delivery and never used. Only 32% of all projects succeeded and that is, were delivered on time,

remained within the planned budget, and had the required features and functions. The figure below shows the relationship between system thinking, project types and project success.

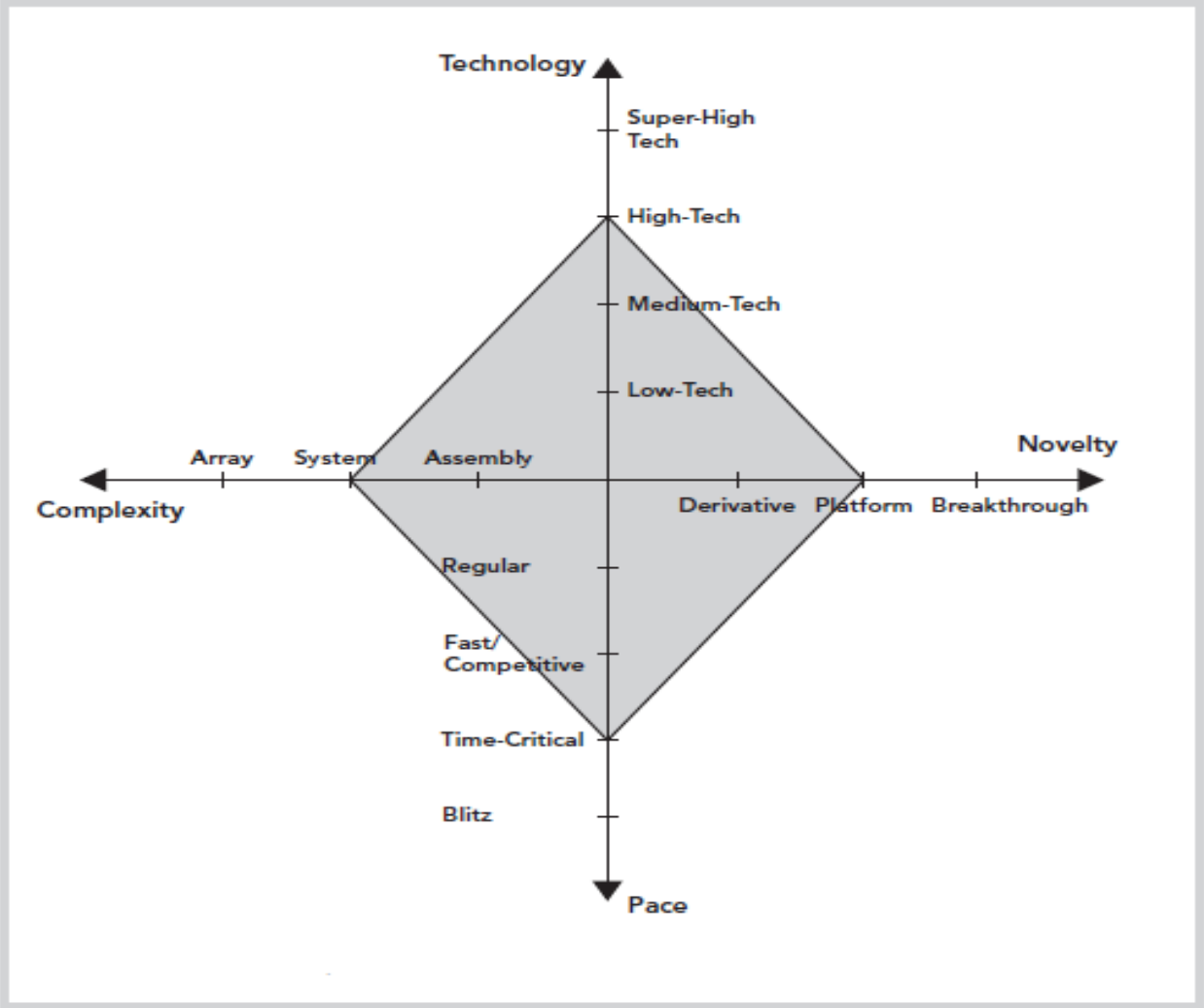


Figure 2-7: System thinking, project types and project success (Bannerman, 2008)

2.5.13 Project failures arising from corporate entrepreneurship

Lichtenthaler (2016:77) maintains that the study "Project failure arising from co-operate entrepreneurship" found that there is no single measure that applies universally to all companies. The appropriate measures depend on the organisation's strategy, technology, and the particular industry and environment in which they compete. Morris et al. (2016:109) assumed that the overarching purpose of a measurement system should be to help the team

rather than top managers, gauge its progress. Kuratko et al. (2015:251) specify that a truly empowered team must play the lead role in designing its own measurement system. Because the team is responsible for a value-delivery process that cuts across several functions, it must create measures to track that process.

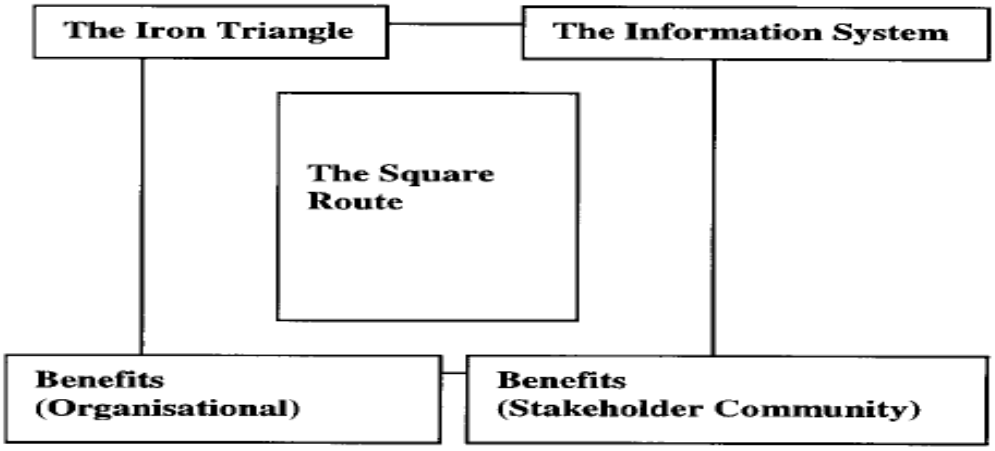


Figure 2-8: Projects square root (Roger, 1999)

2.6 Product (project deliverable) success factors

According to Wasson (2015:7), the production phase of a system's life cycle requires a delivered system to operate as per the engineering designs and specifications. The major requirements of the system during its operational life is that it must be affordable, function safely, perform as required, and be reliable as long as it is needed. Harris et al. (2015:13) define system effectiveness as the extent to which the product or system satisfies user demands. Elements of systems effectiveness are:

2.6.1 System availability

Hamanaka and Takahashi (2015:88) define availability as the probability that the equipment or system will perform its intended functions for a determined period. This measure records the uptime and downtime of equipment or a system to determine its availability. Barringer (1997:4)

assumes that the factors which affect equipment availability include hardware, software, process, human and interfaces. Different types of availability are:

- Inherent availability – as observed by maintenance personnel and excludes supply, administrative and preventative maintenance delays.
- Achieved availability – as observed by maintenance including corrective and preventative maintenance, but excluding administrative and supply delays.
- Operational availability – as seen by users including mean downtime

Kossiakoff et al. (2011:484) indicate that for a system to produce effective results for production purposes, it must always be ready for service and should have no failures.

2.6.2 System reliability

Kossiakoff et al. (2011:455) maintain that system reliability is a probability of no failure operations over a period of time. Reliability of plant systems is always dependent on the entire process, because failure of one system or equipment affects the performance of the whole, either partially or fully. Barringer (1997:6) agrees that there should be a supplier-use failure-free warranty period under specified operating conditions during the design life of the equipment or system. Kossiakoff et al. (2011:492) point out that investment is required to improve reliability, but it is expected that reliability improvements will increase availability. In order to improve system reliability, system upgrades underwent subsystem modifications to maintain the effectiveness of the system considering changing user requirements and technological developments. Highly effective systems will deliver a high level of reliability.

2.6.3 System capability

Kossiakoff et al. (2011:506) conclude that capability measures how well the system or equipment is performing its production function compared to user expectations. Barringer (1997:7) holds that capability is normally a product of utilisation which is a ratio of time spent on productive efforts to the total time consumed, multiplied by efficiency, which is a measure of input and output work. A higher system or equipment capability is preferred for higher system

effectiveness. Incorporating technological advancement to improve system capability is always necessary but brings other risks.

2.6.4 System maintainability

Kossiakoff et al. (2011:505) state that maintainability refers to how long it takes to reinstate the equipment functionalities after it failed. This includes all actions necessary for retaining an item or restoring an item to a specified condition with its characteristics being determined by equipment design. Higher system maintainability is preferable for a highly effective system.

2.6.5 System effectiveness

Barringer (1997:9) believes that the post-development stage of a system starts with the production phase, which contains two major outputs, namely: installed operation system and, operating and maintenance documentation. System effectiveness is achieved by multiplying capability, maintainability, reliability and availability to a single value. Barringer (1997:9) points out that the system effectiveness can be improved by improving the factor of the effectiveness formula. Kossiakoff et al. (2011:516) maintain that the technical efforts from concept development and engineering development during different stages of the system's life cycle, are mainly focused on achieving the performance objectives of the system.

2.7 Organisation benefits realisation

According to Johansson et al. (2016:653), successful organisational changes occupy a gap between the current situation and targeted future situation that appears in strategic plans by realising business benefits while enabling the organisation to identify, prioritise and support its most relevant initiatives, while evaluating its level of success.

2.7.1 Business value added

Hammer (2015:2) defines business value as any form of value that determines the health and well-being of the firm in the long run, including net benefit realised by project customers. Hammer (2015:384) indicates that projects are undertaken to deliver unique value to the organisation by delivering products or services that provide new offerings to customers. Johansson et al. (2016:662) state that competitors will find ways to satisfy the needs requirement if any business becomes complacent, not creating new value for its customer. According to Xie et al. (2014:2), the following steps are critical for projects to deliver business value:

- Understand the project vision – the project manager must understand the project vision, believe in the purpose of the project and consider it as worthy of the effort required.
- Business value of the project must be clear – the project manager must understand how the project vision translates into business value, which is often expressed in monetary terms.
- Project manager champions business value to the project team – the project team must understand the vision and business value offered by the project.
- Develop an environment to effectively deliver value – the project manager must provide a constraint-free environment where the project team can deliver the project efficiently.
- Measure the realisation of the business value – this step requires continuous measurement and must occur throughout the project. The organisation must continue to measure the increased value of the project impact towards improved value.

Serrador and Pinto (2015:1042) maintain that measuring a project's success based on its ability to deliver quality scope on time and within budget, is not enough and is repressive for the project in the 21st century. Projects continue to thrive in both the public and private sectors of the economy with investments of trillions of dollars annually. Organisations invest resources through effective use of portfolios, programmes and project management by employing the ability to establish processes to obtain greater business value from project investment. However, unfortunately, there are still significant failure rates. Joslin and Müller (2015:1382) point out that thousands of projects commence every day around the world, with some being well-conceived, and others starting without careful consideration about whether the project should be executed or not. Butticè et al. (2017:201) indicate that portfolio and project management as a process of choosing a project to execute, differ from organisation to organisation. However, the notion that project managers must consider the value that will be

delivered to the customer before beginning with work, is fast increasing since project measurement is starting to consider deliverable performance, which is mostly viewed as system engineering work.

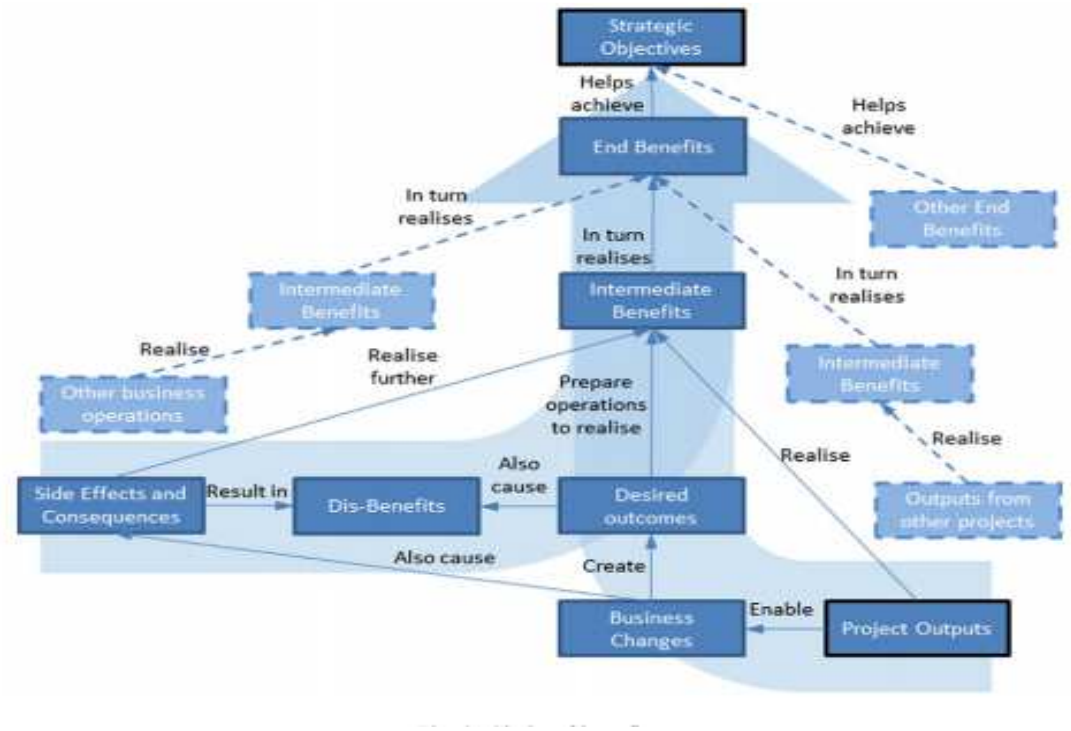


Figure 2-9: Chain of benefits (Serra and Kunc, 2015)

Turner (2014:209), indicates that ownership of envisioning and identifying the purpose of a project, and the business value that will be delivered as a result of executing the project, lies outside the bounds of the project. Serra and Kunc (2015:58) believe that project managers are not considered to be responsible for the business value, thus creating a skewed point of view, because project managers must understand the vision of the project and deliver the identified business value to the customer through project execution. Hall and Roelich (2016:288) believe that organisations will achieve the following goals by implementing a value measurement system to measure project management performance.

- Assist project management improvement initiatives for future marketing
- Determine objective accomplishing of a project management improvement initiative
- Compare project management improvement initiatives costs to benefits

- Identify the business impact of the implementation of project management improvement initiatives.

Turner (2014:189), holds that achieving a project's predetermined business value is the key aspect of evaluating project success. Project managers will make better decisions regarding projects to be executed if they understand the value the projects add, while the team focuses on value delivery.

2.7.2 Benefits realisation management

According to Hafeez et al. (2016:482), one of the key solutions towards developing business strategies that lead to project success, can be achieved through benefits realisation management (BRM) practices. BRM is measured through project strategy, project realisation, project planning and project review, while project success is measured by the project output, project goals and the project customer. Serra (2016:3) holds that recognising project, programmes and portfolio management as sets of tools to manage organisational change, will present an opportunity to master management of strategic change, which will result in organisational success. Serra and Kunc (2015:20) allege that from a strategic perspective, project success rates can be increased by utilising benefits realisation management as set tools of practices, which will focus on creating strategic value for the organisation by prioritising investment required by business strategy. This will also ensure that even after the end of a project, deliverables and the organisational life cycle will realise expected benefits through business operations. The figure below shows the relationship between project management (PM) and benefits management (BM).

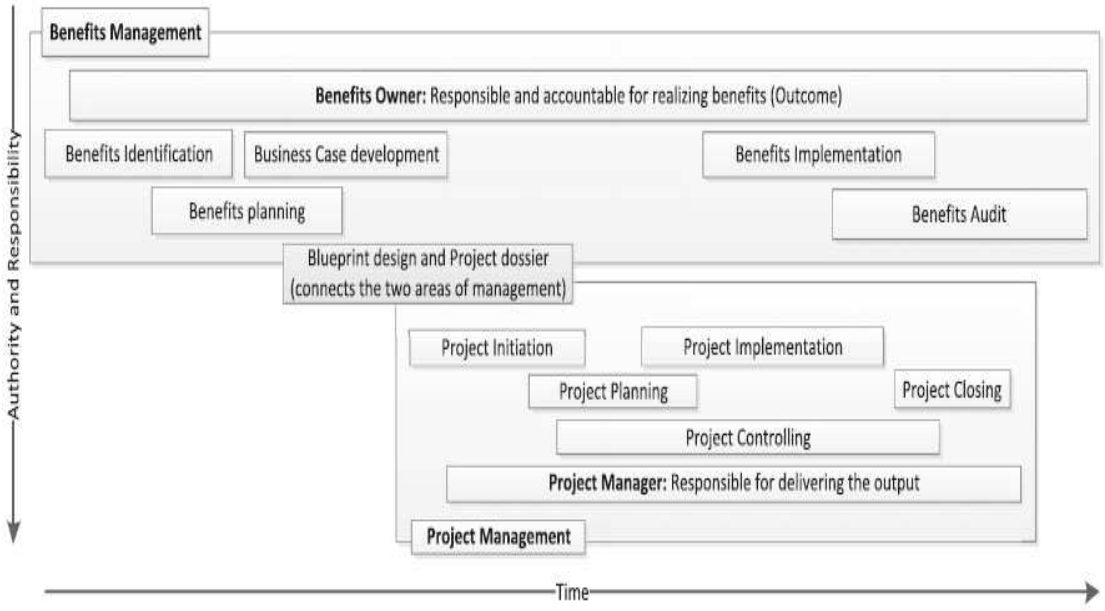


Figure 2-10: Relationship between PM and BM under project benefits framework (Badewi, 2016)

Serra and Kunc (2015:18) point out that business realisation management influence the successful execution of business strategy and contains a set of practices that influences project success in creating value to the business. This is performed by identifying how project success should look like, identifying success factors and success criteria. The project benefits which are measurable and quantifiable improvement expressed financially to justify investment are an increment in business value from shareholders perspective. Serra (2016:7) specifies that the process of benefits realisation makes benefits happen and ensures stakeholders are fully aware of progress made throughout the entire process.

2.7.3 Governance enabling organisation strategic success

According to Too and Weaver (2014:7), project governance must ensure that best project management practices, policies and standards are achieved through all life cycle stages by defining the way decisions are made (how), events where decision making takes place (where), roles and responsibilities in the process of decision making (who), decision type (what) and the objective of the decision making process (why). Muller (2017:22) claims that project portfolio governance, which includes project selection, authorisation, prioritisation and cancellation are

performed within a standard set of rules and decisions recorded, communicated and implemented enabling smooth project progress throughout its life cycle. According to Kaiser et al. (2015:7), for organisations to achieve business success, they must succeed in projects and programmes most relevant to their strategy, because effective project governance enables strategic business success. Rolstadås et al. (2014:644) assert that project stakeholders must be aware of the business value that the project aims to deliver to the organisation and the risks associated with the project delivery process, project management performance and the business value the project aims to deliver to the organisation.

2.8 Life cycle management constraints (delays/failure/underperformance)

Mir and Pinnington (2014:211) hold that in the context of power plant projects, delays can be defined in terms of the extra time required to finish a project beyond its originally planned time compensated or not compensated. Project failure is not matching or exceeding the success criteria according to Braglia and Frosolini (2014:105). Izmailov et al. (2016:102) believe that all stakeholders in a project desire to finish a project on time, under planned budget, with high quality and safely. According to Samset and Volden (2016:304), most research indicate the effect of delays as time overrun, cost overrun, disputes, arbitration, litigation and total project abandonment.

2.8.1 Causes of failure in power plant life cycle projects

According to Byrne and Shepherd (2015:24), design errors are identified as first reasons for cost and schedule overrun. Proper representation of the client's requirements is important in achieving good technical input requirements during project execution. Design with errors, means incorrect or insufficient representation of project deliverables, which lead to incorrect application techniques in achieving result while attempting to correct errors, which lead to delay and cost overrun. Project estimations are done based on the produced designs which mean that errors will affect both cost and schedule. Designs that are done without extensive investigation of site conditions could not eliminates potential, or scope creep and contract revision, since the actual site conditions start to vary during project execution.

According to Sage et al. (2014:551), causes of design errors in projects relate to specifications errors, planning and scheduling errors. According to Yamakawa et al. (2015:222), achieving accurate design entails good technical and administrative skills coupled with good communication from the design teams and a design process that is properly planned with proper review points.

Sage et al. (2014:551) hold that scope changes also contribute to delay in projects. All project plans, estimations, schedules, quality and base lines are usually designed in the initial project scope, so changes during execution will require the entire initial project plan to be reviewed such as developing a reviewed budget, schedule and quality, which require more time and resources. Ikediashi et al. (2014:10) point out that poor scope-change management could result in disputes that require time and money to be spent on arbitration and litigation for what the contractor or the client believes he is entitle to. To achieve proper control of scope change, it is important to first identify the fact that change is inevitable in a project. It could also be beneficial for the successful outcome of the entire project to integrate a proper change management plan, which is a proactive approach involving relevant project stakeholders and incorporating their needs throughout the project life. According to Hughes et al. (2016:19),it is important to measure the success of attaining the project scope.

According to Hughes et al. (2016:8), inappropriate and inadequate procurement or a faulty contractual management system, is another major reason for cost overrun and delay in projects. A contract that has not specified the entire project scenario may lead to disputes in the contract system (Hughes et al., 2016:28). The contract must comprehensively specify every relevant aspect of the project since failing to do so may lead to long chains of negotiations. A contractual agreement with unclear clauses can potentially lead to disputes and poor contractor selection, as well as unethical behaviour, and challenges regarding the contract bid amount. Differences between the winning bid and the engineer’s estimate will cause delays and cost overrun. Poor selection of contractors due to low bids and no technical capability to handle the project, lead to schedule delays, poor quality or unacceptable final results and a contract management system with clients that have a slow payment schedule.

Wagner (2016:18) assumes that project complexity, which is defined in terms of the size of the project, contributes to problems. Projects with high a degree of complexity usually result in complex plans, schedules and estimations. Project complexity is also defined in terms of the diversity of stakeholders with different interests and long chains of communication with slow feedback. To minimise the effect of project complexity, comprehensive planning should be

done, incorporating every relevant aspect of the project scope, milestones, a detailed work breakdown, structure, delivery time, stakeholders, and methodology to be used. Project closure contains potential factors that can lead to delays and cost overrun.

Shepherd (2014:32) believes that project delays can be reduced or totally eliminated using a proper project performance monitoring and control system that will integrate all the key activities of each project phase. Other tactics to achieving a project with little or no delay and cost overrun is in the definition of project success factors and criteria. Damoah et al. (2018:18) suggest that the integration of these factors will lead to a better understanding of the issues which the project manager needs to address and to design a control system that will monitor these issues.

2.8.2 Constraint in construction projects

According to Kelly et al. (2014:204), there are four basic ways to categorise types of delays:

2.8.2.1 Critical or noncritical

According to Alhomidan (2013:4), any delays that affect the project milestone or the project's date of completion, are referred to as critical delays, while delays not affecting project completion are non-critical. The project completion date depends on the project itself, the project schedule (critical path), the contract requirements for sequence phasing and the physical constraint of a project.

2.8.2.2 Excusable or non-excusable

According to Nurdiani et al. (2016:173),an excusable delay is a delay that is due to an unforeseen events beyond the contractor's or the subcontractor's control, mostly linked to events such as general labour strikes, acts of God, floods, changes directed by owners, omissions in plans and specifications, late response by governing authorities and changed site conditions. Toloba et al. (2015:171) assumes that non-excusable delays are events that are foreseeable by the contractor and within his span of control. Diaz et al. (2017:17) point out that the most common ones are delays caused by subcontractors, late deliveries by suppliers, poor workmanship by a contractor or subcontractor or unfair labour practices.

2.8.2.3 Compensable or non-compensable

Mahamid and Dmaidi (2013:866) allege that compensable delays are delays where contractors are entitled to additional compensation and time extensions. Only excusable delays can be compensable. Non-compensable delays mean that although an excusable delay may have occurred, the contractor is not entitled to any added compensation resulting from the excusable delay.

2.8.2.4 Concurrent or non-concurrent

Mahamid and Dmaidi (2013:317) agrees that the concept of concurrent delay has become a very common presentation as part of some analysis of construction delays. The concurrency argument is not only from the standpoint of determining the project's critical delays, but also from the standpoint of assigning responsibility for damages associated with delays to the critical path.

2.8.2.5 Construction delay quantitative analyses

Toloba et al. (2015:171) allege that a vital section specified in the construction contract is the performance period or time of project execution, which is established prior to bidding. The successful execution of construction projects and keeping them within estimated cost and the prescribed schedules depend on a methodology that requires sound engineering judgment. Głuszak and Leśniak (2015:184) indicate that the delay factors are grouped into the following nine major categories:

- Materials –cause delays related to delivery, damage, shortages, material changes and manufacturing of material.
- Labour – labour s and skills shortages
- Equipment – shortage of equipment, delays related to failure, delivery of equipment, productivity of an operator.
- Financing – finance requirements and progress payments paid by owners

- Environment – social and cultural impact, geological conditions, climatic conditions
- Changes – delay as a result of errors, omissions and scope changes by owners.
- Government relations – labour visa requirements, permits, government procedure
- Contractual relationships – contractual relationship problems among parties involved in a project with varying and conflicting interest.
- Scheduling and controlling technique – a lack of management expertise in project control poor scheduling and planning practices, poor record keeping and maintenance.

Maués et al. (2017:173) maintain that concurrent delays are more complicated; these are delays that occur when more than one factor causes a delay during the project at the same time or in overlapping periods of time.

2.9 Power plant performance management theory

There are several theories that play a role in influencing both project success and optimal life cycle management which are:

2.9.1 Project management body of knowledge (PMboK)

According to Maués et al. (2017:180) the PMBoK summarises the most important knowledge in project management and provides project managers with guidelines to address the increasing demand for project management solutions. Vaughan and Parker (2015:8) hold that the main argument against the PMBoK approach is that a single methodology does not fit all kinds of projects. For example, managing a construction project requires a different approach to managing a hi-tech project. Managing a complex project requires different methodology than managing a less complex project. Wyrick et al. (2015:94) indicated that project control systems indicate the direction of change in preliminary planning variables compared with actual performance and that the successful performance of a project depends on appropriate planning.

According to Memon et al. (2011:23), the design of a project control system is an important part of the project management effort and project professionals widely recognise that a lack of planning and monitoring plays a major role in causing project failure. Papke-Shields and Boyer-

Wright (2017:173) hold that project performance can be improved if more attention is given to the control systems, and thus strongly recommends that projects should be controlled through risk management, quality monitoring, and an integrated information management system.

2.9.2 Earned value method (EVM)

Czemplik (2014:425) believes that there are different project monitoring and control systems, but that the earned value method (EVM) is the most common and recommended technique for monitoring and controlling project execution. Subramani et al. (2014:147) state that this method integrates projects' scope, time and cost through periodic measurements of actual costs and work completion. Titarenko and Titov (2017:9) purport that the practical application of EVM presents challenges, such as revised cash flow and schedule and the inability to consider the critical path on the calculations.

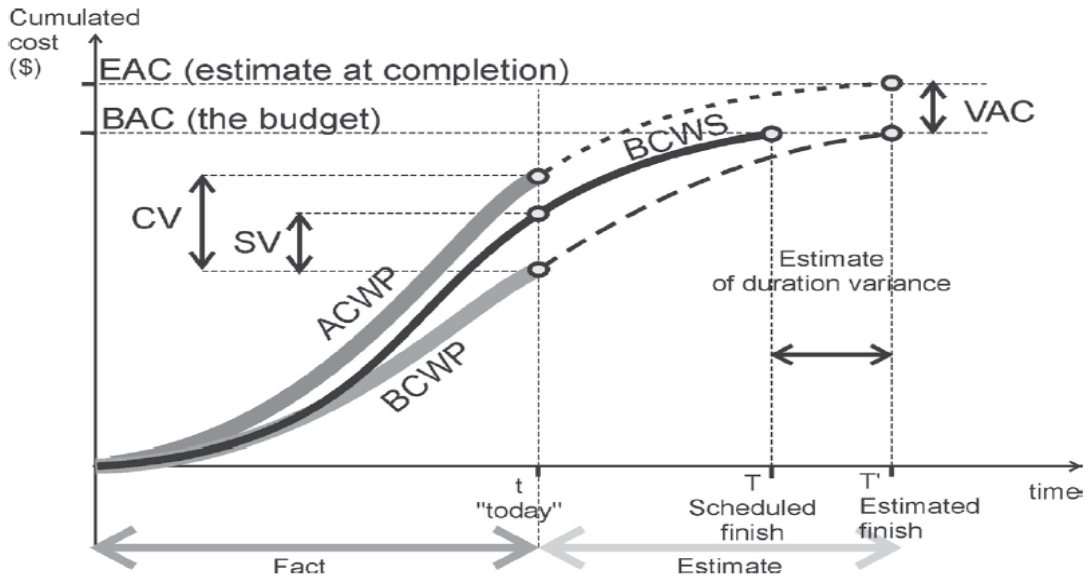


Figure 2-11: Earned value curves (Ziółkowska, 2015)

2.9.3 Required performance method (RPM)

Arcuri and Hildreth (2007:8) introduced the RPM method which is a forward-looking project control system that takes data from progress monitoring and applying expanding factors based

on the contractor's ability to complete the work timely. This procedure was designed to ensure people who have limited years of experience can identify potential project slippages by eliminating subjectivity when forecasting. This method also offers an early warning system allowing preventative measures and corrective action to minimise the potential damage. The figure below indicates the relationship between the ability to correct and the cost of corrective action.

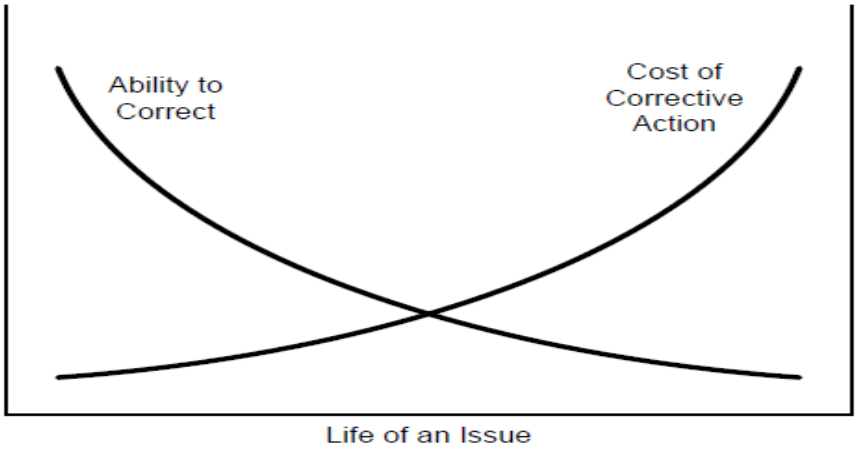


Figure 2-12: Ability to correct vs. cost of corrective action (Arcuri and Hildreth, 2007)

Yan and Zhenghong (2014:3) indicate that the critical success factor for project management is meeting or exceeding requirements through utilising a measure of fit to determine if the solution completely satisfies the functional requirements and non-functional requirements.

2.9.4 Multidimensional project control system (MPCS)

Machen et al. (2016:72) present the multidimensional control system which monitors the gap between the actual performance results and planning variables. Zemenkov et al. (2015:315) indicate that this method requires that the project's current state must be translated into yield terms, which are expressed as a gap vector specification that represents the multidimensional deviation from the global project control specification (GPCS). Rozenes et al. (2004:110) point out that to narrow the gap, corrective action must be taken by adjusting remaining activities by improving planned variables to actual performed results. The figure below indicates a gap between planned and actual values of a given variable.

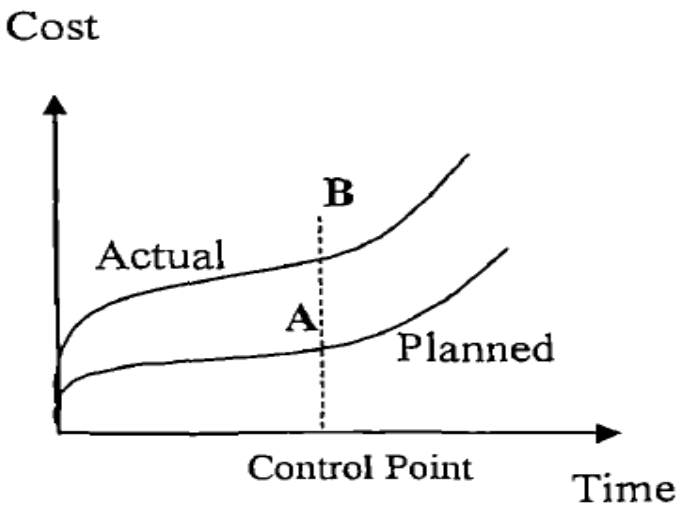


Figure 2-13: The gap between planned and actual values of a given variable (Rozenes et al., 2004)

According to Goetsch and Davis (2013:18), total quality is an approach to business that attempts to maximise the competitiveness of an organisation through the continual improvement of the quality of its products, services, people, processes and environment. The total quality management (TQM) approach targets everything that affects quality for continuous improvement. The end results of effective application of total quality, include superior value, global competitiveness and organisational excellence. Goetsch and Davis (2013:17) held that the plan-do-check-act (PDCA) cycle is considered an operating principle of the ISO management system incorporated in TQM used for continuous improvement of products, services, processes and systems. The steps are:

1. Plan - objectives must be established and the plan put in place
2. Do - implement the plan
3. Check - measure action results and determine if the results satisfy the objective
4. Act - make adjustments to the plan and go back to step one.

TQM principles are applicable to virtually every organisation and its use in project control can increase the added value of the system's performance; it should therefore serve as guidelines for any organisation that manages projects.

2.9.5 Performance management

Buckingham and Goodall (2015:44) argue that quality improvement is the use of a deliberate and defined improvement process and the continuous ongoing effort to achieve measurable improvements in performance. Gerrish (2016:58) alleges that performance management use data for decision-making by setting objectives, as well as measuring and reporting progress toward those objectives, and engaging in quality-improvement activities when desired progress toward those objectives is not being made. The figure below illustrates factors that constitute quality management.



Figure 2-14: Factors that constitute quality management (Evans, 2013)

Evans (2013:14) supposed that risk monitoring and control must be an ongoing process that consists of keeping track of identified risks, monitoring residual risks and identifying new risks, ensuring the execution of risk plans, and evaluating their effectiveness in reducing risk to facilitate project success.

2.9.6 Theory of constraint (TOC)

Mabin (2015:24) states that the TOC's fundamental principle is that every system, sub-system or organisation has one constraint that limits performance. He argues that, if improvement

activities are implemented anywhere except on constraint, performance cannot improve. Chawla and Kant (2017:17) indicate that if an organisation's performance needs to be improved, effective management of capacities and capabilities of the organisation through proper constraint management is vital. Gupta (2016:16) indicates that the TOC's five-step implementation process is:

- Identify the system's constraints – know what restricts performance.
- Decide how to exploit the system's constraints – decide how the constraints will be addressed.
- Subordinate everything else to the above decision – use the organisation's resources maximally to exploit the constraints.
- Elevate the system's constraints – the system cannot perform to infinity, as a result another constraint will arise.

Gupta (2016:18) points out that the critical-chain scheduling method using time buffers, provides a simple tool for monitoring projects and setting realistic due dates.

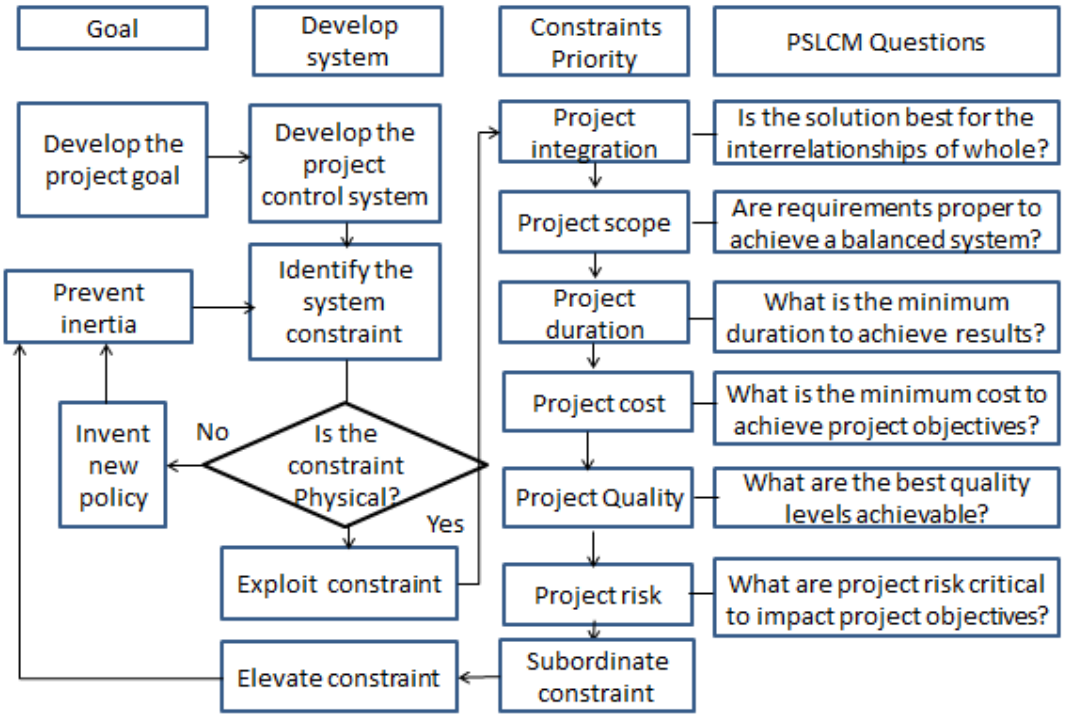


Figure 2-15: TOC in Product Lifecycle and Supply Chain Management (PSLCM) environment

Rossi Filho et al. (2016:22) emphasise that the danger, however, lies in its oversimplification, which can lead to real-life problems that TOC tools are not capable of handling. Implementation of the critical chain in complex projects might, therefore, be problematic.

2.9.7 Statistical process control

Oberoi et al. (2016:667) point out that assessing ongoing quality enables the project manager to identify activities that were not performed successfully compared to a quality breakdown structure (QBS). This indicates that the overall quality objectives make it easier for the project manager to assess, at any time, the overall quality simply by comparing its actual quality with the planned quality identifying all deviations. Oberoi et al. (2016:668) found that the quality of a project is associated with customer focus, rework reduction, and conformance to the technical specifications. Baig et al. (2015:10) adapted a new technique to provide dynamic real-time monitoring of time, cost and technical performance-related project parameters, thus achieving control by monitoring the project performance on the project control chart. Statistical process control is the best method of separating common cause's variation from special causes of variations making it possible to completely eliminate special causes and maintain process consistency. Lim et al. (2014:20) believe that this should assist the organisation to improve the system and avoid treating special causes as common causes.

2.9.8 Technical performance measurement (TPM)

Kaslow et al. (2018:4) anticipate that TPM attributes of the system are elements to determine how well a system or system elements are certifying a technical requirement or goal. Pisano (2002:3) allege that TPM involves a technique of predicting the future value of a key technical performance parameter of the higher-level end product under development based on current assessments of products lower in the system structure. Turanoglu Bekar et al. (2016:678) indicate that although TPM generates useful information and data about performance, little is available in the program management community on how to integrate these measures into a meaningful measure of the overall performance risk.

TPM define the planned progress of selected technical parameters making it possible to continuously verify the degree of anticipated and actual achievement of technical parameters and comparing them with the anticipated value. Bekar and Kahraman (2016:8) suppose that when these measures are selected, it is important to identify performance parameters that significantly qualify the entire system and that each parameter can periodically be measured. Agee (2018:4) indicates that TPM forecasts the value to be achieved for key parameters, monitor incorporation and the results of two critical technologies.

Kaslow et al. (2018:3) revealed that the effectiveness equation is a figure of merit which is helpful when deciding which component(s) detract from performance measures. The components of the effectiveness equation are:

- Availability – the system will operate for a given time without failure
- Reliability - the chances that the system will be available to perform its functions
- Maintainability – the system will be repaired without excessive lost maintenance time
- Capability – the system will perform its intended production activity according to the standard.

The relationship according to Bekar and Kahraman (2016:2) can best be expressed by the formula:

$$Effectiveness = Availability\ (A) * Reliability\ (R) * Maitainability(M) * Capability\ (C)$$

Kaslow et al. (2018:3) point out that the most important issue is to determine the system effectiveness value of a system at the lowest cost to owner, using the life cycle cost (LCC) as expressed in the formula below:

$$System\ effectiveness = \frac{Effectiveness}{Life\ cycle\ cost}$$

2.9.9 Financial measure

According to Chisholm et al. (2016:420), companies cannot be measured universally because measure depends on industry, environment, technology and organisational strategy. Ozawa et

al. (2016:204) suspect that the commonly used formula to investigate project management investment is return on investment calculated as follows:

$$Return\ on\ investment\ (ROI) = \frac{Nett\ benefits}{Costs}\ X\ 100$$

Vallejo and Wehn (2016:10) suppose that the results are achieved by placing a Rand (monetary) value on the data that is used to measure net benefits which originates from different measure increased quality of output converted to rand value, improved profit in Rand's value and cost savings. Saeidi et al. (2015:3) note that the LCC of any piece of equipment is the total lifetime cost to purchase, install, operate, maintain, and dispose of that equipment. According to Frenning (2001:7), the life cycle cost of a system can be calculated using the formula below:

$$Cost\ effitiency = \frac{Total\ benefits}{LCC}$$

Cost–benefit analysis is often used by organisations to appraise the desirability of a given policy. It is an analysis of the expected balance of benefits and costs, including an account of foregone alternatives and the status quo.

2.9.10 Data envelope analysis (DEA)

According to Cook et al. (2014:3), DEA, also sometimes called frontier analysis, is a performance measurement technique which can be used for evaluating the relative efficiency of decision-making units (DMUs) in tasks, projects, products and organisations. DMUs are distinct units within an organisation that have flexibility regarding some of the decisions it makes with limited freedom relating to these decisions (Wei and Wang, 2017:31). According to LaPlante and Paradi (2015:38), Frontier Analyst is designed to help organisations to measure and improve their performance by comparing the relative efficiency of organisational units such as tasks, projects and products where inputs are processed to generate outputs.

Emrouznejad et al. (2016:10) assume that Frontier Analyst takes account of all the important factors that affect a unit's performance to provide a complete and comprehensive assessment of efficiency by converting the multiple inputs and outputs into a single measure of productive efficiency. Cook et al. (2015:330) understand that Frontier Analyst generates efficiency scores for all units being analysed, showing how much inefficient units need to reduce their inputs or

increase their outputs in order to become efficient. According to Olesen and Petersen (2015:188), efficiency can be calculated as follows:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

According to Emrouznejad et al. (2016:7), an efficiency study does not only provide an efficiency score for each unit, but also indicates by how much and in what areas an inefficient unit needs to improve in order to be efficient. This information can enable targets to be set, which could help guide inefficient units to improved performance. The need for a new project framework emerges from various issues and criticisms related to current project management methodologies which neglect project benefits. According to Kao (2014:14), existing project management methodologies are primarily concerned with output delivery, often neglecting outcome and benefit achievement resulting in more utilities becoming preoccupied with efficient output delivery, completing projects on time as compared to effective outcome generation.

The DEA methodologies not only highlight the central role of project benefits, but also identifies processes that contribute directly to their successful achievement. Mardani et al. (2017:1304) describe DEA) as a technique developed in operations research and management science for measuring the efficiency of DMUs in the public and private sectors by observing data on multiple inputs and outputs. An efficiency ranking of zero to 100% by comparing its performance utilising DMUs, compares its performance in relation to the comparison set and determines its efficiency ranking, which has a range of zero to 100%. The DEA methodology considers all resources used and services provided, and compares it with the best practice units. According to Serra and Kunc (2015:55), the figure below indicates how DEA can be used to identify performance gaps and benefits realisation.

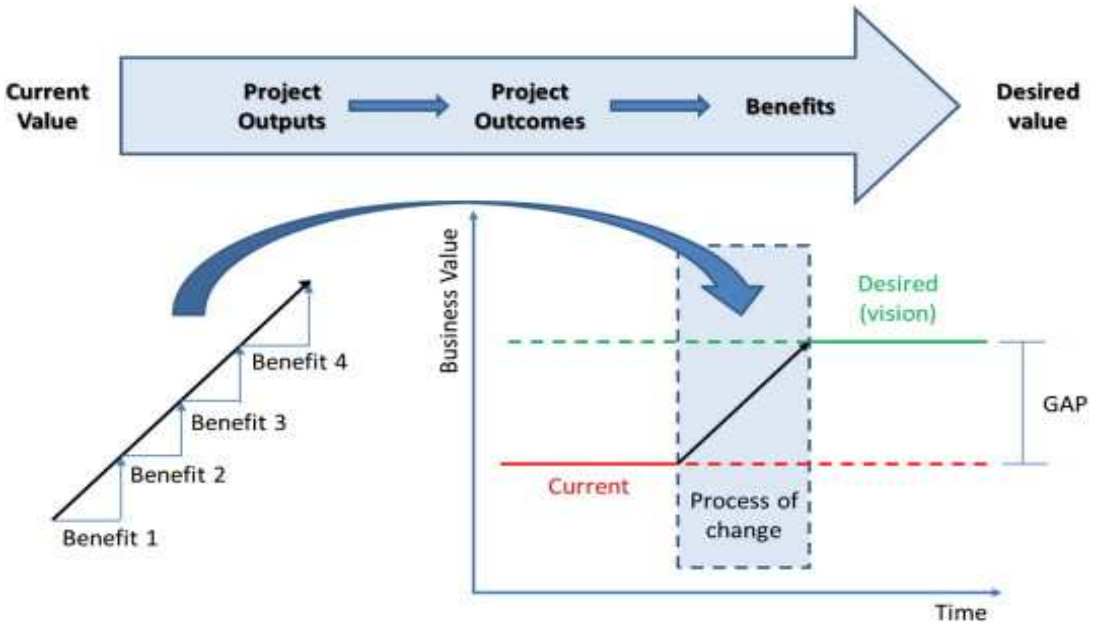


Figure 2-16: Performance gaps and benefits realisation (Serra and Kunc, 2015)

Zhang and Luo (2016:231) describe project management as the application of knowledge, skills and techniques to execute projects effectively and efficiently. It is a strategic competency for organisations, enabling them to tie project results to business goals and thus, better compete in their markets. Atici and Podinovski (2015:77) state that efficiency and project management are subjects explored extensively by the scientific community and also relevant for any company Engineering projects cost include engineering design, procurement of required material and equipment, human hours worked, premises and tools usage.

Wei and Wang (2017:30) hold that the cost can also be attributed directly to the project or a general proportion of completion time. Engineering project costs normally vary inversely proportional to the completion time, ,starting at minimum possible completion time of the project which is determined by technical parameters which can be achieved by utilising more resources, allowing overtime, reducing the manufacturing period of materials and using advanced technology. When power plants are on outages, the start-up date for a unit is the milestone observed by all stakeholders in the project.

Abbott and Doucouliagos (2003:92) indicate that constraints that normally affect life cycle project schedule completion, include long lead time equipment. Ross and Droge (2002:27) state that comparing planned values with the actual value after completing activities, can assist in determining the efficiency of any process involved in delivering a project. This information can be used to compare activities, projects and performance of project management teams.

According to Fandel (2007:527), the equation below shows a comparison of the scheduled time and anticipated cost with the actual ones after the completion of the project which will provide the efficiency ratio:

$\pi_{pc} = \frac{C_{pd}}{C_p}$ Where:

$\pi_{pc} = Project\ cost\ efficiency$
$C_{pd} = Anticipated\ cost$
$C_p = Actual\ cost$

The same can be done with project duration:

$\pi_{pt} = \frac{T_{pd}}{T_p}$ Where:

$\pi_{pc} = Project\ duration\ efficiency$
$T_{pd} = Scheduled\ time$
$T_p = Actual\ time$

Tone (2001:501) cites that the total project efficiency includes project scope efficiency, time efficiency, cost efficiency and quality efficiency. Fandel (2007:507) specifies that the overall efficiency of a project management process can be calculated as follows:

$$\pi_{pm} = f(\pi_{Pi}, \pi_{PS}, \pi_{PT}, \pi_{PC}, \pi_{pq,\pi_{PR)}}$$

Charnes et al. (1985:93) points out that the data envelope analysis linear programming is concerned with the optimisation (minimisation and maximisation) of a linear function, while satisfying a set of linear equality and/or inequality constraints or restrictions. In standard form, all constraints are expressed as equalities with all variables non-negative. In a standard form:

$$Maximise \sum_{K=1}^{n} C_k X_k$$

$$Subjected\ to \sum_{K=1}^{n} A_{hk} X_k = B_k \quad for\ K = 1 \ldots\ldots\ldots m$$

$$X_j \geq 0 \quad \mathrm{k} = 1 \ldots \ldots \ldots \mathrm{m}$$

In canonical form, all variables are non-negative and the constraints are of the ≥ type (for minimisation problems) or ≤ 0:

$$Maximise \sum_{K=1}^{n} C_k \, X_k$$

$Subjected\ to\ \sum_{K=1}^{n} a_{hk} \, X_k \ \leq \ b_h \ i = 1 \ldots\ldots\ldots\ldots M$

$$X_j \geq 0 \quad \mathrm{k} = 1 \ldots\ldots\ldots \mathrm{m}$$

Avkiran (2001:60) believes that traditional project management had a higher incidence of engineering projects of large dimension; however, with the constant changes of markets and corporate environments, project management is increasingly becoming a process in the dynamics of companies. Xu et al. (2009:633) hold that efficiency and project management are subjects explored extensively by the scientific community and are relevant for any company.

2.9.11 Project management and system engineering

Akundi et al. (2018:3) indicate that to use system engineering in project management, there must be a business, a market, or a regulatory requirement for the product, project or programme, as well as performance requirements against which successful completion is measured. While the project manager manages the project life cycle, the systems engineer manages the technical baseline of the product under development. Martínez et al. (2017:118) acknowledge that the project manager and systems engineer share requirements management responsibilities, and by working closely together they keep the project on track. Wasson (2015:324) reveals that the systems engineer must keep the project manager informed regarding technical requirement risks that have the potential to affect the project risk profile. If a key supplier is having difficulty maturing the technical aspects of the design, it may pose a risk to the project and should be recorded in the risk register as a cost, schedule, and supplier risk to the project

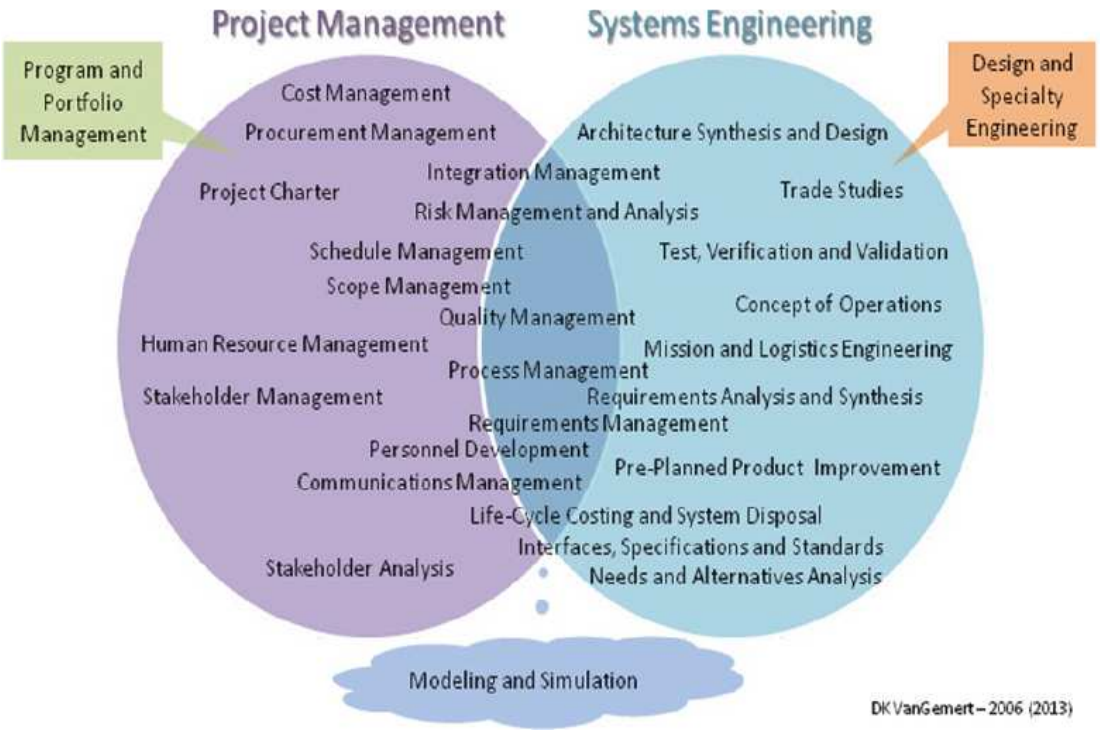


Figure 2-17: Project management and systems engineering inter-relationship (Kennedy, 2017)

2.9.12 Factorial design

Khorasani et al. (2011:14) allege that a design experiment objective is to illustrate the impact of specific changes to the process input in order to normalise, minimise or maximise the outcome by manipulating the input. Design experiment is used to determine the impact that specific input has on a process, individually or collectively. By varying factors in different levels and recording the results of the impact, it is possible to understand the impact of each variable within the process and the degree of its results. The analysis of inputs, as well as the results, determine the level of input needed to arrive at the optimal results, by first determining the quality characteristics to be examined and the desired effect. Understanding the goals and factors, a level is achieved through brainstorming and a cause and effect investigation can be performed. AlcheikhHamdon et al. (2015:95) emphasise that determining variation among treatments is completed by adding the square of each observation commonly referred to as sum of squares, followed by distributing variations among different types that can occur, comprising:

- Grand mean effect - variation caused by items under a test

- Effect of factors - variations caused by individual factors within an experiment
- Reputational error effect – variations caused by number of trials performed

Montgomery et al. (2009:258) believe that the important part of the design experiment is to determine the importance of factors achieved by determining the minimum significance variance required for a measurement to be considered significant. The total variation, which is a variation that has occurred among all treatments, is determined by adding squares of each observation.

2.10 Conclusion

According to Shenhar and Dvir (2007:22), no organisation will survive today without successful identification and implementation of projects because projects drive innovation and change, and make organisations better, stronger and more efficient. Yet in the field of business strategy, project management has been largely overlooked. The fact that most projects still fail, suggests that conventional project management does not meet current business needs. Malach-Pines et al. (2009:277) indicate that new project models need to be investigated to provide new frameworks and a common language relating to project management, thus making an important contribution to the overall asset life cycle management. By reading and implementing the strategies to reinvent project management, the following lessons will be leant to:

- Adapt the right management style to each project
- Understand inherent uncertainties, complexities and variables
- Communicate unforeseen developments accurately to team members
- Identify specific project-unique performance drivers
- Strategically and realistically allocate project resources.

Reinventing project management can provide a long-awaited new methodology that will revolutionise the way we think about projects. This study shows how to create a blueprint for achieving success and cost-effective project outcomes of enduring and far-reaching value.

Turner and Müller (2005:109) acknowledge that a project should be optimised for all involved parties; it should thus be undertaken as a partnership, working cooperatively and rationally towards mutual beneficial outcomes which are requirements for project success. The components of project success include project success criteria that measure both quantitative

and qualitative requirements. The requirements are dependent on variables by which we judge whether or not we reached a successful outcome.

Turner and Müller (2005:114) point out that by weighing project performance against the benchmarks of success, we are able to judge the different weightings different project managers allocate to the success criteria and how well they performed against the criteria. This gives an opportunity to evaluate project managers in terms of the type of project, nationality, age, gender, level of education, and job tittle. According to Padgett (2009:86), it is useful to identify key performance indicators (leading and lagging) used to measure success criteria that can be tracked throughout the project, to see whether the project will be delivered successfully and measure up to expectations. The main purpose of project methodology and framework is to aid in controlling the entire management processes through effective decision making and problem solving to deliver the project successfully.

2.11 Chapter overview

Chapter 2 Literature survey

Chapter 2 presents a comprehensive literature review about life cycle management, project constraint, project success criteria and project success factors. Other authors' views on the topic of project success and failure factors were explored to determine how their findings relate to this research.

Chapter 3 Research methodology

Chapter 3 presents the research methodology and the sequence in which the study was conducted. The structure of the chapter includes the establishment of the research population, the process of investigation, the format of analysing the data received, administration and development of the research instrument, and how the data collected will be interpreted and presented. The chapter also looks at how information will be verified and validated by comparing the conclusions to similar research done in the past.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter presents the research strategy, which consists of a process to examine variables and measures in order to discover knowledge through scientific search for source and consequence. Most research performed in engineering, project and construction use mixed (qualitative and quantitative) methodology which was also the case with this study.

3.1 Introduction

The project management and system engineering domain has produced extensive literature in the past decade. It is important to understand the volume of existing knowledge in both fields, when choosing the form of research study.This will assist in ensuring that the research data is valid and reliable and that the results are creditable. Research studies can be explorative, normative, descriptive, or explanative. Where there is existing knowledge in the study field, explorative study is preferred. When the research purpose is to describe characteristics of the research object with no related explanations and there is existing knowledge on the subject, a descriptive study is preferred. If knowledge and understanding about a subject is available and the research purpose is to guide and suggest arrangements, a normative study approach is preferred. An explanative study is used when the purpose is both to describe and explain, which requires research for a deeper understanding of the subject.

In this thesis, the normative and descriptive study methods will be used. Descriptive study will be used to explain current methods in completing life cycle projects, while the normative approach will be used to suggest new working methods providing guidance for further improvement. Empirical research studies, which is the collection and analysis of primary data based on direct observation or experiences in the field, has a number of different approaches to research strategies.

3.2 Research method

Borrego et al. (2009:58) point out that research (qualitative or quantitative) involves an explicit, disciplined, systematic approach to discovery, while applying methods appropriate to the research question. Three research methods are:

- Quantitative research method – an approach where the researcher uses positivist claims to develop knowledge, carry out experiments and collects data through a predetermined instrument to yield statistical results.
- Qualitative research method – an approach in which the investigator makes knowledge claims based on constructivist perspectives. The researcher collects data with the primary objective of developing themes from the data.
- Mixed research method – an approach that combines qualitative and quantitative research methods.

Yilmaz (2013:319) suggests that the epistemology, theoretical perspective, methodology and methods should be considered when designing a research study. Brannen (2017:27) holds that research strategies must be distinguished by conditions such as posed research question, extent of control that an investigator has over actual behavioural events and degree of focus on contemporary as opposed to historical event. Palinkas et al. (2015:541) specify that the type of research question and variables involved in the research will differentiate the strategies available to the researcher. The mixed research method will be used in this thesis by first applying a quantitative approach (Survey and Delphi technique) and the qualitative approach (theory development and case study).

3.3 Research design

According to Lewis (2015:473), research design refers to the overall strategy chosen to integrate the different components of the study in a comprehensible and coherent way, ensuring that the research problem is effectively addressed. It constitutes the blueprint for the collection, measuring, and analysis of data. Ioannidis et al. (2014:167) indicate that the relevant method identified must be most appropriate and able to deal with the variety of data and evidence. The survey primary data collection method was selected for this study, which will identify and

examine the correlation between success factors and delay factors and rank the most critical success factors for power plant life cycle projects to improve project and plant performance. The three-stage Delphi technique using a panel of experts was used to verify and validate the survey's selected factors. The theory of a project success life cycle model is developed focusing on the finalised Delphi confirmed factors. The model is then put to use through case studies and the results are used to verify and validate the model effectiveness to resolve the said problem. Conclusions are subsequently drawn and recommendations are made for future studies. The figure below illustrates the research design for this study.

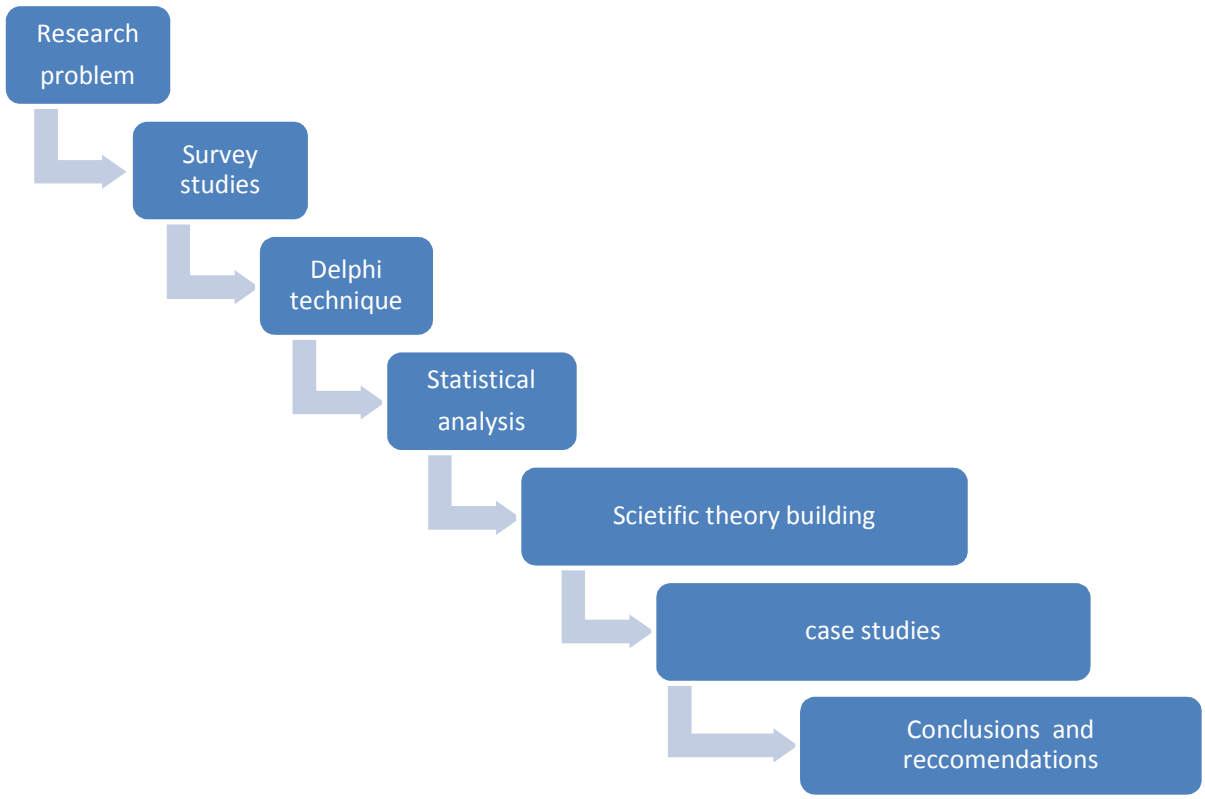


Figure 3-1: Research design process

3.4 Survey

According to Chaudhry and Khan (2016:573), a survey is a procedure in which data is methodically composed from a population through some form or direct solicitation such as questionnaires, face to face interviews, telephone interviews or mail.

3.4.1 Problem statement

The power industry landscape in Africa continuously experiences disruptions mostly due to existing business models and systems and methods of operation, as well as the blend of players and the electricity subsector. Due to the constraint in which power plants are constructed and operated, it can be expected that there will be differences in efficiency and performance. Real plant design constraints also limit power plant efficiency beyond utilities' control, which is not necessarily a result of ineffective design or operation. Several factors are perceived to affect efficiency of power plants, but this study focuses on efficiency problems due to design and maintenance which is subdivided into plant design, deterioration, plant maintenance and component availability. It is believed that improving access to power will go a long way towards eliminating poverty and unemployment, while providing an opportunity for entrepreneurial spirit. Due to challenges that African countries have in terms of capital borrowing, ensuring that they install generating capacity to meet or exceed its designed capacity, becomes a necessity.

3.4.2 Questionnaire design and sampling plan

A survey (primary data source) was conducted on a randomly sampled group in the population to investigate the objectives of this study of which findings will be used to draw conclusions and make recommendations. The results were compared to the key elements of an effective project management process in order to address the research objective as set out by Kothari (2004:100), who indicates that the design of the questionnaire can be split into three elements, namely to determine the questions to be asked, select the question type for each question and specify the wording; then design the question sequence and overall questionnaire layout. The questionnaire was designed to measure elements of success (project, product, organisational) and constraint (project, product, organisational). The following steps were followed to implement the research project:

- A pilot study was conducted to verify and validate the need for a research plan. Five people, who also form part of the research population, were chosen to complete an informal survey questionnaire. The aim was to establish whether the questionnaire was

correctly structured and how people could relate project success and constraint to different elements of project management.

- A conceptual framework was developed based on the information gathered during the pilot study, including criteria for the target participants. A literature study was conducted to gain knowledge about project management systems and best project principles. During the pilot study, queries were made regarding some questions and clarity was provided, which resulted in some amendments to the questionnaire. Some participants also noted that the questionnaire was straight forward.
- The final survey design was based on the pilot study and literature review results. The survey was sent to participants and it was completed in six month. Data received was collected, captured and assigned correctly. Data was analysed to determine the research findings, which were used to formulate conclusions and recommendations.

An online system monkey survey was used to collect data for the survey, which also assisted with basing statistical analysis. The survey plan was as below:

Table 3-1: Survey questionnaire plan

Category	**Number of questions**
Project success factors	35
Product success factors	13
Organisational success factors	4
Project delay/failure factors (constraints)	27
Total	**79**

Random sampling was used for this survey giving every object equal selection probability. In this technique, each member of the population has an equal chance of being selected as a subject. The entire process of sampling is done in a single step with each subject selected independently of the other members of the population.

3.4.3 Data collection

A questionnaire survey was distributed to individuals who were working or had worked for power utilities that were members of the Association of Power Utilities of Africa (APUA) which represents north, south, east, west and central power pools. The total research population 489

participant was identified and 228 were random sampled for the study. This was done to reduce overall costs of performing the study. The individuals targeted were project managers, system engineers, consultants, contractors and supplies to determine the critical project success factors, project deliverable (products) critical success factors, organisational/corporate critical success factors and critical power utility constraints.

The research population was identified through monkey survey research historical database which contains all historical participant classified in their demographics, according to reseach conducted using the platform before which allows new and future researchers to include anyone who qualify or meet requirements of the new study. Association of Power Utilities of Africa (APUA) use this platform for all their surveys to gather data regarding African power utilities. A stratitified random sample was used to divide potential samples into mutualy exclusive groups based on catergories of interest in the research. The main purpose was to organize the potentential samples into homogenious subset before sampling. The respondents were classified according to:

- Power plants life cycle project experience
- Qualifications (Engineering and project managent)
- Positions (Engineers, managers)
- Stake holder type (Consultant, Owners, contractor)

The survey data collection was carried out through an online web system monkey survey. The respondents were sent survey links via emails and statistical data was collected using the online software, which produce statistical results as participants responds. The survey was done for a period of six month (10/02/2017 to 15/08/2017), The monkey survey web system functionality of continuously reminding all participants who have not completed the survey on a weekly basis, has assisted to improve the survey success rate. A Likert scale was used to measure the level of agreement or disagreement as follows:

- Strongly disagree = 1
- Disagree = 2
- Neither agree nor disagree = 3
- Agree = 4
- Strongly agree = 5

3.4.4 Coding data

Data coding according to Chaudhry and Khan (2016:583) refers to the process of assigning numerals or other symbols to answers so that responses can be put into a limited number of categories or classes. Research data was categorised into four groups, as follows:

- Projects success (Coded – S)
- Product success (Coded – P)
- Organisational or corporate success (Coded – Q)
- Failure/delay factors (Coded – F)

In this survey, data is organised into groups called categories and presented in a table which provides the number of items evaluated in each group. Such an item frequency table provides a better overall view of the distribution of data and enables someone to rapidly comprehend important characteristics of the data. The table below shows how different categories of data were coded in the questionnaire.

Table 3-2: Questionnaire data coding

Code	Project success categories	Number of Items
S1	Effective governance	4
S2	Goals and objectives	3
S3	Commitment	2
S4	Capable sponsors	3
S5	Secure funding	3
S6	Project planning and review	7
S7	Supportive organisations	3
S8	Competent project teams	3
S9	Aligned supply chain	2
S10	Proven methods and tools	3
S11	Appropriate standards	2
P	**Product success categories**	**Number of Items**
P1	Added value success	2
P2	User satisfaction	5

P3	System created	3
P4	System experienced	3
Q	**Business categories**	**Number of Items**
Q1	Organisational/corporate success	4
F	**Delay/failure factors categories**	**Number of Items**
F1	Causes of project failure by owners	5
F2	Causes of project failure by contractors	6
F3	Causes of project failure by consultants	4
F4	Causes of project failure by labour and equipment	5
F5	Causes of project failure by contracts	2
F6	Causes of project failure by contract relationship	5

3.4.5 Data analysis and type of analyses

According to Nardi (2018:121), survey data analyses is about identifying similar characteristics in the voter group, identifying levels of variations to indicate variable relationship and to identify different group types. This is done in order to categorise, manipulate and summarise data to find solutions to the research questions. Correlation analysis studies the joint variation of two or more variables for determining the amount of correlation between two or more variables.

3.4.6 Validity of the test instrument

According to Kothari (2004:81), research test instrument validity refers to the degree to which the instrument represents a concept of the measured research. Validity is concerned with the extent to which an instrument measures what it is intended to measure. Quantifying research variables measurement involves operationalisation of contrasts in defined variables and the development and application of instruments or tests. A measure is said to have content validity only if there is general agreement among experts that the instrument covers all aspects of the item being measured.

Kothari (2004:82) holds that the reliability and validity of the measures are key indicators of the quality of a measuring instrument. The test instrument was evaluated in this research for content validity. The research plan, which included a copy of the research proposal, was sent to the North West University's statistical committee members and to project management

consultants to review the test instrument and determine how well the chosen items represented the defined constructs. Based on the suggested clarifications, revisions, recommendations and points of critique, some modifications were made to improve the test instrument.

3.4.7 Reliability of the test instrument

Bonett and Wright (2015:8) direct that reliability refers to the instrument's ability to provide consistent results in repeated use. Three methods were used to measure reliability of the test instruments:

- Test-retest or alternative test method.
- Internal consistency, and
- Split-halves method.

The internal consistency method is the most common measure in which individual items of the scale should all be measuring the same construct and is highly inter-correlated. Kothari (2004:87) noted that the reliability of an instrument is closely associated with its validity; an instrument cannot be valid unless it is reliable. However, the reliability of an instrument does not depend on its validity. Responsiveness is the ability of a measure to detect change over time in the construct of interest.

Cronbach's coefficient is the most widely used objective measure of reliability (internal consistency). The generally agreed upon lower limit for Cronbach's alpha is 0.70. An internal consistency analysis was performed to assess the reliability aspects of Likert Scale variables. The Cronbach's alpha range was between 0.7096 and 0.8867. The alpha values indicate that the test instrument of this study is a sufficiently reliable measure.

3.4.8 Data analysis techniques

Statistical methods were used to analyse interpreted data collected through the survey questionnaires, including factor analysis, measuring variation, measuring association and

descriptive statistics. The descriptive design was chosen due to its ability to analyse single variables and rank measured variables within each concept.

The purpose of correlation tests is to find out whether there is a relationship and what is the extent of the relationship? Correlations close to +1.0 (or -1.0) designate strong positive (or negative). Correlations close to 0 designate little or no relationship between two variables. Factor analysis was used to detect the structure of the relationships between variables and find underlying categories that best describe the construct.

The Chi-Square test was used to measure variations mainly to test any significant differences between groups or variables. It is useful as a general test to check whether significant differences exist between groups in contingency tables. It is only considered significant when the distance is less or equal to 0.05. Results analysis was done using Pearson correlation coefficient, analysis of variance (ANOVA) and independent T- test.

3.5 Delphi technique

Disterheft et al. (2015:16) believe that the Delphi technique is an approach to gather data and opinions of experts. According to Bonett and Wright (2015:2), the value of a consensus-forming technique is based on the assumption that the opinions of a group of experts will be more accurate than the opinions of an individual expert, correlating for individual bias and misinformation. According to Ameyaw et al. (2016:998), the Delphi method is a survey which is steered by a monitor group, comprising several rounds of a group of experts, who are anonymous among each other and for whose subjective-intuitive prognoses a consensuses is aimed at.

Kermanshachi et al. (2016:590) presume that it delivers qualitative as well as quantitative results, and has explorative, predictive and even normative elements. Thomas et al. (2015:298) note that Delphi is widely used to establish as objectively as possible a consensus on a complex problem, in circumstances where accurate information does not exist or is impossible to obtain economically, or inputs to conventional decision making. Decision-making literature gives evidence that the ideas generated from a group format lead to increased accuracy, confidence, and satisfaction over individual generation.

3.5.1 Delphi planning

A Delphi study needs-assessment was conducted with the purpose of identifying the critical success factors that affect the success of power plant life cycle projects, as well as critical delays/constraints associated with those projects. A two-stage Delphi technique utilising a panel of experts was performed to verify and validate the factors identified in the survey. The results of the survey questionnaire were used to prepare a Delphi stage-one questionnaire. A Delphi stage-one questionnaire was used to prepare a Delphi stage-two questionnaire and Delphi stage two was used to prepare a stage-three which ranks the impact of the factors according the various PMBoK areas. The most highly rated items from the survey (averaged above 3.5) were sent to the expert panel to add new ones. A Likert scale was used to measure the level of agreement or disagreement as follows:

- Strongly disagree = 1
- Disagree = 2

- Neither agree nor disagree = 3
- Agree = 4
- Strongly agree = 5

The experts' consensus would require an achievement of four (4) Likert scale points, which represent 80%. The results of the Delphi questionnaires are as follows:

Table 3-3: Delphi technique plan

Category	Number of questions
Project success factor	10
Product success factors	5
Organisational success factors	4
Project delay/failure factors (constraints)	6
Total	**25**

3.5.2 Expert panel setup

A total of 48 expert's wich consist of 12 from north, 17 from south, 8 from east, 7 west and 4 central power pools were identified to participate in this Delphi study covering all regions. The requirements for the experts' panel members were as follows:

- A minimum academic qualification of a degree in engineering, project management/construction/technology management
- Professionally registered with the engineering or project management professional bodies
- A minimum of 15 year experience working in power plant projects
- Work experience on capital value of more than US$ 5 Million

A letter explaining the purpose and scope of the research study was sent to all members of the expert panel via ectronic mail. The expert parnel was represented by north, south, east, west and central power pools. Panel of experts represented:

- 12 power utilities
- 16 contractors
- 4 Consulting firms

3.5.3 Administering Delphi study

A three-stage Delphi technique data collection process was undertaken through the online web system monkey survey. A survey link was sent to the panel of experts via emails anonymously and statistical data was collected using the online software monkey survey for academic purpose, which produce statistical results as participants respond. Results can be viewed as they are received. The survey was done for a period of three months (01/09/2017 to 30/11/2017). The monkey survey web system has functionality that continuously reminds all panel experts who have not completed the survey on a weekly base, which assisted to improve the survey success rate.

3.5.4 Data Interpretation

Final data interpretation is prepared online as data is received on the monkey survey. On completion, data which include tables and graphs, is downloaded to a Word or Excel database. The results are then used to evaluate the scope, purpose, insight and specific issues. This data can be used to respond the research hypotheses as stated in Chapter One, compared with the existing theory in Chapter Two.

3.6 Scientific theory building process

According to Shepherd and Suddaby (2017:60), the two stages that constitute the building of theory are the descriptive stage and the normative stage. Researchers building descriptive theory proceed through three steps:

- Observation - Researchers observe phenomena and describe how it can be measured.
- Categorisation – Researchers classify the phenomena into categories
- Association - Researchers discover the association between the category-defining attributes and the outcomes observed.

Macdonald et al. (2018:4348) state that the confusion and contradiction that often accompany descriptive theory become resolved when researchers, through detailed empirical and ethnographic observation, move beyond statements of correlation to define what causes the outcome of interest. The figure below shows the transition from descriptive theory to normative theory.

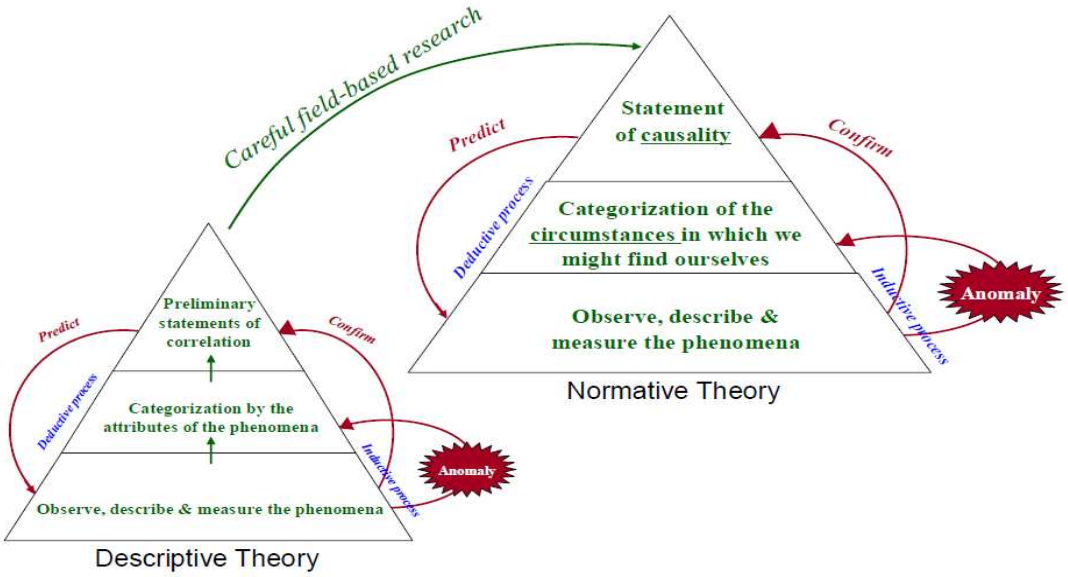


Figure 3-2: The transition from descriptive theory to normative theory (Kreps, 2018)

The Survey and Delphi results will be used to form a preliminary statement of correlation of a descriptive theory which will be developed to build a life cycle management model that will be used to measure performance in power plants.

3.7 Case study

According to MEYER (2015:58), a case study is a research strategy that investigates the properties, actions, attitudes and social structures of individuals, groups and institutions by applying a method such as participants observation, interviews and analysis. Yazan (2015:135) allege that a case study is an approach that facilitates exploration of a phenomenon within its context using a variety of data sources. De Massis and Kotlar (2014:17) believe that an effective case study must transfer specific knowledge and learning by employing participants in a

situation to think through real-life selections with which decision makers are confronted. Russell and Norvig (2016:44) hold that the most common case studies in systems engineering are:

- Decision-oriented case studies – this type of case study typically builds up until a decision-maker is confronted with open-ended choices, which leaves the reader to analyse the evidence and make serious decisions based on contextual analysis.
- System failure case studies – this type of case study examines disastrous failures and the systemic weaknesses that contributed to them. Participants focus on developing a better understanding of how small, seemingly insignificant problems can combine into dramatic failures.
- Cases of interest – this type of case study illustrates the importance of simple practices that can have serious consequences if improperly or inadequately executed.

A case of interest case study was used to verify and validate the new integrated model with the rationale that organisations learn more effectively when knowledge is shared in a way that can be used in an organisation and that it relates to personal experience. This is achieved by using history to assist us to move fast past the familiar human experience, building a learning context and fostering the systems-thinking skills required by a learning organisation.

3.8 Conclusion

The research procedures were benchmarked with the procedure in an article titled “Research design: qualitative, quantitative, mixed methods” by Creswell and Clark (2017:5), which explains the do’s and don’ts of conducting research. It was evident that all research procedures explained in this chapter meet the research design requirements explained in the article. It was also emphasised that proper research design makes the actual work easier due to an absence of major errors.

It was furthermore noticed that surveys are appropriate for a descriptive phase while case studies are appropriate for an explanatory type of investigations. Casual enquiry explanations can only be developed by the experiment.

3.9 Chapter overview

Chapter 3: Research Methodology

Chapter 3 presents the experimental design of the project management process and the sequence in which the study was conducted, as well as the way in which data was collected and delineated. The structure of the chapter includes the establishment of the research population, the process of investigation, the format of analysing the data received, administration and development of the research instrument, and how the data collected will be performed and presented. The chapter also looks at how information will be verified and validated by comparing the conclusions to similar research done in the past.

Chapter 4: Experimental design

Chapter Four discusses the data collection process. This chapter outlines the manner in which data was collected, analyses techniques and statistical methods used to identify causes of delays in project management.

CHAPTER 4

DATA COLLECTION

This chapter explains how data collection, which according to Whitney et al. (1998:74), is the process of gathering and measuring information on variables of interest in an established systematic way that enables the researcher to answer stated research questions, test hypotheses, and evaluate if outcomes was achieved. The data collection component of research is common, but methods vary. Nonetheless, ensuring accurate and honest collection of data is essential to maintaining the integrity of research.

4.1 Introduction

The information collected in this research was obtained following a methodological procedure in order to be considered relevant, rigorously obtained and capable of scientific evaluation. Primary data collection for this research had to be conducted because the existing literature review does not contain necessary data for statistical analysis. Survey studies were performed and the three-stage Delphi technique was performed to obtain experts' consensus on critical factors and constraints.

4.1.1 Primary data collection

Primary data collection, according to Pakseresht and Asgari (2012:391), can be collected in several ways, but the decision of selecting a method to use must be based on the nature of the information required, the resources available and the survey objectives. Most researchers identified that historical research examination (understanding what happened in the past) can be used to solve present problems. Using experiments, relevant behaviour of a phenomenon can be manipulated, but with case studies, contemporary events are examined providing two sources of evidence, which are direct observation and systematic interviewing. The table below shows relevant situation for different research strategies.

Table 4-1: Relevant situations for different research strategies (Yin, 2003)

Strategy	Forms of research questions	Requires control over behavioural events	Focuses on contemporary events
Experiment	How, why	Yes	Yes
Survey	Who, what, where, how many how much	No	Yes
Archival analysis	Who, what, where, how many how much	No	Yes/No
History	How, why	No	No
Case study	How, why	No	Yes

In this study, a case study was selected as the most appropriate method to respond to the research hypothesis identified in Chapter One, because of its ability to address different forms of evidence including observations, documents, artefacts and interviews. For the purpose of conducting this research, survey was the data collection method selected to identify critical success factors and critical constraints in projects, product and the organisation. Statistical analysis which includes the Pearson correlation coefficient, Spearman correlation coefficient and analysis of variance will be used to determine how different factors correlate with each other. The Delphi technique, using an expert panel, was quantified to rank the most critical success factors and constraint important to develop a life cycle model in power plants. A life cycle management theory specifically focusing on process, system and variance approach is developed and a model constructed. The model case study is applied to test the performance of the developed model. Finally, design of experiment (DOE) was used for model verification and validation.

4.1.2 Research hypothesis testing

A first round survey questionnaire was conducted to assess the relative importance of life cycle project success, product success and organisational success. A questionnaire was designed using well researched recognised factors as referenced by project management researchers below:

1. Section A – Demographic characteristics: Salleh (2009)
2. Section B – Project success factors: Pakseresht and Asgari (2012), Salleh (2009), Besteiro et al. (2015)

3. Section C – Project delay/constraints/failure factors: Salleh (2009)
4. Section D – Project product success: Ika and Donnelly (2017), Serrador and Turner (2015), Stark (2015)
5. Section E – Organizational success: Cserháti and Szabó (2014), Duffield and Whitty (2015)
6. Section F – Life cycle management theory: Campbell et al. (2016)

Section A of the survey collects information to evaluate the validity of the project for this study by gathering information on the research population demographics such as project type, cost, and duration and contract type. **Section B addresses the research hypotheses one:**

H_1 : There is a significant relationship between project, product (project deliverable) and organisational (corporate) success factors in power plants.

Although there are many factors researched and published by numerous authors that affect project success, this study argues that if the focus is maintained only on critical ones, project management success could be greatly realised. To satisfy this hypothesis, critical project success factors identified by Pakseresht and Asgari (2012:388) were used to evaluate their effects on life cycle power plant projects. The survey questionnaire consists of 12 parts:

Part one

This part of the questionnaire focused on project governance, which is the management framework within which project decisions are made. The respondents were asked to specify their responses to questions by indicating, using a Likert scale from one to five, their degree of agreement. The purpose is to discover if the existing framework is logical, robust and repeatable to govern an organisation's capital investments.

Part two

This part of the questionnaire focused on project goals and objectives and whether they are aligned to the overall business goals. Respondents were asked to indicate their responses to evaluate those categories, since poorly defined goals and objectives, or goals without objectives, miss milestones, push a project into overrun, and lead to territory battles, personality clashes and unhappy clients. The objective is that only projects that support the business objectives must be executed. The Likert scale of one to five was used to indicate the degree of agreement.

Part three

This part of the questionnaire was fixated on project commitment, which evaluates continuous fine-tuning of project requirements and deliverables while adhering to project scope, budget and time constraints. This evaluates whether a project's lack of commitment is identified and addressed to minimise project risks. It also looked at whether the projects emergent opportunities are used correctly. It furthermore focused on the flexibility of project teams to deal with change. A Likert scale of one to five was used to evaluate respondent's degree of agreement.

Part four

Part four of the questionnaire focused on sponsor's capabilities to support the project which equates to the executive accountability of a project by which a project is defined and funded, agreed with all interested parties suitably resourced from inception to completion, notably including the appointment and pragmatic support of a project manager. A Likert scale of one to five was used to measure the respondent's degree of agreement.

Part five

Part five of the questionnaire focused on project funding security. Respondents were requested to evaluates the funding security of projects and if necessary contingent funding are identified during the early stages of projects development. This could be due to project new opportunities that will increase organisation competitiveness. A Likert scale of one to five was used to measure the respondent's feedback.

Part six

Part six of the questionnaire focused on project planning and review. Respondents were asked to evaluate the responsiveness of the project team towards project planning process and flexibility to respond to unforeseen circumstances. A Likert scale of one to five was used to measure the respondents' degree of agreement.

Part seven

Part seven of the questionnaire focused on organisational support towards the project and the project team. Respondents were asked to evaluate the organisational environment where teams manage power plant life cycle projects to understand whether it is positive or negative. A Likert scale of one to five was used to measure the respondents' degree of agreement.

Part eight

Part eight of the questionnaire focused on project team competencies to execute the project correctly. Respondents were asked to evaluate project teams if they meet the desired skill required to execute specific projects and if those skills matters on the project. A Likert scale of one to five was used to measure the respondents' degree of agreement.

Part nine

Part nine of the questionnaire focused on supply chain management alignment to the project requirement. Respondents were asked to rate the alignment of procurement and supply chain management to projects. A scale of one to five was used to measure the respondents' degree of agreement.

Part 10

Part ten of the questionnaire focused on project management tools and techniques used during the project life cycle. Respondents were asked to rate the utilisation of project tools and techniques while managing projects. A scale of one to five was used to measure the respondents' degree of agreement.

Part 11

Part eleven of the questionnaire focused on standards applicable to the project. Respondents were asked to indicate their views about the degree of complying with standards (health, safety and environment). This included all other specification requirements crucial for overall project success. A Likert scale of one to five was used to measure the respondents' degree of agreement.

Part 12

Part twelve of the questionnaire focused on triple constraint. Respondents were asked to appraise according to their experience on life cycle projects, the project compliance to the triple constraints (on time, on cost and meeting requirements). A Likert scale of one to five was used to measure the respondent's degree of agreement.

Section C addressed hypothesis number two:

H_2 : There is an association between critical success factors and constraints in power plant life cycle management projects.

A survey was designed to obtain project parties' views based on their field experience regarding those factors that cause delays or failure of a project. The target population was project sponsors, contractors, owners, engineers and consultants involved in power plant life cycle projects. To obtain the necessary technical data, respondents were required to be part of project teams. The survey questionnaire consisted of six parts. Statistical analyses were performed to measure the significance of the correlation.

Part one

Part one of the questionnaire focused on causes of project failure/delay caused by owners. The respondents were asked to rate failure factors associated with owners or within owners' control using a Likert scale of one to five to determine the level of agreement.

Part two

Part two of the questionnaire focused on the causes of project failure/delay caused by contractor. The respondents were asked to rate failure factors associated with contractors or within contractors' control, using a Likert scale of one to five to indicate their level of agreement.

Part three

Part three of the questionnaire focused on causes of project failure/delay caused by consultants. The respondents were asked to rate failure factors associated with consultants or within consultants' control, using a scale of one to five to indicate their level of agreement.

Part four

Part four of the questionnaire focused on causes of project failure/delay caused by labour and equipment. The respondents were asked to rate failure factors associated with labour and equipment, using a Likert scale of one to five to indicate their level of agreement.

Part five

Part five of the questionnaire focused on causes of project failure/delay caused by contract-related issues. The respondents were asked to rate failure factors associated with contracts, using a Likert scale of one to five to indicate their level of agreement.

Part six

Part six of the questionnaire focused on causes of project failure/delay caused by contractual relationships. The respondents were asked to rate failure factors associated with contractual relationships, using a Likert scale of one to five to indicate their level of agreement.

Section D addressed hypothesis number three:

H_3 : Critical success factor importance may be verified and validated through evaluating each factor against PMBoK area across the system life cycle.

A survey was designed to obtain project parties' view about the importance of knowledge in projects, product and the organisation (across life cycle phases). The aim here was to determine the relationship between failed projects and failed product, successful project to failed product and failed project to successful product. The survey questionnaire consists of four parts:

Part one

Part one of the questionnaire focused on project efficiency and added value for success that the project product offers. Take note that the product is what most stakeholder use to determine project success or failure. Respondents were asked to rate the project, using the Likert scale of one to five to determine their agreement.

Part two

Part two of the questionnaire focused on project user satisfaction and respondents were asked to rate the level of satisfaction, using a Likert scale of one to five.

Part three

Part three of the questionnaire focused on project system experience by evaluating the system performance towards supporting organisational performance and that the system is not creating secondary problems (not offering a solution compromising other requirements). A Likert scale from one to five to indicate the degree of agreement.

Part four

Part four of the questionnaire focused on project overall performance over its life cycle concentrating on economic life cycle cost and overall equipment effectiveness as the primary measure. Respondents were asked to rate these factors, using a Likert scale from one to five to indicate the degree of agreement.

Section E addressed hypothesis number four:

H_4: There are best life cycle management practices as a result of theory advancements in modelling which will assist to improve power plant life cycle monitoring, control and management.

A factorial design was used to measure the relationship between project team dynamics and management techniques towards overall project results. This was done by using a design of experiments (DOE) to determine the low and high limits at which the input variable must be set and the impact on the measured project success factors.

Part one

The following procedure was followed:

1. Select life cycle project randomly, executed within the last 10 years
2. Use the project model to measure project performance and convert overall score to percentage (project success weight indicators (Chan, 2002:25)
3. Evaluate the controllable input variable at different treatment levels (real success factors)
4. Measure output variables to determine the output variability (triple constraint)
5. Calculate probability values
6. Calculate the effects on output per change in input variable
7. Calculate sum of squares (SS) using formula
8. Calculate the analysis of variance (ANOVA)
9. Plot main effects and interacting effects, then interpret results.

Part two

The correlation tests are performed to determine the relationship. Statistical process control can be used to measure project success and failure, highlighting averages and control points. Projects used as case study were life cycle projects completed by August 2017. Project files were used as sources of evidence.

Section E addressed hypothesis number five:

H_5: Good project management practices combined with benefits management will increase the probability of success in delivering business value.

At this stage, a theory is developed to understand integrated life cycle management practices defined by identified critical factors of success which influence life cycle projects. The results are correlated to value added in a business, which is a true measure of corporate success. This will evaluate why a project can only be considered successful if predetermined value to customers or stakeholders is delivered, ensuring that the business makes better decisions regarding projects to be executed and the project manager focuses holistically on important things that are required for the team to deliver value.

4.2 Statistical method

4.2.1 Chi-square

The chi-square is a statistical measure used in the context of sampling analysis for comparing a variance to a theoretical variance. This test is a technique which makes it possible to test:

- Significance of association between two attributes
- The homogeneity or the significance of population variance
- The goodness for fit.

The chi-square value will be used to measure the significance of population variance and will be used to judge if a random sample has been drawn from a normal population with the mean and a specific variance. Using the chi-square as a test of population variance, we have to calculate the value of x^2 to test the null hypothesis.

$$(x)^2 = \frac{\sigma^2}{\sigma^2}(n-1)$$

Where s*s*2 = variance of the samples *p*2 = variance of the population; (*n* – 1) = degrees of freedom, *n* being the number of items in the sample.

By comparing the calculated value with the table value of x^2 for (*n* – 1) degrees of freedom at a given level of significance, we may either accept or reject the null hypothesis. If the calculated value of x^2 is less than the table value, the null hypothesis is accepted, but if the calculated value is equal or greater than the table value, the hypothesis is rejected.

4.2.2 Relative importance index

The analysis was aided by the use of a statistic package where scores assigned to each factor by the respondents were entered and consequently the responses from the questionnaires were subjected to statistical analysis for further insight. The contribution of each factor was examined and the ranking of the attributes in terms of their criticality as perceived by the respondents, was done through the relative importance index (RII), which was computed using the equation and the results of the analysis as presented using the following formula:

$$\mathrm{RII} = \frac{\sum W}{A * N} (0 < RII < 1)$$

Where: W - is the weight given to each factor by the respondents and ranges from 1 to 5, (where "1" is "strongly disagree" and "5" is "strongly agree"); A - is the highest weight (i.e. 5 in this case) and; N – is the total number of respondents.

4.2.3 Spearman's rank correlation

Spearman's rank correlation coefficient was used to identify and test the strength of a relationship between two sets of data. The advantage of this method is that it does not require assumption of normality and of homogeneity of variance. The method also improves accuracy by measuring medians compared to other methods that measure mean ensuring that two or more erratic data impacts are negligible. This method measure of relationship between variables and also the direction and strength of those variables using statistics, which fall between +1 (perfect positive relationship - agreement) and -1 (perfect negative relationship – disagreement). It is calculated using the following formula:

$$\mathrm{R}^{I}S = 1 - [\ \frac{(6\sum d^2)}{n^3\ - n}$$

Where R is the Spearman's rank correlation coefficient between two parties, d is the difference between ranks assigned to variables for each cause, n is the number of pairs of rank. The following procedure is followed when applying Spearman's rank correlation:

1. State the null hypotheses
2. Rank data from highest to lowest and confirm tied ranks
3. Subtract two sets of ranks to get the difference (d)
4. Square the difference value
5. Add squared value of d to get d squared
6. Use the formula above to calculate RS
7. Get results and determine correlation.

4.2.4 Analyses of variance (ANOVA)

ANOVA is an extremely useful technique used when multiple sample cases are involved. The significance of the difference between the means of two samples can be judged through either *z*-test or the *t*-test. This technique enables us to perform this simultaneous test and as such is considered to be an important tool of analysis that researchers can use. The basic principle of ANOVA is to test for differences among the means of the populations by examining the amount of variation within each of these samples, relative to the amount of variation between the samples using the formula below:

$$F = \frac{\text{Estimate of population varience based on between samples varience}}{Estimate\ of\ population\ varience\ based\ on\ within\ samples\ varience}$$

The procedure to perform ANOVA is as follows:

1. Obtain the mean of each sample
2. Work out the mean of the sample means
3. Take the deviations of the sample means from the mean of the sample means and calculate the square of such deviation
4. Divide the result of the above step by the degrees of freedom between the samples to obtain variance or mean square between samples
5. Obtain the deviations of the values of the sample items for all the samples from the corresponding means of the samples and calculate the squares of such deviations and then obtain their total.
6. Divide the results of the above step by the degrees of freedom within samples to obtain the variance or mean square within samples.

4.3 Survey results

4.3.1 Survey sampling method

A stratified random sample was used to separate the research population which includes engineers, contractors, consultants and owners into strata (mutually exclusive sets) and perform a simple random sample using Excel from each stratum. The figure below shows the population stratified random sample:

Table 4-2: Population stratified random sample

	Survey		Three-stage Delphi	
Category	**Population proportion**	**Sample size N = 214**	**Population proportion**	**Sample size N = 10**
Owners	12.00%	26	10.00%	1
Engineers	34.00%	73	30.00%	3
Contractors	34.00%	73	40.00%	4
Consultants	20.00%	43	20.00%	2
Total	**100.00%**	**214**	**100%**	**10**

A questionnaire survey was sent out to individuals who worked in the power-generation environment in Africa (Association of Power Utilities of Africa (APUA)) to determine critical project success factors, project deliverable (products) critical success factors, organisational/corporate critical success factors and critical power utility constraints. A two-stage Delphi technique utilising a panel of experts was performed to verify and validate the factors identified. Stage-three Delphi was performed to identify the impact of each factor in relation to PMBoK guidelines.

4.3.2 Survey sampling results

The survey data collection was completed utilising the online web system monkey survey. The respondents were sent survey links via emails and statistical data was collected using the online software, which produce statistical results as participants responds. Respondents were asked to respond using a five-point Likert scale where 1: strongly disagree, 2: disagree, 3: Neither agree nor disagree, 4: Agree and 5: Strongly agree, in order to indicate their level of agreement. The figure below summarises the survey and Delphi results.

Table 4-3: Survey and Delphi research study results summary

Questionnaire	**Population**	**Sample**
Request sent	489	228
Request accepted	423	214
Not returned	61	14
% Response	**87%**	**90,70%**

4.4 Survey demographics

The research questionnaire consisted of nine demographics characteristics questions classified in terms of age, sex, education level, type of organisation they represent, occupation level, years of experience, engineering field and the project involved based on the contract sum. The figure below indicates that 42% of participants were between the ages of 30 and 39 years, 41% from 40 to 49 years, 10% from 50 to 59 years and 7% between 20 to 29 years. The survey demographics were as follows:

Question 1: What is your age?

The figure below indicates the ages of the research participants.

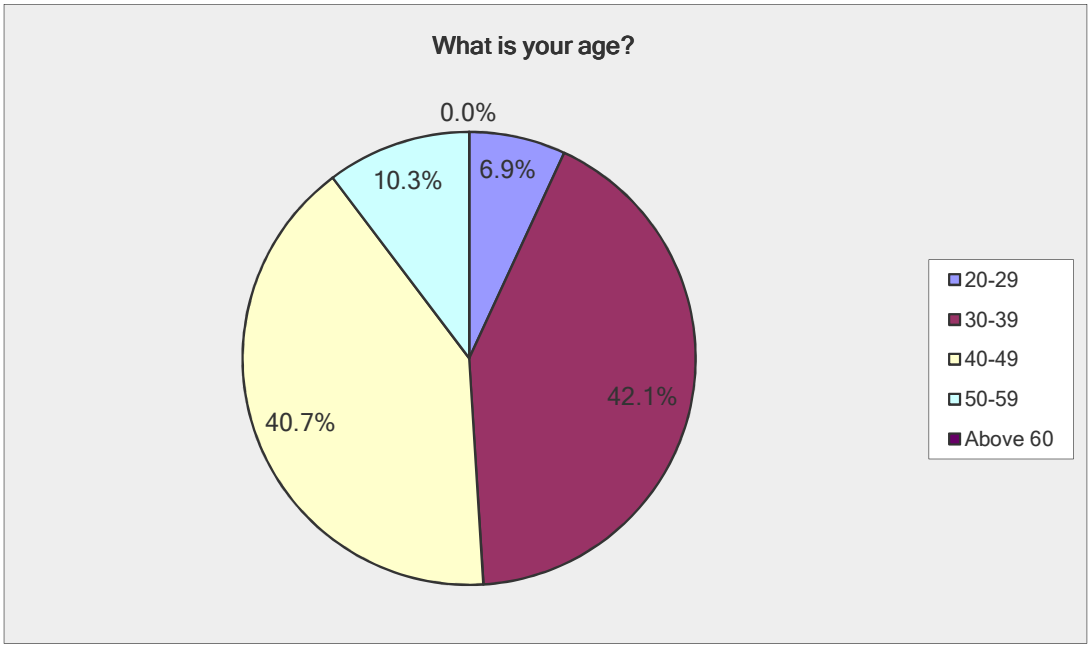


Figure 4-1: Age demographic

Question 2: What is your sex?

The figure below indicates that 76% of the research participants were males as compared to 24% female.

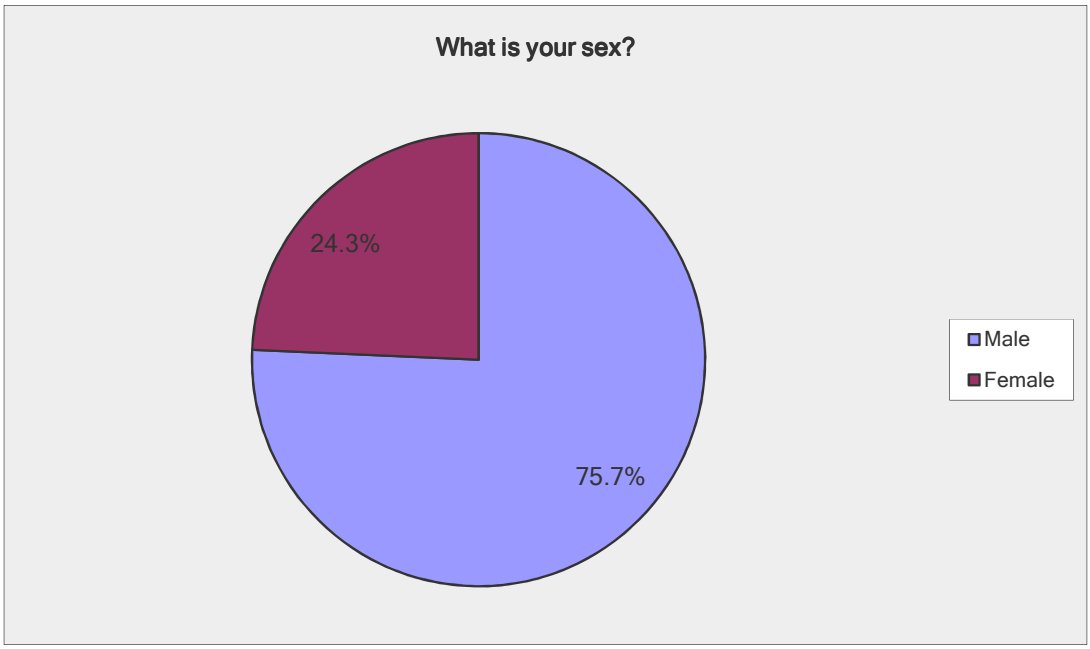


Figure 4-2: Sex demographic

Question 3: What is your highest education level?

The figure below indicates that 29% of participants had a technical degree, 19% had an honours degree, 20% a diploma, 16% a master and less than 3% had a doctoral qualification.

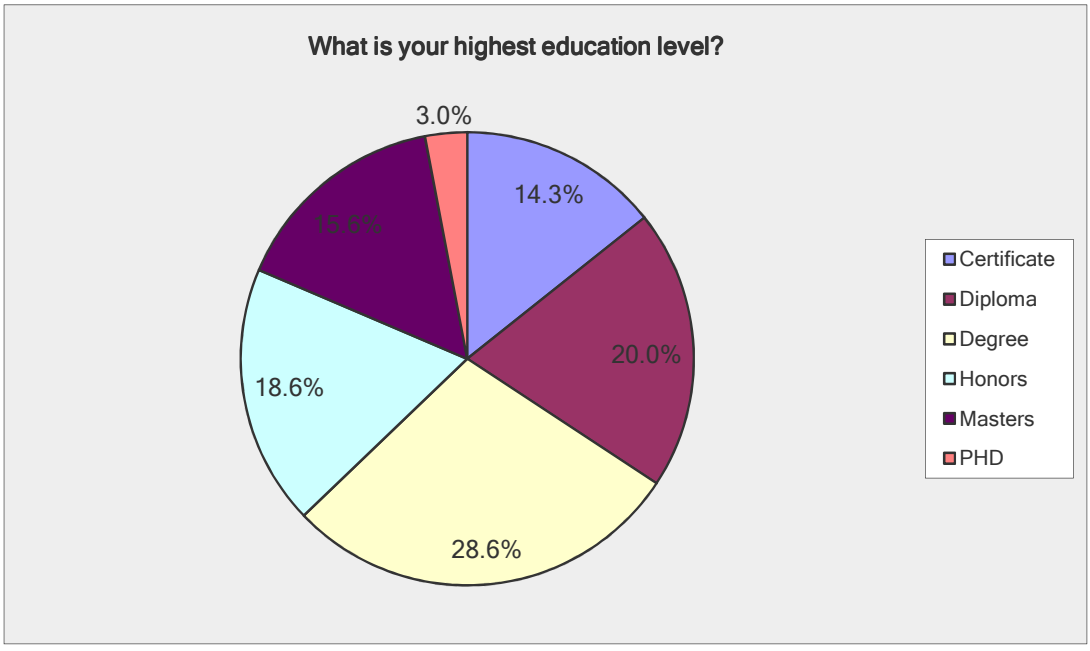


Figure 4-3: Education demographic

Question 4: What organisation do you work for?

The figure below indicates that 34% of participants were contractors, 12% sponsors, 20% consultants and 34% engineers.

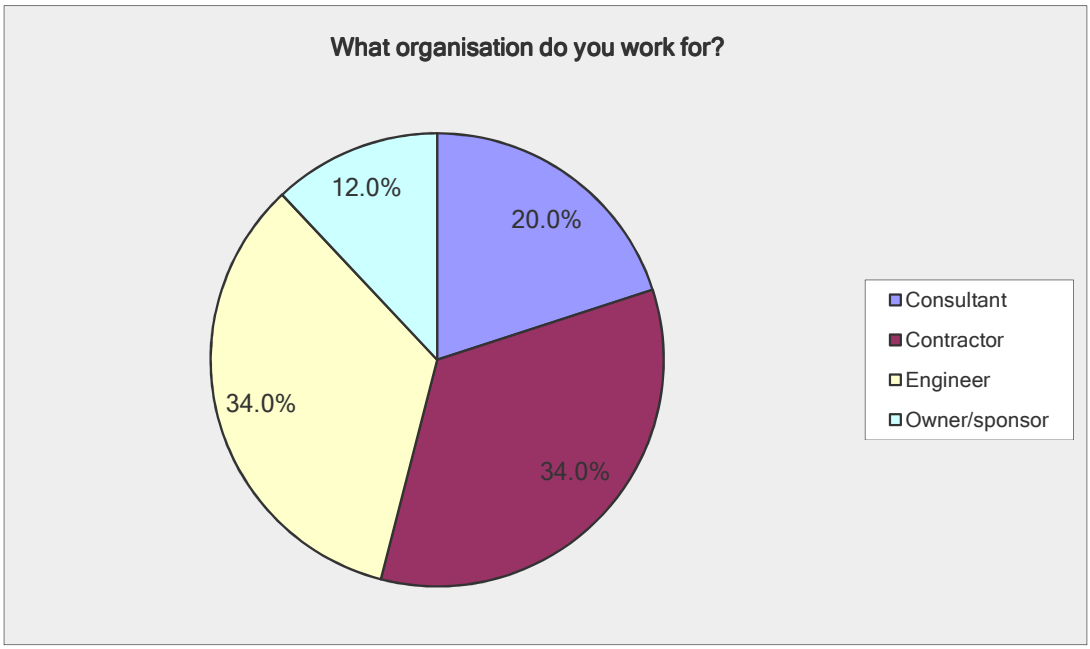


Figure 4-4: Organisation demographic

Question 5: What is your occupation?

The figure below indicates that 16% of participants were managers, 33% engineers/technologists, 17% project managers, 17% project coordinators, 15% non-managerial and 2% executives.

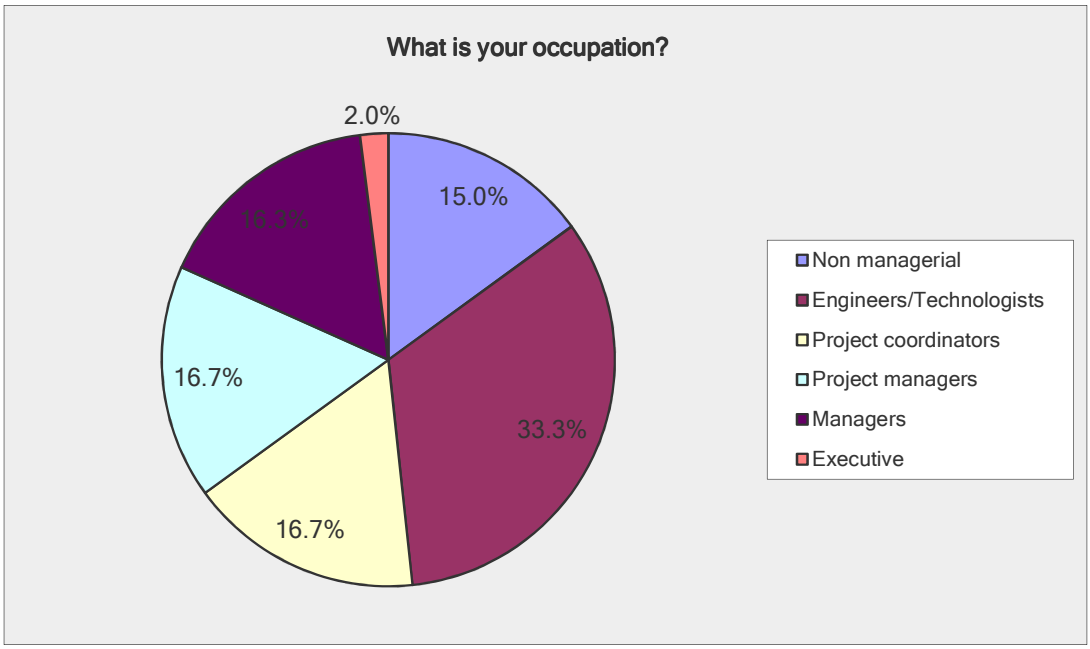


Figure 4-5: Occupation demographic

Question 6: How many years of experience do you have?

The figure below indicates that 13% of participants has more than 16 years of experience, 28% has six to 10 years, 38% has 11 to 15 years and 21% has less than five years of experience.

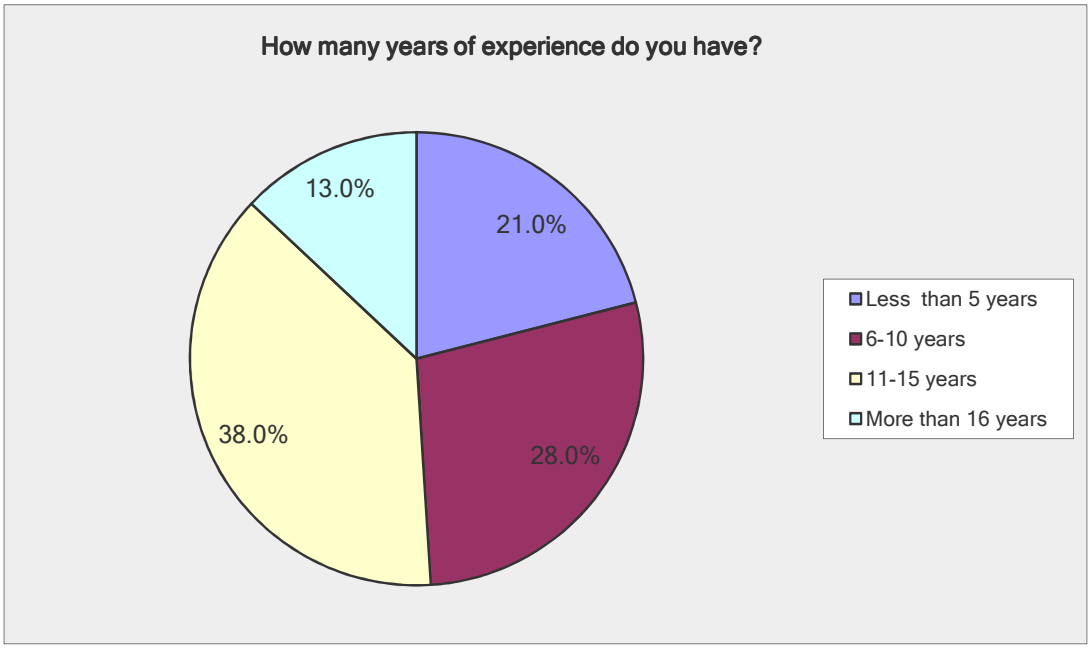


Figure 4-6: Experience demographic

Question 7: What is your engineering field of specialty?

The figure below indicates that the engineering field of 29% of participants is mechanical engineering, 27% electrical engineering, 24% process instruments, 12% chemical engineering and 8% civil engineering.

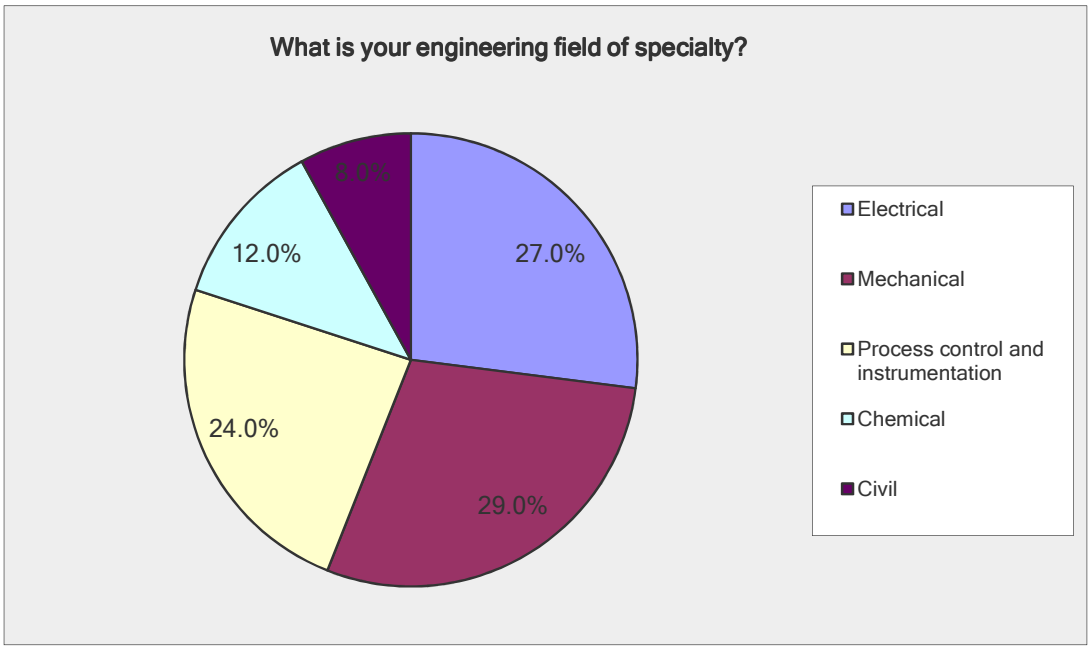


Figure 4-7: Engineering field of specialty

Question 8: Indicate your project involvement by contract sum

The figure below indicates that 71% of research participents performed projects above US$10 million, 14% between US$1 million and US$10 million and 14% perfomed less than US$1 million.

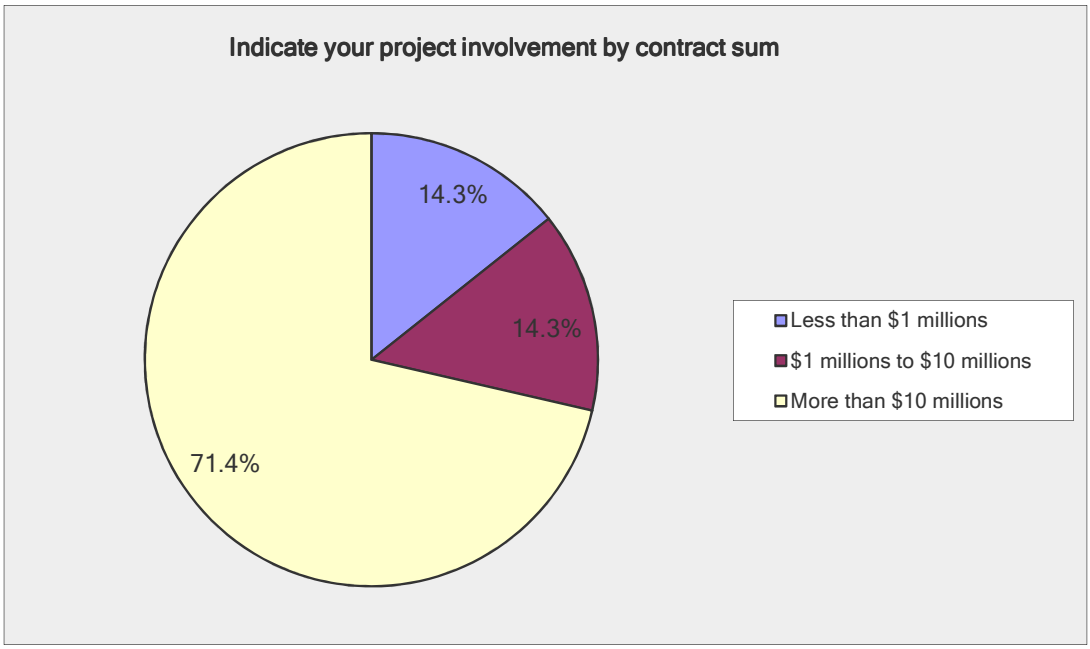


Figure 4-8: Project involvement by contract sum

4.5 Research findings and results

The survey data was analysed according to provided demographics. The overall score was used to determine the importance of each factor. Each factor's relative importance index (RII) and its average were calculated and were used for ranking the importance level.

4.5.1 Project success

Organisations should concentrate on the more efficient factors called the critical success factors, considering their restrictions, but identifying the factors that could not provide the organisation's success. Ranking and categorising this factor could provide solutions to managing organisations' projects and portfolios, thus achieving reliability and a more desirable record, which can lead to the organisation's success. Project management responsibilities and structures are key to project delivery.

Question 9: What is the importance of effective governance in a project?

The figure below indicate that the most important factors affecting project success in terms of project effective governance are firstly, having clear reporting lines. Secondly, clearly identified leardership.Thirdly, clarity how authourity is distributed and lastly, clear regular communications.

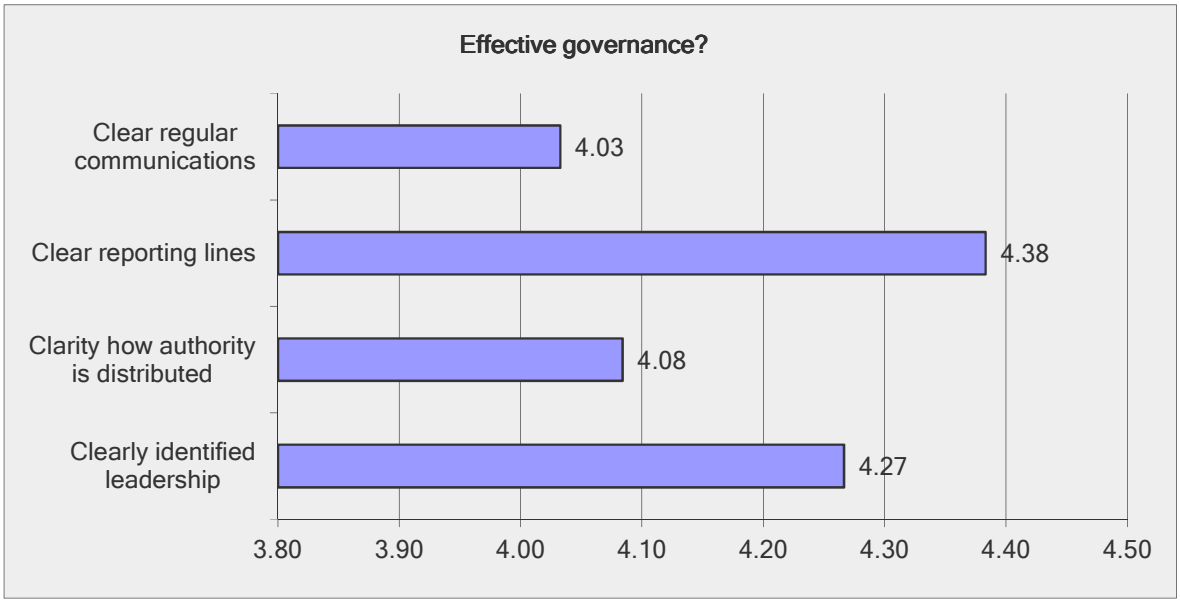


Figure 4-9: Effects of governance towards project success

Question 10: What is the importance of goals and objectives in a project?

The figure below indicate that the most important factors affecting project success in terms of project goals and objectives are firstly, project leardership that has a clear vision. Secondly, goal that are clearly specified and recognised by all stakeholders and lastly, subsidiary objectives that are clearly specified.

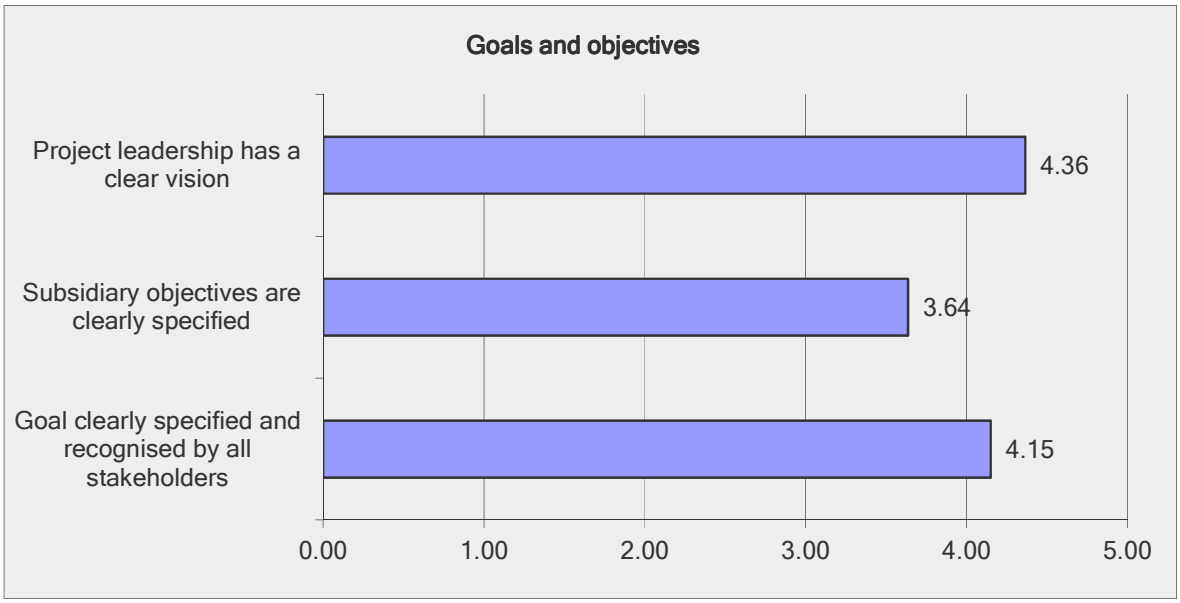


Figure 4-10: Effects of goals and objectives towards project success

Question 11: What is the importance of organisational commitment in projects?

The figure below indicate that the most important factors affecting project success in terms of organisational commitment are firstly, project leardership that maintains commitment and secondly, recorgnizing lack of commitment and dealing with it.

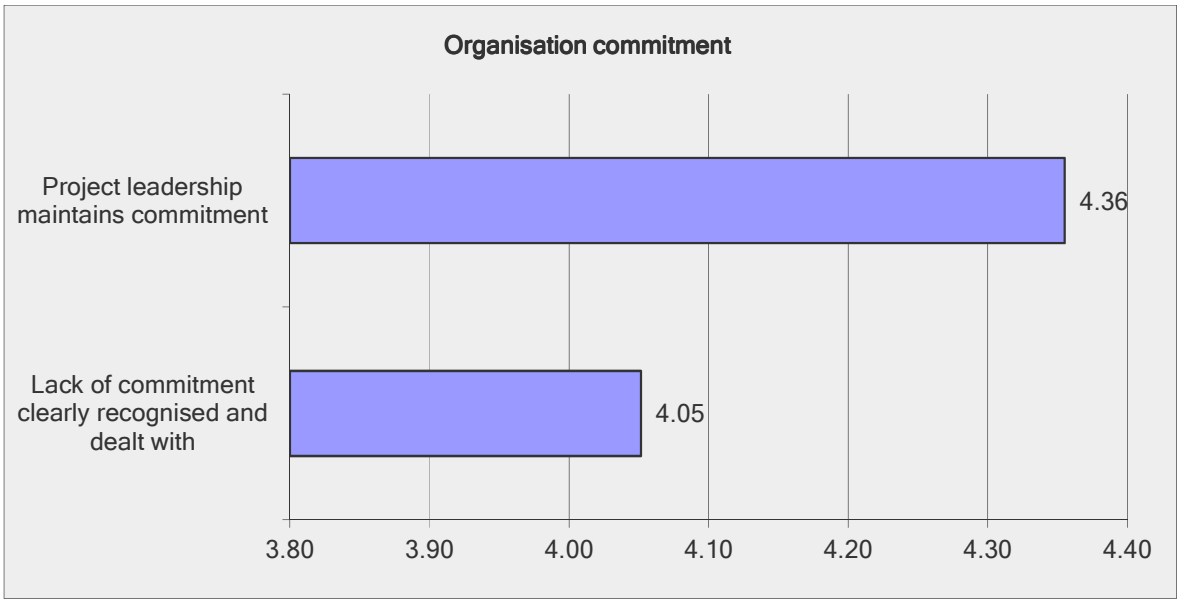


Figure 4-11: Effects of goals and objectives towards project success

Question 12: What is the importance of capable sponsors in project?

The figure below indicate that the most important factors affecting project success in terms of project sponsors capability are firstly, project that has active sponsors. Secondly, project sponsors that have ultimate responsibility and accountability and thirdly, project sponsors that stay in a role for the life cycle of the project.

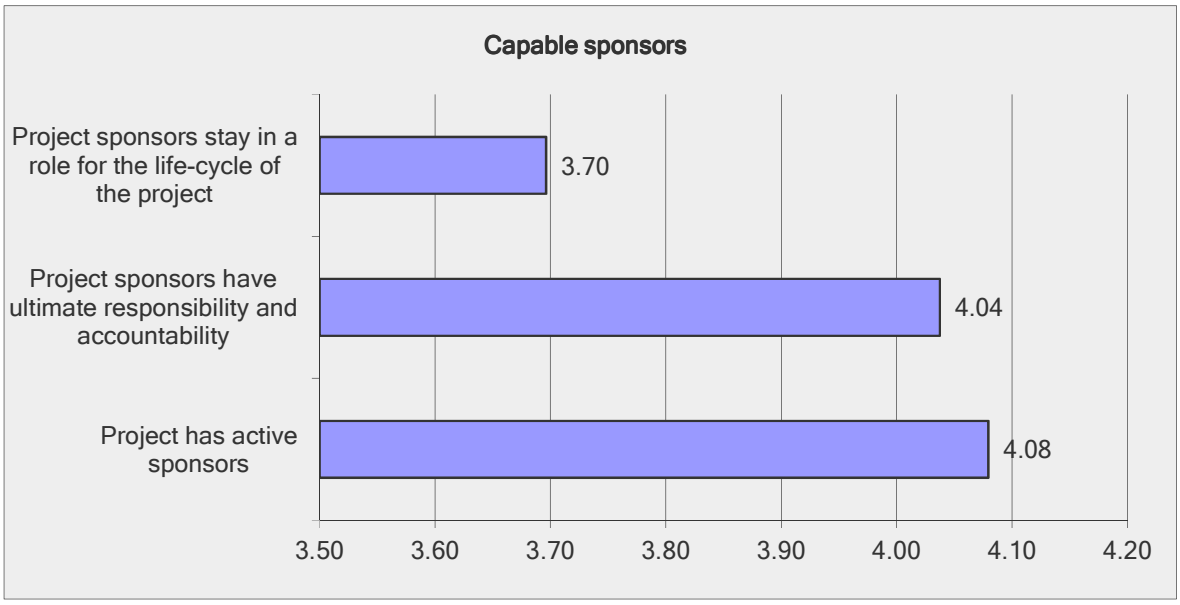


Figure 4-12: Effects of capable sponsors towards project success

Question 13: What is the importance of secure funding in a project?

The figure below indicate that the most important factors affecting project success in terms of secure funding are firstly, project that has a secure funding base. Secondly, tight control of budgets and thirdly, needs for contingency funding that are recognised from the start.

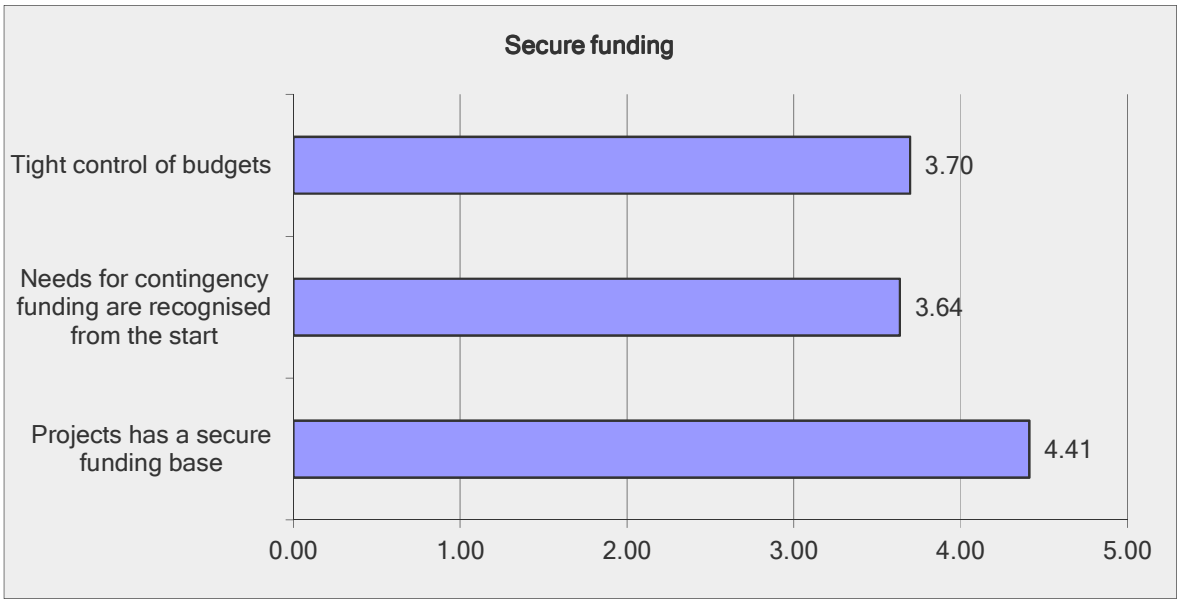


Figure 4-13: Effects of secure funding towards project success

Question 14: What is the importance of project planning and review in a project?

The figure below indicate that the most important factors affecting project success in terms of project planning and review are firstly, flexibility to respond to unforeseen circumstances. Secondly, effectiveness of the early project stages and thirdly, post project review is undertaken.



Figure 4-14: Effects of project planning and review towards a project success

Question 15: What is the importance of supportive organisations in a project?

The figure below indicate that the most important factors affecting project success in terms of organisational support are firstly, project team that has influencing skills to engage. Secondly, organisations that provides embedded support for project activities and thirdly, the environment in which the project operates friendly and hostile.

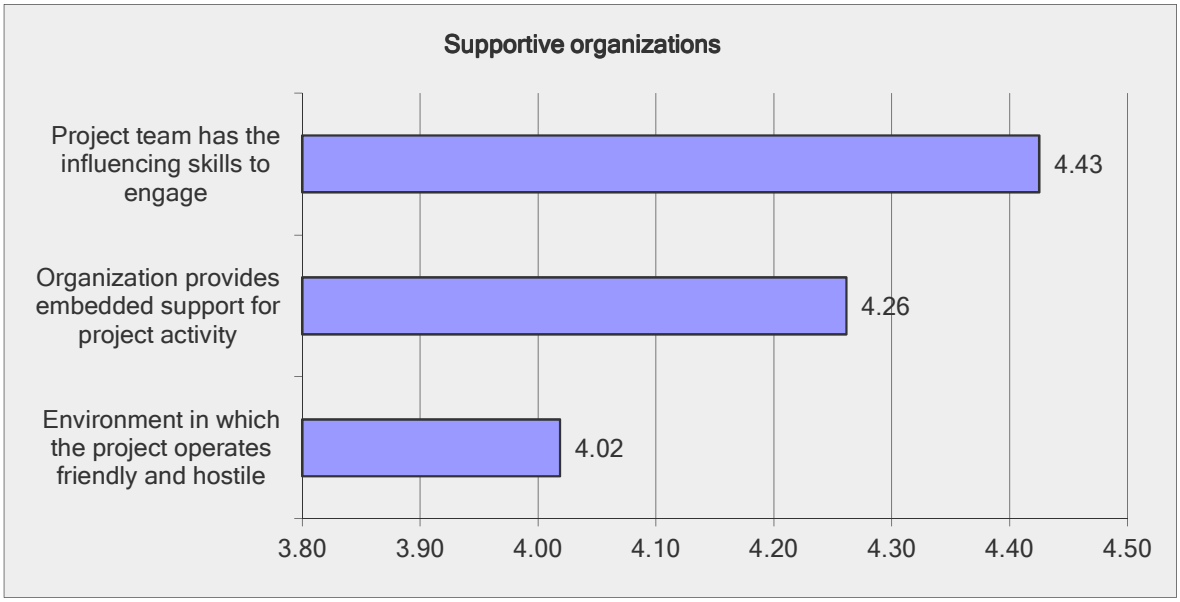


Figure 4-15: Effects of supportive organisations towards project success

Question 16: What is the importance of competent project teams in project?

The figure below indicate that the most important factors affecting project success in terms of competent project teams are firstly, team members that are fully competent in their roles. Secondly, project team that engages in positive behaviours which encourages success and thirdly, project proffesionals that are fully competent.

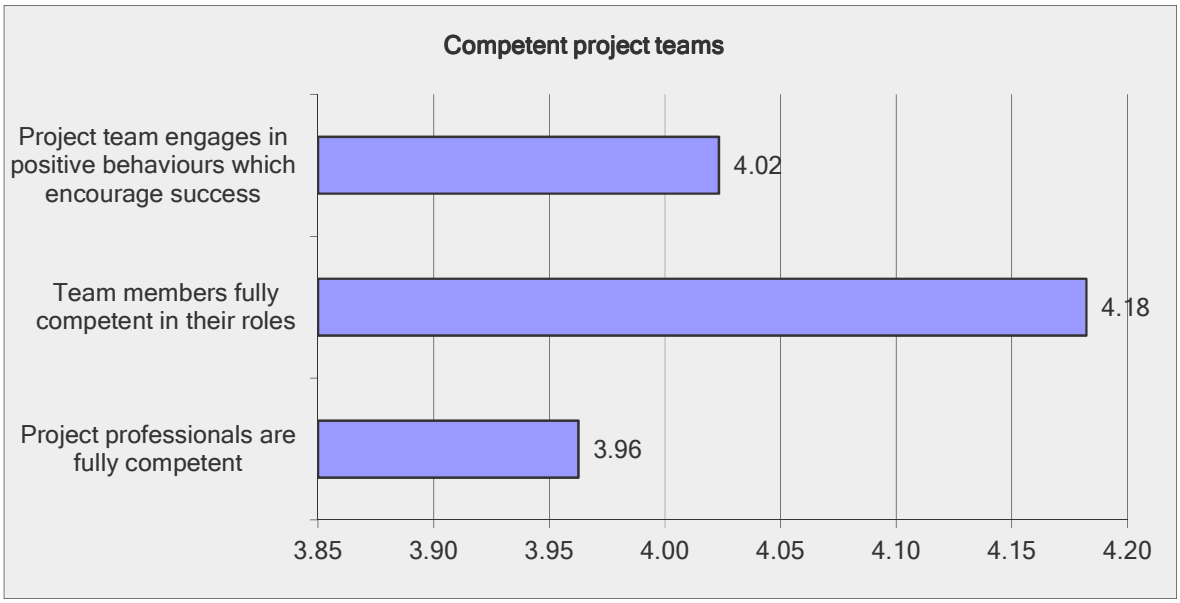


Figure 4-16: Effects of competent project teams on project success

Question 17: What is the importance of aligned supply chain in a project?

The figure below indicate that the most important factors affecting project success in terms of aligned supply chain are firstly, direct and indirect suppliers are aware of project needs and schedules and secondly, tiers of supply chain are co-ordinated.

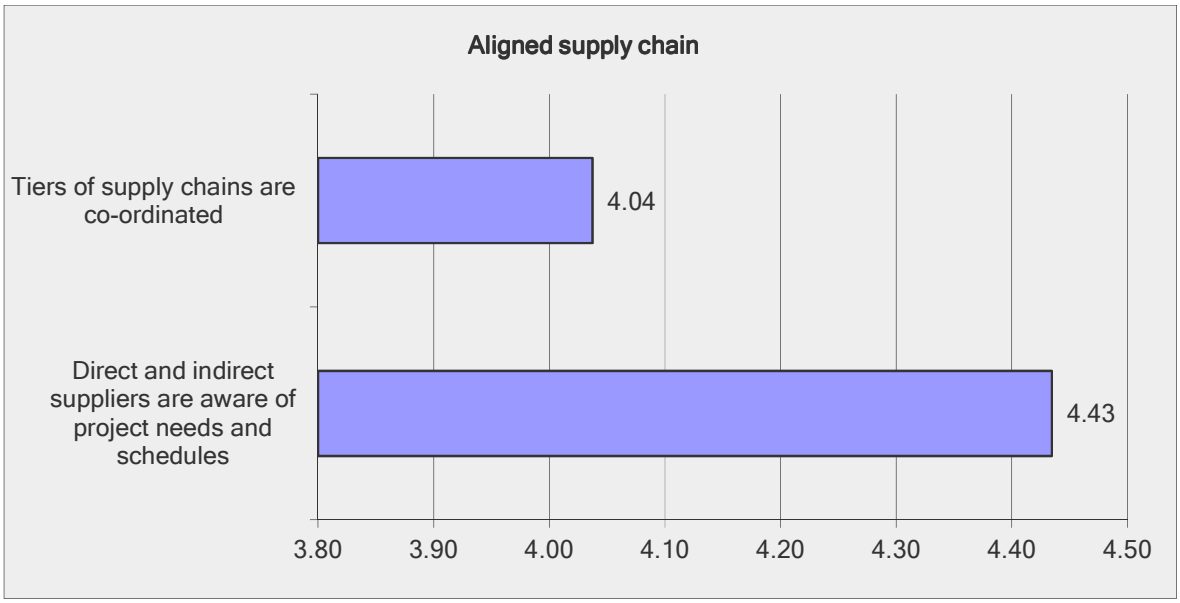


Figure 4-17: Effects of aligned supply chain on project success

Question 18: What is the importance of proven methods and tools in a project?

The figure below indicate that the most important factors affecting project success in terms of proven methods and tools are firstly, project management techniques are applied. Secondly, management tools, methods and techniques are applied and thirdly, maintaining an effective balance between flexibility and robustness.

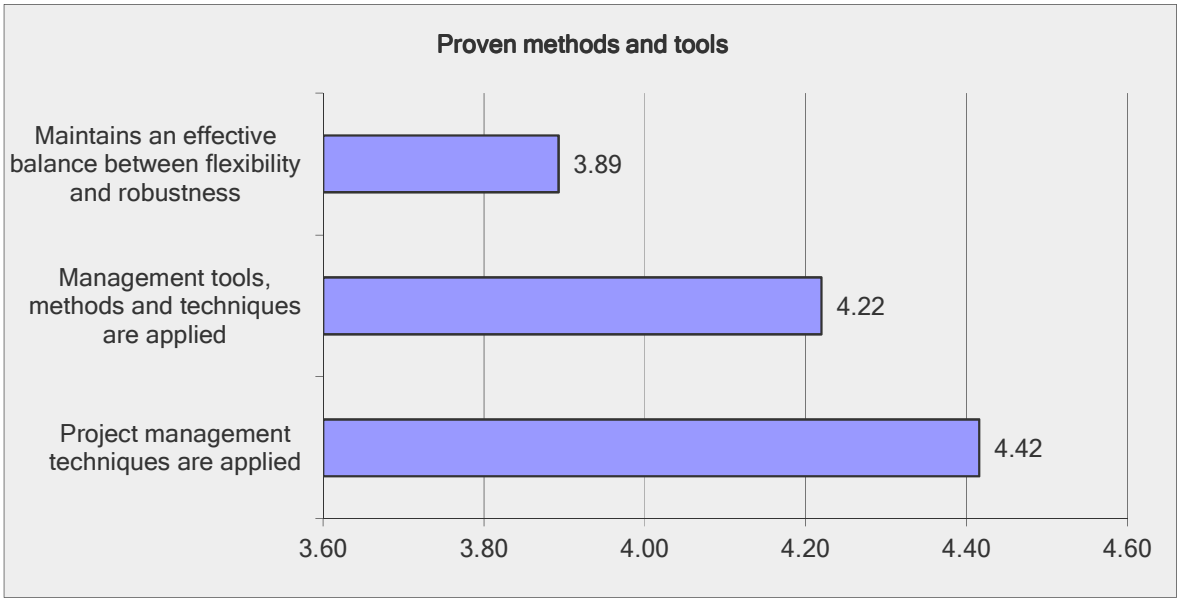


Figure 4-18: Effects of proven methods and tools on project success

Question 19: What is the importance of appropriate standards in a project?

The figure below indicate that the most important factors affecting project success in terms of appropriate standards are firstly, standards are actively used to drive quality of outputs and secondly, adherence to all standards is regurlarly monitored.

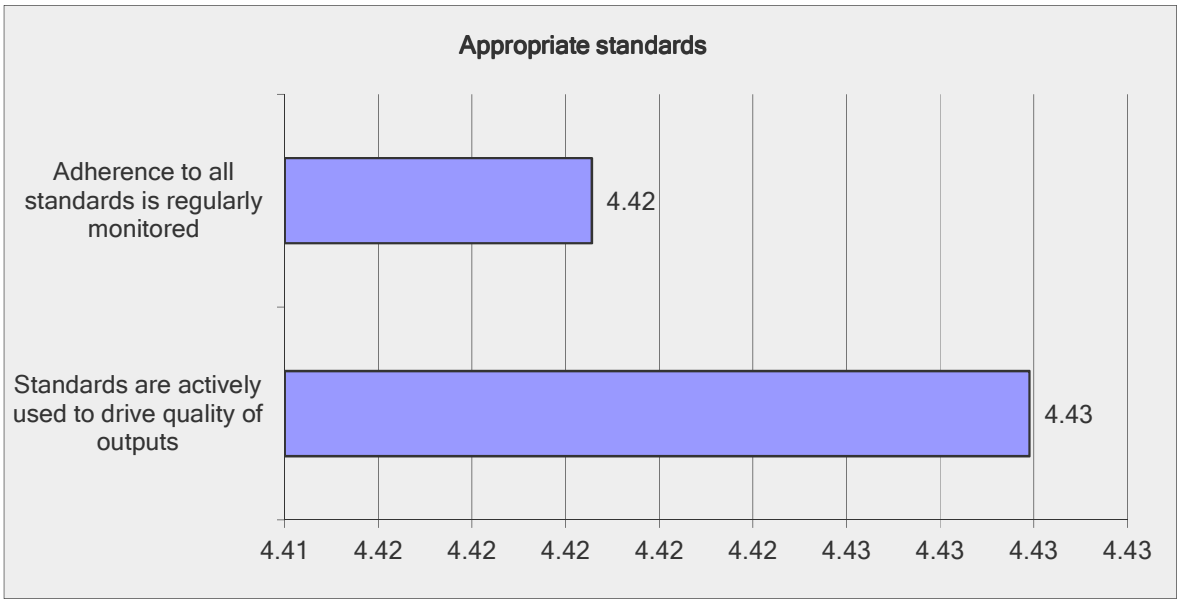


Figure 4-19: Effects of appropriate standards on project success

Question 20: What is the importance of triple constraint in a project?

The figure below indicate that the most important factors affecting project success in terms of triple constraint are firstly, right quality (meeting all specification requirements). Secondly, within duration and thirdly, within cost.

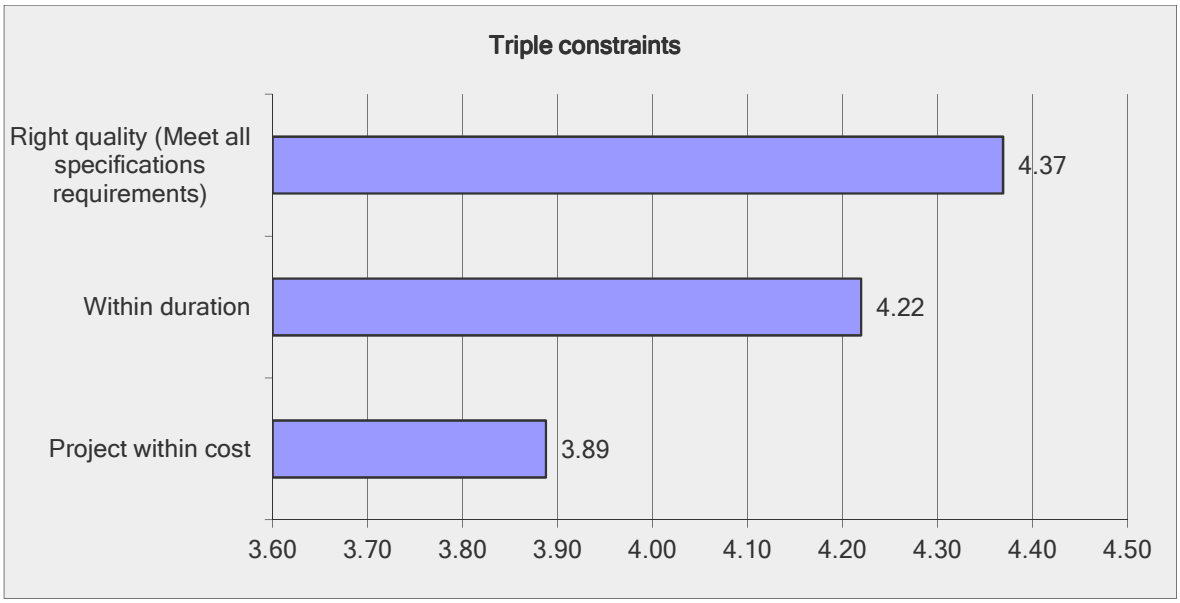


Figure 4-20: Effects of triple constraint on project success

4.5.2 Project failure factors

Project failure factors are those factor that if not addressed will affect the overall of a project. These factors originate from defferent project stackeholders including owners, contractors and consultants.

Question 21: What are the causes of delay by owners?

The figure below indicate that the most important factors causing project delays by owners are firstly,decision making. Secondly, payment of completed work.Thirdly, unrealistic contract duration and owner coordination, and lastly, unclear requirements

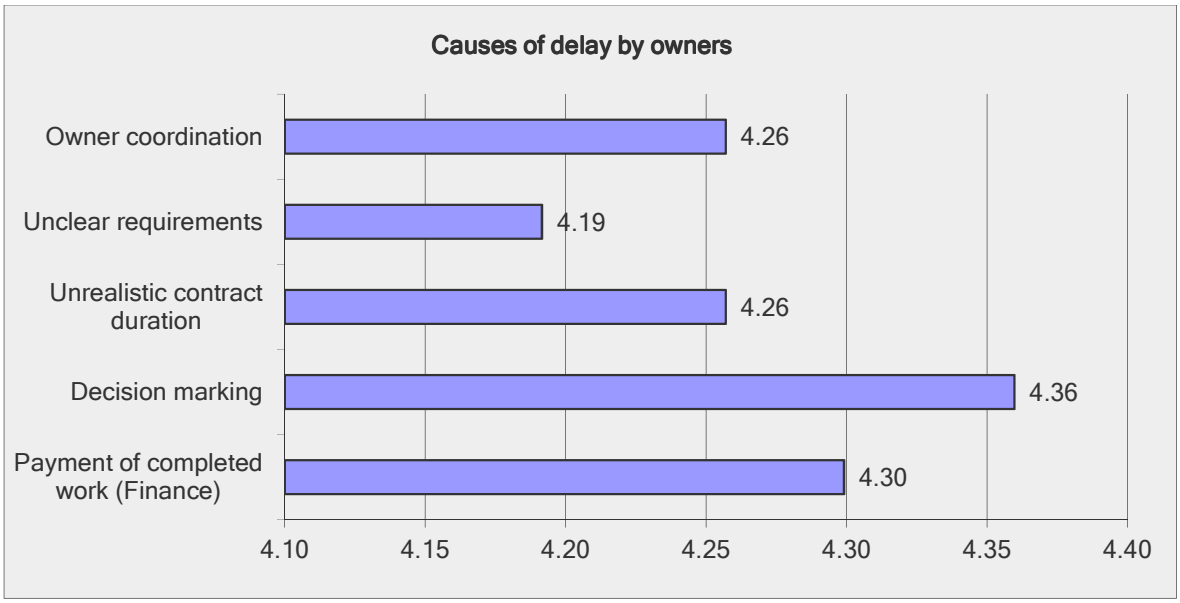


Figure 4-21: Owner causes of project failure/delay

Question 22: What are the causes of delay by contractors?

The figure below indicate that the most important factors causing project delays by contractors are firstly,construction methods. Secondly, site management.Thirdly, subcontracting. Fouthly, proper planning and lastly, lack of experience and construction errors.

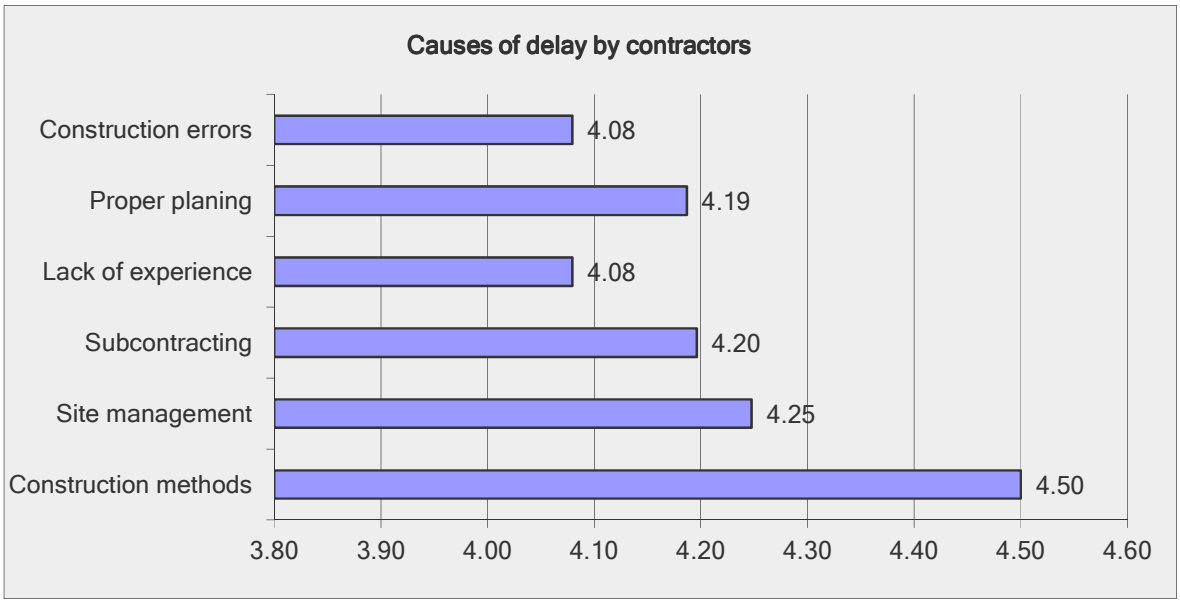


Figure 4-22: Contractor causes of project failure/delay

Question 23: What are the causes of delay by consultant?

The figure below indicate that the most important factors causing project delays by consultants are firstly,waiting time for approvals. Secondly, quality control and assurance .Thirdly, drawing and specification approvals, and lastly, contract management.

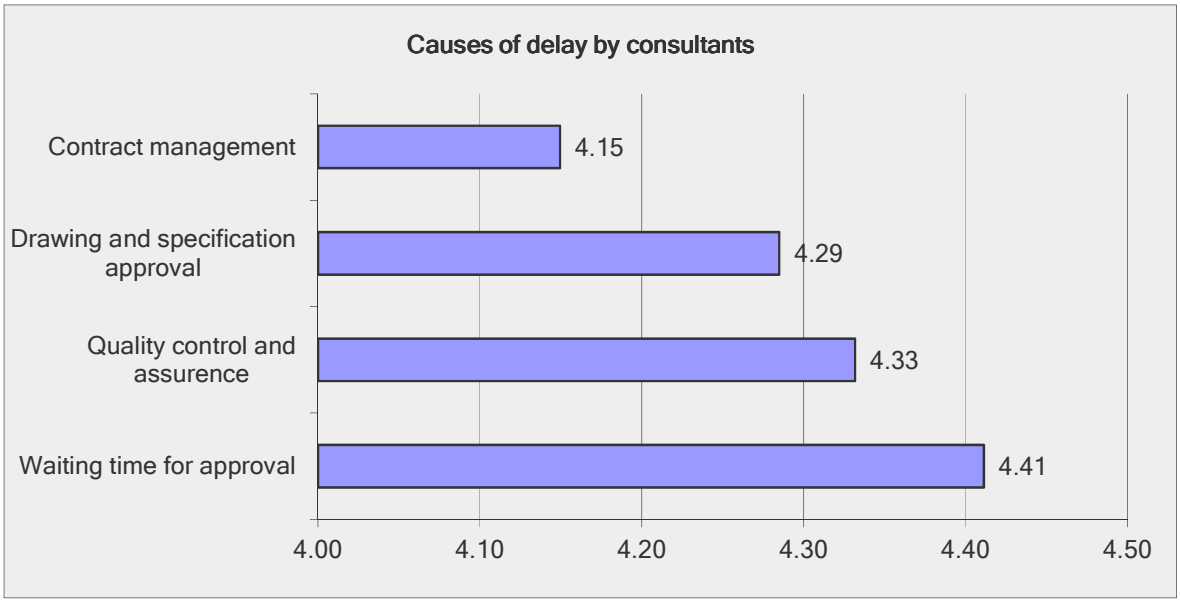


Figure 4-23: Consultants causes of project failure/delay

Question 24: What are the causes of delay by labour and equipment?

The figure below indicate that the most important factors causing project delays by labour and equipment are firstly, material quality and equipment availability. Secondly, labor productivity.Thirdly, material shortage and fouthly, labor supply.

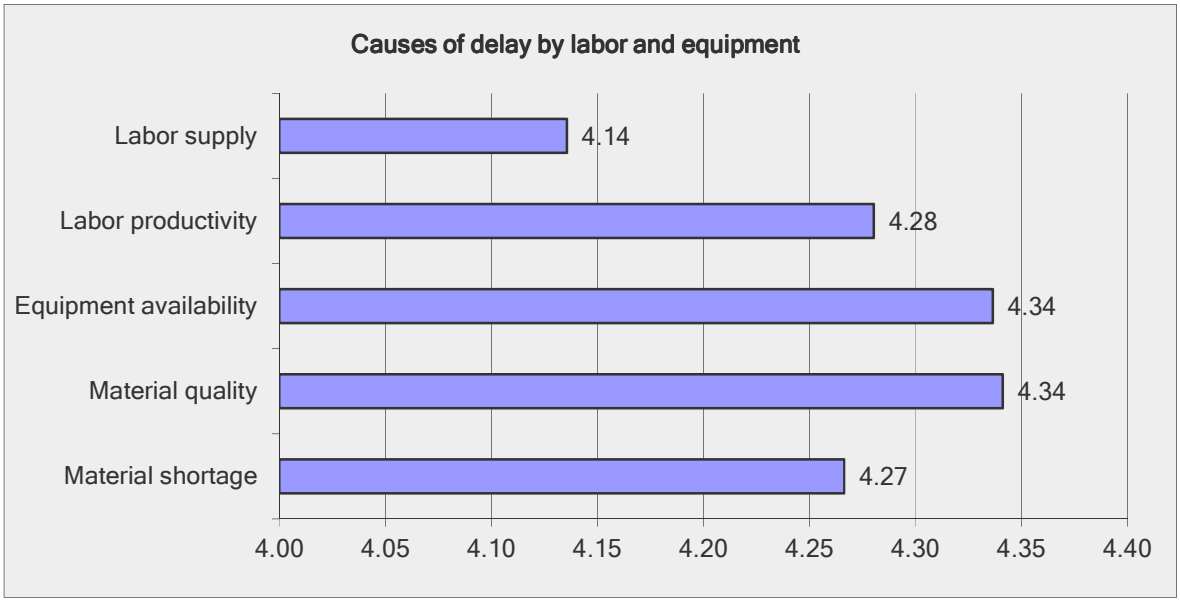


Figure 4-24: Labour and equipment causes of project failure/delay

Question 25: What are the causes of delay by contract relationship?

The figure below indicate that the most important factors causing project delays by contract relationship are firstly, discripancy in contract documents. Secondly, change orders and thirdly, the type of contract used.

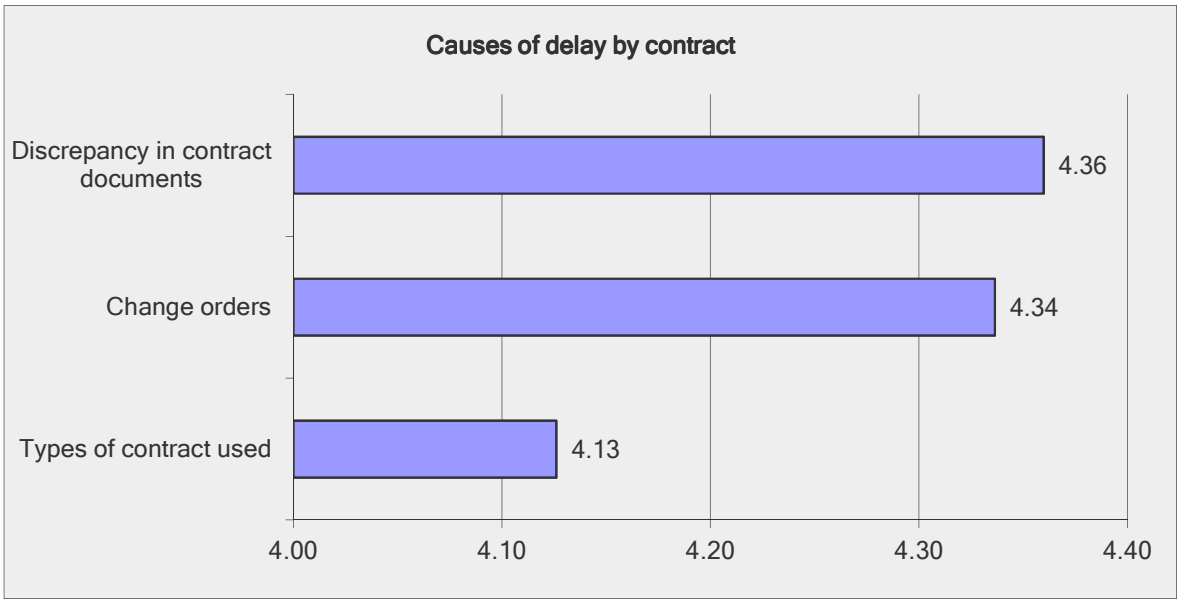


Figure 4-25: Contract causes of project failure/delay

Question 26: What are the causes of delay by contract relationship?

The figure below indicate that the most important factors causing project delays by contract relationships are firstly, inappropriate communication. Secondly, regulatory changes. Thirdly, unfavourable site conditions. Fouthly, disputes and lastly, organisational structure.

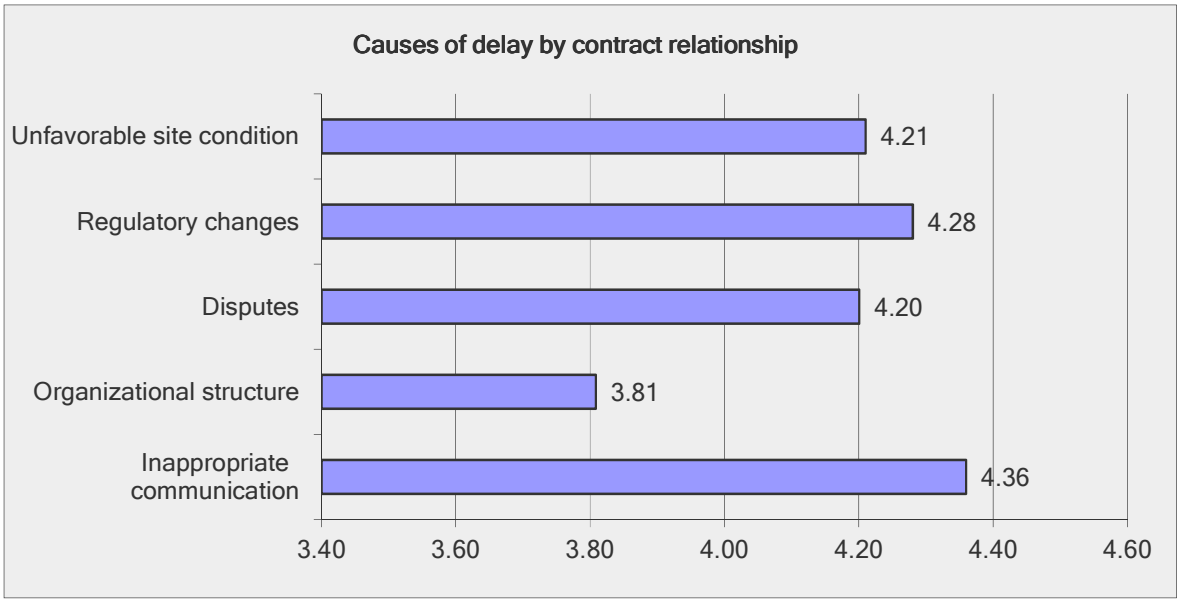


Figure 4-26: Contract relationships causes of project failure/delay

4.5.3 Product success factors

Product success deals with the project's final product. It focuses on the fact that project managers must not only focus on short-term criteria mostly meeting time and cost constraints, but should also focus on long-term objectives such as satisfying requirements and ensuring that the delivered system is fit for purpose and all project stakeholders are satisfied by the product.

Question 27: What are the effects of product value added towards project product success?

The figure below indicate that the most important effects of product value added towards project product success are firstly, improved effitiency of the system. Secondly, improved efficiency in other areas. Thirdly, value for money and fouthly, real benefits outperforms focusted benefits.

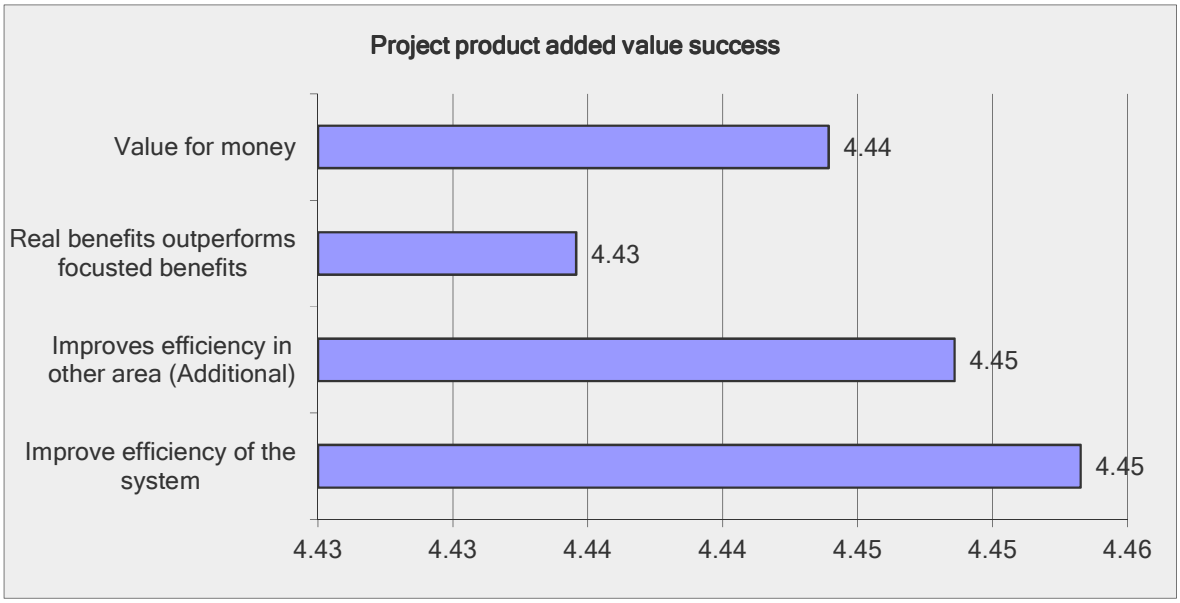


Figure 4-27: Effects of product added value towards project product success

Question 28: What are effects of product user satisfaction towards project product success?

The figure below indicate that the most important effects of product user satisfaction towards project product success are firstly, minor and major upgrades required to improve reliability.

Secondly, adhere to occupational health and safety act. Thirdly, continuous good interaction with the enviroment. Fourthly, all fuctional requirements realised and lastly, not limit other system performence.

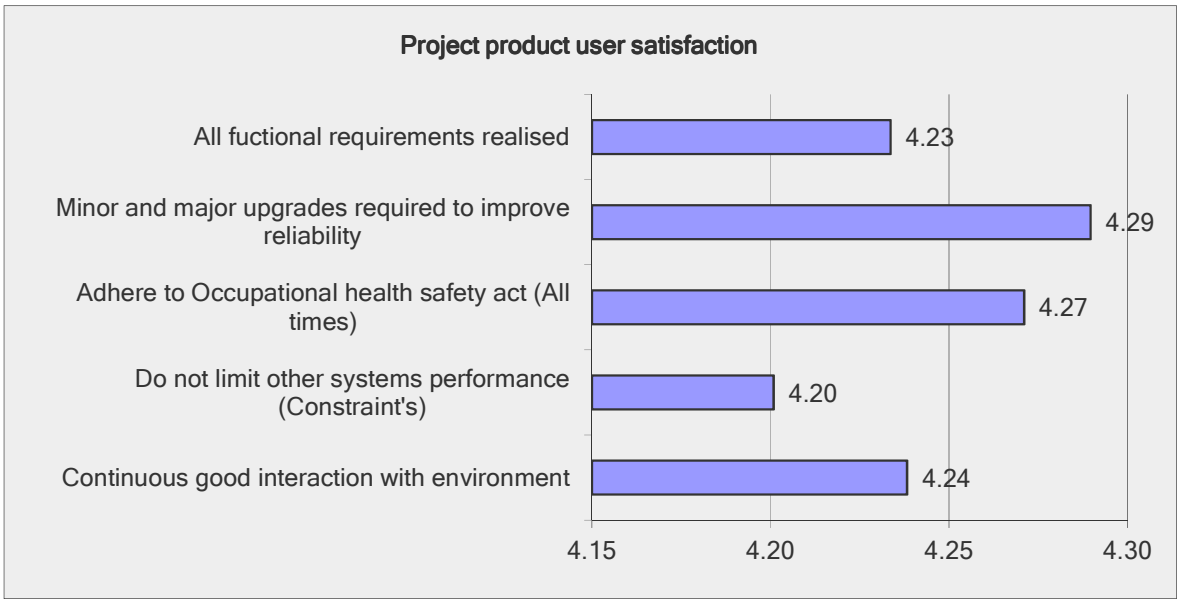


Figure 4-28: Effects of product user satisfaction towards project product success

Question29: What are the effects of project product system on project product success?

The figure below indicate that the most important effects of project product system created towards project product success are firstly, unexpected disruptions beyond the control of project management. Secondly, deficiencies of the predecessor system eliminated and thirdly, no secondary effects to other systems.

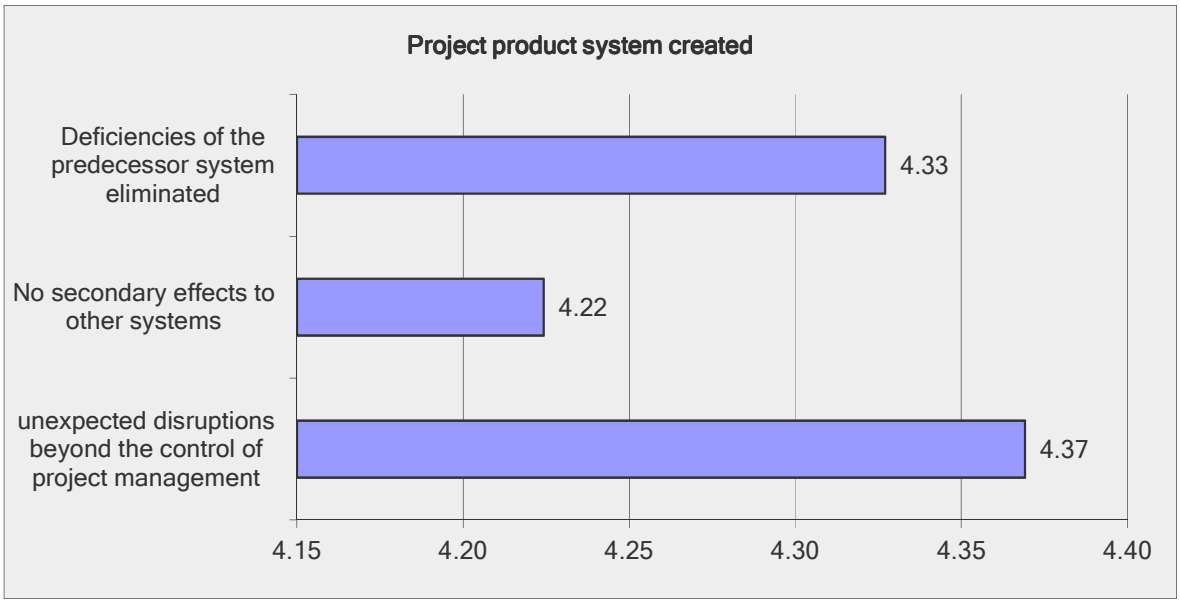


Figure 4-29: Effects of project product system on project product success

Question 30: What are the effects of system experience on project product success?

The figure below indicate that the most important effects of project product system esperienced towards project product success are firstly, within economic life cycle cost. Secondly, recent technology and great cost savings are achieved and thirdly, satisfactory overall equipment effectiveness.

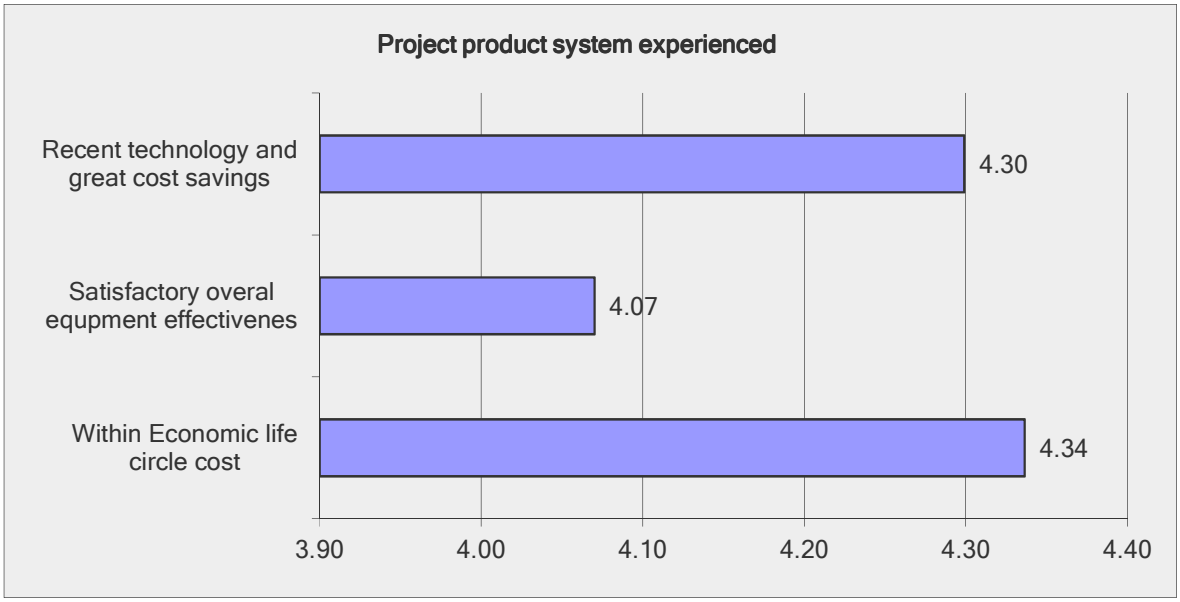


Figure 4-30: Effects of system experience towards project product success

4.5.4 Organisational success factors

Organisations view projects as drivers of change. These are strategic initiatives focusing on improving the probability of the organisation to get closer to its goal. The table below shows the summary of respondents on critical organisational success factors.

Question 31: What are the effects of project product towards project organisational success?

The figure below indicate that the most important effects of project product towards project organisational success are firstly, business benefits are realised. Secondly, strategic benefits are realised. Thirdly, new core competence are realised and fourthly, new organizational capability realised.

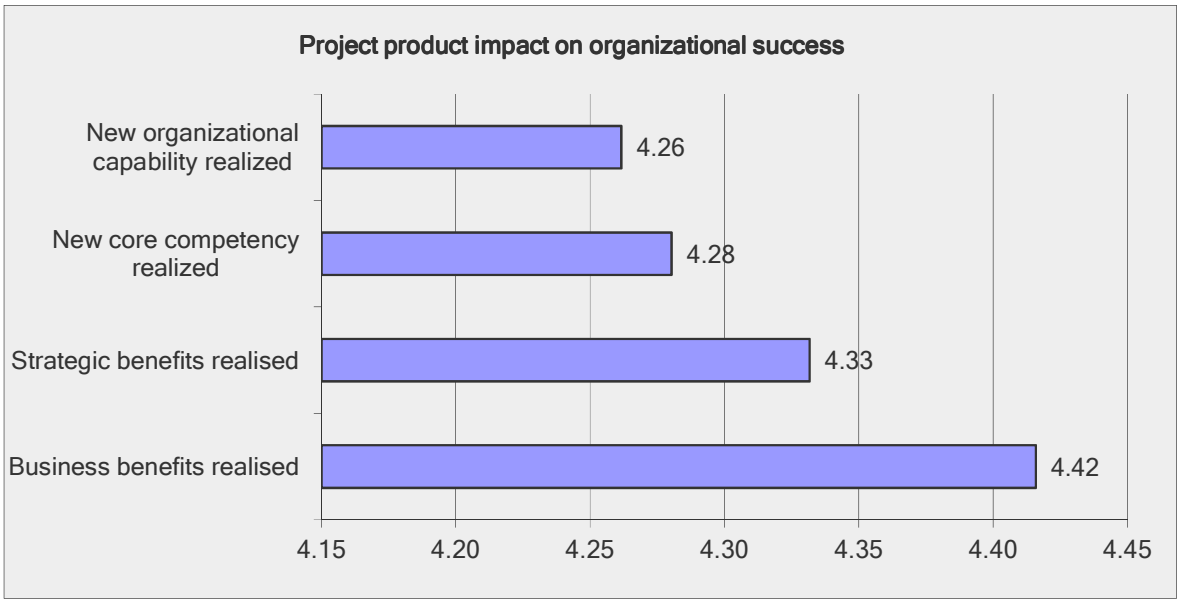


Figure 4-31: Effects of project product towards project organisational success

4.6 Survey results

The results of the survey recognise significant success, failure, product and product success factors identified by the power plant professionals in Chapter 4. These factors were the most significant factors identified to determine project success and their impact will be further investigated in Chapter 5.

4.6.1 Project success

The project data was analysed from the perspectives of owners, contractors, consultants, subcontractors and engineers. Each individual success factor's RII indicated by respondents, was calculated for inclusive exploration. By assigning ranks to each success factor, the project success factors for power plant life cycle projects were identified. The table below shows the ranking of success factors based on the responses of all respondents. The number of respondents who selected a level of importance was grouped in terms of their respective scores. The RII and average score for project success factors were calculated and summarized in the table below.

Table 4-4: Average score for project success factors

Success factors		1	2	3	4	5	R 11	Mean	SD
Effective governance	clearly identified leadership			9	139	66	0.580	4.266	0.162
	clarity how authority is distributed	5	7	12	131	59	0.548	4.084	
	clear reporting lines			2	128	84	0.712	4.383	
	clear regular communications	10	15	5	112	72	0.657	4.033	
Goals and objectives	Goal clearly specified and recognised by all stakeholders	3	1	17	133	60	0.557	4.150	0.374
	Subsidiary objectives are clearly specified	14	24	23	118	35	0.417	3.636	
	Project leadership has a clear vision	2			128	84	0.708	4.364	
Commitment	lack of commitment clearly recognised and dealt with	12	16	3	101	82	0.739	4.051	0.154
	Project leadership maintains commitment	2		1	128	83	0.703	4.355	
Capable sponsors	Project has active sponsors			28	141	45	0.457	4.079	0.214
	Project sponsors have ultimate responsibility and accountability	2	3	14	161	34	0.333	4.037	
	Project sponsors stay in a role for the life-cycle of the project	10	24	13	141	26	0.309	3.696	
Secure funding	Project has a secure funding base			1	124	89	0.751	4.411	0.431
	Needs for contingency funding are recognised from the start	21	17	18	121	37	0.413	3.636	
	Tight control of budgets	7	15	38	130	24	0.343	3.696	
Project planning	First, start-off, phase of the project is effective	2	4	15	157	36	0.354	4.033	0.191
	Pre-project planning is thorough and considered			1	119	94	0.793	4.435	
	Regular and careful progress (time, scope, cost) monitoring				144	70	0.589	4.327	

	Realistic time schedules	3	5	7	154	45	0.410	4.089	
	Active risk management	8	0	4	141	61	0.532	4.154	
	Flexible to respond to unforeseen			1	136	77	0.650	4.355	
	Post-project review is undertaken (lessons for the future)	2	1	2	127	82	0.699	4.336	
Supportive organisations	Environment in which the project operates friendly and hostile	11	2	19	122	60	0.572	4.019	0.204
	Organisation provides embedded support for project activity	1	1	10	131	71	0.628	4.262	
	Project team has the influencing skills to engage				123	91	0.765	4.425	
Competent project teams	Project professionals are fully competent	8	7	19	131	49	0.486	3.963	0.113
	Team members fully competent in their roles	3	2	8	141	60	0.534	4.182	
	Project team engages in positive behaviours which encourage success		0	29	151	34	0.367	4.023	
Aligned supply chain	Direct and indirect suppliers are aware of project needs and schedules				121	93	0.782	4.435	0.28
	Tiers of supply chains are co-ordinated	4	8	16	144	44	0.434	4.037	
Proven methods and tools	Project management techniques are applied	3	2	2	103	104	0.887	4.416	0.264
	Management tools, methods and techniques applied		8	3	137	66	0.579	4.220	
	Maintains an effective balance between flexibility and robustness	14	17	13	104	66	0.636	3.893	
Appropriate standards	Standards are actively used to drive quality of outputs	1	1	3	110	99	0.844	4.430	
	Adherence to all standards is regularly monitored			5	114	95	0.813	4.421	0.006

Spearman's rank correlation coefficient was used to measure the degree of agreement between groups. A positive correlation was shown, which indicate that there is a significant relationship at 0.05 level (2 tailored)

Table 4-5: Spearman's correlation (project success factors)

Critical project success factors			**Owner**	**Engineer**	**Contractor**	**Consultant**
Spearman's rho	**Owner**	Correlation coefficient	1	0.7468.	0.9456	0.704
		Sig (2 tailored)		0.00482.	0.03739.	0.01739
		N	214	214	214	214
	Engineer	Correlation coefficient	0.5867.	1	0.6134	0.7134
		Sig (2 tailored)	0.0192.	0.00321.	0.00482.	0.00282.
		N	214	214	214	214
	Contractor	Correlation coefficient	0.4531	0.5123	1	0.6312
		Sig (2 tailored)	0	0	0	0

		N	214	214	214	214
	Consultant	Correlation coefficient	0.461	0.782	0.631	1
		Sig (2 tailored)	0.0292	0.00891	0.0569	0.00432
		N	214	214	214	214

4.6.2 Project delay/failure

Data analysis was done in respect of all stakeholders. Each individual delay or failure factor RII specified by respondents was calculated for inclusive exploration. By assigning ranks to each success/delay factor, the project failure factors for power plant life cycle projects were identified. The RII and average scores for project failure factors were calculated and are summarized in the table below.

Table 4-6: Average score for project failure factors

Causes of project failure/delay		**1**	**2**	**3**	**4**	**5**	**R 11**	**Mean**	**SD**
Owners	Payment of completed work (Finance)	2	2	3	130	77	0.662	4.299	0.061
	Decision making	4	3	5	102	100	0.864	4.360	
	Unrealistic contract duration	4	4	2	117	85	0.732	4.257	
	Unclear requirements	8	6	4	115	81	0.711	4.192	
	Owner coordination	4	3	5	124	78	0.679	4.257	
Contractors	Construction methods			1	105	108	0.911	4.500	0.155
	Site management	2	5	17	104	86	0.782	4.248	
	Subcontracting		10	18	106	80	0.742	4.196	
	Lack of experience	5	11	23	98	77	0.737	4.079	
	Proper planning	2	5	25	101	81	0.763	4.187	
	Construction errors	4	3	28	116	63	0.618	4.079	
Consultants	Waiting time for approval		5	4	103	102	0.879	4.411	0.109
	Quality control and assurance				143	71	0.597	4.332	
	Drawing and specification approval			16	121	77	0.693	4.285	
	Contract management		3	18	137	56	0.527	4.150	
Labour and equipment	Material shortage		3	3	142	66	0.569	4.266	0.083
	Material quality	1	1	13	108	91	0.805	4.341	
	Equipment availability	5	3	5	103	98	0.849	4.336	
	Labour productivity	5	2	13	102	92	0.819	4.280	
	Labour supply			43	99	72	0.726	4.136	
Contract	Errors in contract documents	7	4	25	97	81	0.765	4.336	0.016
	Change order			17	108	89	0.796	4.360	
Contract relationship	Inappropriate communication	4	2	5	105	98	0.846	4.360	0.213
	Organisational structure	11	17	18	124	44	0.463	3.808	
	Disputes	1	2	16	129	66	0.605	4.201	
	Regulatory changes			5	144	65	0.561	4.280	

	Unfavourable site condition	2	4	5	139	64	0.562	4.210	

Spearman's rank correlation coefficient was used to measure the degree of agreement between groups. A positive correlation was shown, which indicates that there is a significant relationship at 0.05 level (2 tailed)

Table 4-7: Spearman's correlation (constraint/failure/delay factors)

Constraint/failure/delay factors			Owner	Engineer	Contractor	Consultant
Spearman's Rho	**Owner**	Correlation coefficient	1	0.451	0.557	0.615
		Sig (2 tailored)		0.00478	0.0479	0.0474
		N	214	214	214	214
	Engineer	Correlation coefficient	0.601	0.713	0.652	0.781
		Sig (2 tailored)	0.0595	0.00518	0.00402.	0.0049
		N	214	214	214	214
	Contractor	Correlation coefficient	0.698	0.673	1	0.662
		Sig (2 tailored)	0.0445	0.00568	0.00452.	0.0594
		N	214	214	214	214
	Consultant	Correlation coefficient	0.661	0.608	0.5901	1
		Sig (2 tailored)	0.0292	0.00891	0.0569	0.00432
		N	214	214	214	214

4.6.3 Project product success factor (project deliverable)

Data analysis was done in respect of all stakeholders. Each individual project product success factor RII specified by respondents were calculated for inclusive exploration. By assigning ranks to each project product success factor, the project product success factors for power plant life cycle projects were identified. The RII and average scores for project product success factors were calculated and are summarised in the table below.

Table 4-8: Average score for product success factors

Product success factors		1	2	3	4	5	R 11	Mean	SD
Added value success	Improves efficiency in other areas (additional)	1	2		107	104	0.8794	4.453	0.03
	Real benefits outperform focused benefits		4	1	104	105	0.8935	4.449	
User satisfaction	Continuous good interaction with environment		4	8	135	67	0.5935	4.238	0.034
	Do not limit other systems' performance		7	11	128	68	0.6159	4.201	
	Adhere to the Occupational Health Safety Act	1	4	8	124	77	0.6785	4.271	
	Minor and major upgrades required to improve reliability	5	7	7	97	98	0.8617	4.29	
	All functional requirements realised	2	7	8	119	78	0.6935	4.234	
System created	unexpected disruptions beyond the control of project management	1	3	10	102	98	0.8589	4.369	0.074
	No secondary effects to other systems	8	4	4	114	84	0.7327	4.224	
	Deficiencies of the predecessor system eliminated	3	4	1	118	88	0.7533	4.327	
System experienced	Within economic life cycle cost	6	5	1	101	101	0.8673	4.336	0.144
	Satisfactory overall equipment effectiveness	1	2	22	145	44	0.4364	4.07	
	Recent technology and great cost savings			13	124	77	0.6841	4.299	

Spearman's rank correlation coefficient was used to measure the degree of agreement between groups. A positive correlation was shown, which indicate that there is a significant relationship at 0.05 level (2 tailored)

Table 4-9: Spearman's correlation (product success factors)

Critical product success factors			Owner	Engineer	Contractor	Consultant
Spearman's Rho	**Owner**	Correlation coefficient	1	0.669	0.865	0.724
		Sig (2 tailored)		0.00592	0.0389	0.0449

		N	214	214	214	214
	Engineer	Correlation coefficient	0.5934	1	0.6134	0.694
		Sig (2 tailored)	0.0692	0.00552	0.00634.	0.02342
		N	214	214	214	214
	Contractor	Correlation coefficient	0.673	0.634	1	0.573
		Sig (2 tailored)	0	0	0	0
		N	214	214	214	214
	Consultant	Correlation coefficient	0.511	0.802	0.714	1
		Sig (2 tailored)	0.0398	0.0567	0.0381	0.00432
		N	214	214	214	214

4.6.4 Organisational success

Data analysis was done in respect of all stakeholders. Each individual organisational success factor RII specified by respondents was calculated for inclusive exploration. By assigning ranks to each organisational success factor, the project organisational success factors for power plant life cycle projects were identified. The RII and average score organisational success factors were calculated and are summarised in the table below.

Table 4-10: Business success factors

Business success factors		**1**	**2**	**3**	**4**	**5**	**R 11**	**Mean**	**SD**
Organisational success	Business benefits realised	1	1	8	102	102	0.8832	4.41589	0.068
	Strategic benefits realised	1	7	10	98	98	0.8664	4.33178	
	New core competency	2	5	10	101	94	0.8299	4.28037	
	New organisational capability	4	2	17	102	89	0.8037	4.26168	

Spearman's rank correlation coefficient was used to measure the degree of agreement between groups. A positive correlation was shown, which indicate that there is a significant relationship at 0.05 level (2 tailored)

Table 4-11: Spearman's correlation (product success factors)

Critical organisational success factors			**Owner**	**Engineer**	**Contractor**	**Consultant**
Spearman's Rho	**Owner**	Correlation coefficient	1	0.716	0.914	0.594
		Sig (2 tailored)		0.00445	0.04456	0.0298
		N	214	214	214	214
	Engineer	Correlation coefficient	0.8102	1	0.6935	0.7945
		Sig (2 tailored)	0.0692.	0.00341.	0.00479	0.00337
		N	214	214	214	214

	Contractor	Correlation coefficient	0.6531	0.534	1	0.773
		Sig (2 tailored)	0.0442.	0.00357.	0.00597	0.00436
		N	214	214	214	214
	Consultant	Correlation coefficient	0.711	0.812	0.721	1
		Sig (2 tailored)	0.0345	0.00951	0.00669	0.00488
		N	214	214	214	214

4.7 Discussion of the results

An RII of 0.70 and a mean of 4.2 were used to identify critical project success factors as shown in the table below.

4.7.1 Critical success factors

The results of the critical success factors obtained from the survey are summarised in the table below:

Table 4-12: Critical project success factors

Project success factors	RII	Mean
Clear reporting lines	0.712	4.383
Project leadership has a clear vision	0.708	4.364
Project has active sponsors	0.739	4.355
Project has a secure funding base	0.751	4.411
Pre-project planning is thorough and considered	0.793	4.435
Project team has the influencing skills to engage	0.765	4.425
Direct and indirect suppliers are aware of project	0.782	4.435
Project management techniques are applied	0.887	4.416
Standards are actively used to drive quality of outputs	0.844	4.430
Right quality (meet all specifications requirements)	0.813	4.421

The five critical success factors identified for further analysis are:

(a) **S1: Project management techniques are applied** – project management tools and techniques make it easy for project managers to plan, organise, co-ordinate, direct and control the combined efforts in order to achieve project success. Project management tools and techniques include work breakdown structures, work accounts, work authorisation processes, schedule planning and financial planning.

(b) **S2: Standards are actively used to drive quality of outputs** – project management requires a process to ensure that the project will fulfill the purpose for which it was undertaken. This includes activities of the overall management function that determine the quality policy, objectives, and responsibilities, and implements them through means

such as quality planning, quality control, quality assurance, and quality improvement, within the quality system.

(c) **S3: Regular and careful progress monitoring** – progress monitoring requires that time should to be taken to plan all aspects of the project, because it saves time and resources later and improves expected project results.

(d) **S4: Pre-project planning is thorough and considered** – project management industry practitioners have long recognised the importance of pre-project planning and its potential impact on project success. Previous researchers have discovered that there is a positive relationship between thorough pre-project planning and enhanced project performance.

(e) **S5: Direct and indirect suppliers are aware of project** – material procurement is an important part of projects due to increased project complexity, changing roles and interactions. The material and construction contracts are normally signed very early during project development, when the chances of unforeseen contingencies are considerable.

4.7.2 Critical delay factors

The delay factors shown in the table below were identified for further analysis

Table 4-13: Project constraint/delay/failure factors

Constrain/delay/failure factors	RII	Mean
Decision making by owners	0.864	4.360
Construction methods by contractors	0.911	4.500
Waiting time for approval consultants	0.879	4.411
Material quality	0.805	4.341
Type of contract used	0.796	4.360
Inappropriate communication	0.846	4.360

The five critical delay/failure factors identified for further analysis are:

(a) **F1: Construction methods by contractors** - project success or failure can be determined by choosing an appropriate project delivery method. Certain methods are not available for certain projects due to variation in state and local regulations. The most forms of construction include design-build, job-order contracting, contractor prequalification, multi prime and best value selection.

(b) **F2: Waiting time for approval consultants** – a literature review of various experts in the field of project management and system engineering confirmed that incomplete

drawings and contract document discrepancies are major causes of project delays, with most being associated with incomplete drawings which require extensive changes and approvals during construction. In the 21st century, most organisations transferred the design responsibility to consultants who are responsible for the design management of the project.

(c) **F3: Decision making by owners** – in project management, critical or non-critical decisions are taken on a daily basis improving the probability of success or failure, but owners have more responsibility and accountability. To ensure unbiased critical decision making requires that complete and accurate data is obtained and logically examined.

(d) **F4: Inappropriate communication** – most project management authors have noted that ineffective communication had a negative impact on successful project execution. The reality is that most projects lack effective communication management, resulting major economic impact. Well thought-out communication strategies and tools designed to manage information are needed for execution.

(e) **F5: Material quality** – Many projects throughout the world are exposed to material quality problems, which require organisations to understand their supplier performance in order to be successful. Due to globalization, companies are supplying materials internationally where error correction becomes difficult or impossible, which requires a fist-time approach towards supply chain and quality management.

4.7.3 Product success factors

The product success factors in the table below were identified for further analysis

Table 4-14: Project product (deliverable) success factors

Product success factors	RII	Mean
Value for money	0.867	4.336
Unexpected disruptions beyond the control of project management	0.859	4.369
Improve efficiency of the system	0.879	4.453
Minor and major upgrades required to improve reliability	0.862	4.290
Satisfactory overall equipment effectiveness	0.893	4.449

The five critical project product success factors identified for further analysis are:

(a) **P1: Value for money** – organisations invest money in projects in order to generate money for an intended period. Value for money invested commonly referred to as return

on investment is important for all project owners. Various researchers have discovered that most projects are executed consuming organisational resources with no benefits to show.

(b) **P2: Improve efficiency of the system** – improving project, product or business efficiencies is important due to improved competition. Organisations that are highly efficient compete easily while inefficient organisations mostly face liquidation. Improving efficiency by developing smooth running systems, include improving quality, improving process and system bottlenecks, reducing downtime and lead times, simplifying, measuring and monitoring system performance.

(c) **P3: Satisfactory overall equipment effectiveness** –**e**nsuring that the system satisfies the overall performance requirements. This means that the overall design function focused on achieving a balanced system devised to provide a practical, holistic solution to the challenge of meeting the project, product or organisation's needs.

(d) **P4: Minor and major upgrades required to improve reliability** – advanced technology provides a wealth of information that allow users to better maintain plant equipment. New products featuring integrated electrical controls are introduced almost daily, but these innovations make legacy equipment seem antique. Adding new system functionalities to existing plant systems can enhance the equipment's function and extend its service life.

(e) **P5: Unexpected disruptions beyond the control of project management** –project manager's performance must include deliverable performance because the success of a product is inseparably linked. This will insure that critical requirements during project execution are attended.

4.7.4 Organisational success factors

The organisational success factors in the table below were identified for further analysis

Table 4-15: Critical organisational/corporate success factors

Organisational/corporate success factors	RII	Mean
Business benefits realised	0.883	4.416
Strategic benefits realised	0.866	4.332
New core competency	0.830	4.280
New organisational capability	0.804	4.262

The four critical organisation/corporate success factors identified for further analysis are:

(a) **Q1: Business benefits realized** – companies undertake projects and change programmes to deliver benefits, but they are often criticized for failing to achieve them. Studies show that over 70% of business improvement projects fail to deliver their expected benefits and even when they are achieved in part, they are often far from fully realised.

(b) **Q2: Strategic benefits realised** – in a highly competitive internal organisational landscape, sponsors and project managers need to present the business case for their projects in order to position the benefits of their proposal against the other potential projects in the portfolio. They must also provide evidence of a clear linkage to the strategic direction of the business.

(c) **O3: New core competency realised** – organisations developed measures that delivered project competency to reduce waste and maximise efficiency. These competencies must be objectively measured to ensure that organisational capabilities are realised.

(d) **O4: New organisational capability realised** – Most researchers indicate that delivering projects that are aimed at implementing strategy, remains a challenge for most organisations. The purpose of strategy is to change an organisation's trajectory and the project linked to the strategy must contribute a fair share in doing just that.

4.8 Critical factors and constraint statistical analysis

Further statistical tests were performed on the critical success factors and constraints identified in the results below. The one-way ANOVA and T-test were performed and results are recoded below.

4.8.1 One-way ANOVA

The one-way ANOVA tests for independent measures are designed to compare the means of four samples as follows:

1 = Owner
2 = Consultant
3 = Contractor
4 = Engineer

Project success

The table below indicates the project success factors for the four groups.

Table 4-16: Critical project success factors for the four groups

	Treatments				
	1	**2**	**3**	**4**	**Total**
N	5	5	5	5	20
ΣX	17.88	20.4	17.58	20.58	76.44
Mean	3.576	4.08	3.516	4.116	3.822
ΣX^2	63.962	83.254	61.827	84.719	293.763
Std. dev	0.0764	0.075	0.0823	0.055	0.291

The table below indicates the result details

Table 4-17: Critical project success factors result details

Source	**ss**	**df**	**ms**	
Between treatments	1.5358	3	0.5119	F = 111.651
Within treatments	0.0734	16	0.0046	
Total	1.6091	19		

The f-ratio value is 111.65104. The p-value is < .00001. The result is significant at p < .05.

Product success factors

The table below shows the product success factor results for the four groups.

Table 4-18: Critical product success factors for the four groups

	Treatments				
	1	**2**	**3**	**4**	**Total**
N	5	5	5	5	20
ΣX	17.23	19.72	16.95	20.03	73.93
Mean	3.446	3.944	3.39	4.006	3.697
ΣX^2	59.417	77.818	57.517	80.297	275.049
Std. Dev	0.1029	0.1031	11.92	0.1194	0.305

The table below shows the product success factor results:

Table 4-19: Critical product success factor results

Source	ss	df	ms	
Between treatments	1.5687	3	0.5229	F=44.093
Within treatments	0.1988	16	0.0124	
Total	1.7675	19		

Organisational success factors

The table below shows the organisational success factor results for the four groups.

Table 4-20: Critical organisational success factors for the four groups

	Treatments				
	1	2	3	4	Total
N	5	5	5	5	20
ΣX	17.79	19.75	17.65	20.04	75.27
Mean	3.558	3.958	3.53	4.08	3.764
ΣX^2	63.378	78.674	62.378	80.721	285.15
Std. dev	0.14.15	0.294	0.136	0.316	0.314

The table shows the product success factor details:

Table 4-21: Critical organisational success factor results

Source	ss	df	ms	
Between treatments	0.972	3	0.324	F=5.759
Within treatments	0.899	16	0.056	
Total	1.8717	19		

Project product constraint

The table below shows the constraints results for the four groups.

Table 4-22: Critical failure factors for the four groups

	Treatments				
	1	**2**	**3**	**4**	**Total**
N	5	5	5	5	20
ΣX	17.32	19.84	17.1	20.13	74.39
Mean	3.464	3.968	3.42	4.026	3.72
ΣX^2	60.017	78.744	58.505	81.075	278.34
Std. dev	0.0716	0.0683	0.0752	0.089	0.294

The table below shows the failure factors results:

Table 4-23: Critical failure factors results

Source	**ss**	**df**	**ms**	
Between treatments	1.5534	3	0.518	F=88.777
Within treatments	0.0933	16	0.0058	
Total	1.6467	19		

4.8.2 Independent T-test

Simplified independent T-test calculations were performed, which include sample means, sums of squares and standard deviations calculated for groups' responses in order to determine whether there are similarities or differences between the two populations.

Project success and failure factors difference scores calculations

Project success (Treatment 1)

N_1: 5
$df_1 = N - 1 = 5 - 1 = 4$
M_1: 3.81
SS_1: 0.02
$s^2_1 = SS_1/(N - 1) = 0.02/(5-1) = 0$

Failure factors (Treatment 2)

N_2: 5

$df_2 = N - 1 = 5 - 1 = 4$

M_2: 3.71

SS_2: 0.02

$s^2_2 = SS_2/(N - 1) = 0.02/(5-1) = 0.01$

T-value calculation

$s^2_p = ((df_1/(df_1 + df_2)) * s^2_1) + ((df_2/(df_2 + df_2)) * s^2_2) = ((4/8) * 0) + ((4/8) * 0.01) = 0$

$s^2_{M1} = s^2_p/N_1 = 0/5 = 0$

$s^2_{M2} = s^2_p/N_2 = 0/5 = 0$

$t = (M_1 - M_2)/\sqrt{(s^2_{M1} + s^2_{M2})} = 0.09/\sqrt{0} = 2.09$

The -value is 2.08768. The p-value is .035136. The result is significant at p < .05.

Product success and failure factors difference scores calculations

Product success (Treatment 1)

N_1: 5

$df_1 = N - 1 = 5 - 1 = 4$

M_1: 3.69

SS_1: 0.05

$s^2_1 = SS_1/(N - 1) = 0.05/(5-1) = 0.01$

Failure factors (Treatment 2)

N_2: 5

$df_2 = N - 1 = 5 - 1 = 4$

M_2: 3.71

SS_2: 0.02

$s^2_2 = SS_2/(N - 1) = 0.02/(5-1) = 0.01$

T-value calculation

$s^2_p = ((df_1/(df_1 + df_2)) * s^2_1) + ((df_2/(df_2 + df_2)) * s^2_2) = ((4/8) * 0.01) + ((4/8) * 0.01) = 0.01$

$s^2_{M1} = s^2_p/N_1 = 0.01/5 = 0$
$s^2_{M2} = s^2_p/N_2 = 0.01/5 = 0$

$t = (M_1 - M_2)/\sqrt{(s^2_{M1} + s^2_{M2})} = -0.02/\sqrt{0} = -0.36$

The t-value is -0.36072. The p-value is .363824. The result is not significant at p < .05.

Organisational success and failure factors difference scores calculations

Organisational success (Treatment 1)

N_1: 4
$df_1 = N - 1 = 4 - 1 = 3$
M_1: 3.82
SS_1: 0.06
$s^2_1 = SS_1/(N - 1) = 0.06/(4-1) = 0.02$

Failure factors (Treatment 2)

N_2: 5
$df_2 = N - 1 = 5 - 1 = 4$
M_2: 3.71
SS_2: 0.02
$s^2_2 = SS_2/(N - 1) = 0.02/(5-1) = 0.01$
T-value calculation

$s^2_p = ((df_1/(df_1 + df_2)) * s^2_1) + ((df_2/(df_2 + df_2)) * s^2_2) = ((3/7) * 0.02) + ((4/7) * 0.01) = 0.01$

$s^2_{M1} = s^2_p/N_1 = 0.01/4 = 0$
$s^2_{M2} = s^2_p/N_2 = 0.01/5 = 0$

$t = (M_1 - M_2)/\sqrt{(s^2_{M1} + s^2_{M2})} = 0.11/\sqrt{0.01} = 1.47$

The t-value is 1.46956. The p-value is .092569. The result is not significant at p < .05.

Project success and product success factors difference score calculations

Project success (Treatment 1)

N_1: 5
$df_1 = N - 1 = 5 - 1 = 4$
M_1: 3.81
SS_1: 0.02
$s^2_1 = SS_1/(N - 1) = 0.02/(5-1) = 0$
Product success (Treatment 2)

N_2: 5
$df_2 = N - 1 = 5 - 1 = 4$
M_2: 3.69
SS_2: 0.05
$s^2_2 = SS_2/(N - 1) = 0.05/(5-1) = 0.01$

T-value calculation

$s^2_p = ((df_1/(df_1 + df_2)) * s^2_1) + ((df_2/(df_2 + df_2)) * s^2_2) = ((4/8) * 0) + ((4/8) * 0.01) = 0.01$

$s^2_{M1} = s^2_p/N_1 = 0.01/5 = 0$
$s^2_{M2} = s^2_p/N_2 = 0.01/5 = 0$

$t = (M_1 - M_2)/\sqrt{(s^2_{M1} + s^2_{M2})} = 0.11/\sqrt{0} = 2$

The t-value is 2.00312. The p-value is .040064. The result is significant at p < .05.

Project success and organisational success difference score calculations

Project success (Treatment 1)

N_1: 5
$df_1 = N - 1 = 5 - 1 = 4$
M_1: 3.81
SS_1: 0.02

$s^2_1 = SS_1/(N - 1) = 0.02/(5-1) = 0$

Organisational success (Treatment 2)

N_2: 5
$df_2 = N - 1 = 5 - 1 = 4$
M_2: 3.77
SS_2: 0.11
$s^2_2 = SS_2/(N - 1) = 0.11/(5-1) = 0.03$
T-value calculation

$s^2_p = ((df_1/(df_1 + df_2)) * s^2_1) + ((df_2/(df_2 + df_2)) * s^2_2) = ((4/8) * 0) + ((4/8) * 0.03) = 0.02$

$s^2_{M1} = s^2_p/N_1 = 0.02/5 = 0$
$s^2_{M2} = s^2_p/N_2 = 0.02/5 = 0$

$t = (M_1 - M_2)/\sqrt{(s^2_{M1} + s^2_{M2})} = 0.03/\sqrt{0.01} = 0.4$

The t-value is 0.40119. The p-value is .34939. The result is not significant at p < .05.

Product success and organisational success difference score calculations

Product success (Treatment 1)

N_1: 5
$df_1 = N - 1 = 5 - 1 = 4$
M_1: 3.69
SS_1: 0.05
$s^2_1 = SS_1/(N - 1) = 0.05/(5-1) = 0.01$

Organisational success (Treatment 2)

N_2: 5
$df_2 = N - 1 = 5 - 1 = 4$
M_2: 3.76

SS_2: 0.15

$s^2_2 = SS_2/(N - 1) = 0.15/(5-1) = 0.04$

T-value calculation

$s^2_p = ((df_1/(df_1 + df_2)) * s^2_1) + ((df_2/(df_2 + df_2)) * s^2_2) = ((4/8) * 0.01) + ((4/8) * 0.04) = 0.02$

$s^2_{M1} = s^2_p/N_1 = 0.02/5 = 0$

$s^2_{M2} = s^2_p/N_2 = 0.02/5 = 0$

X^2

$t = (M_1 - M_2)/\sqrt{(s^2_{M1} + s^2_{M2})} = -0.07/\sqrt{0.01} = -0.66$

The t-value is -0.66273. The p-value is .263067. The result is not significant at p < .05.

4.9 Critical analysis

The research procedures were benchmarked with the procedure in an article titled “Research design: qualitative, quantitative, mixed methods” by Creswell and Clark (2017:15), which explains the do’s and don’ts of conducting research. It was evident that all research procedures explained in this chapter meet the research design requirements explained by Creswell. It was also emphasised that proper research design makes the actual work easier due to an absence of major errors.

4.10 Conclusion

The purpose of this study is to identify and rank the critical factors in power plant life cycle projects, which are commonly used to determine organisational priorities. Placing more emphasis on these factors, their effectiveness could be maximised by ensuring that strategies are put in place to deliver results as desired by organisations. These factors will also assist project managers in utilising the resources and facilities and consequently reforming their use pattern which will results in improved success. Identified factors will also accelerate organisations’ successful achievement by quickly removing the existing barriers of failure, especially in competitive conditions and enforcing high performance which will directly yield

overall success. Probable perceptual errors and imaginations of the project managers will be prevented based on the importance of some factors in relation to other factors and realise the factor prioritisation, while impeding the realisation of various errors. These factors as identified will also be used to help the organisation to implement the strategic plans successfully.

4.11 Chapters overview

Chapter 4 Data collection and results analysis

This chapter outlined the manner in which data was collected, as well as analyses techniques and statistical methods used to identify success factors and constraint in life cycle management and project management.

Chapter 5 Delphi methodology

This chapter explains the analysis used to determine correlation between critical delay/failure factors and critical success factors. The Delphi technique is conducted to determine expert opinions.

CHAPTER 5

DELPHI METHODOLOGY

Chapter 5 presents an analysis of the research results and explains how data from the research questionnaire was evaluated. A Delphi technique using consensus forming by a group of senior project managers was used to verify and validate that the identified critical success factors in the project are indeed correct.

5.1 Introduction

In chapter four, participants' ranked the factors' importance using a scale (Likert scale) of one to five and then calculate an average score from an expert panel. The five most significant critical success factors and delay/failure factors determining project, product and organisational success were selected for further investigation, and are indicated in the table below.

Table 5-1: Survey results (critical factors identified)

Project success factors	**Delay/failure factors**
S1: Project management techniques are applied	F1: Construction methods by contractors
S2: Standards are actively used to drive quality of outputs	F2: Waiting time for approval consultants
S3: Regular and careful progress monitoring	F3: Decision making by owners
S4: Pre-project planning is thorough and considered	F4: Inappropriate communication
S5: Direct and indirect suppliers are aware of project	F5: Material quality
Product success factors	**Organisational success**
P1: Value for money	O1: Business benefits realised
P2: Improve efficiency of the system	O2: Strategic benefits realised
P3: Satisfactory overall equipment effectiveness	O3: New core competency realised
P4: Minor and major upgrades required to improve reliability	O4: New organisational capability realised
P5: Unexpected disruptions beyond the control of project management	

5.2 Three-stage Delphi technique

Critical success factors and critical constraints were sorted by the average score and only the ones with an average score of four and above where identified to be critical. The mean rank was used to identify the top five critical factors or constraints to be used for modelling. The analysis was aided by the use of a statistical package where scores assigned to each factor by the respondents were entered. The responses from the questionnaires were consequently subjected to statistical analysis for further insight. The contribution of each factor was examined and the ranking of the attributes in terms of their criticality as perceived by the respondents was done by use of the relative importance index (RII) which was computed using the equation and the results of the analysis are presented using the formula:

$$\mathrm{RII} = \frac{\sum W}{A * N} (0 < RII < 1)$$

Where: W - is the weight given to each factor by the respondents and ranges from 1 to 5, (where 1 is 'strongly disagree' and 5 is 'strongly agree'); A - is the highest weight (i.e. 5 in this case) and; N – is the total number of respondents.

5.2.1 Delphi round one

Delphi first-round questionnaire was sent out and participants were asked to anonymously evaluate the most needed success factor to prevent the most delaying factor in power plant life cycle projects. Participants ranked from one (most important/needed) to five (least important/needed) critical strategies required in the short-, medium- and long-term for better power plant project life cycle project delivery. Questionnaires were sent via web link (Monkey survey) through email to the experts' addresses simultaneously with hidden identity to ensure experts participated independently. Additional suggestions could also be provided by experts including to form part of the Delphi third round. The table below shows the second-round ranking of the most needed success factor for the power plant life cycle project.

Table 5-2: Delphi round one project success factor results

	Ranking for participants			

Project success factors	A	B	C	D	E	F	G	H	I	J	Mean	Median	Importance
S1	1	2	1	1	1	2	1	1	2	1	1.3	1	1
S2	3	1	2	2	3	1	2	3	1	3	2.1	2	2
S3	2	3	4	3	2	4	3	2	3	2	2.8	3	3
S4	4	4	5	5	5	3	5	5	5	4	4.5	5	5
S5	5	5	3	4	4	5	4	4	4	5	4.3	4	4
S1: Project management techniques are applied													
S2: Standards are actively used to drive quality of outputs													
S3: Regular and careful progress monitoring													
S4: Pre-project planning is thorough and considered													
S5: Direct and indirect suppliers are aware of project													

The table below shows the second-round ranking of the most needed product success factors for the power plant life cycle project represented in the table.

Table 5-3: Delphi round one product success factor results

	Ranking for participants												
Product success factor	A	B	C	D	E	F	G	H	I	J	**Mean**	**Median**	**Importance**
P1	1	1	2	2	1	1	1	2	2	1	1.4	1	1
P2	4	5	4	3	4	5	4	4	5	4	4.2	4	4
P3	5	4	5	5	3	4	5	5	4	5	4.5	5	5
P4	2	3	1	1	2	2	2	1	3	2	1.9	2	2
P5	3	2	3	4	5	3	3	3	1	3	3	3	3
P1: Value for money													
P2: Improve efficiency of the system													
P3: Satisfactory overall equipment effectiveness													
P4: Minor and major upgrades required to improve reliability													
P5: Unexpected disruptions beyond the control of project management													

The table below shows the second -round ranking of the most needed organisational success factors for the power plant life cycle project represented in the table below.

Table 5-4: Delphi round two organisational success factor results

	Ranking for participants												
Organisational success	A	B	C	D	E	F	G	H	I	J	**Mean**	**Median**	**Importance**
O1	3	4	3	3	3	4	3	3	3	4	3.3	3	3
O2	1	1	2	1	1	1	1	2	1	1	1.2	1	1
O3	2	2	3	3	2	2	3	2	3	2	2.4	2	2
O4	4	3	4	4	4	3	4	4	4	3	3.7	4	4
O1: Business benefits realised													
O2: Strategic benefits realised													
O3: New core competency realised													
O4: New organisational capability realised													

5.2.2 Delphi round two

The questionnaire was adjusted for round three; participants were asked to review original responses about the ranking of critical factors and compare them to round two group results. This was done to create a consensus among experts, confirming key issues identified in the second round, thus increasing an opportunity to get a deeper perspective on the evaluation process. The table below shows the final ranking of the most needed project success factors for the power plant life cycle project represented in the table.

Table 5-5: Delphi round two project success factor results

	Ranking for participants												
Project success factors	A	B	C	D	E	F	G	H	I	J	**Mean**	**Median**	**Importance**

S1	1	2	1	1	1	2	2	1	2	1	1.4	1	1
S2	3	1	2	2	3	1	1	3	1	3	2	2	2
S3	2	3	4	3	2	3	3	2	3	2	2.7	3	3
S4	4	4	5	5	5	4	5	5	5	4	4.6	5	5
S5	5	5	3	4	4	5	4	4	4	5	4.3	4	4
S1: Project management techniques are applied													
S2: Standards are actively used to drive quality of outputs													
S3: Regular and careful progress monitoring													
S4: Pre-project planning is thorough and considered													
S5: Direct and indirect suppliers are aware of project													

The table below shows the final ranking of the most needed product success factors for the power plant life cycle project represented in the table.

Table 5-6: Delphi round two product success factor results

	Ranking for participants												
Product success factor	A	B	C	D	E	F	G	H	I	J	**Mean**	**Median**	**Importance**
P1	1	2	2	2	1	1	1	2	2	1	1.5	1	1
P2	4	5	4	3	4	4	4	4	5	4	4.1	4	4
P3	5	4	5	5	3	5	5	5	4	5	4.6	5	5
P4	2	3	1	1	2	3	2	1	3	2	2	2	2
P5	3	1	3	4	5	2	3	3	1	3	2.8	3	3
P1: Value for money													
P2: Improve efficiency of the system													
P3: Satisfactory overall equipment effectiveness													
P4: Minor and major upgrades required to improve reliability													
P5: Unexpected disruptions beyond the control of project management													

The table below shows the final ranking of the most needed organisational success factors for the power plant life cycle project.

Table 5-7: Delphi round two organisational success factor results

	Ranking for participants												
Organizational success	A	B	C	D	E	F	G	H	I	J	**Mean**	**Median**	**Importance**
O1	3	4	3	4	3	4	3	3	3	4	3.4	3	3
O2	1	2	2	1	1	1	1	2	1	1	1.3	1	1
O3	2	1	3	3	2	2	3	2	3	2	2.3	2	2
O4	4	3	4	3	4	3	4	4	4	3	3.6	4	4
O1: Business benefits realised													
O2: Strategic benefits realised													
O3: New core competency realised													
O4: New organisational capability realised													

5.2.3 Delphi round three

Most participants, who were systems engineers, indicated that the project management tools tended to reflect the application of methods in systems engineering management, more than in project management. Responses for each factor were compared with respect to each of the nine PMBoK areas. Likert scale rankings for each factor were used, and the average of all factors for each project management knowledge area was taken as the final score of a factor impact on the overall body of knowledge.

The T-test was used to compare the expert panel's perceptions about the influence of each success factor on each of the nine PMBoK areas. For the T- test, two groups were tested at a level of significance based on a p value of 0.05. A value < 0.05 signifies that the test is significant and that the conclusion can be drawn from the results. If the p value is > 0.05, the test is insignificant and no conclusion can be drawn.

5.2.3.1 Project critical success factors' impact on PMBoK areas

The table below indicates the survey results (degree of agreement) on the effects of project success factors on each PMBoK area.

Table 5-8: Project success vs project knowledge area

Success factor	Integration	Scope	Time	Cost	Quality	Human	Communications	Risk	Procurement	Total
S1	4.8	3.8	4.7	4.8	4.9	3.8	3.4	4.1	3.2	**4.1666**
S2	4.5	4.4	4.2	4.4	4.5	4.2	4.1	4.7	3.7	**4.3**
S3	4.2	4.1	4	4.5	4.3	3.5	3.6	4.8	3.8	**4.0888**
S4	4.7	4	4.3	4.1	4.2	3.7	4.6	4	3	**4.0666**
S5	4.6	4.4	4.5	4.3	3.2	3.9	4.7	4.1	3	**4.0777**
Total	**4.56**	**4.14**	**4.34**	**4.42**	**4.22**	**3.82**	**4.08**	**4.34**	**3.34**	
T test	0.024	0.031	0.041	0.042	0.045	0.074	0.057	0.045	0.058	
S1: Project management techniques are applied										
S2: Standards are actively used to drive quality of outputs										
S3: Regular and careful progress monitoring										
S4: Pre-project planning is thorough and considered										
S5: Direct and indirect suppliers are aware of project										

T-test integration management calculation.

N1: 5

df1 = N - 1 = 5 - 1 = 4

M1: 3

SS1: 7.68

s21 = SS1/(N - 1) = 7.68/(5-1) = 1.92

Treatment 2

N2: 5

df2 = N - 1 = 5 - 1 = 4

M2: 4.52

SS2: 1.01

s22 = SS2/(N - 1) = 1.01/(5-1) = 0.25

T-value calculation

s2p = ((df1/(df1 + df2)) * s21) + ((df2/(df2 + df2)) * s22) = ((4/8) * 1.92) + ((4/8) * 0.25) = 1.09

s2M1 = s2p/N1 = 1.09/5 = 0.22

s2M2 = s2p/N2 = 1.09/5 = 0.22

t = (M1 - M2)/√(s2M1 + s2M2) = -1.52/√0.43 = -2.31

Therefore:

The t-value is -2.30621. The p-value is .024992. The result is significant at p < .05.

The t-value is -2.30621. The p-value is .024992. The result is not significant at p < .01.

5.2.3.2 Critical delay/failure factor impacts on PMBoK areas

The table below indicates the survey results on the effects of project failure factors on each PMBoK area.

Table 5-9: Project failure factors vs project knowledge area

Success factor	Integration	Scope	Time	Cost	Quality	Human	Communications	Risk	Procurement	Total
F1	4.8	3.8	4.7	4.8	4.9	3.8	3.4	4.1	3.2	**4.1666**
F2	4.5	4.4	4.2	4.4	4.5	4.2	4.1	4.7	3.7	**4.3**
F3	4.2	4.1	4	4.5	4.3	3.5	3.6	4.8	3.8	**4.0888**
F4	4.7	4	4.3	4.1	4.2	3.7	4.6	4	3	**4.0666**
F5	4.6	4.4	4.5	4.3	3.2	3.9	4.7	4.1	3	**4.0777**
Total	**4.56**	**4.14**	**4.34**	**4.42**	**4.22**	**3.82**	**4.08**	**4.34**	**3.34**	
T test	0.025	0.031	0.041	0.041	0.045	0.0746	0.0579	0.0449	0.058	
F1: Construction methods by contractors										
F2: Waiting time for approval by consultants										
F3: Decision making by owners										
F4: Inappropriate communication										
F5: Material quality										

5.2.3.3 Project product critical factors impact on PMBoK areas

The table below indicates the survey results on the effects of project product success factors on each PMBoK area.

Table 5-10: Project product success vs project knowledge area

Success factor	Integration	Scope	Time	Cost	Quality	Human	Communications	Risk	Procurement	Total
P1	4.2	3.8	4.2	4	4.5	3.7	3.4	3.8	4.5	4.0111
P2	4.4	4.2	4.1	4.2	4.2	4.2	3.6	4.2	3.5	4.0666
P3	3.9	4.3	3.8	3.9	4.1	3.5	2.7	4.1	3.3	3.7333
P4	4.2	4	3.8	3.8	3.8	3.4	3.1	3	3.3	3.6
P5	4.1	4.4	3.9	4.3	3.8	3.6	3	3.7	3.2	3.7778
Total	**4.16**	**4.14**	**3.96**	**4.04**	**4.08**	**3.68**	**3.16**	**3.76**	**3.56**	
T-total	0.0218	0.071	0.061	0.052	0.032	0.062	0.061	0.049	0.071	
P1: Value for money										
P2: Improve efficiency of the system										
P3: Satisfactory overall equipment effectiveness										
P4: Minor and major upgrades required to improve reliability										
P5: Unexpected disruptions beyond the control of project management										

T-test integration management calculation.

Treatment 1

N1: 5

df1 = N - 1 = 5 - 1 = 4

M1: 3

SS1: 7.06

s21 = SS1/(N - 1) = 7.06/(5-1) = 1.76

Treatment 2

N2: 5
df2 = N - 1 = 5 - 1 = 4
M2: 4.52
SS2: 1.01
s22 = SS2/(N - 1) = 1.01/(5-1) = 0.25

T-value Calculation

s2p = ((df1/(df1 + df2)) * s21) + ((df2/(df2 + df2)) * s22) = ((4/8) * 1.76) + ((4/8) * 0.25) = 1.01

s2M1 = s2p/N1 = 1.01/5 = 0.2
s2M2 = s2p/N2 = 1.01/5 = 0.2

t = (M1 - M2)/√(s2M1 + s2M2) = -1.52/√0.4 = -2.39

Therefore:

The *t*-value is -2.39318. The *p*-value is .021819. The result is significant at $p < .05$.

The t-value is -2.39318. The p-value is .021819. The result is not significant at $p < .01$.

5.2.3.4 Critical organisational success factors impact on PMBoK areas

The table below indicates the survey results of the effects of organisational success factors on each PMBoK area.

Table 5-11: Results of critical organisational success factor effects on PMBoK areas

Success factor	Integration	Scope	Time	Cost	Quality	Human	Communications	Risk	Procurement	Total
Q1	4.2	3.8	4.2	4	4.5	3.7	3.4	3.1	3.1	3.7776
Q2	4.4	4.2	4.1	4.2	4.2	4.2	3.9	3.7	3	3.9889
Q3	3.9	4.3	3.8	3.9	4.1	3.5	4.2	3.8	3.3	3.8666
Q4	4.2	4	3.8	3.8	3.8	3.4	3.4	4	2.8	3.6888
Total	4.175	4.075	3.975	3.975	4.15	3.7	3.725	3.65	3.05	
T-total	0.002	0.061	0.057	0.055	0.051	0.071	0.052	0.049	0.078	
Q1: Business benefits realised										
Q2: Strategic benefits realised										
Q3: New core competency realised										
Q4: New organisational capability realised										

T-test integration management calculation.

Treatment 1

N1: 4

df1 = N - 1 = 4 - 1 = 3

M1: 2.72

SS1: 3.51

s21 = SS1/(N - 1) = 3.51/(5-1) = 0.88

Treatment 2

N2: 4

df2 = N - 1 = 4 - 1 = 3

M2: 4.52

SS2: 1.01

s22 = SS2/(N - 1) = 1.01/(5-1) = 0.25

T-value Calculation

s2p = ((df1/(df1 + df2)) * s21) + ((df2/(df2 + df2)) * s22) = ((4/8) * 0.88) + ((4/8) * 0.25) = 0.56

s2M1 = s2p/N1 = 0.56/5 = 0.11
s2M2 = s2p/N2 = 0.56/5 = 0.11
t = (M1 - M2)/√(s2M1 + s2M2) = -1.8/√0.23 = -3.79

The t-value is -3.78801. The p-value is .002663. The result is significant at p < .05.
The t-value is -3.78801. The p-value is .002663. The result is significant at p < .01.

The final results for critical factors and constraints are summarised in the table below.

Table 5-12: Factors' importance and priority

Project critical success factors	**Mean**	**RII**	**Rank**
S1: Project management techniques are applied	4.166667	0.774803	1
S2: Standards are actively used to drive quality of outputs	4.3	0.770079	2
S3: Regular and careful progress monitoring	4.088889	0.765354	3
S4: Pre-project planning is thorough and considered	4.066667	0.754331	4
S5: Direct and indirect suppliers are aware of project	4.077778	0.741732	5
Product (deliverable) critical success factors	**Mean**	**RII**	**Rank**
P1: Value for money	4.011111	0.748031	2
P2: Improve efficiency of the system	4.066667	0.762205	1
P3: Satisfactory overall equipment effectiveness	3.733333	0.746457	4
P4: Minor and major upgrades required to improve reliability	3.6	0.705512	5
P5: Unexpected disruptions beyond the control of project management	3.777778	0.730709	3
Organisational/corporate critical success factors	**Mean**	**RII**	**Rank**
Q1: Business benefits realised	3.905512	0.781102	1
Q2: Strategic benefits realised	3.850394	0.770029	3
Q3: New core competency realised	3.92126	0.784252	2
Q4: New organisational capability realised	3.606299	0.72126	4
Critical delay/failure/constraints	**Mean**	**RII**	**Rank**
F1: Construction methods by contractors	3.811111	0.765354	1
F2: Waiting time for approval Consultants	3.433333	0.744882	2
F3: Decision making by owners	3.488889	0.743307	3
F4: Inappropriate communication	3.355556	0.730709	4
F5:Material quality	3.655556	0.703937	5

5.3 Correlation coefficients

This section answers the question of how project, product and organisational success factors correlate with constraint/delay/failure in power plant life cycle management. A Pearson

correlation coefficient was used to measure the strength and direction of the relationship between ratings of critical project success and delay factors on the projects. As shown in the table below, the results indicate that there is a significant correlation between all five critical success factors and delay factors.

Table 5-13: Correlation coefficient project success and failure factors

	F1	F2	F3	F4	F5
S1	0.931	0.871	0.691	0.689	0.713
S2	0.871	0.782	0.645	0.678	0.602
S3	0.712	0.694	0.832	0.785	0.745
S4	0.916	0.783	0.832	0.678	0.634
S5	0.892	0.779	0.789	0.678	0.897
S1: Project management techniques are applied			F1: Construction methods by contractors		
S2: Standards are actively used to drive quality of outputs			F2: Waiting time for approval Consultants		
S3: Right quality (meet all specifications requirements)			F3: Decision making by owners		
S4: Pre-project planning is thorough and considered			F4: Inappropriate communication		
S5: Direct and indirect suppliers are aware of project			F5: Material quality		

The Pearson correlation coefficient was used to measure the strength and direction of the relationship between ratings of critical product success and delay factors on the projects. As shown in the table below, the results indicate that there is a significant correlation between all five critical success factors and delay factors.

Table 5-14: Correlation coefficient product success and failure factors

	F1	F2	F3	F4	F5
P1	0.961	0.874	0.678	0.931	0.787
P2	0.884	0.793	0.735	0.895	0.846
P3	0.777	0.678	0.893	0.856	0.785
P4	0.987	0.874	0.925	0.982	0.967
P5	0.783	0.845	0.874	0.889	0.856
P1: Value for money			F1: Construction methods by contractors		
P2: Improve efficiency of the system			F2:Waiting time for approval Consultants		
P3: Satisfactory overall equipment effectiveness			F3: Decision making by owners		
P4: Minor and major upgrades required to improve reliability			F4: Inappropriate communication		
P5: Unexpected disruptions beyond the control of project management			F5: Material quality		

The Pearson correlation coefficient was used to measure the strength and direction of the relationship between ratings of critical organisational/corporate success and delay factors on the projects. As shown in the table below, the results indicate that there is a significant correlation between all five critical success factors and delay factors.

Table 5-15: Correlation coefficient organisational success and failure factors

	F1	F2	F3	F4	F5
Q1	0.984	0.933	0.845	0.876	0.865
Q2	0.897	0.896	0.792	0.834	0.875
Q3	0.789	0.896	0.678	0.985	0.845
Q4	0.856	0.945	0.873	0.943	0.956

Q1: Business benefits realised	F1: Construction methods by contractors
Q2: Strategic benefits realised	F2:Waiting time for approval Consultants
Q3: New core competency realised	F3: Decision making by owners
Q4: New organisational capability realised	F4: Inappropriate communication
	F5: Material quality

5.4 Statistical methods

Statistical analysis was done for each category of collected data using statistical analysis software (SPSS). The following statistical instruments were used in this study.

5.4.1 Pearson correlation coefficient

Correlation between sets of data is a measure of how well they are related. We can categorise the type of correlation by considering as one variable increases what happens to the other variable:

- Positive correlation – the other variable has a tendency to also increase;
- Negative correlation – the other variable has a tendency to decrease;
- No correlation – the other variable does not tend to either increase or decrease.

The starting point of any such analysis should thus be the construction and subsequent examination of a scatterplot. In this study, *r* was used to measure the strength and direction of the relationship between ratings of critical factors.

Table 5-16: Pearson correlation coefficient

Pearson coefficient	∑	Mean	SSx	∑	Mean	SSx	N	∑	r
1. Project success vs project failure	3.806	0.76	0	3.72	0.743	0	5	0	0.856
2. Project success vs product success	3.806	0.76	0	3.69	0.739	0	5	0	0.989
3. Project success vs organisation success	3.806	0.76	0	3.78	0.756	0	5	0	0.935
4. Failure factor vs product success	3.715	0.74	0	3.69	0.739	0	5	0	0.858
5. Failure factor vs organisational success	3.715	0.74	0	3.78	0.756	0	5	0	0.852
6. Product vs organisational success	3.693	0.74	0	3.78	0.004	0	5	0	0.888

Pearson correlation coefficient results analysis

The following results were realised from the table above:

1. The value of R is 0.856. This is a strong positive correlation, which means that high project success variable scores go with high project failure variable scores (and vice versa). The value of R^2, the coefficient of determination, is 0.7321.
2. The value of R is 0.989. This is a strong positive correlation, which means that high project success variable scores go with high product success variable scores (and vice versa). The value of R^2, the coefficient of determination, is 0.9781.
3. The value of R is 0.9352. This is a strong positive correlation, which means that high project success variable scores go with high organisation success variable scores (and vice versa). The value of R^2, the coefficient of determination, is 0.8746.
4. The value of R is 0.858. This is a strong positive correlation, which means that high failure factor variable scores go with high product success variable scores (and vice versa). The value of R^2, the coefficient of determination, is 0.743.
5. The value of R is 0.8521. This is a strong positive correlation, which means that high failure factor variable scores go with high organisational success variable scores (and vice versa). The value of R^2, the coefficient of determination, is 0.7261.
6. The value of R is 0.8882. This is a strong positive correlation, which means that high product success variable scores go with high organisational success variable scores (and vice versa).The value of R^2, the coefficient of determination, is 0.7889.

5.4.2 Analysis of variance (ANOVA)

The one-way ANOVA was performed to compare the means between the groups of interest and determines whether any of those means are statistically significantly different from each other. Specifically, it tests the null hypothesis:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \cdots = \mu_k$$

Where μ = group mean and k = number of groups. If, however, the one-way ANOVA returns a statistically significant result, we accept the alternative hypothesis H_1, where there are at least two group means that are statistically significantly different from each other. The hypothesis test was developed in order to understand the relationship between different factor groups.

- Null hypothesis two (2): H_0 : There is no association between critical success factors and constraints in power plant life cycle management projects.
- Alternative hypothesis two (2): H_1 : There is an association between critical success factors and constraints in power plant life cycle management projects.

The table below shows the one-way ANOVA results for the critical success factors

Table 5-17: One-way ANOVA results

	Treatments				
	Project success	**Product success**	**Organisational success**	**Failure factors**	**Total**
N	5	5	5	5	20
∑X	20.7	19.1889	19.5222	17.7444	77.1556
Mean	4.14	3.8378	3.9044	3.5489	3.8578
∑X2	85.7362	73.7962	76.3819	63.1075	299.0217
Std. dev.	0.0977	0.1959	0.199	0.1834	0.2688

The ANOVA results are summarised in the table below:

Table 5-18: ANOVA results summary

Source	SS	df	MS	
Between-treatments	0.8882	3	0.2961	F = 9.77633
Within-treatments	0.4845	16	0.0303	
Total	1.3727	19		

The f-ratio value is 9.77633. The p-value is .000666. The results between the four groups are significant at $p < .05$.

5.4.3 T-test

The third phase of the Delphi method evaluated the effect of each factor related to the nine PMBoK areas. The T-test which is an inferential statistical test that determines whether there are statistically significant differences between the means in two unrelated groups, was performed to determine the overall average score and final T-test score.

In this research, significance is evaluated based on the p-value where a low p-value indicates that the test is significant and conclusions can be drawn. The table below indicates the factors that were within the T-test value < 0.05, which signifies that the test is significant.

Table 5-19: T-test results summary

Success factor	Unit	Integration	Scope	Time	Cost	Quality	Human	Communication	Risk	Procurement	Average
Project factors	Average	4.56	4.14	4.34	4.42	4.22	3.82	4.08	4.34	3.34	4.14
	T-test	0.02	0.03	0.04	0.04	0.04	0.07	0.06	0.04	0.06	0.05
Product success	Average	4.16	4.14	3.96	4.04	4.08	3.68	3.16	3.76	3.56	3.84
	T-test	0.02	0.07	0.06	0.05	0.03	0.06	0.06	0.05	0.07	0.05
Organisational success	Average	4.18	4.08	3.98	3.98	4.15	3.70	3.73	3.65	3.05	3.83
	T-total	0.00	0.06	0.06	0.06	0.05	0.07	0.05	0.05	0.08	0.05
Failure factor (constraint)	Total	4.56	4.14	4.34	4.42	4.22	3.82	4.08	4.34	3.34	4.14
	T-test	0.02	0.03	0.04	0.04	0.04	0.07	0.06	0.04	0.06	0.05
Total	Score	4.36	4.12	4.15	4.21	4.17	3.76	3.76	4.02	3.32	3.99
	T-test	0.02	0.05	0.05	0.05	0.04	0.07	0.06	0.05	0.07	0.05

5.4.4 Independent T-test

The independent T-test is an inferential statistical test that determines whether there is a statistically significant difference between the means in two unrelated groups. The null hypothesis for the independent T-test is that the population means from the two unrelated groups are equal. Proof is required in most cases that the null hypothesis is rejected and that the alternative hypothesis is accepted, where the population means are not equal. In this research, significance is evaluated based on the p-value where a low p-value indicates that the test is significant and conclusions can be drawn.

Table 5-20: Independent T-test

Indipendent T tests	s^2_p	s^2_{M1}	t
1. Project success vs project delay	0.01	0	2.09
2. Project success vs product success	0.01	0	2
3. Project success vs organisation success	0.01	0	0.34
4. Failure factor vs product success	0.02	0	0.36
5. Failure factor vs organisational success	0.02	0	0.02
6. Product success vs organisational success	0.02	0	-1.02

Independent T test results analysis

The following results were attained as per the table above:

1. The relationship between project success factors and project failure/delay factors achieved a *t*-value of 2.08768. The *p*-value is 0.035136. The result is significant at $p < .05$.
2. The relationship between project success factors and product success factors achieved a *t*-value of 2.00312. The *p*-value is 0.040064. The result is significant at $p < .05$.
3. The relationship between project success factors and organisational success factors achieved a t-value of 0.34093. The p-value is 0.37097. The result is not significant at $p < .05$.
4. The relationship between project delay/failure factors and project product success factors achieved a t-value of 0.36072. The p-value is 0.363824. The result is not significant at $p < .05$.
5. The relationship between project success factors and project failure/delay factors achieved.

6. The relationship between project product success factors and organisational success factors achieved a t-value of -1.01989. The p-value is 0.168815. The result is not significant at $p < .05$.

5.5 Nine knowledge areas' relative importance

The PMBoK is the most recognised guide for project management professionals. It defines the nine knowledge areas (also referred to as KAs) required to manage projects. The knowledge area contribution to the overall success of the project, its product and the organisation was evaluated to determine the relative importance of each knowledge area related to the overall project. The figure below indicates the overall importance ranking of the nine knowledge areas.

Table 5-21: Nine knowledge areas' relative importance

Knowledge area (KA)	Project	Product	Organisation	Failure/constraint	Mean	Rank
Integration	4.56	4.16	4.175	4.56	4.36375	1
Scope	4.14	4.14	4.075	4.14	4.12375	5
Time	4.34	3.96	3.975	4.34	4.15375	4
Cost	4.42	4.04	3.975	4.42	4.21375	2
Quality	4.22	4.08	4.15	4.22	4.1675	3
Human resources	3.82	3.68	3.7	3.82	3.755	8
Communication	4.08	3.16	3.725	4.08	3.76125	7
Risk	4.34	3.76	3.65	4.34	4.0225	6
Procurement	3.34	3.56	3.05	3.34	3.3225	9

The Pareto principle, which is the basis of the 80/20 rule, namely that 20% of variables will account for 80% of the results, was applied. The application of this rule is supported by the results shown in the table above, which confirms that different knowledge areas (KAs) have unequal impacts on project success. The null hypothesis for the t-test is that the population means from the two unrelated groups are equal:

- **Null hypothesis three (3): H_0 : Critical success factor importance may not be verified and validated through evaluating each factor against the PMBoK areas across the system life cycle.**

Proof is required in most cases that the null hypothesis is rejected and that the alternative hypothesis is accepted, where the population means are not equal:

- **Alternative hypothesis three (3): H_1 : Critical success factor importance may be verified and validated through evaluating each factor against the PMBoK areas across the system life cycle.**

The null hypothesis is rejected and the alternative hypothesis is accepted. The table above presented evidence that knowledge areas contribute differently towards the overall project success. This will assist project professionals to prioritise knowledge areas that contribute most and ignore the listed impact variables.

5.6 Significant factors theoretical relationship summary

The impacts of the different factors on the body of knowledge were sorted according to their total T-test scores. The knowledge areas score equal to four or less were considered insignificant and ignored. The knowledge area priorities were numbered according to the t-test values with numbers closer to zero as high priority and further from zero as low priority.

Table 5-22: Critical factors' impact on PMBoK area

Factor	Integration	Scope	Time	Cost	Quality	Risk	Total
Project success	1	2	3	4	5	6	3.5
Project failure	4		1	2	3	5	3
Product success	1				2	3	2
Organisation success	1					2	1.5
T-total	**1.8**	**2**	**2**	**3**	**3.3**	**4**	**13.9**

Sanvido et al (1992:102) point out that by using the project model, the success and performance of a project can be examined. The absolute value of the rating is indicative of the client's perception of the performance and success of the project. Chan and Kumaraswamy (2002:25) reviewed Sanvido's work on empirical studies from management journals to develop a conceptual framework on critical success factors. This resulted in five groups of independent

variables which were identified as project related, procurement related, project management related and project participant related.

However, with artificial intelligence, researchers found tools and algorithms that more effectively address complex environments and project uncertainty during normal project development, while algorithms address specific goals. These include the identification of critical success factors and the prediction of project success. Atkinson (1999:441) believes that the project status model (PSM) is used to monitor and indicate changes in project status through constant updates during the project and at a certain point after it ends, thus assisting the project manager to monitor the progress of the project and its results. DeLone and McLean (1992:24) propose a compressive model for project success by merging the success dimensions from project management streams and information systems. They believe that these will assist project managers to assess the likely success early in the development stages.

Measuring and comparing the performance of life cycle projects is an important task. Controlling and monitoring projects for maximum impact must therefore be achieved through early design and planning, as well as monitoring and using the correct matrix for interpretation. This will result in a project plan that is aligned with a better response to the risks identified during project design, planning and execution. To determine critical factor priorities, a scale was used as shown in the table below:

Table 5-23: Weight factors for the final project success factors

Project management success factor	**Relative Important Index (RII)**	**Weighted value**	**Corresponding weighting**
Integration ($X_{1,2,3,4,5}$)	0.789	3.2	0.230
Scope (X_1)	0.765	3	0.216
Time (X_2)	0.758	3	0.216
Cost (X_3)	0.732	2	0.144
Quality (X_4)	0.726	1.7	0.122
Risk (X_5)	0.682	1	0.072
Sum		**13.9**	**1**

The project management success (PMS) equation is therefore:

$$\boldsymbol{PMS} = \frac{\mathbf{3.2}}{\mathbf{13.9}}(\boldsymbol{I}) + \frac{\mathbf{3}}{\mathbf{13.9}}(\boldsymbol{S}) + \frac{\mathbf{3}}{\mathbf{13.9}}(\boldsymbol{T}) + \frac{\mathbf{2}}{\mathbf{13.9}}(\boldsymbol{C}) + \frac{\mathbf{1.7}}{\mathbf{13.9}}(\boldsymbol{Q}) + \frac{\mathbf{1}}{\mathbf{13.9}}(\boldsymbol{R}) \ldots\ldots\ldots\ldots\ldots (\mathbf{3})$$

$$\boldsymbol{PMS} = \mathbf{0.23}(\boldsymbol{I}) + \mathbf{0.216}(\boldsymbol{S}) + \mathbf{0.216}(\boldsymbol{T}) + \mathbf{0.144}(\boldsymbol{C}) + \mathbf{0.122}(\boldsymbol{Q}) + \mathbf{0.0719}(\mathrm{R}) \ldots\ldots\ldots\ldots (4)$$

$$\mathbf{PMS}(\mathbf{X_1}) = \mathbf{0.23}(\mathbf{X_{1.1,2,3,4,5}}) + \mathbf{0.216}(\mathbf{X_1}) + \mathbf{0.216}(\mathbf{X_2}) + \mathbf{0.144}(\mathbf{X_3}) + \mathbf{0.122}(\mathbf{X_4}) + \mathbf{0.0719}(\mathbf{X_5})$$

Where:

$X_{1,2,3,4,5}$ = interdependency
X_1 = Scope
X_2 = Time
X_3 = Cost
X_4 = Quality
X_5 = Risk

Maylor (2003:53) specifies that factual evidence is used when a project is pronounced a success. However, different authors show a lack of consensus and objectivity as to what constitutes a successful project. The mutual questions are what constitutes a successful project? How do we measure project success? How can our efforts towards project management succeed? Ashley (1987:75) indicates that to identify factors that have a significant effect on the success of a construction project, several construction project personnel should be interviewed to identify factors that influenced average projects and outstanding projects, as well as the principal measure of project success and factors showing a strong correlation to project outcome.

5.7 Approach to theory building (process, variance and systems)

Poole et al (2000:42) state that an approach is defined as a researcher's choice of the types of concepts and relationships used to construct the theory. In project management and systems engineering, there has been a growing interest in theory building. Below is the evaluation of the three theory building approaches according to Poole et al (2000:44):

- Variance approach - in terms of theoretical concepts, the variance approach focuses on properties of entities, often called variables or factors. It is assumed that these properties can have different values even though the property itself has a fixed meaning.
- Process approach - in terms of theoretical relationships, the process approach focuses on accounting for an outcome by reference to a sequence of events involving the focal actors. The process approach focuses on entities participating in events. If the entities can act, they are often referred to as focal actors
- System approach - it derives from a conviction that the world is comprised of wholes and interacting parts, not merely entities, properties, and events. The systems approach is based on the insight that the interrelations of certain components may result in an entity (system) with its very own properties. This approach looks at systems holistically,

emphasizing the interrelations of the system's components, the properties and boundaries of the system and its environment.

Combining theoretical approaches offers a particularly significant opportunity to improve theory in this research in light of the results. It can be argued that the insistence on exclusion of variables from process research unnecessarily limits the variety of theories constructed.

5.8 Verifications and validations

Systems engineering defines verification as "actions used to test accuracy of any element (task, service, system, requirements)". Objective evidence is required to prove that desired results were achieved. Systems engineering defines validation as "activity that ensures and provides confidence that the system will accomplish its intended use". The purpose of validation is to establish output compliance compared to input.

North-West University's Faculty of Engineering defines 'verification' as "confirming that a suggested solution to a problem is properly applied", and 'validation' as "confirming that the suggested solution to the problem essentially solves the problem". The concern is the end product. Both definitions focus on ensuring that the proposed solution will actually solve the problem.

With the above definitions in mind, the investigator must be clear about defining the problem and its desired solution so that the research design can be continuously verified and validated against the requirements. The researcher must plan his/her research design in such a way that verification and validation become part of every milestone aimed at ensuring that deviation can be identified and addressed earlier rather than later.

In this research, the research hypotheses were verified by performing a Delphi technique, with an understanding that industrial experts when they agree separately on what the problem is and how it can be resolved, will be more accurate to resolve the problem at hand. The researcher validated this research document by determining whether it provides solutions for life cycle project failure in power plants and if the solution is fit for the intended purpose.

5.9 Critical analysis

According to an article by Davies (2002:189) titled “The real success factor in projects”, the only effective means of learning through operational experience in project conglomerates explicit with implied knowledge, encourages people to learn and to embed that learning into continuous improvement of project management processes and practices, which will result in project management maturity in an organisation.

Jacob & McClelland (2001:4) in a study titled “Theory of constraint project management” point out that changing how people manage projects is tantamount to changing an organisation, but the right people must be brought into the project at the right time, in just the right way. The theory of constraint thinking process is a developed methodology to address policy constraints and create breakthrough solutions, using a common-sense focus on what to change, what to change to, and how to cause the change driving project continuous improvement based on the organisation’s operational experience.

Bobera and Trninić (2006:7) in an article titled “Total quality management (TQM) integration in project management “indicate that to realise a successful project, it is necessary to integrate all the aspects of quality into all the activities developing continually, application of methods and technologies, as well as a project team that understands its roles. Andersen, Birchall, Jessen & Money (2006:284) in an article titled “Exploring project success” indicate that the possibility to compare the management of projects allows for new performance indicators to be developed putting more focus on other aspects which include short- and long-term objectives to ensure that what is carried out performs in the best possible way.

5.10 Conclusions

According to Porter (2016:1), project control and monitoring for maximum impact can be achieved by early monitoring during the planning phase, using the right Metrix interpretation, effective monitoring and control, which result in project plan alignment, as well as risk identification and response during monitoring.

This research also developed literature on the topic of organisational success, which project researchers are silent about. The results indicate that there is a direct and indirect link between organisational success and project success, for example improved business processes can lead

to improved competencies (cost reduction, operational efficiencies), and successful research and development can result in new product development, thus increasing business revenue streams.

The model delivered by this research also proves that measuring a project's level of success will definitely improve project management competency. The theory proved that utilising an overall measure of success (indicated in percentage) will make it easy to compare life cycle management projects. A project life cycle success measurement model was presented, which can be easily applied in power plants, as well as any other plant as long as industry success factors are calibrated.

5.11 Chapter overview

Chapter 5: Delphi methodology

This chapter explains the analysis used to determine correlation between critical delay/failure factors and critical success factor. The Delphi technique is used to determine expert opinions.

Chapter 6: Project success life cycle Model (PSLCM)

Chapter Six discusses the development of a project model that will be used to ensure that power plant projects are fit for purpose, and that they perform at the right time, the right cost and the right quality. This model should provide deliverables that are always acceptable taking into consideration all constraints present.

CHAPTER 6

PROJECT SUCCESS LIFE CYCLE MODEL (PSLCM) DEVELOPMENT

This chapter scientifically documents the author's original contribution to the science of project management and system engineering, references this contribution to academic requirements and validates it through case studies.

6.1 Introduction

Four requirements must be achieved for theory to provide benefits to researchers which are developing a concept, defining domain, defining key relationships and predicting claims. The chapter structure is graphically presented in the figure below:

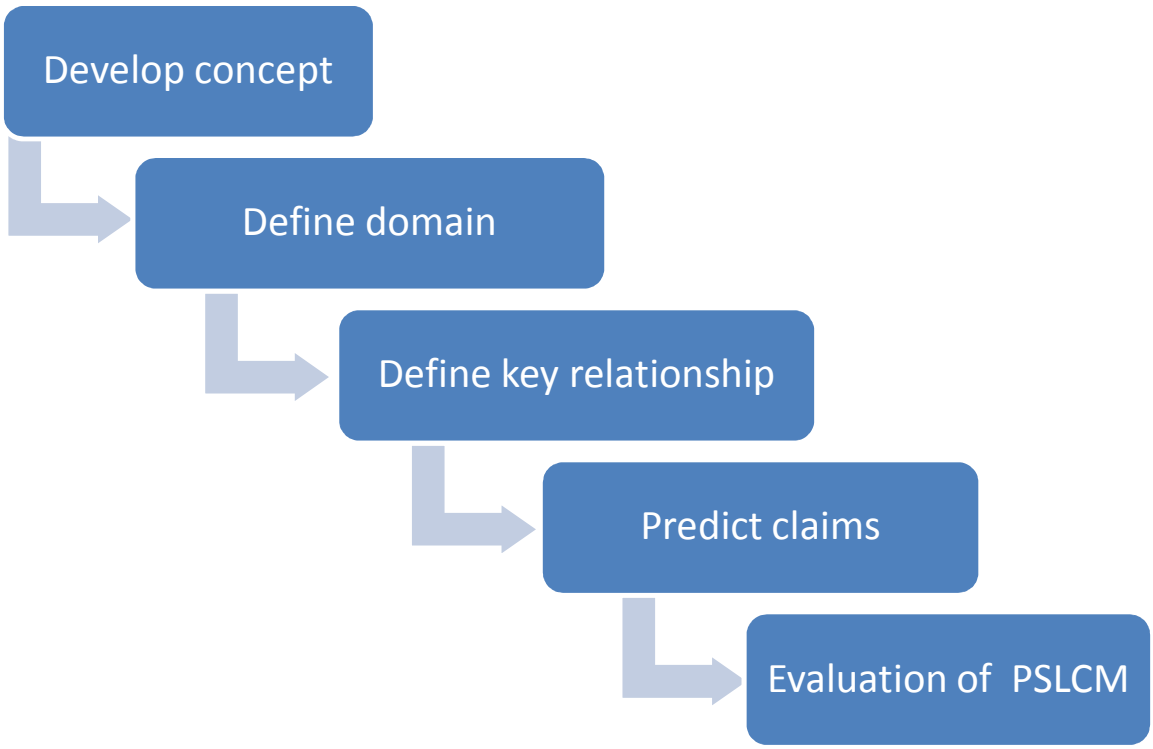


Figure 6-1: Chapter structure

According to Wacker (1998:375), theory is important for researchers and practitioners to provide analysis frameworks, clear expectations of the pragmatic world and to provide efficient methods to develop knowledge.

6.2 Develop the concept

The core concepts required for the development of a project success life cycle model (PSLCM) theory, relate to the improved detailed understanding of life cycle management and elements of success factor interdependency during different project, product and organisation stages of the life cycle.

Van de Ven et al. (2000:20) agree that an approach is defined as a researcher's choice of the types of concepts and relationships used to construct the theory. In project management and systems engineering, there has been a growing interest in theory building. Below is the evaluation of the three theory-building approaches according to Van de Ven et al. (2000:44):

- Variance approach - in terms of theoretical concepts, the variance approach focuses on properties of entities, often called variables or factors. It is assumed that these properties can have different values even though the property itself has a fixed meaning.
- Process approach - in terms of theoretical relationships, the process approach focuses on accounting for an outcome by reference to a sequence of events involving the focal actors. The process approach focuses on entities participating in events. If the entities can act, they are often referred to as focal actors.
- Systems approach - it derives from a conviction that the world is comprised of wholes and interacting parts, not merely entities, properties, and events. The systems approach is based on the insight that the interrelations of certain components may result in an entity (system) with its own properties. This approach looks at systems holistically, emphasizing the interrelations of the system's components, the properties and boundaries of the system and its environment.

6.2.1 Plant life cycle management components

Buede and Miller (2016:17) indicate that life cycle models may be used under specified conditions to establish and test a hypothesis and to discover effects. Blanchard (1998:3) asserts that models are often used to evaluate significant effects of inputs on outputs as part of process and sub process analysis, to determine the input levels required to achieve the desired results (outputs). Beemsterboer and Kemp (2016:75) hold that the power plant integrated life cycle management models formed on the basis of understanding project life cycle models, asset life cycle models, product (deliverable) life cycle models, and business life cycle models, can be used at a point of greatest leverage. This can be done by improving efficiency of the design process reducing design costs, reducing complexity (product, material, labour) and eliminating late engineering design changes.

Plant life cycle models are powerful tools in cost-saving efforts by minimising variations in projects, processes, and sub processes, as well as tasks and activities, which will improve overall efficiency and effectiveness. Blanchard and Reppe (1998:4) believe that past practices have a significant impact on the overall cost of a system, creating an imbalance between cost and effectiveness. The complexities of many systems have been greater with the ever-increasing emphasis on performance, while sacrificing other key design parameters such as reliability and quality. The overall effectiveness of a system is proportional to life cycle cost as shown in the figure below.

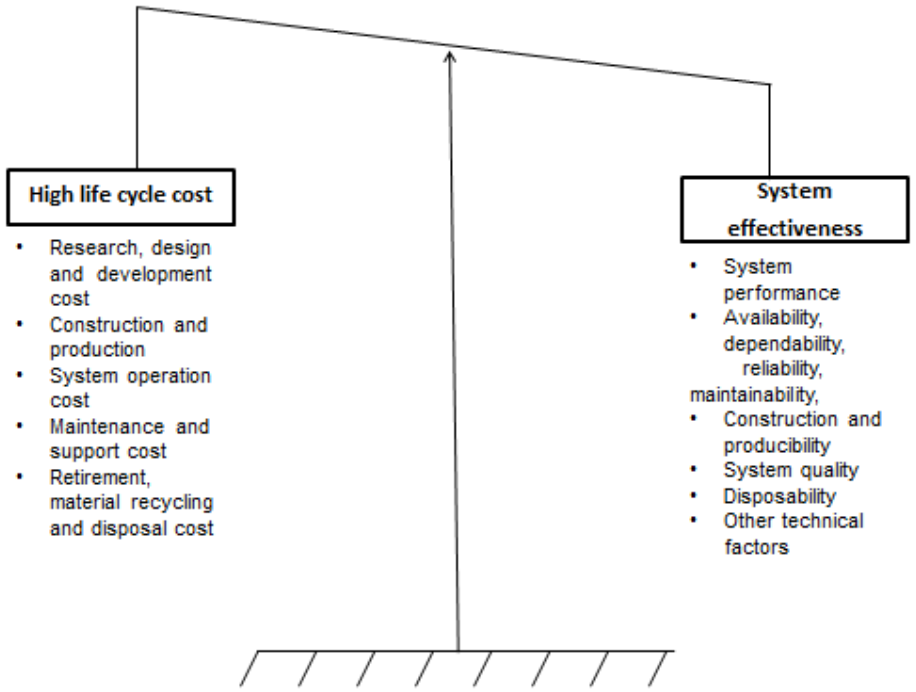


Figure 6-2: The imbalance between system cost and effectiveness factors (Blanchard and Reppe, 1998)

According to Blanchard and Reppe (1998:12), there are three aspects of a process that should be analysed by an integrated plant life cycle model, namely:

- Inputs (factors, variables, process inputs): The types of variables are controllable, uncontrollable and interdependence (mixed) factors.
- Process conditions (levels, settings, quantity, rate): This aspect relates to process conditions required to transform inputs into desired outputs.
- Outcomes (responses, output): Output characteristics, consistency and appearance are measurable outcomes influenced by the inputs and process.

According to Cadle and Yeates (2001:30), life cycle management models must focus on both the delivery portion of a project and the business value portion of a project. This is a holistic way of evaluating projects, which will easily measure project success. Barringer (1997:3) indicates that effectiveness can be best elaborated by the formula below:

$$\text{Effectiveness} = \text{Availability (A)} * \text{Reliability (R)} * \text{Capability (C)} * \text{Maintainability(M)} \ldots\ldots\ldots (6.1)$$

Where:

- Availability – the chance of the equipment or system to perform its duty
- Reliability – the system will operate for a certain period without failure
- Capability – the system can perform production activity to standard
- Maintainability – can be repaired with no excessive lost time.

6.2.2 Purpose of using integrated models for optimisation

Goodman and Ignacio (1999:4) found that the use of different models, tools and technology by engineers and analysts, resulted in a large gap between system engineering activities in current practices of system development. This, in turn, resulted in inefficiencies and quality issues that were very costly to fix. Evbuomwan and Anumba (1998:588) indicate that the need for an integrated model with analysis capability is evident. This requires measurement capabilities to be developed to bridge the existing gap through integrating modelling tools, process integration and design optimisation, and by developing capabilities to analyse realistic methods. This integrated approach will allow design teams, project management teams and operational teams to continuously analyse and trade off studies throughout the process and respond quickly to changes in requirements and design configuration.

Blanchard (1990:4) asserts that the model must also focus on interdependencies and their impact on the whole, while identifying factors and their level of impact (positive or negative). A system constitutes a complex combination of resources in the form of human beings, materials, equipment, software, facilities, data, and money. To accomplish various functions often requires large numbers of personnel, equipment, facilities and data.

The goal of asset manufacturing is to design the most reliable products or systems. However, limited information about the operating conditions, as well as operators' limited knowledge of equipment reliability is a constraint. To design highly reliable systems, the following factors must be taken into consideration:

- First, the inherent reliability of the equipment or installation must be determined (design stage reliability).
- Secondly, the inherent reliability must be maintained and component life upgraded (process operation reliability).

- Thirdly, best practices must be adopted to prolong product and equipment life (maintenance operation reliability).

It is vitally important that there is continuous interaction between designers and operators through an equipment life cycle, because their combined knowledge will lead to the overall availability and reliability of the installation. Early life cycle interaction planning based on industry success factors and a constraint management strategy, will result in a balanced life cycle management strategy. The outcome will be a high return on investment (ROE) at an optimal life cycle cost (LCC). The figure below illustrates the basic engineering system.

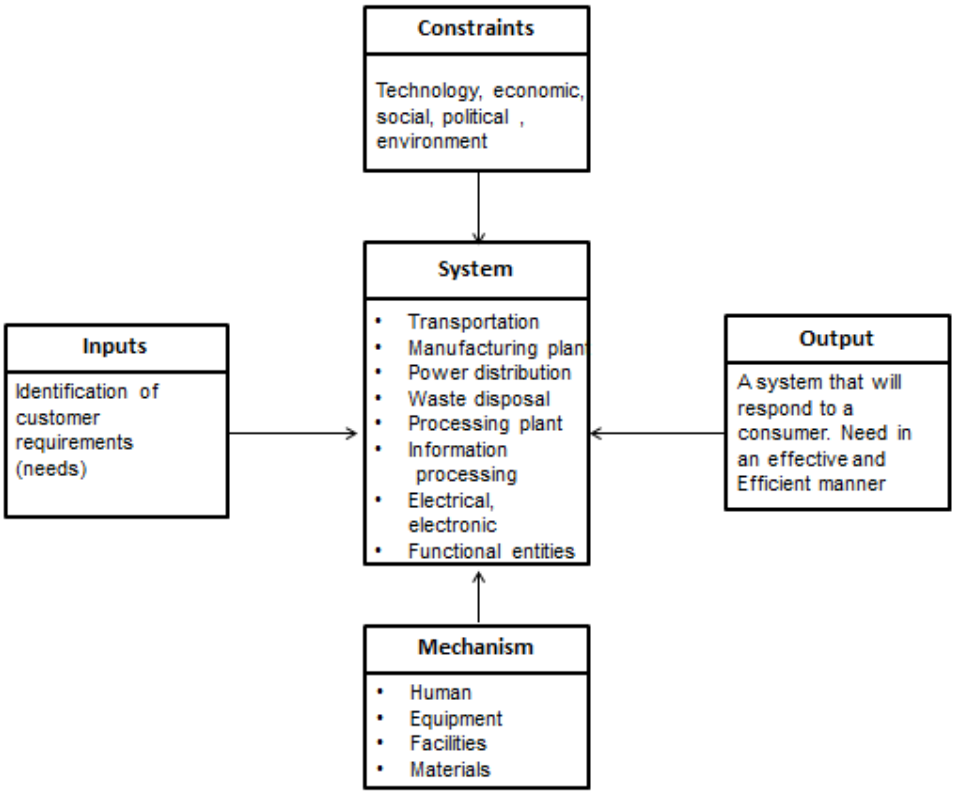


Figure 6-3: The basic engineering system (Blanchard ,1998)

According to Goodman and Ignacio (1999:81), the key output of a technical planning process using a model, is to carry out a structured and defendable basis for allocation of limited resources to enable the delivery of sustainable performance in line with organisational expectations. These include safety, legal and statutory compliance, as well as sustainment or enhancement of projects to improve availability, reliability, capability and maintainability. As a result of these key outputs, costs from technical plans become key assumptions in plant life

determination models. These provide control for investments and operational spending for the next business cycle. Kerzner and Kerzner (2017:252) suggest that the success of technical planning processes hinges on a detailed framework to prescribe the necessary activities and interventions required to achieve utilities' expectations. Teixeira et al. (2015:136) indicates that the process input allows optimisation of limited resources to achieve the maximum output from a power plant.

Kogan et al. (2017:705) holds that the model's basic focus is on comparing estimated, calculated, allocated and measured values in order to determine overall efficiency at any stage of a process. The major focus of PSLCM is to integrate different project inputs and outputs with different measuring units to a single efficiency value performed through a continuing verification of the degree of anticipated achievement of financial and technical parameters.

McGhee and McAliney (2007:62) point out that models are used to identify deficiencies that jeopardize the ability of the system to meet a performance requirement by selecting and identifying deficiencies that can jeopardize the ability of the system in meeting a performance requirement. This includes design parameters, performance parameters and process errors.

6.2.3 Technical performance measure (TPM)

According to Brodlie et al. (2005:33), TPMs are traditionally defined and evaluated to assess how well a system is achieving its performance requirements. Magee et al. (2016:238) emphasise that although TPMs generate useful information and data about performance, limited information is available in the programme management community on how to integrate these measures into a meaningful measure of the overall performance. According to Cicmil et al. (2017:19), individual TPMs may be combined to measure and monitor the overall performance of a system.

Serrador and Turner (2015:33) believe that the approach consists of integrating individual technical performance measures in a way that produces an overall efficiency index. Muller (2017:67) specifies that the computed index shows the degree of performance risk presently in the system. It identifies risk-driving TPMs, enables monitoring time-history trends, and reveals where management should target strategies to reduce or eliminate the performance risks of the system. Wysocki (2011:326) indicates that TPM is very useful to technical managers, mainly to ensure that inexperienced project managers focus holistically on project parameters rather than focusing on the triple constraint.

According to Alleman et al. (2015:6), TPM involves a technique of predicting key performance parameter future values, based on current low-level assessments. According to Nicholas and Steyn (2017:23), performance variances that can jeopardise the achievement of high-level requirements, must be identified quickly by continuous verification of actual, planned and anticipated values. Estimation errors result in tolerance bands due to variations above tolerance levels, which help to alert managers when the degree of expected variation is exceeded. The figure below illustrates an example of the TPM identification (development) process.

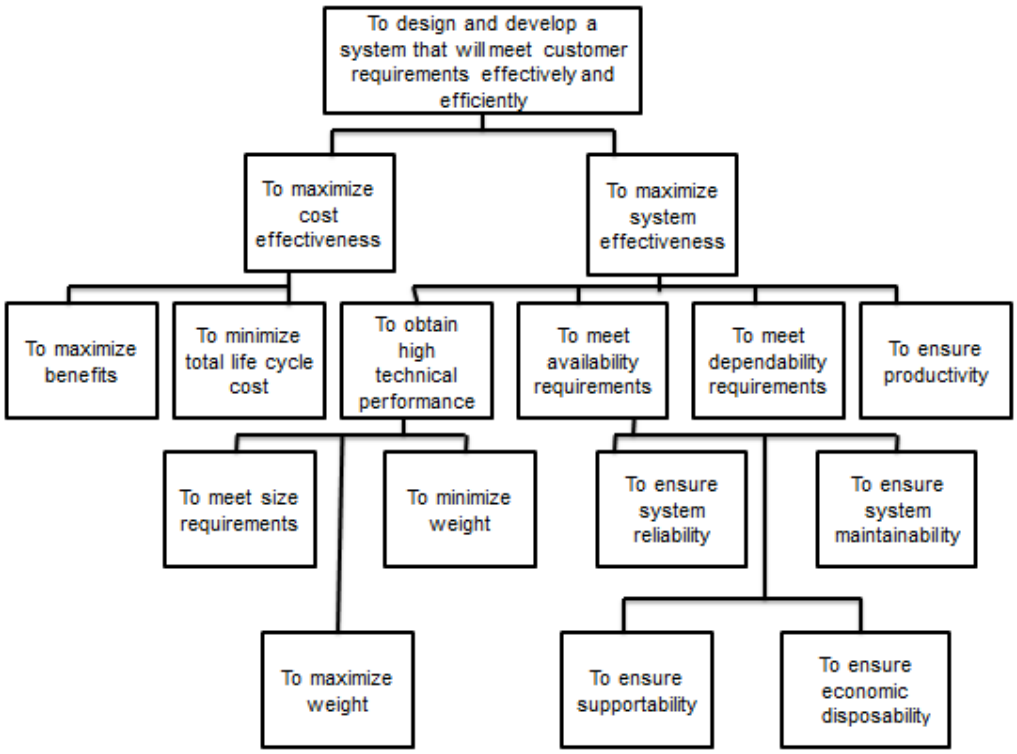


Figure 6-4: TPM development process according to Burke (2001)

Nicholas and Steyn (2017:23) indicate that the central limit theorem specifies that variance of the sum is equal to the sum of the variance on an individual distribution if a number of independent probability distribution is summated. In most utilities, the problems associated with project, product cost and time performance risks are evident. Managers often do not realise that they are not dealing with risks, but with variations. The application of mathematical statistics, also known as statistical process control (SPC) to control process variations, is used to continuously improve performance by understanding input output process effects on the quality of the desired outcomes. Measuring different variables requires that all variables are converted into one unit so that they can mathematically be represented as a single value.

6.2.4 Data envelope analysis (DEA)

Cook et al. (2014:2) asserts that DEA is a technique developed in operations research and management science for measuring the efficiency of decision making units (DMU) in the public and private sectors, by observing data on multiple inputs and outputs. Wei and Wang (2017:32) hold that the DEA methodology considers all resources used and services provided, and compares it with the best practice units. DEA can be used to offer a variety of models that use multiple inputs and outputs to compare two or more processes. By using the three-efficiency calculation, it will be easy to identify all performance gaps from one process to the next process.

Longo et al. (2018:328) believe that efficiency and project management are subjects explored extensively by the scientific community and are also relevant to any company. Azadeh et al. (2014:41) indicate that the cost of engineering projects includes engineering design, and procurement of material and equipment, as well as human hours worked, premises and tools usage. Sánchez (2015:325) specifies that the cost can also be attributed directly to the project or a general proportion of completion time.

Sudhaman and Thangavel (2015:962) designate that engineering project costs normally vary inversely proportional to the completion time, starting at the minimum possible completion time of the project. This is determined by technical parameters that can be achieved by using more resources, allowing for overtime, reducing manufacturing periods of materials and using advanced technology.

6.2.5 Process interdependency

Larson et al. (2014:13) assert that the design experiment objective is to illustrate the impact of specific changes to the process input in order to normalise, minimise or maximise the outcome by manipulating the input. Design experiments are used to determine the impact of a specific input on a process, individually or collectively. By varying factors on different levels and recording the impact of the results, it is possible to understand the impact of each variable within the process and the degree of its results. The analysis of inputs, as well as the results, determines the level of input needed to arrive at the optimal results, by first determining the quality characteristics to be examined and the desired effect. Understanding the level of goals and factors is achieved through brainstorming, as well as a cause and effect investigation.

According to Larson et al. (2014:14), determining variation among treatments is completed by adding the square of each observation, commonly referred to as the sum of squares, followed by distributing variations among different types that can occur, comprising:

- Grand mean effect - variations caused by items under a test
- Effect of factors - variations caused by individual factors within an experiment
- Reputational error effect - variations caused by the number of trials performed.

The important part of the experiment is determining the importance of the factors achieved by determining the minimum significance variance required for a measurement to be considered significant. The total variation, which is a variation that has occurred among all treatments, is determined by adding squares of each observation.

6.3 Define domain

PSLCM is specifically relevant to efficiency generating in a project identified through project portfolio management, which rely on both proactive and reactive planning processes. The model indicates that all data can be allocated a number, and that numbers make analysis easier. PSLCM is a life cycle control and monitoring system that employs the system engineering principle of “achieving a balanced system” in life cycle management. This method focuses on ensuring that all stakeholders, including designers, project managers, operators and maintainers, look beyond their immediate functions so that the best solution is offered for the market. This method indicates that project management (process) success is equally important to product/project deliverable success, which in turn is equally important to organisational success, but these factors are interdependent. This method also points out where strategic decisions (or lack of it), limit performance.

The implementation domain of PSLCM include existence of hidden barriers of project failure which can have unintended consequences such as unclear requirements, change orders, drawings and specifications approval, as well as errors during construction. Furthermore, the final condition which guaranteed the implementation domain of PSLCM includes measurements, control and monitoring systems which drive actions that move towards the project and organisational goal.

6.4 Define key relationships

Chapman (2018:4) points out that measuring performance is an important function of any engineering model and having an appropriate performance measure facilitates communication of a definite arrangement for moving towards achieving business goals and targets. Beriha et al. (2011:220) believe that developing operational excellence assists companies to improve their global competitiveness. The figure below indicates efficiency and variations in a process.

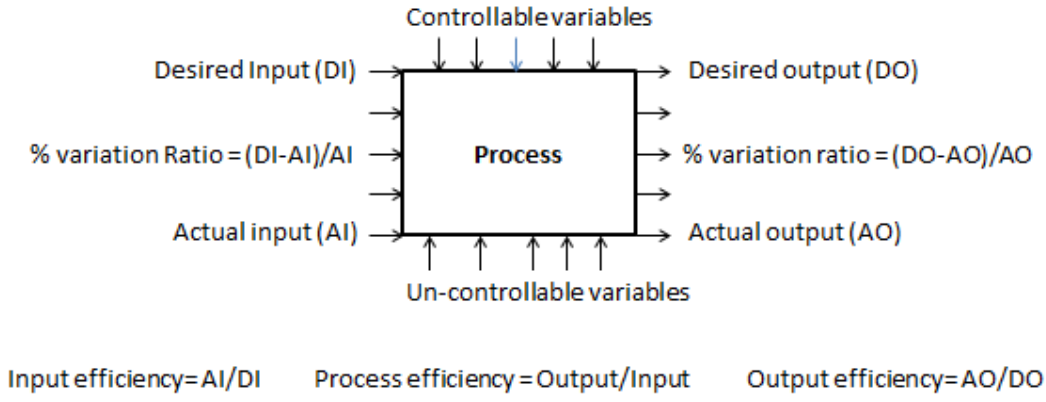


Figure 6-5: Efficiency and variation in a process

In complicated processes with multiple inputs and outputs, which are also interdependent, the process efficiency can be calculated as follows:

$$Process\ effitiency\ = \frac{Weighted\ Sum\ of\ Outputs}{Weighted\ Sum\ of\ Inputs} \quad \text{..... (6.2)}$$

To evaluate actual inputs to desired inputs, the input efficiency can be calculated as follows:

$$Input\ effitiency\ = \frac{Actual\ Input}{Desired\ Inputs} \quad \text{..... (6.3)}$$

To evaluate actual outputs to desired outputs, the output efficiency can be calculated as follows:

$$Output\ effitiency\ = \frac{Actual\ Output}{Desired\ Output} \quad \text{..... (6.4)}$$

The weighted input efficiency can be calculated as follows:

$$E_k = \frac{\sum_{j=1}^{M} u_j \, O_{jk}}{\sum_{i=1}^{n} V_i \, I_{ik}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6.5)}$$

Where:

$V_i = weight\ for\ input\ i$
$U_j = weight\ for\ input\ j$
$E_k = Efficiency\ of\ a\ DMU\ (0\%\ to\ 100\%)$

The PSLCM problem-solving methodology aims to maximise system effectiveness by managing multiple constraints (impact of variability), while being flexible to address the challenges at hand. The overall efficiency of a project management process can be calculated as follows:

$$PMS(\mu) = \frac{u_1 X_{1j+}\ u_1\ X_{2j\ +\cdots}}{v_1 a_{1j} + v_2 a_{2j} + \cdots.} \ldots\ldots\ldots\ldots\ldots\ldots \text{(6.6)}$$

Where:

$PMS(\mu)$ = Project management success efficiency

$u_1 =$ Weight given to output 1

$X_{1j} =$ Amount of output 1 from unit j

$v_1 =$ Weight given to input 1

$a_{1j} =$ Amount of input 1 to unit j

The overall efficiency of a project deliverable can be calculated as follows:

$$PPS(\mu) = \frac{u_1 Y_{1j+}\ u_1\ Y_{2j\ +\cdots}}{v_1 b_{1j} + v_2 b_{2j} + \cdots.} \ldots\ldots\ldots\ldots\ldots\ldots \text{(6.7)}$$

Where:

$PPS(\mu)$ = Project product success efficiency

$Y_{1j} =$ Amount of output 1 from unit j

$b_{1j} =$ Amount of input 1 to unit j

The overall efficiency of a corporate success can be calculated as follows:

$$OS(\mu) = \frac{u_1 Z_{1j+}\ u_1\ z_{2j\ +\cdots}}{v_1 c_{1j} + v_2 c_{2j} + \cdots.} \ldots\ldots\ldots\ldots\ldots\ldots \text{(6.8)}$$

$OS(\mu)$ = Organisational success efficiency

Z_{1j} = Amount of output 1 from unit j

c_{1j} = Amount of input 1 to unit j

This is the final value that is used to compare project performance at all stages of the life cycle, assisting the organisation to easily identify inefficiencies.

6.5 Develop an integrated model

A PSLCM development framework appreciates that there are hardly any similar problems in complex and dynamic power plant environments. This makes it difficult to solve non-standard problems using conventional ways and for the traditional project management approach that focuses on planning to solve complex problems in a restricted way. According to Hutt et al. (2017:530), for a mission to be considered a success, it should perform in three areas:

- Meet or exceed business performance requirements
- Meet or exceed system performance requirements
- Meet or exceed project management requirements.

Vesonder et al. (2018:21) hold that although there are interdependencies in a project, its product (deliverables) and its contribution to the organisation, there is no theory that confirms that project success results in product success, which will lead to organisational success. Although some projects have failed, they produced a product that exceeded expectations and generated more revenue for their organisation.The figure below indicates PSLCM development framework.

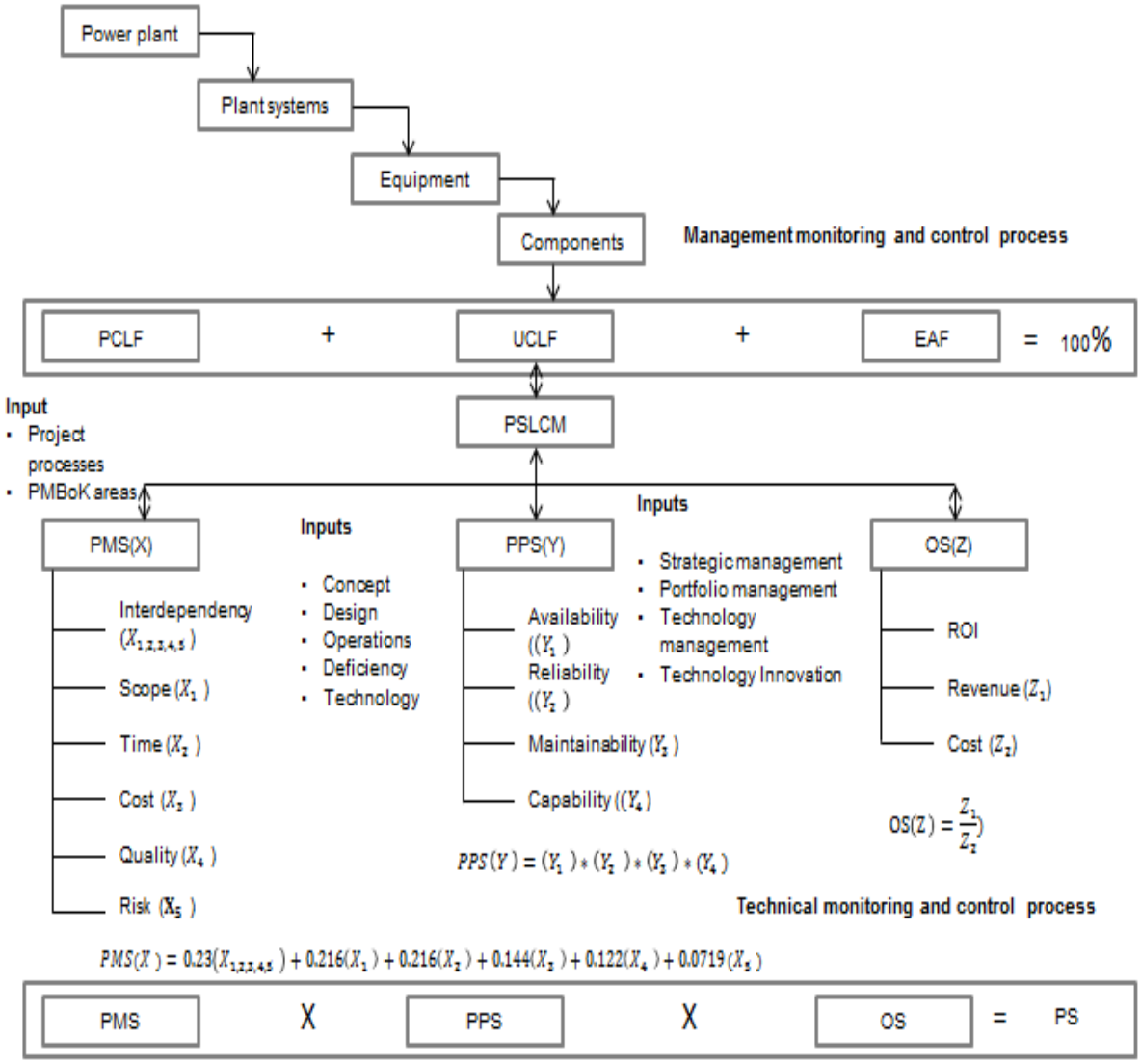


Figure 6-6: PSLCM development framework

The three sub-processes provide the building blocks to calculate project, product and organisational performance.

Sub process 1: Project management success (PMS)

The figure below shows critical factors and outputs of a project management process

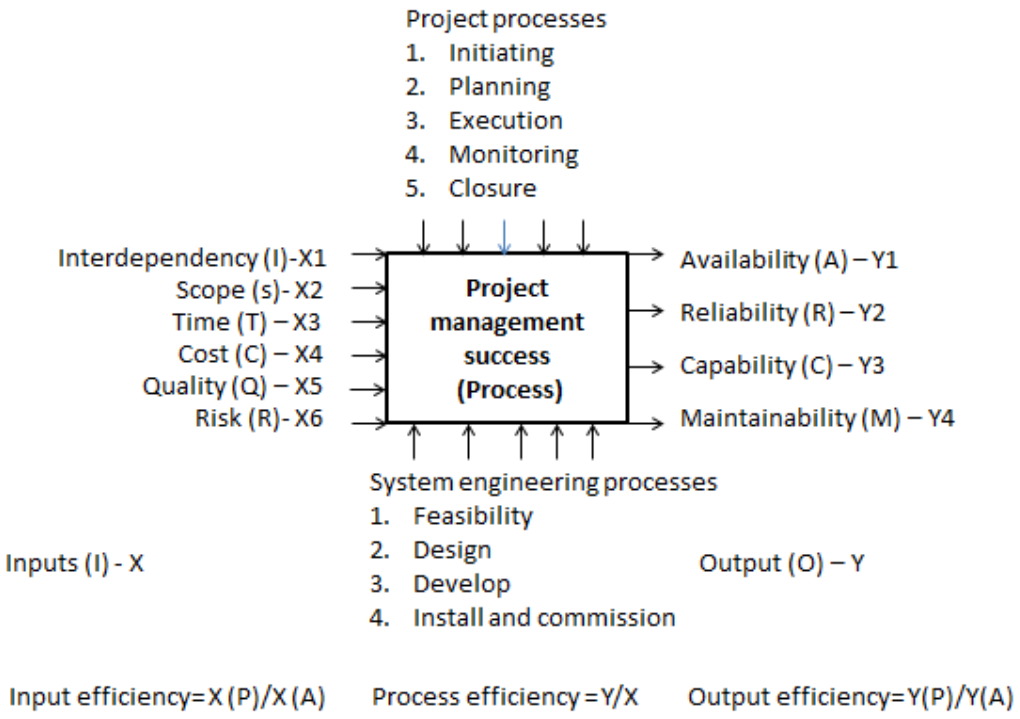


Figure 6-7: PSLCM project management process

Sub process 2: Project product management success process (PPS)

The figure below shows critical factors and outputs of a project management process

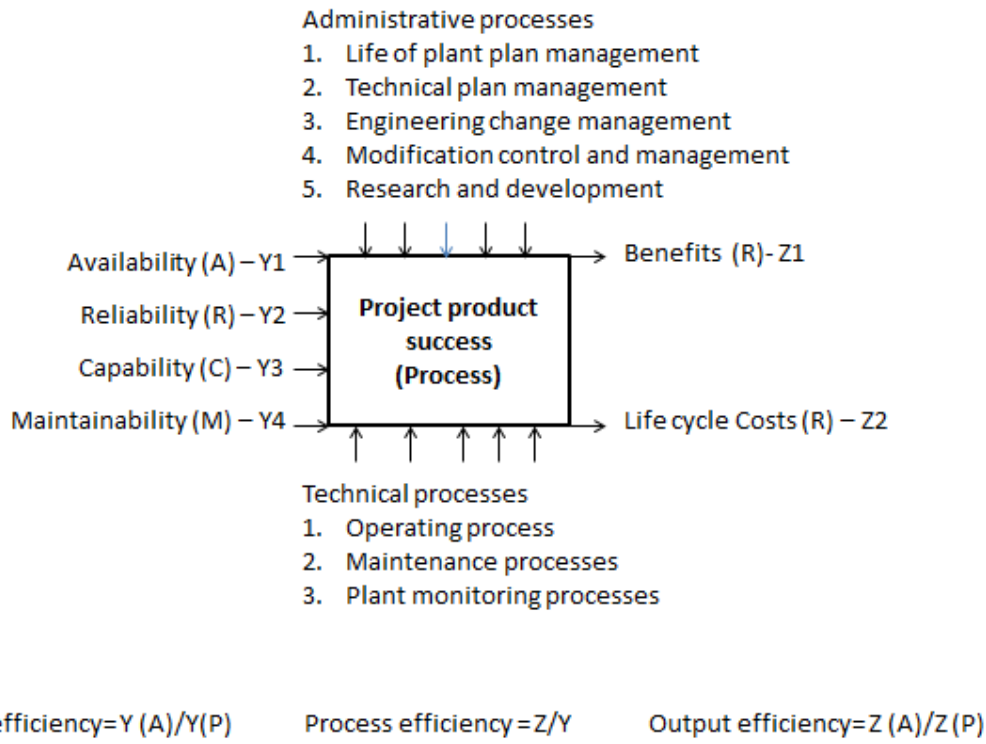


Figure 6-8: PSLCM project product success management process

Sub process 3: Organisational/Corporate success management process (OS/CS)

The figure below shows critical factors and outputs of a project management process

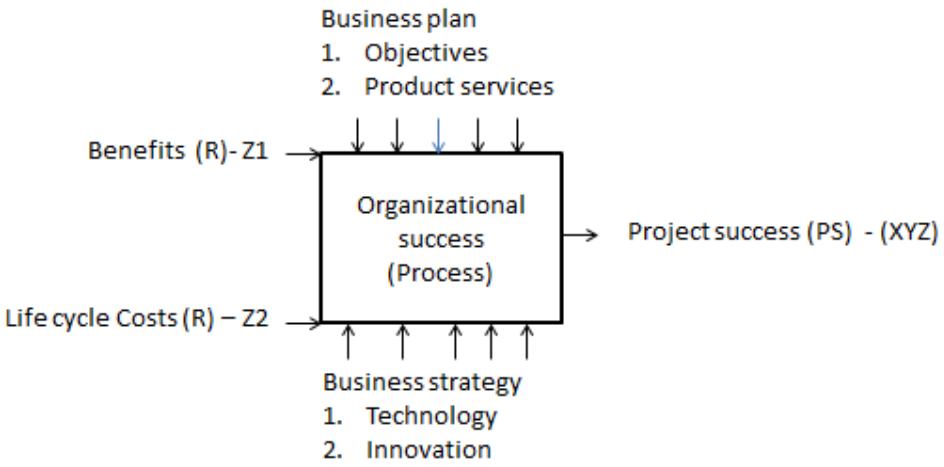


Figure 6-9: PSLCM organisational success management process

The survey statistics analysis contributed towards a direction for further investigation, by demonstrating that life cycle project success is directly proportional to project management success, its product success and its impact on the organisation. This section describes the components and concepts towards PSLCM.

$$\textbf{Project Succes } (\mathbf{PS}) = \textbf{Project management success } (\mathbf{X}) * \textbf{project product success } (\mathbf{Y}) * \textbf{Organisational success } (\mathbf{Z}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{6.9})$$

$$\mathbf{PS} = (\mathbf{X}) * (\mathbf{Y}) * (\mathbf{Z}$$

Power plant life cycle management data collection method

PSLCM requires real data from system and subsystem interdependencies, aimed at achieving its multiple goals by producing a web of interlinked relationships, where every project in an

organisation contributes to its strategic/corporate plan. The figure below illustrates how basic overall monitoring produces data used with the PSLCM to evaluate performance and interdependency effectiveness.

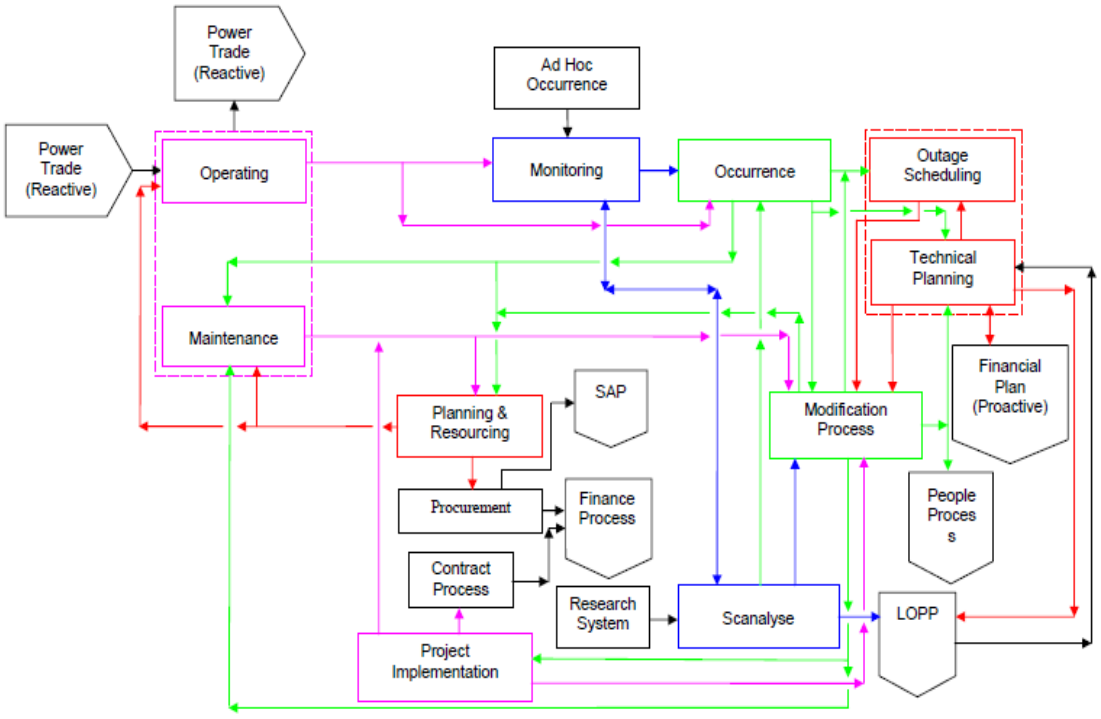


Figure 6-10: PSLCM system and processes monitoring

Each process input and output connects the entire process flow to understand the overall effect of each sub-process. Due to the increasing need for power, there is an increasing demand on plant availability and efficiency, while older systems from former technology fail to meet these requirements. Resource project interdependencies, knowledge interdependence and technology interdependence must be considered to maximise the benefits of life cycle management. This takes place when something else is developed from existing knowledge as a result of advancement in life cycle management; this is due to collaborations that surge strategic interaction towards the strategic direction established by the organisation. The two PSLCM processes are:

- Proactive processes – these processes are well planned processes that the organisation follows to deliver projects and products and power plants that always meet and exceed customer expectations. It includes business plan processes, life of plant plan (LOPP)

management, technical plan processes, outage plan processes and project execution processes.

- Reactive processes – these are not planned processes that are followed as a results of current system deficiencies, obsolescence or advancement in technology which include operating processes, maintenance processes, plant monitoring processes, resource planning and scheduling processes, and the deviation process.

The diagram below illustrates the process interdependency management of the PSLCM processes.

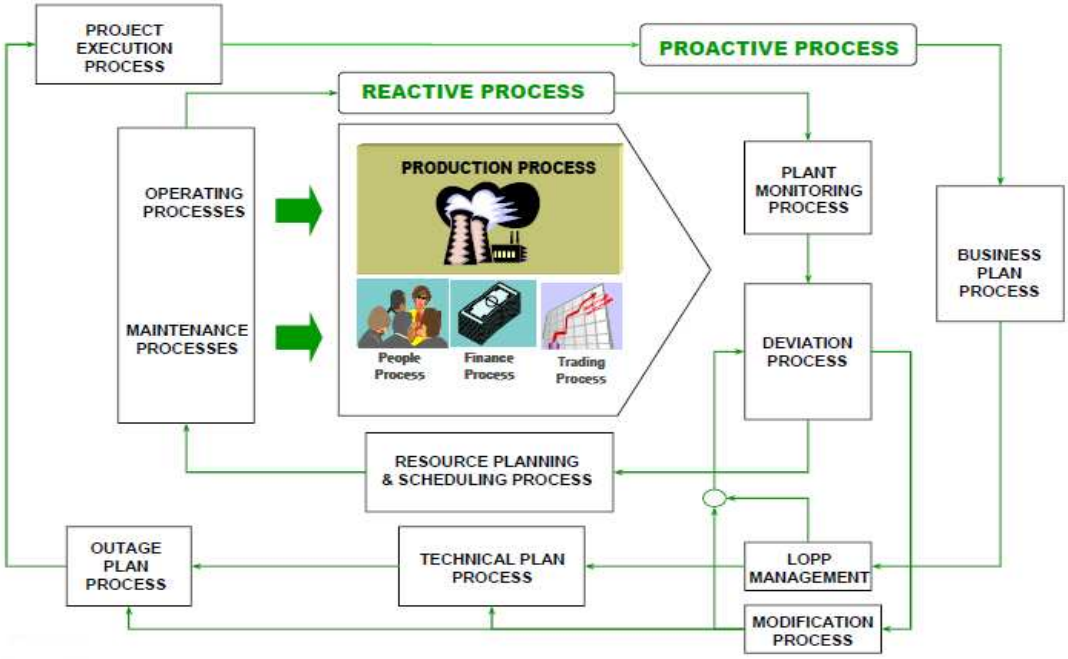


Figure 6-11: PSLCM process interdependency management

From the above, it could be deduced that plant success (PS) through its life cycle is directly proportional to project management success (PMS), project product success (PPS) and organisational success (OS) indicated by the mathematical relationship below:

$$\mathbf{PS\,(Y) = \; X(PMS) * Y(PP) * Z(OS)} \ldots\ldots\ldots\ldots\ldots \textbf{(6.10)}$$

Where:

$$\mathbf{PMS(X_1) = 0.23(X_{1,2,3,4,5}) + 0.216(X_1) + 0.216(X_2) + 0.144(X_3) + 0.122(X_4) + 0.0719(X_5)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(6.11)}$$

PMS = Project management success

$X_{1,2,3,4,5}$ = Factors interdependency

X_1 = Scope

X_2 = Time

X_3 = Cost

X_4 = Quality

X_5 = Risk

$$\mathbf{PPS}(\mathbf{Y}) = (\boldsymbol{Y_1}) * (\mathbf{Y_2}) * (\boldsymbol{Y_3}) * (\mathbf{Y_4}) \text{.....} \quad \textbf{(6.12)}$$

PPS = Project product success

(Y_1) = System availability

Y_2 = System reliability

Y_3 = System maintainability

Y_4 = System capability

$$\boldsymbol{OS}(\boldsymbol{Z}) = (\tfrac{Z_1}{Z_2}) \text{.....} \quad \textbf{(6.13)}$$

OS = Organisational success

Z_1 = Capital/Revenue

Z_2 = Costs (LCC)

Substituting equation (10), (11), and (12) into equation (9):

$$\boldsymbol{PS}(\boldsymbol{Y}) = [\mathbf{0.23}(\boldsymbol{I}) + \mathbf{0.216}(\boldsymbol{S}) + \mathbf{0.216}(\boldsymbol{T}) + \mathbf{0.144}(\boldsymbol{C}) + \mathbf{0.122}(\boldsymbol{Q}) + \mathbf{0.0719}] * [\boldsymbol{A} * \boldsymbol{R} * \boldsymbol{M} * \boldsymbol{C}] * \left[\frac{Z_1}{Z_2}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{14})$$

Therefore, change in input-output efficiency can be calculated as follows;

$$\Delta_{\boldsymbol{\mu}} = \left(\frac{\Delta\_\boldsymbol{\mu O_i}}{\Delta - \boldsymbol{\mu i_i}}\right) \text{.....} \quad \textbf{(6.15)}$$

Where:

$\Delta\_\mu O_i$ = Change in efficiency input of a variable

$\Delta - \mu i_i$ = Change in effitiency output for a variable

Substituting equation (15) into equation (14)

$$\boldsymbol{PS} = \left[\mathbf{0.23}\left(\left(\frac{\Delta\mu O_i}{\Delta\mu i_i}\right)\boldsymbol{i}\right) + \mathbf{0.216}\left(\left(\frac{\Delta\mu O_i}{\Delta\mu i_i}\right)\boldsymbol{S}\right) + \mathbf{0.216}\left(\left(\frac{\Delta\mu O_i}{\Delta\mu i_i}\right)\boldsymbol{T}\right) + \mathbf{0.144}\left(\left(\frac{\Delta\mu O_i}{\Delta\mu i_i}\right)\boldsymbol{C}\right) + \mathbf{0.122}\left(\left(\frac{\Delta\mu O_i}{\Delta\mu i_i}\right)\boldsymbol{Q}\right) + \mathbf{0.0719}(\left(\frac{\Delta\mu O_i}{\Delta\mu i_i}\right)\boldsymbol{r}\right] * \left[(\left(\frac{\Delta_{\mu o_i}}{\Delta\mu i_i}\boldsymbol{A}\right) * \left(\frac{\Delta_{\mu o_i}}{\Delta\mu i_i}\boldsymbol{R}\right) * \left(\frac{\Delta_{\mu o_i}}{\Delta\mu i_i}\boldsymbol{M}\right) * \left(\frac{\Delta_{\mu o_i}}{\Delta\mu i_i}\boldsymbol{C}\right)\right] * \left[\frac{\left(\frac{\Delta_{\mu o_i}}{\Delta\mu i_i}\right)\boldsymbol{R}}{\left(\frac{\Delta_{\mu o_i}}{\Delta\mu i_i}\right)\boldsymbol{C}}\right] \ldots\ldots\ldots\ldots\ldots (\mathbf{6.16})$$

The above equation monitors both efficiency and effectiveness of a system and its processes.

Project success life cycle model (PSLCM)

The model representing the above formula has a holistic view of life cycle performance measurement and applies system thinking and process thinking simultaneously, which provides more benefits than the two models used separately. This proposed model also provides a tool to calculate process efficiency, which will make it easy to identify system problems compared to process problems. The proposed model easily guides designers, project managers and operators by providing information that is normally only available to them through other methods, thus improving decision making because the information gap is eliminated. The proposed integrated model is illustrated in the figure below (summary of model).

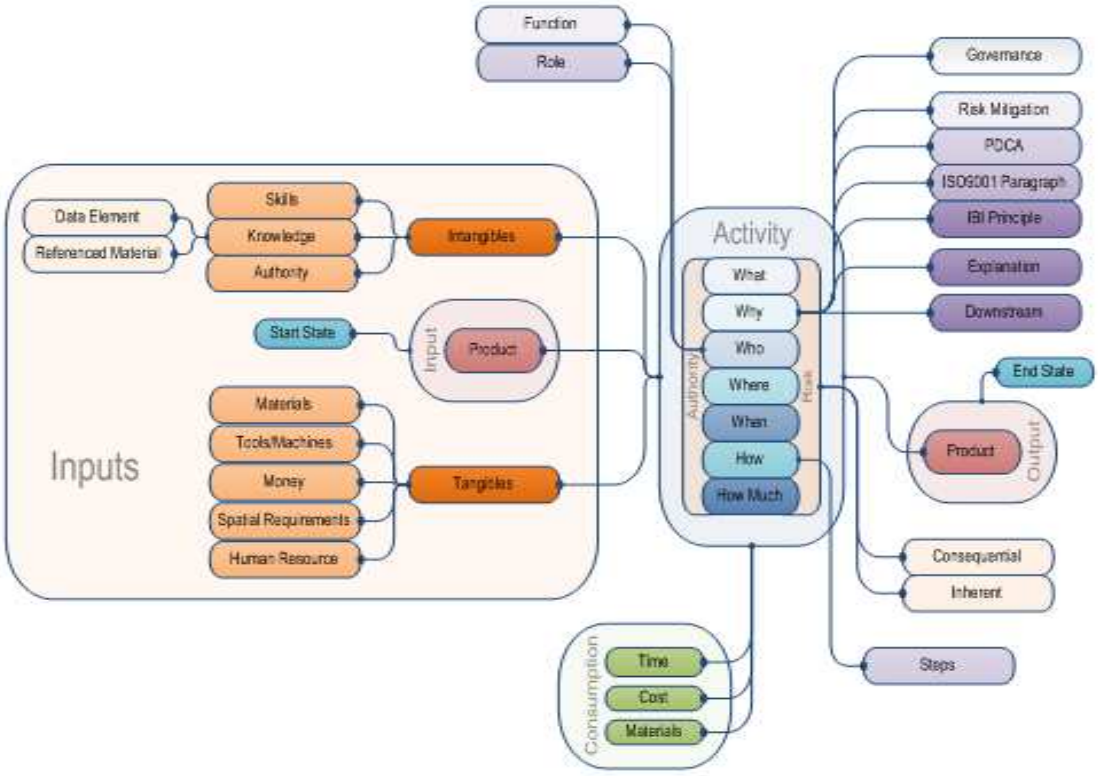


Figure 6-12: Project success life cycle model (PSLCM)

The PSLCM problem solving method aims to improve team competencies and adaptive ability to bring about the required transparency and a detailed understanding of how elements of the system affect system effectiveness. The existence of a system, its interaction and interdependency, is rooted in the connectivity of one element with others, which constitutes a network that must be dealt with as a whole.

Systems scenario analysis and planning provide a way for engineers to systematically integrate political, economic, and socio-cultural aspects of complex, large-scale engineering systems into the understanding of the operation and evolution of these systems. It also enables consideration of how emerging technology may change the way engineering systems operate and change over time (life cycle). Developing the intellectual dexterity and agility of engineers regarding how different perspectives and interpretations of science and technology, especially risk and how risk is managed and communicated, along with the ability to communicate clearly the overarching goal of the system, can minimise the impact of constraint present in engineering systems. The figure below indicates the PSLCM stages.

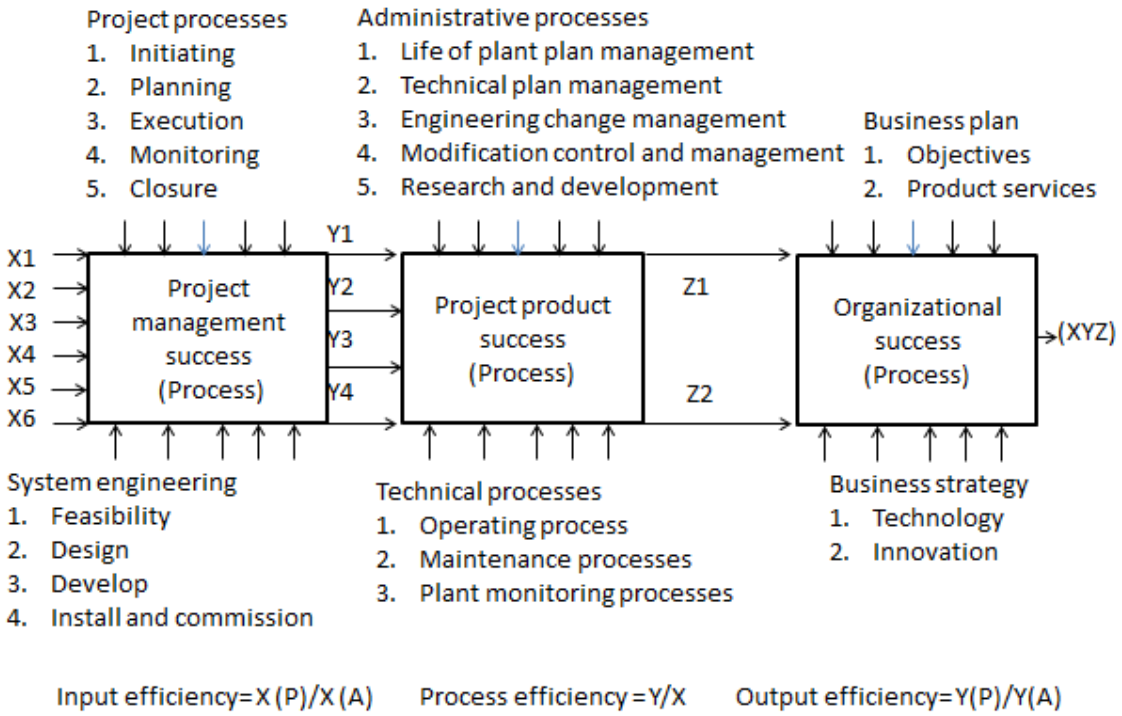


Figure 6-13: PSLCM stages

By understanding the input output relationship in systems and processes, the most influential variables of success x (input) on the response y (output) can establish the maximum and minimum points to determine the nominal point, identify how to control inputs to reduce output variability and to determine where influential X must be controlled so that the uncontrollable variables' effects are minimised.

6.6 Predict claims

PSLCM provides understanding to apply critical success factors and efficiency measurements to accurately monitor and control life cycle management processes.

The most commonly used project universal control system is the earned value method (EVM), which does better to inform the project manager how the project is progressing, providing completion values for costs and schedule performance. The EVM presented challenges, namely taking into account activity criticality when the completion date had passed where schedule and cash flow need to be revised. The PSLCM avoids this by calculating future values using the

critical path while considering the current performance efficiencies or inefficiencies to be part of the prediction equation of calculating future values (making it easy to provide early warnings and avoiding non-critical activities to be critical) of five critical project success factors as indicated in the formula below:

$$\boldsymbol{PMS(V)} = \mathbf{0.23}\left(\frac{\Delta Output_i}{\Delta input_i}\right) + \mathbf{0.216}\left(\frac{\Delta Output_s}{\Delta input_s}\right) + \mathbf{0.216}\left(\frac{\Delta Output_t}{\Delta input_t}\right) + \mathbf{0.144}\left(\frac{\Delta Output_c}{\Delta input_c}\right) + \mathbf{0.122}\left(\frac{\Delta Output_q}{\Delta input_q}\right) + \mathbf{0.0719}\left(\frac{\Delta Output_r}{\Delta input_r}\right) \ldots \ldots (\mathbf{6.17})$$

PSLCM provides understanding to utilise critical factor variation measurements to accurately calculate project future values, taking into consideration up to date performance. PSLCM reaffirms that:

$$\boldsymbol{FP} = \boldsymbol{CP}\ (\boldsymbol{PUD}) + \left[\left(\frac{\boldsymbol{A}-\boldsymbol{P}}{\boldsymbol{P}}\right)\boldsymbol{PFP} + \boldsymbol{PFP}\right) \ldots \ldots \ldots (\mathbf{6.18})$$

Where:

FP = Future performance (performance at a certain point)

CP = Current performance (performance to date)

A = Actual value

P = Planned value

PFP = Future planned performance (at a specific point)

Note

$$\boldsymbol{Variation\ ratio} = \left(\frac{\boldsymbol{A-P}}{\boldsymbol{P}}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(6.19)}$$

PSLCM provides understanding to utilise efficiency of an effectiveness measure (actual vs planned) to identify the design accuracy and application gaps

Prediction 1

We predict that utilising PSLCM to measure and control project deliverable success will determine priority needed to eliminating bad habits (design practices, student syndrome) and bring significant performance improvement (80:20 principle determining critical few from trivial many).

Therefore

Identifying progress performance at different stages of the project life cycle make it easy to identify process and system interdependencies, which will make it easy to perform continues improvement. This methodology bridge eliminates a gap between design, planning, execution and operations

Prediction 2

We predict that utilising PSLCM will integrate project management principles and system engineering principles focusing more on the overall objectives, providing logical process to improve success, setting the stage to develop an improved theory for performance measurement and control.

Therefore

The system process variation theory has proven that the process dependency and interdependency between variables must be managed carefully at any stage, and that changes in design must follow a thought process that predicts all future values so that highly informed decisions can be taken.

How the PSLCM measuring and control system differs from conventional methods

Initiatives to monitor and manage project performance accurately at all life cycle stages are not new. The common project control system used is the earned value method which provides more problems with regard to measuring overall performance. The critical chain project management introduced problems that could not be solved while using the same process and the inaccuracies of measuring project progress solely based on time performance. PSLCM contributes a more detailed understanding of performance measurement and management by using process critical factors weighed according to their different levels of contribution. PSLCM provides a unique understanding of how completion values can be calculated at any specific date considering up to date efficiencies and inefficiencies. The PSLCM equations provide unique guidance on how to identify and develop different progress measurements and tracking.

The combination of reducing variation, improved measurement accuracy and better control of project, product and organisation, presents an opportunity to improve life cycle management performance. By utilising PSLCM, it is predicted that measuring and controlling asset performance over its life cycle will be very easy, which will improve management decision making, providing accurate information in time. This method also combines technical measures and financial measures by calculating efficiencies which allow a single measure of performance to be used for measuring overall performance. The null hypothesis four for the modelling theory is that:

- **H_0 : There are no best life cycle management practices as a result of theory advancements in modelling that will assist to improve power plant life cycle monitoring, control and management.**

The alternative hypothesis for the modelling theory is that:

- **H_1 : There are best life cycle management practices as a result of theory advancements in modelling that will assist to improve power plant life cycle monitoring, control and management.**

The PSLCM theory indicates that different life cycle modelling produces different results depending on industry type, organisational capability, technology management and innovation levels. The alternative hypothesis is therefore acceptable and the null hypothesis in this research is rejected.

6.7 Discussion of PSLCM

According to Wacker (1998:361), scientific knowledge must provide a method of categorising and organising objects. PSLCM describes the categorisation and identification of project success components in section 6.2 by defining the sub process components. This new technology provides opportunities for a new level of focus.

Scientific knowledge must also provide predictions regarding future events. The predictive claims of PSLCM are presented in section 6.4.

Scientific knowledge must furthermore explain past events providing *a sense of understanding about events causes.* The identification and discussions of individual components in section 6.2 provide explanations of past events, specifically providing additional insight into the motivations for poor project monitoring.

Rozenes et al. (2004:110) state that scientific knowledge must provide the potential to control future events. The relationships underlying PSLCM, as summarised in section 6.3, and the predictive claims presented in section 6.4, provide measurements and controls to influence future projects.

In summary, PSLCM complies with the requirements stated by Kaplan (1998:334) for scientific knowledge to provide value.

The value provided by PSLCM is demonstrated in the validation case studies as reported in Chapter 7. Researchers consider theorising an important role in considering variance, process and system approach, suggesting an integrated approach which can be used to improve the field's ability to predict, understand and explain important phenomenon.

6.8 Conclusion

The chapter provided a summary of a project success life cycle model (PSLCM). This methodology was analysed to comply with the requirement of good theoretical study and has complied with all requirements of an engineering model. The PSLCM presents an opportunity for cost saving, improving operational efficiencies and constraint management, which will move more organisations closer to their bottom line, to generate income now and in furfure.

PSLCM also integrates technical measures with financial measures in an equation by calculating efficiency so that an overall representation of how much the project, its product and organisation has performed and if all requirements are met. This will assist project stakeholders to think beyond their immediate activities, which will improve performance at all stages.

6.9 Chapter overview

Chapter 6: Project life cycle model (PSLCM) development

Chapter 6 explained the development of a project model that can ensure that all power plant projects are fit for purpose, performed at the right time, the right cost and the right quality.

Chapter 7: PLCM verifications and validation

Chapter 7 demonstrates PSLCM verifications and validation. Project case studies will be used to verify the effectiveness of PSLCM to measure, control and manage project activities from project initiation until project delivery.

CHAPTER 7

PSLCM VERIFICATION AND VALIDATION

The PSLCM model is developed to measure and control the performance of a project, as well as its product and business processes that deliver those products simultaneously. This model compares the performance of projects, products and corporate performance at different stages throughout their useful life by measuring input, process and output efficiency in each decision making unit (DMU). Technical performance measures (TPM) are used to measure overall performance, while data envelope analysis (DEA) is used to compare the measured performance objectively.

7.1 Introduction

Improving project, product and organisational efficiency is the most important function of a project management office. This is about ensuring that project processes are improved without improving project input so that project outputs can be maximised, and project efficiency improved. The PSLCM aims to improve project efficiency by measuring inputs and outputs of tasks, activities, project, programmes and corporate success, so that inefficient areas can be identified through its decision making units (DMUs). This method also measures the efficiency of DMUs so that inefficient business processes, system development processes and project management processes can be easily determined. These show that an integrative system is needed that can indicate the project's status during the project's life cycle.

7.2 Methodology to evaluate performance efficiency

The objective of the PSLCM control system, is to minimise the variations that exist between system design, project development and operations support by measuring efficiency and variations. The inputs represent the flow of data and materials into the process from the outside. The processing step includes all tasks required to effect a transformation of the inputs. The outputs are the data and materials flowing out of the transformation process. Should there be a gap between design, planning, execution, operations and performance, a warning is indicated in order to take corrective action.

7.3 Performance efficiency using DEA methodology

The PSLCM methodology is designed for project multi-dimensional control and can be applied in parallel for different projects, project deliverables and organisational impact. DEA methodology is applied in a technical performance and financial measure through decision making units producing outputs measured at a specific control point. To represent the necessary information and adjusting input and output requirements, a four stage method was developed.

7.3.1 Define input and output

The PSLCM control system requires a standard framework for control when implemented with DEA and TPM, which resonates from identifying success factors in an organisation so that all projects in that organisation can be compared and reporting performed uniformly. The organisation inputs data that will be measured generally in three stages:

System development

System effectiveness is a measure of value received, indicating how well product, process or services satisfy user needs or requirements. The effectiveness scale varies from 0 – 100% with higher values better than low values. The formula is:

$$System\ effectiveness = Availability * reliability * capability * maintainability \ldots\ldots (7.1)$$

Availability: The chance of the equipment or system being available to perform its duty. The numbers consist of a design value that the system needs to achieve to meet the needs. Actual values are recorded during operations which justify if the system is achieving its design requirements.

Reliability: The system will operate for a given time without failure. Actual values are recorded compared with design value to justify if the system is achieving functional requirements. The scale is 0 - 100% favouring higher values.

Capability: The system can perform its intended production activity according to the standard. The scale of 0 - 100% is used when designing and monitoring capability, with higher value aspired.

Maintainability: The system will be repaired without excessive lost maintenance time. A scale of 0 - 100% is used to measure against the design value.

Project development

The project management success (PMS) equation was developed and presented in Chapter 5, taking into consideration the critical success factors and constraint in power plant life cycle management projects. The PMS equation is:

$PMS = 0.23(I) + 0.216(S) + 0.216(T) + 0.144(C) + 0.122(Q) + 0.0719$(R)…… (7.2)

Interdependency: PSLCM focuses on the effect of interdependencies of project success factors. The above formula acknowledges that interdependencies account for 23% influence to ensure that the project succeeds or fails. This factor is then used during DEA as input and output weighted factors.

Scope: The scope of a project utilising PSLCM is measured using work packages. The number of work packages is identified with all resources, capacity, requirements and facilities required to perform and complete the task. The formula above indicates that power plant project scope determination and accuracy account for 21,6% success. This factor is then used during DEA as input and output weighted factors.

Time: The research indicates that 21,6% relate to time management performance. Planned time is compared to actual time measure to determine time efficiency. This factor is then used during DEA as input and output weighted factors.

Cost: according to the research, 14,4% is a result of cost related challenges in power plant projects. The actual task and activities are continuously compared to the plan and variation is measured.

Quality: Project complexity determines how quality control must be performed by determining follow up levels required for performing the project. Quality efficiency is measured by comparing the quality plan to the project actual data. The values are normally between 0 - 100%, but values outside the range are also acceptable depending on emergent issues including changes in requirements and specification addressed during execution

Risk: A scale of 0 - 100% is used to measure risk efficiency that existing in the task, activity and in a project. A high value indicates compliance to project risk mitigation strategies. Depending on changes that happen during execution not limited to scope and requirement changes, values above 100% are also acceptable. Research conclusions in Chapter 5 indicates that managing risk accounts to 7% influence in power plant project.

Organisational development

The third stage of the PSLCM is the organisational success or corporate success, which focuses on linking tasks, activities and projects to business benefits. At this stage, measurable improvement resulting from an outcome which has a tangible value expressed in monetary or resource terms, is quantified. This requires an organisation to develop a benefit realisation process that helps to realise, prepare and manage for planned benefits through the project, product and organisation life cycle. The benefits-cost analyses (efficiency) are used to measure performance, using a scale of 0 - 100%.

$$Life\ cycle\ cost - benefits\ analyses = \frac{Output}{Input} = \frac{Benefits\ (Monetory\ value)}{Cost\ (Monetory\ value)}. \quad (7.3)$$

This calculation enables organisations to maximise the entire benefit maximisation from changes using a structured approach to manage the realisation of benefits, which translates business objectives into measurable, identifiable, benefits that can be systematically tracked.

The most common measure used in projects is the return on investment (ROI), which is a performance measure, used to evaluate the efficiency of an investment or compare the efficiency of a number of different investments. ROI measures the amount of return on an investment, relative to the investment's cost. To calculate ROI, the benefit (or return) of an investment is divided by the cost of the investment. The result is expressed as a percentage or a ratio. This measure is not adopted at this stage, because there are different costs at different stages of the life cycle management, which would be difficult to account for if this formula was used. However, the formula can be used independent of the model.

7.3.2 PSLCM implementation

The PSLCM model views projects as powerful strategic tools used by organisations to create a competitive advantage and economic value added. Today, business results rely on project managers to take total responsibility as new strategic leaders to guide its future direction. Organisations' short- and-long term goals require a strategic management view to align project efforts. Project control and monitoring is very important because it provides and understanding with regard to where the project is going (project progress) so that when the project deviates significantly, corrective action can be taken.

Case study: Ash water recovery

The continuous operation of an ash water recovery system for Unit 1 to 6 (Stage I to IV) round the clock and the operation of the ash water recovery, broadly involves supplying m^3/h clear water by means of operating various pumps and auxiliaries horizontal centrifugal clear water pumps of 550 200 m^3/h, sludge disposal pumps of capacity 200 m^3/h, dosing/metering pumps of 1200 l/h capacity, lime dosing pumps of 1 200 m^3/h capacity, and preparation tanks fitted with a high-speed agitator. Motor driven flash mixers with turbine type agitators, dewatering pumps by operating various manual/electrically operated valves (butterfly, sludge, gate, globe, sluice). The figure below indicates basic project planning data.

Table 7-1: Project input data

DMU	Task Name/Work package	Successor	Cost (R)	Time(t)	Scope (WP)	Quality (HI)	Risk (H)
1	Contract documentation		30992.192	7.5	4	8	4
2	Process design	1	309724.8	10	6	8	7
3	Mechanical design	2	193054.4	16	5	7	3
4	Electrical design	2	106869.84	15	4	8	2
5	Automation design	2	74345.04	11	10	9	4
6	Design integration and review	3,4,5	149688	10	9	8	2
7	Procurement and delivery	6	26790417.81	15	16	8	2
8	Installation	7	4113301.808	32.5	32	7	3
9	Commissioning	8	466294.752	5	16	6	4
	Total		32234688.64	122	102	69	31

Phase 1 of PSLCM: Project management success (PMS)

Like earned value methodology, PMS is used to measure project progress. PSLCM is also used to calculate completion values at any project stage. By using efficiencies calculation, future values are more accurate if variations of the current task are used to accurately calculate the final values. The figure below shows actual project data (A) during execution as compared to the planned values.

Table 7-2: Project desired and actual data

MU	Successor	Costs		Duration		Scope		Quality		Risk	
		P	A	P	A	P	A	P	A	P	A
1		30992.192	27180.15238	7.5	8	4	4	6	5	4	3
2	1	309724.8	359900.2176	10	12	6	6	16	14	7	7
3	2	193054.4	222591.7232	16	17	5	5	18	18	3	3
4	2	106869.84	125251.4525	15	16	4	4	12	12	2	2
5	2	74345.04	66910.536	11	13	10	10	15	14	4	3
6	3,4,5	149688	131575.752	10	8	9	9	22	20	2	2
7	6	26790418	23254082.66	15	18	16	16	34	34	2	2
8	7	4113301.8	4611011.327	32.5	37	32	31	72	68	13	11
9	8	466294.75	409873.087	5	7	16	16	40	38	4	4
	Total	32234689	29208376.9	122	136	102	101	235	223	41	46

DEA is used to measure efficiency with multiple inputs and multiple outputs, assuming that there is no random noise, measurement errors or outlier cases in the data. The weighted input efficiency can be calculated as follows:

$$E_k = \frac{\sum_{j=1}^{M} u_j \, O_{jk}}{\sum_{i=1}^{n} V_i \, I_{ik}} \quad \text{..... (7.4)}$$

Where:

$V_i = weight\ for\ input\ i$
$U_j = weight\ for\ input\ j$
$O_{jk} = Output\ data$
$I_{ik} = Input\ data$
$E_k = Efficiency\ of\ a\ DMU\ (0\%\ to\ 100\%)$

Using this method, the number of variables does not matter because the correct data that is used to represent input and output is known. The table below indicates efficiencies DMU:

Table 7-3: Project DMU efficiency calculations

DMU	Cost(eff)	Time(eff)	scope (eff)	Quality (eff)	Risk (eff)	Interdependency (eff)
1	0.88	1.07	1.00	0.83	0.75	0.58
2	1.16	1.20	1.00	0.88	1.00	1.22
3	1.15	1.06	1.00	1.00	1.00	1.23
4	1.17	1.07	1.00	1.00	1.00	1.25
5	0.90	1.18	1.00	0.93	0.75	0.74
6	0.88	0.80	1.00	0.91	1.00	0.64
7	0.87	1.20	1.00	1.00	1.00	1.04
8	1.12	1.14	0.97	0.94	0.85	0.99
9	0.88	1.40	1.00	0.95	1.00	1.17
Total	**0.91**	**1.11**	**0.99**	**0.95**	**1.12**	**1.06**

After calculating the efficiencies of a DMU, the efficiency values are substituted in their respective variables on the project management success formula below:

$$PMS\ (Y) = [0.23(I) + 0.216(S) + 0.216(T) + 0.144(C) + 0.122(Q) + 0.0719(R)] \ldots. (7.5)$$

PMS utilises TPM to integrate different measurements into a holistic measure of the overall project performance. The figure below indicates variable's performance and the overall task performance.

Table 7-4: Project DMU overall milestone performance and PMS

DMU	Interdependency (i)	Scope(S)	Time(T)	Cost (c)	Quality (Q)	Risk (R)	PMS
1	0.134473333	0.216	0.2304	0.126288	0.101666667	0.05925	0.868078
2	0.280623	0.216	0.2592	0.167328	0.10675	0.079	1.108901
3	0.281764375	0.216	0.2295	0.166032	0.122	0.079	1.094296
4	0.287530667	0.216	0.2304	0.168768	0.122	0.079	1.103699
5	0.171245455	0.216	0.255272727	0.1296	0.113866667	0.05925	0.945235
6	0.147032727	0.216	0.1728	0.126576	0.110909091	0.079	0.852318
7	0.239567998	0.216	0.2592	0.124992	0.122	0.079	1.04076
8	0.227242353	0.20925	0.245907692	0.161424	0.115222222	0.066846	1.025892
9	0.268886101	0.216	0.3024	0.126576	0.1159	0.079	1.108762
Total	**0.244919312**	**0.2138824**	**0.240786885**	**0.13048075**	**0.115770213**	**0.088634**	**1.034474**

Research results in Chapter 5 provide evidence that the above critical factors used in PMS calculations generally fall under two types, namely (1) those that the project manager must

maximise (integration, scope and quality) and (2) those that must be minimised (time, cost and risk). The variation ratio of a task or project can be calculated by determining the difference between planned and actual values, divided by the planned values as shown in the formula below. The variations ratio of time, cost and risk can be calculated as follows:

$$Tv \text{ or } Cv \text{ or } Rv = \left(\frac{A- P}{P}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7.6)$$

Scope, integration and quality should be maximised. The equation to measure the variation ratio is indicated below.

$$Iv \text{ or } Sv \text{ or } Qv = \left(\frac{P - a}{P}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7.7)$$

V = Variation ratio
P = Planned value (target)
A = Actual value

$$PMS\ (V) = \left[0.23\left(\frac{P-a}{P}\right) + 0.216\left(\frac{a-p}{P}\right) + 0.216\left(\frac{a-p}{P}\right) + 0.144\left(\frac{a-p}{P}\right) + 0.122\left(\frac{P-a}{P}\right) + 0.0719\left(\frac{P-a}{P}\right)\right] \ldots\ldots\ldots\ldots (7.8)$$

The table below indicates the results of the above formula:

Table 7-5: DMU variability

DMU	Task name/Work package	Inter (V)	Scope (V)	Time (V)	Cost (V)	Quality(V)	Risk (V)	PMS (V)
1	Contract documentation	0	0	0.0144	-0.01771	-0.020334	-0.0198	-0.0434
2	Process design	0	0	0.0432	0.02333	-0.01525	0	0.051278
3	Mechanical design	0	0	0.0135	0.02203	0	0	0.035532
4	Electrical design	0	0	0.0144	0.02477	0	0	0.039168
5	Automation design	0	0	0.03927	-0.0144	-0.008134	-0.0198	-0.00301
6	Design integration and review	0	0	-0.0432	-0.01742	-0.011091	0	-0.07172
7	Procurement and delivery	0	0	0.0432	-0.01901	0	0	0.024192
8	Installation	-1.029E-06	-0.00675	0.029907	0.01742	-0.006778	-0.0122	0.021648
9	Commissioning	0	0	0.0864	-0.01742	-0.0061	0	0.062876
	Total	**-1.515E-07**	**-0.002117**	**0.02478**	**-0.01352**	**-0.006229**	**0.00966**	**0.012577**

During project closure, the final tasks' performance and variation values are indicated in the table below:

Table 7-6: Project performance and variation

ID	Task name/Work package	PMS	PMS (V)
1	Contract documentation	0.868078	-0.043396
2	Process design	1.108901	0.051278
3	Mechanical design	1.09429638	0.035532
4	Electrical design	1.10369867	0.039168
5	Automation design	0.94523485	-0.003011
6	Design integration and review	0.85231782	-0.071715
7	Procurement and delivery	1.04076	0.024192
8	Installation	1.02589242	0.0216482
9	Commissioning	1.1087621	0.062876
	Total	**1.03447366**	**0.0125767**

Phase 2 of PSLCM: Project product success (PPS)

At this stage, the project phase is closed and the project product is handed over for production and operations. The equipment performance and technical performance measures are compared to design values. The table below compares monthly designed value and achieved value during the first 14 months of operation.

Table 7-7: Project system performance data

DMU	Availability		Reliability		Maintainability		Capability	
	Design	Achieved	Design	Achieved	Design	Achieved	Design	Achieved
Month 1	0.93	0.71	0.85	0.58	0.82	0.87	0.87	0.92
Month 2	0.93	0.97	0.85	0.67	0.82	0.85	0.87	0.93
Month 3	0.93	0.91	0.85	0.88	0.82	0.85	0.87	0.89
Month 4	0.93	0.98	0.85	0.94	0.82	0.88	0.87	0.85
Month 5	0.93	0.96	0.85	0.87	0.82	0.92	0.9	0.88
Month 6	0.93	0.94	0.85	0.92	0.82	0.87	0.87	0.89
Month 7	0.93	0.95	0.85	0.9	0.82	0.96	0.87	0.92
Month 8	0.93	0.96	0.85	0.77	0.82	0.86	0.87	0.91
Month 9	0.93	0.97	0.85	0.93	0.82	0.87	0.87	0.82
Month 10	0.93	0.94	0.85	0.94	0.82	0.92	0.87	0.92
Month 11	0.93	0.96	0.85	0.93	0.82	0.97	0.87	0.97
Month 12	0.93	0.84	0.85	0.84	0.82	0.89	0.87	0.91

Month 13	0.93	0.83	0.85	0.96	0.82	0.87	0.87	0.92
Month 14	0.93	0.98	0.85	0.94	0.82	0.92	0.87	0.96

Using DEA methodology, the efficiency of the project performance is calculated. The return on investment and the breakeven point are used as two major measures for organisational success. These measures are broken down into monthly measures so that confidence can be gained that the project will perform accordingly. The table below shows the system effectiveness, efficiency and return on investment progress in the 14-month period.

$$\mathrm{PPS(Y)} = \text{System effectiveness} = (A) * (\mathrm{R}) * (\mathrm{C}) * (\mathrm{M}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7.9)$$

Substituted equation (7.4) into (7.9) to calculate efficiency of availability, reliability, capability and maintainability efficiencies, applying output/input between design and achieved value during the 14-month operation period.

$$\mathrm{PPS(Y)} = \left(\frac{\sum_{j=1}^{M} u_j A_{jk}}{\sum_{i=1}^{n} V_i A_{ik}}\right) * \left(\frac{\sum_{j=1}^{M} u_j R_{jk}}{\sum_{i=1}^{n} V_i R_{ik}}\right) * \left(\frac{\sum_{j=1}^{M} u_j C_{jk}}{\sum_{i=1}^{n} V_i C_{ik}}\right) * \left(\frac{\sum_{j=1}^{M} u_j M_{jk}}{\sum_{i=1}^{n} V_i M_{ik}}\right) \ldots\ldots\ldots\ldots\ldots \quad (7.10)$$

Table 7-8: PPS efficiency 14-month period results

DMU	A(eff)	R(Eff)	M(eff)	C(eff)	PPS
Month 1	0.763441	0.682353	1.060976	1.057471	0.584465
Month 2	1.043011	0.788235	1.036585	1.068966	0.91099
Month 3	0.978495	1.035294	1.036585	1.022989	1.074232
Month 4	1.053763	1.105882	1.073171	0.977011	1.221857
Month 5	1.032258	1.023529	1.121951	0.977778	1.159052
Month 6	1.010753	1.082353	1.060976	1.022989	1.187381
Month 7	1.021505	1.058824	1.170732	1.057471	1.33903
Month 8	1.032258	0.905882	1.04878	1.045977	1.02581
Month 9	1.043011	1.094118	1.060976	0.942529	1.141176
Month 10	1.010753	1.105882	1.121951	1.057471	1.326161
Month 11	1.032258	1.094118	1.182927	1.114943	1.489576
Month 12	0.903226	0.988235	1.085366	1.045977	1.01334
Month 13	0.892473	1.129412	1.060976	1.057471	1.130893
Month 14	1.053763	1.105882	1.121951	1.103448	1.442707
Average	**0.990783**	**1.014286**	**1.08885**	**1.039464**	**1.146191**

Phase 3 of PSLCM: Organisational or corporate success (OS)

Organisational success is calculated by taking into consideration the project life cycle cost and the benefits through sales (based on the equipment/plant rate). When the system is in operation, life cycle cost and benefits (in monetary value) are recorded for the month/year of operation as shown in the table below.

Table 7-9: Project life cycle cost and benefit

DMU	O&M	LCC	Sales /Monthly	Total Sales	OS	Breakeven point
		29208377			Benefits/cost	
Month 1	61432	29269809	1715843	1415843	0.04837213	
Month 2	58213	29328022	1972456	3388299	0.115531113	
Month 3	44200	29372222	2278143	5666442	0.192918398	
Month 4	41233	29413455	2189231	7855673	0.267077534	
Month 5	45872	29459327	2192453	10048126	0.341084711	
Month 6	42345	29501672	2123523	12171649	0.412574889	
Month 7	47234	29548906	2212543	14384192	0.486792711	
Month 8	41234	29590140	2378342	16762534	0.566490529	
Month 9	45612	29635752	2212453	18974987	0.640273514	
Month 10	39145	29674897	2278453	21253440	0.716209397	
Month 11	43981	29718878	2185678	23439118	0.788694583	
Month 12	44218	29763096	2114567	25553685	0.858569454	
Month 13	51678	29814774	2179423	27733108	0.930180054	
Month 14	54351	29869125	2340100	30073208	1.006832577	**Breakeven point**

Phase 4 of PSLCM: Project overall success (PS)

PSLCM performance of a project recorded on a monthly basis. The final value for project management success is used in all future calculations. The system effectiveness (availability, reliability, capability and maintainability) is used to measure monthly performance reported under project product success (PPS). Project product success is calculated directly with the return on investment required after a specified period measuring progress monthly. The table below indicates the 14-month PSLCM project results. The formula used was deduced from the power plant success factor study in Chapter 5 as follows:

$Project\ success\ (PS) = Project\ management\ success(PMS) * Project\ product\ success(PPS) * Organisational\ success\ (OS)$ ……(7.11).

Table 7-10: Project overall performance

DMU	PMS	PPS	OS	PS
Month 1	1.034474	0.584465	0.04837213	0.029246445
Month 2	1.034474	0.91099	0.115531113	0.108875916
Month 3	1.034474	1.074232	0.192918398	0.214383373
Month 4	1.034474	1.221857	0.267077534	0.337580491
Month 5	1.034474	1.159052	0.341084711	0.408963395
Month 6	1.034474	1.187381	0.412574889	0.506771505
Month 7	1.034474	1.33903	0.486792711	0.674300835
Month 8	1.034474	1.02581	0.566490529	0.601144546
Month 9	1.034474	1.141176	0.640273514	0.755853765
Month 10	1.034474	1.326161	0.716209397	0.982552652
Month 11	1.034474	1.489576	0.788694583	1.215320892
Month 12	1.034474	1.01334	0.858569454	0.900015233
Month 13	1.034474	1.130893	0.930180054	1.088197901
Month 14	1.034474	1.442707	1.006832577	1.502639167
Average	**1.034474**	**1.146191**	**0.526542971**	**0.666131865**

The annual performance of the plant system can be displayed as data changes as indicated in the table below:

Table 7-11: Project plant system's performance life cycle monitoring

DMU	Power plant system	PMS	PPS	OS	PS
2017	1. FD & PA fans	0.812	0.791	0.841	0.540168
	2. ID fans & smoke stacks	0.871	0.896	0.943	0.735932
	3. Milling plant (horizontal tube mills)	0.951	0.813	0.915	0.707444
	4. PF system and burners	0.823	0.931	0.889	0.681163
	5. Boiler	0.773	0.841	0.983	0.639041
	6. Soot blower/Air heaters and ducting	0.832	0.889	0.896	0.662725
	7. Flue gas cleaning (ESP)	0.931	0.921	0.975	0.836015
	7. Flue gas cleaning (FFP)	0.925	0.951	0.891	0.78379
	8. Bottom ash removal	0.851	0.891	0.914	0.693032
	9. Dust-handling plant, AWR & AWRR	0.887	0.931	0.879	0.725876
	10. Steam piping system	0.981	0.991	0.903	0.87787
	11. Turbine and condenser	0.914	0.926	0.887	0.750725
	12. Condensate system	0.791	0.857	0.854	0.578915
	13. Feed water system	0.845	0.885	0.879	0.657338

	14. Cooling water system	0.883	0.934	0.931	0.767816
	15. Generator	0.851	0.843	0.847	0.607632
	16. Unitised and common C&I	0.892	0.965	0.875	0.753183
	17. Unitised electrical	0.921	0.943	0.923	0.801628
	18. Fuel oil plant	0.881	0.894	0.945	0.744295
	19. Coal plant	0.889	0.956	0.932	0.792092
	20. Water treatment plant	0.845	0.879	0.976	0.724929
	21. Mixed ash plant	0.885	0.967	0.954	0.816428
	22. Common C&I	0.861	0.676	0.832	0.484254
	23. Common electrical	0.786	0.814	0.865	0.55343
	24. Civil	0.987	0.987	0.974	0.948841
	25. Ancillary systems	0.915	0.945	0.887	0.766967
	26. Auxiliary plant	0.875	0.897	0.931	0.730719
	Average plant performance	**0.876222**	**0.896815**	**0.908185**	**0.71712**

This means that the contribution of the life cycle project impact to the organisation by delivering technological advancement or eliminating current deficiencies, can be easily monitored and determinations can be made if the projects were worth undertaking.

Table 7-12: Power utility PSLCM performance 2017 (Foster and Briceño-Garmendia, 2009)

Power utility	Counties	PMS	PPS	OS	PS (PSLCM)
ESKOM	South Africa	0.971	0.924	0.883	0.79223113
ENEO	Cameroon	0.932	0.913	0.884	0.75220974
NAWEC	Gambia	0.897	0.845	0.824	0.62456316
LEC	Lesotho	0.814	0.864	0.845	0.59428512
EDM	Mozambique	0.778	0.865	0.887	0.59692439
EWSA	Rwanda	0.792	0.895	0.854	0.60534936
STEG	Tunisia	0.956	0.875	0.796	0.665854
SONELGAZ	Algeria	1.041	0.945	0.963	0.94734644
SNE	Congo Brazzaville	0.835	0.841	0.987	0.69310595
ECG	Ghana	0.978	0.945	0.956	0.88354476
LEC	Liberia	0.746	0.783	0.794	0.46378969
NAMPOWER	Namibia	0.879	0.845	0.824	0.61203012
SINELAC	Rw-DRC-Bur	0.789	0.814	0.845	0.54269787
UEGCL	Uganda	0.756	0.978	0.878	0.6491651
PRODEL-EP	Angola	0.852	0.934	0.897	0.7138039
CIE	Côte d'Ivoire	0.813	0.925	0.918	0.69035895
VRA	Ghana	0.934	0.891	0.901	0.74980679
GECOL	Libya	0.714	0.789	0.714	0.40222904
NIGELEC	Niger	0.784	0.878	0.821	0.56513699
SENELEC	Senegal	0.812	0.934	0.942	0.71442034

ZESCO	Zambia	0.878	0.845	0.934	0.69294394
ENDE-EP	Angola	0.834	0.895	0.876	0.65387268
CI ENERGIES	Côte d'Ivoire	0.923	0.914	0.897	0.75672893
GRIDCo	Ghana	0.945	0.945	0.985	0.87962963
ZESA	Zimbabwe	0.795	0.845	0.804	0.5401071
SBEE	Benin	0.824	0.876	0.878	0.63376147
EDD	Djibouti	0.885	0.956	0.895	0.7572237
EDG	Guinea Conakry	0.834	0.887	0.878	0.64950752
ESCOM	Malawi	0.835	0.945	0.901	0.71095658
BPC	Botswana	0.946	0.928	0.961	0.84365037
EEHC	Egypt	0.923	0.894	0.947	0.78142841
EDM-SA	Mali	0.834	0.887	0.857	0.63397261
TCN	Nigeria	0.825	0.913	0.894	0.67338315
MWRE	Sudan	0.981	0.932	0.842	0.76983386
EAGB	Guinea Bissau	0.832	0.887	0.912	0.67304141
SNE	Chad	0.878	0.867	0.847	0.64475842
SONABEL	Burkina Faso	0.795	0.815	0.876	0.5675823
EEP	Ethiopia	0.854	0.889	0.914	0.69391428
KenGen	Kenya	0.887	0.862	0.884	0.6759011
ONEE	Morocco	0.913	0.902	0.883	0.72717346
ENERCA	CAR	0.7485	0.845	0.813	0.51420827
REGIDESO	Burundi	0.798	0.846	0.851	0.57451691
CEB	Benin/Togo	0.814	0.864	0.897	0.63085651
SEEG	Gabon	0.794	0.877	0.845	0.58840561
	Average	**0.855648**	**0.886341**	**0.879182**	**0.67105025**

7.3.3 Design of experiment (DOE)

To determine the effects of the variables inputs on performance and variation, an experiment was used to study the performance of project processes and system represented by a model. The process is visualized as a combination of operations, machines, methods, people and any other resources that will be used to transform input to output that has observable response variables. PSLCM in this stage proves the interdependency of factors and the impacts they have towards success or failure. The same factor has an impact on variation are experimented in different input output combination. The table below shows the three inputs that will be experimented to see their effects on the outputs.

Table 7-13: PSLCM input

PSLCM phase	Low level (%)	Factorial low	Mid to high (%)	Factorial high
Project management success (PMS)	< 0.7 or 70%	-1	> 0.7 or 70%	1
Project product success (PPS)	< 0.7 or 70%	-1	> 0.7 or 70%	1
Organisational success (OS)	< 0.7 or 70%	-1	> 0.7 or 70%	1

Data envelope analysis makes it possible to use different variable with different measuring units by calculating individual efficiencies and that the factors linked to these processes where evaluated before and the table below links the above processes to these factors.

Table 7-14: PSLCM alignment

Process	Technical Performance measure	Description	DEA measurements
Project management success	Interdependency	Efficiency	Efficiency
	Scope	Work packages	Efficiency
	Time	Days	Efficiency
	cost	Rand	Efficiency
	Quality	Compliance	Efficiency
	Risk	Mitigation	Efficiency
Project product success	Availability	Percentage	Efficiency
	Reliability	Percentage	Efficiency
	Capability	Percentage	Efficiency
	Maintainability	Percentage	Efficiency
Organisational success	Life cycle cost	Rand	Efficiency
	Benefits	Rand	Efficiency

The objective of this experiment is to determine which variables are most influential on the response y, determine the maximum and minimum points to determine the nominal point, identify how to control inputs to reduce output variability and to determine where influential X must be controlled so that the uncontrollable variables effects are minimised. The results of running all combination of chosen factor at two levels (high and low) are shown in table below. The order was randomised to offset any lurking variable to the process.

Table 7-15: Experiment for performance and variation

Project	PMS (X)	PPS(Y)	OS(Z)	Performance(PS)	Variation(V)
1	-1	-1	-1	28.26	3.99
2	1	-1	-1	36.49	2
3	-1	1	-1	38.09	1.58
4	1	1	-1	50.09	0.58
5	-1	-1	1	41.01	0.94
6	1	-1	1	58.46	0.18
7	-1	1	1	65.15	0.02
8	1	1	1	87.09	0.01

Coded factor levels indicated by mathematical symbols minus and plus are used to depict actuals levels respectively. The following formula is used to calculate effects per input variables.

$$Effects\ (Y1\ or\ Y2) = \frac{\sum X(+)}{n} - \frac{\sum X(-)}{n}$$

In this experiment, the effects of the one three factor (X,Y,Z), three two factor interaction (XY,XZ, YZ) and one three factor interaction (XYZ), which gives a total of seven effects. To estimate the overall mean, one degree of freedom was used to estimate the overall mean. The table below indicates the calculated effect on the output (y) by each input combination (X). Main effects and interaction impacts to the output can be observed.

Table 7-16: PSLCM input interdependency

Project	X	Y	Z	XY	XZ	YZ	XYZ	Performance(PS)	Variability(V)
1	-1	-1	-1	1	1	1	-1	28.26	3.99
2	1	-1	-1	-1	-1	1	1	36.49	2.00
3	-1	1	-1	-1	1	-1	1	38.09	1.58
4	1	1	-1	1	-1	-1	-1	50.09	0.58
5	-1	-1	1	1	-1	-1	1	41.01	0.94
6	1	-1	1	-1	1	-1	-1	58.46	0.18
7	-1	1	1	-1	-1	1	-1	65.15	0.02
8	1	1	1	1	1	1	1	87.09	0.01
Effects (PS)	**23.53**	**19.05**	**98.78**	**2.07**	**4.79**	**7.34**	**0.18**	**50.58**	
Effects (V)	**-0.94**	**-1.23**	**-7.00**	**0.44**	**0.56**	**0.69**	**-0.06**		**1.16**

Calculate absolute value of effects

Effects must be converted to absolute values before plotting them using very sensitive scale in order to detect significant outcomes. The half normal, which is a graph plainly based on a

positive half of a curve is used to accommodate the absolute value scale (This is like folding a bell shaped curve, folding it in half at the mean). The half normal plot Y axis display cumulative probability of getting a results below given levels by adjusting the scale to account for using the effect absolute value. Before data is plotted in the probability paper, data points were sorted in ascending order, cumulative probability (0-100%) scale was divided into equal segments and data plotted at the midpoint of each probability segments. The probability segment of a full segment is 100% divided by 7 variables which results 14.28. Dividing the answer by two for the half graph, we get 7.14% as the lowest point in the midpoint of the first segment. The table below shows how values will be plotted on a half normal probability graph for performance.

Table 7-17: Absolute value for effect in performance

Point	Effects	Absolute value of effects	Cumulative probability
1	Z	24.70	7.14%
2	X	23.53	21.43%
3	Y	19.05	35.71%
4	YZ	7.34	50%
5	XZ	4.79	64.29%
6	XY	2.07	78.57%
7	XYZ	0.18	92.86%

The table below shows how values will be plotted on a half normal probability graph for variations.

Table 7-18: Absolute value for effects on variation

Point	Effects	Absolute value of effects	Cumulative probability
1	**Z**	**-1.75**	7.14%
2	**Y**	**-1.23**	21.43%
3	**X**	**-0.94**	35.71%
4	**YZ**	**0.69**	50%
5	**XZ**	**0.56**	64.29%
6	**XY**	**0.44**	78.57%
7	**XYZ**	**-0.06**	92.86%

The Pareto analyses summarises a graphic representation of the principle offering a simpler view of effects via a bar graph depicting the 80/20 principle. The figure below shows the Pareto chart for effects on performance. The few factors on the left are identified as the vital few, while all those on the right are considered the trivial many.

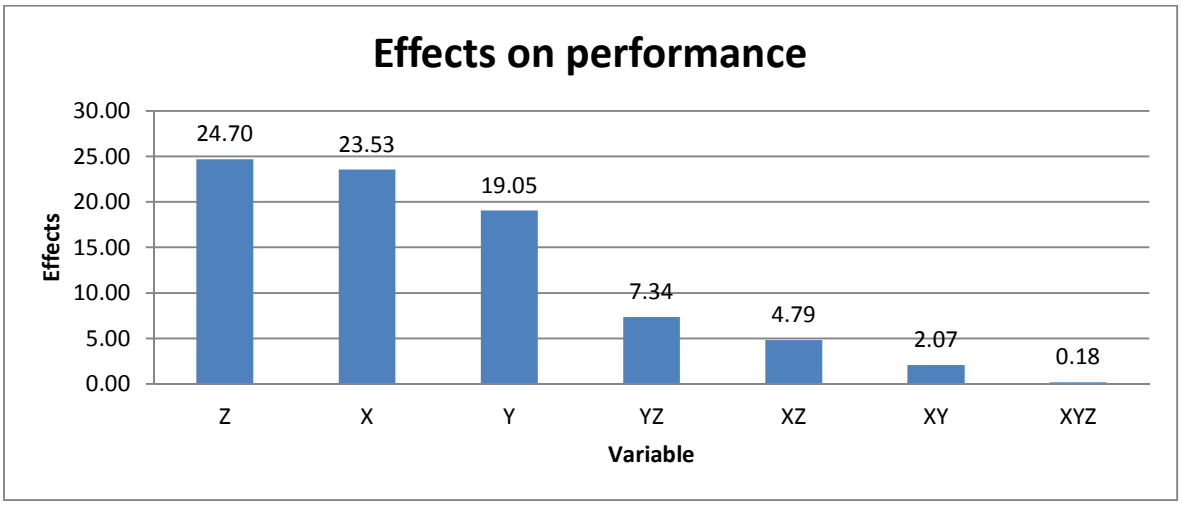


Figure 7-1: Pareto chart of effects of PSLCM performance

The figure below shows the Pareto for variations.

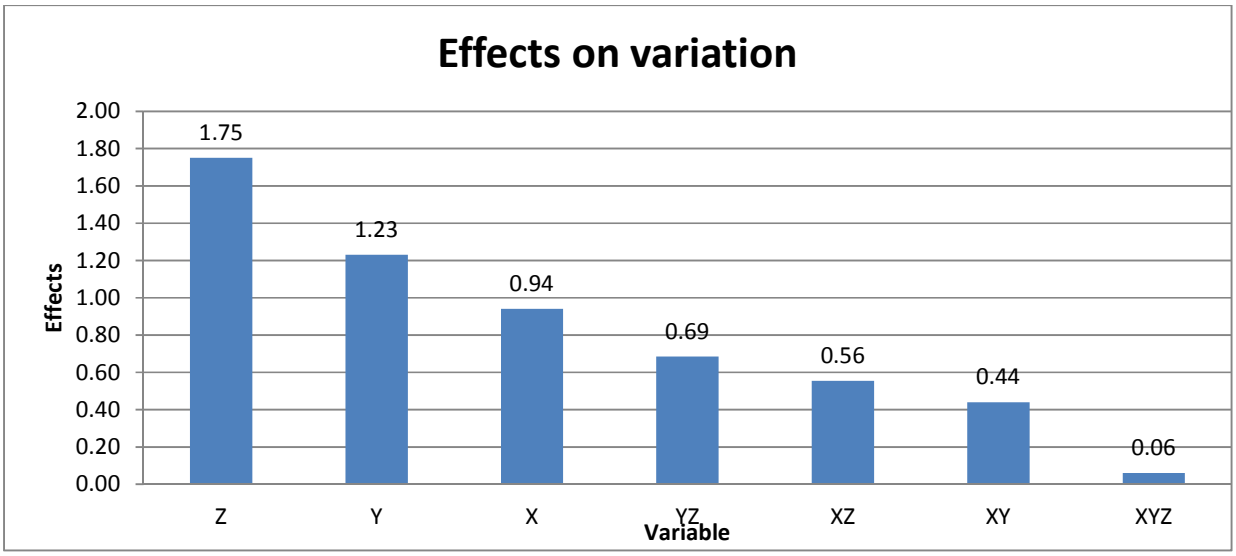


Figure 7-2: Pareto chart of effects of PSLCM variation

The two main interaction factors for this project are systems effectiveness and return the project will have in the business. Both of the measured responds are greatly impacted by factor

interaction which requires much attention. The table below shows data for interaction between those factors.

Table 7-19: Half normal for performance and variation

Standard	Y	Z	PS	V
1,2	-1	-1	32.375	2.995
3,4	1	-1	44.09	1.08
5,6	-1	1	49.735	0.56
7,8	1	1	76.12	0.015

The results achieved by the half normal plot and Pareto analyses can be verified by performing an analysis of variance (ANOVA) and the diagnostic of residual error to confirm the integrity of statistical data. To calculate the sum of square, the following formula was used;

$$Sum\ of\ squares\ (SS) = \frac{N}{4}(Effects)^2$$

The actual ANOVA is depicted by adding the resulting sum of squares as per formula below

$$SS_{Model} = SS_X + SS_Y + SS_z$$

The residual, which is the estimation of error, will use small effects closer to zero calculated using this formula:

$$SS_{residual} = SS_{XY} + SS_{xz} + SS_{yz} + SS_{zyz}$$

The table below shows the ANOVA values for performance

Table 7-20: ANOVA for performance

Source	Sum of squares	DF	Mean squares	Prob > F
SS model	3053	3	1018	< 0.005
X	1107	1	1107	< 0.005
Y	726	1	726	< 0.005
Z	1220	1	1220	< 0.005
Residual	163	4	40.75	
Core total	3216	7		

The table below shows the ANOVA values for variation

Table 7-21: ANOVA for variation

Source	Sum of squares	DF	Mean squares	Prob > F
SS model	16	3	5.3	< 0.005
x	7	1	7	< 0.005
y	3	1	3	< 0.005
z	6	1	6	< 0.005
Residual	1.96	4	0.49	
Core total	17.96	7		

Most of the statistical homework required to support the earlier decision has been finalised, but a final step is taken for utter protection alongside specious results by checking the assumption underlying the analysis of variance (ANOVA).

Predictive equation modelling response

This is a good place to provide details of PSLCM tested in the analysis of variance (ANOVA) because this model is a mathematical equation used to predict a given response using the linear model equation below:

$$\gamma = \beta_0 + \beta_2 X_2 + \beta_3 X_3 + \beta_{23} X_2 X_3$$

Where

Y = Predicted response

β_0 = intercept

β_1 = Model co-efficient for the input factor

X = Input factors

Fitted model for project performance with three factors which are project efficiency, system effectiveness, and return on organisational benefits, in coded form is:

$$Performence\ (Y1\ (pred)) = 50.58 + 11.8(X) + 9.525\ (Y) + 12.35(Z)$$

The actual performances are compared to the predicted performance and depict the residual value. The figure below indicates predicted performance and residual values for each performance (difference between actual and predicted)

Table 7-22: Actual vs predicted values for performance

Project	X	Y	Z	Actual(PS)	Predicted (PS)	Residual
1	-1	-1	-1	28.26	16.9	11.36
2	1	-1	-1	36.49	40.5	-4.01
3	-1	1	-1	38.09	36	2.09
4	1	1	-1	50.09	59.3	-9.21
5	-1	-1	1	41.01	42	-0.99
6	1	-1	1	58.46	62	-3.54
7	-1	1	1	65.15	60.7	4.45
8	1	1	1	87.09	84.25	2.84

Variation fitted model code:

$$Variation(V\ pred) = 1.16 - 0.47(X) - 0.615\ (Y) - 0.876(Z)$$

The figure below indicates predicted variation and residual values for each variance (difference between actual and predicted)

Table 7-23: Actual vs predicted values for variation

Project	X	Y	Z	Actual(PS)	Predicted (PS)	Residual
1	-1	-1	-1	3.99	3.56	0.43
2	1	-1	-1	2	2.18	-0.18
3	-1	1	-1	1.58	1.89	-0.31
4	1	1	-1	0.58	0.95	-0.37
5	-1	-1	1	0.94	1.37	-0.43
6	1	-1	1	0.18	0.43	-0.25
7	-1	1	1	0.02	0.2	-0.18
8	1	1	1	0.01	0.36	-0.35

At this stage, we have eight data points. Calculating half normal will be done exactly like we did it earlier. 100 %/8 = 12.5 % for a full normal plot. For a half normal 12.5/2 = 6.25%. The figure below indicates normal a plot of residuals for performance.

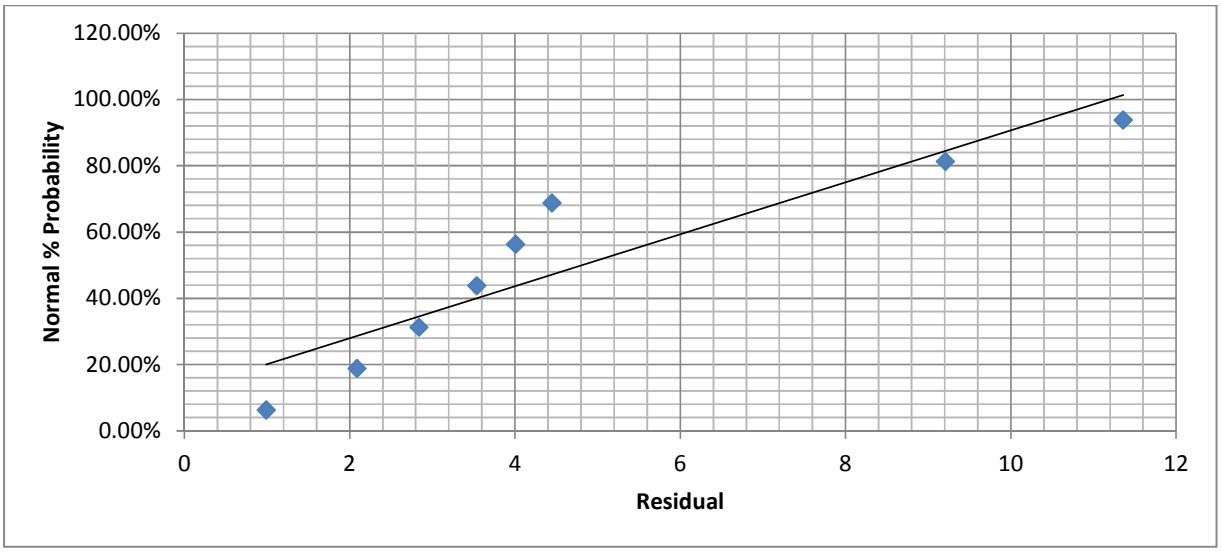


Figure 7-3: Normal plot for residual for performance

The figure below indicates a normal plot of residuals for variations.

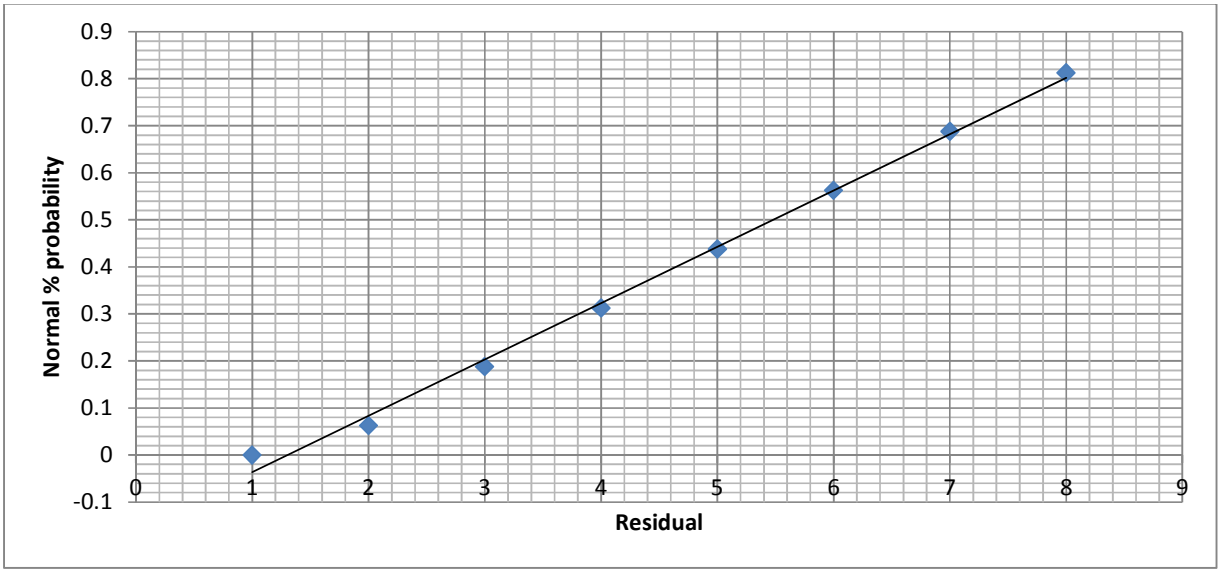


Figure 7-4: Normal plot for residual for variation

The figure below indicates residual and predicted values for performance.

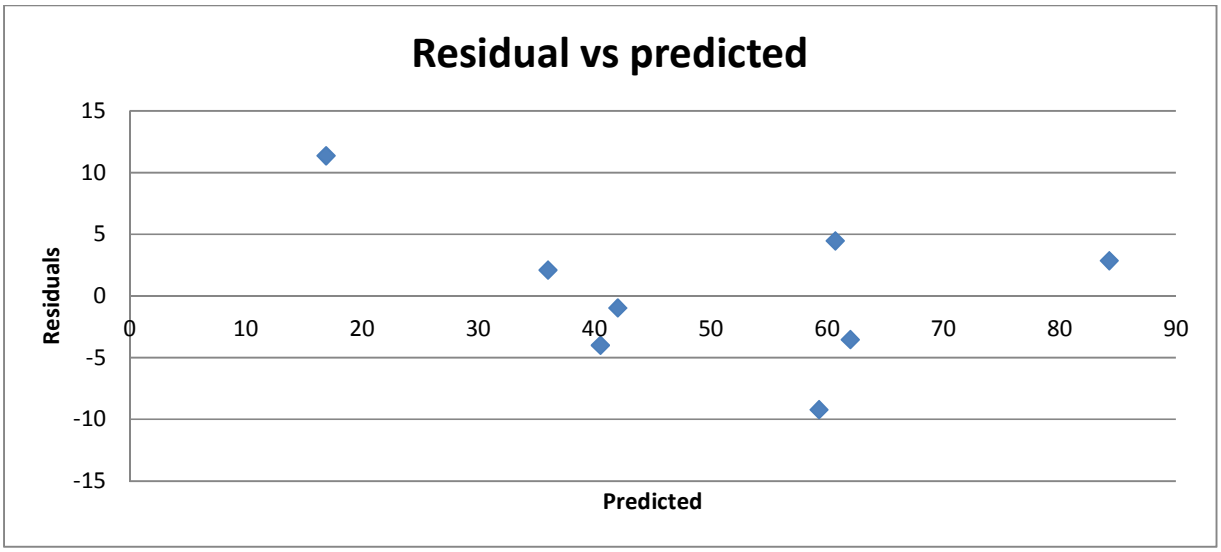


Figure 7-5: Residual vs predicted performance (PS)

The figure below indicates residual and predicted value for variation.

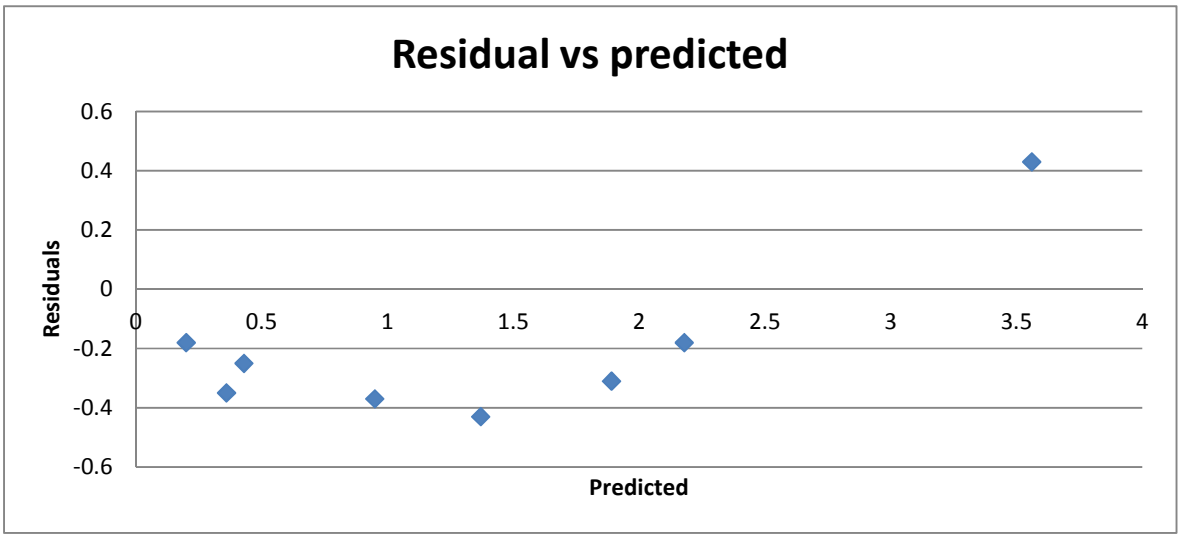


Figure 7-6: Residual vs predicted variation

In all the above graphs, a pattern exists where residuals increase with predicted levels which support underlying statistical assumption of constant variance but ANOVA is very robust to deviations from normality and consistency of variance.

7.4 Summary and conclusion

The PSLCM is a life cycle management control system which examines performance of activities, project and project deliverables, relating it to the organisational performance using a large number of dimensions. Variations between strategy plan, project execution and operational results are calculated by measuring the efficiency of each process and sub-process so that underperformance can be identified. Applying data envelope analysis (DEA) to both input and output allows comparison at different stages of the project life cycle. This methodology makes it easy to compare the project within a company, in an industry or a country that is dependent on the success factors. The success factor effects are then used as weights to adjust the input output values sizing factors.

This methodology has proven beyond a reasonable doubt that it is the best method to plan, monitor and control projects through their life cycles. The method also revealed that the interdependency of project variables play an important role in the success or failure of projects, products and the organisation. PSLCM also utilise a mathematical equation dependent on project data, to calculate predicted values, which allow a project to be compared against itself. This is a major breakthrough in the project management field since project failure or success can be objectively stipulated with a mathematical backup to prove the case, while not relying on benchmark data only, but also relying on specific project product data.

During project implementation, PSLCM use variance percentages to calculate future value, meaning that the current performance (efficiencies and inefficiencies) are utilized as a reference performance until project completion. This means that current inefficiencies are considered when future values are calculated, which make the reviewed dates more accurate.

7.5 Chapter overview

Chapter 7 demonstrates PSLCM verifications and validation.

Project case studies will be used to verify the effectiveness of PSLCM to measure, control and manage project activities from project initiation until project delivery.

Chapter 8: Conclusion and recommendations.

This chapter provides a conclusion to the study, discusses the research limitations of the research and the contribution to new knowledge. It also provides recommendations and implications for further research.

CHAPTER 8

CONCLUSION AND RECOMMENDATIONS

The purpose of this research is to identify critical success factors and constraints which impact the power plant life cycle project, product and the organisation (corporate success). The relationship between project success factors, product success factors and organisation (corporate) success factors was examined as identified in the thesis literature study. The relationships between critical success factor and critical constraint/delay/failure factors at any stage of the project, product and organisation life cycle was also evaluated and five critical success factor (for project and its products), four organisational success factors (corporate success) and five constraints/delay/failure factors were identified for further analysis, to determine whether critical success factors have more influence in avoiding the critical failure factors which will contribute towards improving the performance of power plants at any stage of the project, product and organisational life cycle, thereby addressing this research gap and providing utilities with more information that will lead to successful project delivery, product that are feet for purpose and organisation achieving the intended benefits (returns on their investment). Finally, an integrated life cycle model is developed to measure, control and manage life cycle performance of project, product and organisations.

8.1 Introduction

The methodology for measuring the project, product and organisational success of a power plant during its entire life cycle was developed and presented. This method is applicable to projects aiming to improve or maintaining plant performance (economic value) with the profitability contribution directly related to hours of operation and the availability and reliability of the equipment. The DEA method is used to calculate efficiencies and a final value, which describes the success of the project, product or corporate performance at a specific point in time into a single overall performance considering critical success factors. The PSLCM model's inclusion of operational and maintenance criteria force all stakeholders to look beyond their direct activities allowing them to correct any discrepancies that they identify with their teams ensuring that all prior errors are rectified before activities are continued. This model requires that all project targeted value is specified before commencement of work and that actual values are measured and efficiency calculated to continuously determine performance.

8.2 Data collection summary

8.2.1 Critical success factors

This research investigated the critical project success factors, critical product success factors and critical organisational success factors relating to power plants life cycle management. The relative importance of various success factors was determined using the relative importance index. The respondent's opinions showed positive consensus about project, product and organisation critical success factors in power plant life cycle management, confirmed by Spearman's correlation test. According to the research, the final RII of the respondents, the five most important project critical success factors that are significant for the success of power plant life cycle management are:

- S1: Project management techniques are applied
- S2: Standards are actively used to drive quality of outputs
- S3: Regular and careful progress monitoring
- S4: Pre-project planning is thorough and considered
- S5: Direct and indirect suppliers are aware of the project

Founded on the research final RII of the respondents, the five most important product (project deliverable) critical success factors that are significant for the power plant life cycle management success are:

- P1: Value for money
- P2: Improve efficiency of the system
- P3: Satisfactory overall equipment effectiveness
- P4: Minor and major upgrades required to improve reliability
- P5: Absent of unexpected disruptions beyond the control of project management

Based on the research's final RII of the respondents, the four most important organisation (corporate) critical success factors important for the power plant life cycle management success are:

- O1: Business benefits realised
- O2: Strategic benefits realised
- O3: New core competency realised
- O4: New organisational capability realised

8.2.2 Critical delay factors

The research investigated the critical constraints/delays/failure factors affecting power plant life cycle management. The relative importance of various constraints/delays/failure factors was determined using the relative importance index (RII). The respondent's opinions showed positive consensus about project product and organisation critical constraints/delays/failure factors in power plant life cycle management confirmed by Spearman's rank-order correlation test. The respondent's final RII revealed that the five critical constraints/delays/failure factors that are important for the success of power plant life cycle management are:

- F1: Construction methods by contractors
- F2: Waiting time for approval consultants
- F3: Decision making by owners
- F4: Inappropriate communication
- F5: Material quality

8.2.3 Relationship between critical success factors (Pearson correlation coefficient)

The Pearson correlation coefficient was used to measure the strength and direction between critical project success factors, critical product success factors and critical organisational (corporate) success factors. These critical success factors were identified from literature and surveys, as well as the Delphi results from consultants, contractors, engineers and owners.

<u>Critical project success factors and product success factors</u>

The results indicate that there is a very strong positive correlation between all five critical project success factors and all five critical product success factors. The theory has proven that it is very difficult to separate the performance of a product from a project because if an endeavor is

successful, it is expected that the product will be successful too, because the two are inseparably linked. The Pearson results showed that:

- Consultants, engineers, contractors and owners agreed that there is a very strong relationship between critical project success factors and critical product success factors in power plants.

Project success factors and organisational success factors

The results showed a strong positive correlation between project success and organisational success. The results demonstrate that projects are developed to achieve certain objectives and when those objectives are reached, the organisational performance is improved. The Pearson correlation results are as follows:

- Consultants showed a positive correlation between critical project success factors and critical organisational factors
- Engineers showed a strong positive correlation between critical project success factors and critical organisational factors
- Contractors showed a moderate positive correlation between critical project success factors and critical organisational factors
- Owners showed a very strong positive correlation between critical project success factors and critical organisational factors

The results also indicate that owners and engineers agree strongly that the correlation between project success factors and organisational success factors is significant. Contractors and consultants agree that most influential projects success factors are proportional to the product success factors. Projects are normally part of portfolio and programs that assist in aligning project objectives.

Product success factor and organisation success factors

The overall results showed that response of consultants, contractors and owners demonstrated that there is a significant relationship between all critical project success factors and organisational success factors. The Pearson correlation results were as follows:

- The findings demonstrate a strong positive correlation between product success factors and organisational success factors rated by engineers, contractors and consultants
- Engineers showed a positive correlation between critical product success factors and organisational success factors.

The overall results of the Pearson correlation coefficient indicate that there is a very strong positive correlation demonstrated by consultants, engineers, contractors and owners between critical project success factors, project product success factors and organisational success factors. This means that the more successful the project becomes, the more successful the product will be and the more successful the organisation will become. The findings demonstrate that participants, namely owners, consultants, contractors and engineers, agreed that there is a significant correlation between all critical success factors, critical product success factors and organisational success factors.

8.2.3 Perceptions and influence of success factors on delay factors (T-test)

The T-test was performed to compare the perceptions of critical success factors and critical delays for five groups, namely consultants and engineers, consultants and contractor's, engineers and contractors, engineers and owners, and contractors and owners. The overall group means were compared with their influence of critical success factors on each constraint/delay/failure factor.

Critical project success factors and constraint/delay/failure factors

The T-test primary results showed that there is generally an agreement between consultants, engineers, contractors and owners with a certain degree of difference in how the groups evaluated the relations between the project critical success factors, critical constraint/delay/failure factors and the influence of each project critical success factor on avoiding each critical failure factor.

The test result showed strong agreement between consultants, contractors, engineers and owners on perceptions regarding critical project success factors and critical constraints/delay/failure factors. The difference has been observed on –

- The direct and indirect suppliers' awareness of project (S5)

Contractors and engineers agreed with each other more than any of the other groups, which can be a result of the degree of involvement by both parties which may be more frequent than the other groups.

Critical product success factors and constraint/delay/failure factors

The primary results of the T-test primary showed that there is generally an agreement between consultants, engineers, contractors and owners with a certain degree of difference in how the groups evaluated the relations between the product critical success factors and critical constraint/delay/failure factors, and the influence of each product critical success factor on avoiding each critical constraint/delay/failure factor.

The results demonstrated an agreement between consultants, engineers, contractors and owners on perceptions regarding the critical product success factors and critical constraints/delay/failure factor. The difference has been observed on –

- Value for money (P1)
- Minor and major upgrades required to improve reliability (P4)

Owners and engineers agreed with each other more than any of the other groups, which can be due to the degree of involvement with the project deliverables by both parties, which may be more frequent than the other groups.

Organisational success factors and constraints/delays/failures

The primary results of the T-test showed that there is generally an agreement between consultants, engineers, contractors and owners with a certain degree of difference in how different groups evaluated the relations between the organisational critical success factors and critical constraint/delay/failure factors, and the influence of each organisational critical success factor on avoiding each critical constraint/delay/failure factor.

The results demonstrated a strong agreement between consultant, engineers, contractors and owners about perceptions regarding critical organisational success factors and critical constraints/delay/failure factors. The difference has been observed on:

- Business benefits realised (Q4)

Consultants and engineers agreed with each other more than any of the other groups which can be a results of the degree of involvement with the project portfolio and program management by both parties, which could be more common than the other groups.

8.2.4 Success factors' influence on constraint/delay/failure factors (One-way ANOVA)

Project success factors and failure factors

Individual ANOVA tests were performed to determine both individual perceptions about the influence of the five critical project success factors relative to each of the critical failure factors. The results on critical success factors that is more influential to prevent failure as using standards to actually drive quality of output (S2) and pre-project planning must be thoroughly considered (S4).

The significant different in the least influential factors was on failure factors regarding inappropriate communication (F4) and waiting time for approval by consultants (F2). Overall, all groups agreed regarding the most influential success factors that are important in avoiding failure factors. The difference in opinion among owners could be as results of believing that most problems are management generated (top down).

Product success factors and failure factors

Individual ANOVA tests were performed to determine both individual perception of the five critical product success factors relative influence to each critical failure factors. The results agree on critical product success factors that are more influential to avoid failure as minor and major upgrades required to improve reliability (P4) and improve efficiency of the system (P2). The different in least influential factors were examined from the perspective of consultants, engineers, owners and contractors. The results showed that construction methods of contractors (F1) and material quality (F5) identified significant differences.

Organisational/corporate success factor and failure factors)

Individual ANOVA was performed to determine the relative influence of both individual perceptions of the five critical organisational success factors on each failure factors. The results agree on critical corporate success factors that are more influential to avoid failure as new core competency realised (Q3) and new organisational capability realised (Q4). The different in least influential factors were examined from the perspective of consultants, engineers, owners and contractors. The results showed that Decision making by owners (F3) and material quality (F5) identified significant differences. Generally, all groups agreed regarding the influence of success factors on failure factors to avoid failure.

8.2.4 The influence of success factors on constraint/delay/failure factors (two-way ANOVA)

The responses of consultants, engineers, contractors and owners, were compared using the two-way ANOVA method to identify the panels' different perceptions about the relative influence of the five critical success factors on each of the individual failure factors.

Project success factors and failure factors

The results showed that there are similarities and differences in different groups' perceptions regarding the influence of critical project success factors on specific delay factors. The group consistently identified 'project management techniques applied' (S1) as the most influential factor to avoid failure and identified the least influential factor as 'direct and indirect suppliers are aware of project' (S5).

Product success factors and failure factors

The results showed that there are similarities and differences in different groups' perceptions regarding the influence of critical product success factors on specific failure factors. The group consistently identified 'improve efficiency of the system' (P2) as the most influential factor to avoid failure, while the least influential factor was identified as 'unexpected disruptions beyond the control of project management' (P5).

Organisational/corporate success factors and failure factors

The results showed that there are similarities and differences in the perceptions of different groups regarding the influence of critical organisational success factors on specific delay factors. The group consistently identified 'strategic benefits realised' (Q2) as the most influential factor to avoid failure, while the least influential as identified as 'new organisational capability realised' (Q4).

8.3 Delphi technique

The three-stage Delphi survey technique using a panel of experts was employed and the panel of experts' viewpoints were consolidated in each round.

8.3.1 Delphi 1st Round

The responses from the first-round Delphi survey were tabulated in Chapter 5 and analysed using average ranking, median ranking and the order of importance to evaluate each factor. The results from panel of experts' responses in the first-round Delphi survey in the ranking of critical project success factors are as follows:

1. Project management techniques are applied (S1)
2. Standards are actively used to drive quality of outputs (S2)
3. Regular and careful progress monitoring (S3)
4. Direct and indirect suppliers are aware of project (S5)
5. Pre-project planning is thorough and considered (S4)

The results of the panel of experts' responses from the first-round Delphi survey in the ranking of critical product success factors are:

1. Value for money (P1)
2. Minor and major upgrades required to improve reliability (P4)
3. Unexpected disruptions beyond the control of project management (P5)
4. Improve efficiency of the system (P2)
5. Satisfactory overall equipment effectiveness (P3)

The results of the panel of experts' responses from the first-round Delphi survey in the ranking of critical organisational success factors are:

1. New core competency realised (Q3)
2. Business benefits realised (Q1)
3. Strategic benefits realised (Q2)
4. New organisational capability realised (Q4)

8.3.2 Delphi 2nd Round

The results of the panel of expert's responses from the second-round Delphi survey was tabulated in Chapter 5. The results in the ranking of critical project success factors are:

1. Project management techniques are applied (S1)
2. Standards are actively used to drive quality of outputs (S2)
3. Regular and careful progress monitoring (S3)
4. Direct and indirect suppliers are aware of project (S5)
5. Pre-project planning is thorough and considered (S4)

The results of the panel of experts' responses from the second-round Delphi survey in the ranking of critical product success factors are:

1. Value for money (P1)
2. Minor and major upgrades required to improve reliability (P4)
3. Unexpected disruptions beyond the control of project management (P5)
4. Satisfactory overall equipment effectiveness (P3)
5. Improve efficiency of the system (P2)

The results of the panel of experts' responses from the second-round Delphi survey in the ranking of critical organisational success factors are:

1. New core competency realised (Q3)
2. Business benefits realised (Q1)
3. Strategic benefits realised (Q2)
4. New organisational capability realised (Q4)

8.3.3 Delphi 3rd Round

The third-round Delphi survey was aimed at the overall effect of critical success factors relating to the nine PMBoK areas. The T-test was used to determine the most critical knowledge areas and only factors with T-test < 0.05 was accepted. The knowledge areas with T-test >5 were ignored because the effect was considered insignificant. The priority factors were:

1. Interdependency (element of integration)
2. Scope
3. Time
4. Cost
5. Quality
6. Risk

The above knowledge area was used to develop a theory for developing a model.

8.4 Research findings and analysis

This research used survey methodology to identify critical success factors and constraints in plant life cycle management projects. The Delphi technique was applied, using a panel of experts to confirm and determine the priority of the factors; this was ultimately used to develop the PSLCM which is used to measure, control and manage project, product (project deliverable) and corporate performance throughout the organisation life cycle. The research findings for each research hypotheses as outlined in Chapter 1, are analysed in the following paragraph:

Hypothesis 1

H_0 : There is no significant relationship between project, product (project deliverable) and organisational (corporate) success factors in power plants.
H_1 : There is a significant relationship between project, product (project deliverable) and organisational (corporate) success factors in power plants.

Previous project management research studies identified critical success factors in different industries, especially in construction industries. No specific study had been carried out in the context of power plants in Africa. Case study methodology was mainly applied in this study, collecting qualitative data, whereas quantitative data had been collected in other studies,

reducing the level of understanding of the actual situation as a result of essential benefits and shortcomings of using these data sets in segregation.

In this research, a case study was used to collect both qualitative and quantitative data providing more strength to the research, while also avoiding the weakness of utilising quantitative and qualitative data in isolation. In this case study, project success factors, product success factors, and corporate success was evaluated considering operational constraints in different stages of the project life cycle. Statistical analyses, which included the ANOVA test, were used to determine the statistical significance of each factor. The five critical success factors, five project product critical success factors, four corporate success critical factors and five constraints were identified and approved through the three-stage Delphi survey technique.

The strength of a linear association between two variables can be measured by the Pearson correlation coefficient where the value r = -1 means a perfect negative correlation and the value r = 1 means a perfect positive correlation.

Project success and product success

The value of R is 0.8852 showing strong positive correlation indicating that the high project success variable scores go with the high product success variable scores (and vice versa). The value of R^2, the coefficient of determination is 0.7836.

Project success and organisational success

The value of R is 0.5555 indicating a moderate positive correlation, which means there is a tendency that high project success variable scores go with high organisational success variable scores (and vice versa).

Product success and organisational success

The value of R is 0.3518 indicating a technically positive correlation, but with the weak relationship between variables (the nearer the value is to zero, the weaker the relationship). The value of R^2, the coefficient of determination is 0.1238.

From the above results H_1 : it is accepted that there is a significant relationship between project, product (project deliverable) and organisational (corporate) success factors in power plants. H_0 is rejected.

Hypothesis 2

H_0 : There is no association between critical success factors and constraints in power plant life cycle management projects.
H_1 : There is an association between critical success factors and constraints in power plant life cycle management projects.

Project success and project delay

The value of R is -0.0124 indicating a technically negative correlation. This means that the relationship between project success factor and project delay/failure/constraints are weak. The negative correlations means that the stronger the project success factors, the weaker the project failure factors (and vice versa)

Product success factors and project failure/constraint/delay factors

The value of R is 0.4513. Although a technically positive correlation, the relationship between your variables is weak (the nearer the value is to zero, the weaker the relationship). The positive correlations means that the stronger the product success factors, the stronger the project constraint/failure/delay factors (and vice versa). This is as a result of advancement in technology and deficiency in the system. This requires that technology innovation and choosing matured technology became central to the systems development process.

Organisational success and constraint/delay/failure factors

The value of R is -0.33 showing a technically negative correlation. The relationship between organisational success factors and failure/constraints/delay variables is weak. The negative correlations mean that the stronger the organisational/corporate success factors, the weaker the project failure/constraint/delay factors (and vice versa). The value of R^2, the coefficient of determination, is 0.1089.

From the above results H_1 : is accepted - there is an association between critical success factors and constraints in power plant life cycle management projects.

Hypothesis 3

H_0 : Critical success factor importance may not be verified and validated through evaluating each factor against a PMBoK area across the system life cycle.
H_1 : Critical success factor importance may be verified and validated through evaluating each factor against a PMBoK area across the system life cycle.

The project, product and organisation critical success factor where evaluated against project management knowledge area in order to determine the priority of critical knowledge areas impact on project, product and organisation success. This was done to identify important factors to be monitored throughout the entire project, product and organisation life cycle. Most project management scholars believed that knowledge area implementation increase the probability of projects success.

The PMBoK guidelines do not indicate the relative importance of each of these knowledge areas and their impact on project success. The nine knowledge areas of focus ranking will help organisations to allocate their limited resources to critical areas that will improve project success. It is unfortunate that although project managers like to follow all the the PMBoK guideline, they often do not have time to cover everything. This leads to bias with respect to the processes they view as being easier, or the most familiar ones risking prioritising knowledge areas of high impact over low impact. The knowledge area prioritisation may help project professionals to improve decision making in all associated processes. However, dissimilar characteristics were observed in different stages of the integrated life cycle and the relevant literature also identifies dissimilar characteristics in different phases.

The study revealed that the knowledge areas with the greatest impact on project success in sequence are integration (interdependency), scope, time, cost, quality and risk.

From the knowledge area importance results presented in Chapter 5, the alternative hypothesis can be accepted: H_1 : Critical success factor importance may be verified and validated through evaluating each factor against a PMBoK area across the system life cycle.

Hypothesis 4

H_0 : There are no best life cycle management practices as a result of theory advancements in modelling that will assist to improve power plant life cycle monitoring, control and management.

H_1 : There are best life cycle management practices as a result of theory advancements in modelling that will assist to improve power plant life cycle monitoring, control and management.

The life cycle integration propositions presented in Chapter 2 and the model presented in Chapter 6 provide more evidence that integrating different life cycle management practices mainly focusing on maximising benefits realisation and management is important for organisations to realise their full potential. The integrated closed-loop life cycle management system ensures that results or outputs are integrated back into the system to continuously improve different phases of the life cycle.

The case study in Chapter 7 has generated evidence that the life cycle management system utilised by most power plants are open-loop systems (lacked integration) not catering adequately for the inter-dependency and intra-interdependency that exist in different stages of the project, its product and the effects on the organisation. The statistical analysis has proven that the dependency on success factors shows strong correlation, indicating that activities or decisions at any of the stages have future implications. The difference between current (open-loop life cycle model) and the desired (closed-loop) life cycle model were identified as:

- The open-loop life cycle management model is the model were there is a weak correlation between project, product and organisational success and where the output is not consistently monitored to provide feedback that will be used to eliminate the problem.
- A closed-loop management model uses feedback where a portion of the output signal is fed back to the input to reduce errors and improve stability. The goal of an integrated life cycle management system is to measure, monitor and control processes accurately, focusing on process output and correcting it before the next process so that the negative impact on other processes can be minimised. This is performed by always comparing the process output to the desired output and by calculating the variance, which will be used as a feedback signal to determine the error to be corrected to bring the system or process back to the original or desired response/value.

The integrated life cycle management model has information of output conditions through calculating input efficiency, process efficiency and output efficiency, which make it better

equipped to handle process or system changes/disturbances in conditions which may reduce its ability to complete the desired task. The main characteristics of PSLCM are:

- To reduce variability by continuously calculating system input output and process efficiency.
- To enhance robustness against external disturbances to the process or system.
- To produce a reliable and repeatable performance.

From the above results H_1 : Is accepted - there are best life cycle management practices as a result of theory advancements in modelling, which will assist to improve power plant life cycle monitoring, control and management.

Hypothesis 5

H_0 : Good project management practices combined with benefits management will not increase the probability of success in delivering business value.
H_1 : Good project management practices combined with benefits management will increase the probability of success in delivering business value.

The literature review in Chapter 2 revealed that organisational change requires strategies that include project execution. While organisations develop and implement projects, programmes and portfolio management techniques, they still fail to implement their strategies. Most professionals believe that if organisations want to be successful in their business strategies, they must succeed in their project execution.

Chapter 5 revealed that projects today have become a major threat in achieving business goals, with haste-to-market imperiousness, outcomes uncertainty, growing complexity, no value guarantees and that business decisions override project requirements and technical decisions. As a result, the PSLCM proposes a new way of managing project decisions. The PSLCM focuses on process/system efficiency calculations with a strong emphasis on benefits realisation supporting the organisation to achieve success shared across the organisation, encouraging improved data capturing for improved decision making, developing a culture based on performance to link each project to strategic objectives and to link business performance, project performance and benefits.

Chapters 6 and 7, indicate that the base of PSLCM stage three, which is organisational/corporate success, focuses on benefits realisation. This is a process to manage, prepare and realize benefits planned through change implementation and managing them by

maximizing the overall benefits. This is opposed to those benefits simply planned requiring a structured approach to manage benefits realisation, by translating business objectives into identifiable, measurable benefits that can be systematically tracked.

The case study in Chapter 7 provides evidence that good benefits-management practices are important contributors to the success of projects, products and of business strategies. The study provides evidence that there is perfect positive correlation between benefits-management practices and business-value delivery. It also revealed that good benefits-management practices implemented without good project management practices cannot result in higher project, product and organisational performance levels. Benefits-management practices must therefore be implemented together with good project, program and portfolio management practices.

From the above results $\mathbf{H_1}$: Is accepted - good project management practices combined with benefits management will increase the probability of success in delivering business value.

8.5 Study conclusion

This research identified critical success factors for project, product and organization during implimatation of plant life cycle management prrograms. Critical constraint/delay/failure factors were identified which are related to project management process, product management and the organisation (this includes policy constraint).

The research findings of this study was compared to similar research in developing countries, particularly those in the BRICS group, namely Brazil, Russia, India, China and South Africa, and the results showed that, irrespective of the fact that countries are exposed to different socio-economic, political and natural environments, similar problems are relevant to project stakeholders. Differences are found in both success factors and delay factors, mostly relating to labour laws (policy constraints) that are affecting efficiency in one country, but not in the others, thus indicating that there are factors caused or aggravated by environment, culture and political conditions.

- The research has demonstrated that there is a strong positive correlation between the successes of a project and its product (deliverable). This is because it is accepted that if the project is a success, its product is also expected to be delivered successfully.

- The research has demonstrated that there is a weak correlation between project product success and organisational success. This is mostly because external constraints beyond the organisation's control, such as market forces, economic growth and market profitability, play a major role in realising value for an organisation
- The research also shows a moderate correlation between project success and organisational success. Projects are used to take advantage of technology advancement or deficiencies in current a system, which is an opportunity to improve efficiency while reducing costs for the organisation.

The findings of this research indicate that life cycle management performance can be improved by focusing on identified success factors and delay factors. Consensus of expert opinion substantiate this sentiment, namely that critical factors of success are crucial to improve overall organisational performance. The model is more relevant to Africa where there are no market constraints (power demand/exceeded supply) but can be apllied else where.

8.6 Achievement of the research objectives

Different approaches towards building theory in engineering and project management are receiving growing interest. The three approaches of building theory, namely the process, variance, and systems approaches were integrated to develop PSLCM with the following benefits:

- Improving understanding of life cycle management concepts - it is now understood that performance of a system, component (lower-level) is affected by system processes and that occurrence of an event is affected by the condition of equipment. It is also understood that the interdependence of factors should be given serious attention because they go a long way towards addressing system or process problems.
- Improving an understanding of life cycle management relationships - by integrating those approach, process by which a relationship among factors occurs and interactions among system, process, parts is understood, and by calculating input, process and output efficiency, makes it easy to identify the source of a problem.
- Improving SAP and primavera data usage - the models provide an opportunity for system integration of SAP and primavera sharing, as well as planning and scheduling data, making it easier to monitor life cycle costs.

- The model can be used to monitor the performance of power utilities over their useful life. The advantage of this model is that it provides more information about the overall technical performance of the organisation. The organisation can partner with financial institutions to provide risk data, which is important for funding purposes, infrastructure development and insurance.
- Comparing utility performance holistically, appreciating different stages of the life cycle and technology utilisation in power plants.

8.7 Contribution to the body of knowledge

This study will contribute to the engineering and project management body of knowledge by integrating knowledge about critical success factors and constraints, and understanding which constraint factors to avoid. The study also evaluates the relationship between project successes, product (deliverables) success, and equates it to corporate success, measuring the asset‘s entire life cycle performance. The research study was performed specifically for African utilities, but it is anticipated that the results of the study will be broadly applicable to most developing countries.

The first contribution was the development of the project success life cycle model (PSLCM). This model focuses on measuring, controlling and managing project activities from project initiation and design to planning and execution and during production and operation. The advantage of this model is that project comparison can be objectively performed with a high level of accuracy, utilising current efficiencies and inefficiencies to determine future performance. The model makes it easy to identify inefficient areas that organisations can utilise for continuous improvement purposes.

The second contribution was to use different measures with different measuring units to develop an equation using efficiencies to calculate one value summarising all measures done in a project. When efficiency is used, different measuring units are converted into percentage units that can be mathematically manipulated.

The third contribution was that project success is mostly measured utilising international benchmarks, which mostly limit organisational innovation. PSLCM develops a mathematical equation based on project input and output data that is used to mathematically calculate predictable values making it easy for a project performance to be compared against itself as

different resources are allocated for a project. This also addresses the issue of over-capacity and under-capacity in projects.

8.8 Research limitations

The research experienced a number of limitations during questionnaire development, including the Delphi technique and experts, as well as data collection and analysis. However, despite the challenges, the researcher collected valid and useful data. The research limitations are:

- Some survey participants, who are individuals working for utilities affiliated to the African Power Utilities Association (APUA), needed clearance from their employers before they could participate in the study. This resulted in delays and due date postponements.
- Most members of the expert panel took longer to respond and commit to be part of the Delphi study.
- There was also a language barrier since some members who were available and willing to participate, were not familiar with English and required the questionnaire to be translated into French.This was ruled out due to extra work required.
- Since this is the first research to evaluate the critical success factors and critical constraints of power plant life cycle management, there was no previous research to compare the results of this study.
- Some project team members had already left Africa or resigned from their jobs when the study was conducted, which made it difficult to get their new email addresses.
- The most commonly used contract method used was NEC, while FIDIC was also used in many instances more especially in new power plant constructions.
- Targeted projects differ in terms of complexity, design, technology and contract type.

8.9 Recommendations for future research

The following recommendations should be considered by future researchers examining critical project success factors and organisational success factors in power plants:

- The research relating to critical success factors and constraints can be used to evaluate the performance of project control systems in different sectors, including construction.

This is because efficient and effective project management results in tangible outcomes for entire aspect planning and scheduling, execution, monitoring and control. It is believed that implementing models that consider both common and industry-specific factors will drastically improve project delivery, while addressing all project, product and organisational obstacles.

- This study will be the first of its kind to identify critical success factors and constraints present in the power plant life cycle in Africa, as well as presenting an integrated single model to measure performance from concept phase until retirement. This research will form a base of empirical research from where further local and international research can be conducted in order to improve system and process performance.
- The same scientific methods used in this research can be used to evaluate the contracting strategies of other technical projects. This type of research can be useful to construction companies and governments since it can highlight gaps between project stakeholders necessitating urgent attention to either development policies or guidelines to standardise and formalise processes were technology and innovation are key. This will assist in ensuring that technology deployed in specific countries is relevant to the needs of the country and that it best serves those countries' needs. It will also assist on identifying the best procurement methods that can be used in Engineering and construction management (ECM), or Engineering procurement construction management (EPCM), or to develop a new approach towards contracting, which will provide improved control.
- This study has developed a mathematical model that ranks success factors in different phases of project life cycle management. This model can be applied in different industries to compare the results with what is generated in power plants so that the recommendations can be made for specific industry models.
- The strong focus on the use of project to achieve strategic objectives will ensure that organisations can strongly focus on benefits realisation management. This will support a stronger investment cycle, linking business performance projects and benefits. The use of these mathematical models will assist power utilities to identify investments that are worth taking versus those that are not worth taking, which will assist in future business decisions and also process improvements.

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APPENDIX

Appendix 1: Invitation letter to participate in survey questionnaire

PHD IN ENGINEERING DEVELOPMENT AND MANAGEMENT (NWU)

TEMPLATE DOCUMENTS

PARTICIPANT INFORMATION SHEET

22 August 2016

Title: A model to optimize power plant life cycle management

Dear Prospective Participant

My name is Lalamani Budeli and I am doing research with Prof Harry Wichers towards a PHD in engineering, development and management Degree, at the North West University in Potchefstroom, South Africa. We are inviting you to participate in a study entitled “A model to optimize power plant life cycle management”.

The aim of the study is to identify factors causing failure or success of life cycle projects in order to develop a model that will ensure consistent delivery of successful project that can be measured objectively through project and product life cycle. I am conducting this research to achieve the following objectives:

- Investigate how life cycle project failure impact on performance in power plants.
- Investigate projects success and failure factors in life cycle projects
- Develop an integrated model for project performance improvement in power plants by ranking success and delay factor based on their consequence towards the cost, schedule and quality requirement. This will assist to concentrate on factor that impact most before considering ones with list impact.
- Develop recommendations to improve the power plants performance.

The survey is structured using Likert scale of one to five therefore not take too much of an effort and time to complete. It is estimated that it shouldn’t take more than 20 to 30 minutes to get the

entire questionnaire completed. If you require any further assistance, please send me an email at ndalamob@gmail.com

Thank you for taking time to read this information sheet and for participating in this study.



Lalamani Budeli

PhD Research Student at North West University

Technical Support Manager: Eskom Lethabo Power Station

Cell: 083 720 4048

Phone: 016 457 5096

Appendix 2: Invitation letter to Delphi survey questionnaire

DELPHI STUDY INFORMATION SHEET

I am currently busy with a PhD in engineering at North West University (NWU), Potchefstroom, South Africa. The study is titled “A model to optimize power plant life cycle management” and my supervisor is Prof Harry Winchers. We invite you to take part of the three stage Delphi consensus study that will be done within a period of three month. This information sheet explain why it is important the research is done and what it involves.

What is a Delphi study?

Delphi technique is an interactive multi stage process performed to form a group consensus by combining expert’s opinion. This is performed by sending structured questionnaire to participants and summary is developed and sent in the next phase.

What is the purpose of the study?

The power industry faces a lot of challenges that affect the management of the power plant life cycle management, which contribute highly in most countries GDP. In emerging country, the installed capacity is very low as compared to the population and ensuring that the power plant are reliable and available to produce what the power plant is design to produce is vital. The power plants are mostly operated by governments, but this study focus on technical issue that are limiting performance of power plants over its useful life. The purpose of this Delphi study is to identify critical success factor that should be considered when a life cycle management model for power plant is developed. These factors will then be discussed and weighed according to the impact they have on the overall performance.

Why have I been invited to take part?

We are keen to gain your views as an established expert in the field about which factors are more important for success and which factors to avoid failure during plant life cycle management programs. We plan to recruit 10 to 20 participants to participate in the study.

What will I be asked to do if I take part?

As a Delphi survey panel member, you will complete an online questionnaire, rate critical factors according to their importance which is estimated to take around one hour. You will afterward receive a reminder of your ratings and a summary of the group's responses which will continue until the group consensus is achieved. A response time of two weeks will be required in order to allow timely conclusion of the study. A reminder will be sent weekly after that for four weeks to improve the survey response.

Who is organizing and funding the research?

The study is self-funded and the results are used solely for academic purposes.

Confidentiality

The study will not require any personal information and identifier numbers only known by the participant. All received responses will be strictly confidential and in no condition will your identity be divulged.

Data protection

The survey responses will be collected online using an online research system monkey survey, utilising an encrypted internet server. Further information is available from: ww.surveymonkey.com. Results will be downloaded to allow analysis by the research team. Data will be stored for the duration of the research project only and then deleted.

Research ethics

The research meets all requirements and has been approved by the ethics committee of the University of North West aiming to assure respect, rigour and responsibility when the research is conducted.

What do I do now?

Please let us know whether or not you would like to take part by replying to this email. If you wish to participate please press yes on the bottom displayed on your screen bellow. Thank you for reading this information sheet and for considering taking part in this research.

If you have any questions or concerns please do not hesitate to contact me.



……..

Mr Lalamani Budeli

PhD Student North West University (NWU)

ndalamob@gmail.com or Budelil@eskom.co.za

0837204048

Appendix 3: Survey demographic characteristics

Demographic characteristic	Frequency	Percentage
Age		
20 - 29		
30 - 39		
40 - 49		
50 more		
Sex		
Male		
Female		
Education		
Certificate		
National diploma		
Degree		
Honours		
Master		
PHD		
Organisation		
owner		
Consultant		
Contractor		
Subcontractor		
Occupation level		
Technical		
Managerial		
Senior management		
Number of years working experience		
Less than 5 years		
6 - 10 years		
11 - 16 years		
More than 16 years		
Field of speciality		
Electrical		
mechanical		
Civil		
Control instrumentation		
Welding (Metallurgical)		
Project involved based on contract sum		
Less than 10 million		
10 - 50 millions		
More than 50 millions		

Appendix43: Success factor		**Importance of success**				
Success factors		1	2	3	4	5
Effective governance	clearly identified leadership					
	clarity how authority is distributed					
	clear reporting lines					
	clear regular communications					
Goals and objectives	Goal clearly specify and recognised by all stakeholders					
	Subsidiary objectives are clearly specify					
	Project leadership has a clear vision					
Commitment	lack of commitment clearly recognised and dealt with					
	Project leadership maintains commitment					
Capable sponsors	Project has active sponsors					
	Project sponsors have ultimate responsibility and accountability					
	Project sponsors stay in a role for the life-cycle of the project					
Secure funding	Project has a secure funding base					
	Needs for contingency funding are recognised from the start					
	Tight control of budgets					
Project planning	First, start-off, phase of the project is effective					
	Pre-project planning is thorough and considered					
	Regular and careful progress (time, scope, cost) monitoring					
	Realistic time schedules					
	Active risk management					
	Flexible to respond to unforeseen					
	Post-project review is undertaken(lessons for the future)					
Supportive organisations	Environment in which the project operates friendly and hostile					
	Organisation provides embedded support for project activity					
	Project team has the influencing skills to engage					
Competent project teams	Project professionals are fully competent					
	Team members fully competent in their roles					
	Project team engages in positive behaviours which encourage success					
Aligned supply chain	Direct and indirect suppliers are aware of project needs and schedules					
	Tiers of supply chains are co-ordinated					
Proven methods and tools	Project management techniques are applied					
	Management tools, methods and techniques applied					
	Maintains an effective balance between flexibility and robustness					
Appropriate standards	Standards are actively used to drive quality of outputs					
	Adherence to all standards is regularly monitored					

Appendix 5: Failure factor

		Importance of delay				
Causes of failure						
Owners	Payment of completed work (Finance)					
	Decision making					
	Unrealistic contract duration					
	Unclear requirements					
	Owner coordination					
Contractors	Construction methods					
	Site management					
	Subcontracting					
	Lack of experience					
	Proper planning					
	Construction errors					
Consultants	Waiting time for approval					
	Quality control and assurance					
	Drawing and specification approval					
	Contract management					
Labour and equipment	Material shortage					
	Material quality					
	Equipment availability					
	labour productivity					
	Labour supply					
Contract	Discrepancies in contract documents					
	Change order					
Contract relationship	Inappropriate communication					
	Organisational structure					
	Disputes					
	Regulatory changes					
	Unfavourable site condition					

Appendix 6: Product success

		Importance of product success				
Product success						
Added value success	Improves efficiency in other area (Additional)					
	Real benefits outperforms focused benefits					
User satisfaction	Continuous good interaction with environment					
	Do not limit other systems performance (Constraints)					
	Adhere to Occupational health safety act (All times)					
	Minor and major upgrades required to improve reliability					
	All functional requirements realised					
System created	unexpected disruptions beyond the control of project management					
	No secondary effects to other systems					
	Deficiencies of the predecessor system eliminated					
System experienced	Within Economic life cycle cost					
	Satisfactory overall equipment effectiveness					
	Recent technology and great cost savings					

Appendix 7: Organizational success

		Importance of business success				
Business success						
Organizational success	Business benefits realised					
	Strategic benefits realised					
	New core competency					
	New organisational capability					

Appendix 8: Delphi first-round survey

	Importance				
	1	2	3	4	5
Project success factors					
S1. Maintains an effective balance between flexibility and robustness					
S2. Regular and careful progress (time, scope, cost) monitoring					
S3. Tiers of supply chains are co-ordinated					
S4. lack of commitment clearly recognised and dealt with					
S5. Organisation provides embedded support for project activity					
S6. Clarity how authority is distributed					
S7. Project sponsors stay in a role for the life-cycle of the project					
S8. Adherence to all standards is regularly monitored					
S9.Team members fully competent in their roles					
S10. Management tools, methods and techniques applied					
Delay factors					
D1. Drawing and specification approval					
D2. Unclear requirements					
D3. Construction errors					
D4. Change order					
D5. Inappropriate communication					
D6. Decision making					
D7. Material quality					
D8. Discrepancies in contract documents					
Product success factor					
P1. All functional requirements realised					
P2. Improves efficiency in other area (Balanced system)					
P3. Continuous good interaction with environment					
P4. Deficiencies of the predecessor system eliminated					
P5. Within Economic life cycle cost					
Organizational success					
O1. New core competency					
O2. Business benefits realised					
O3. Strategic benefits realised					
O4. New organisational capability					

Appendix 9 (a): Delphi second round-survey - Project critical success factor

	Ranking for participants												
Project success factors	A	B	C	D	E	F	G	H	I	J	**Mean**	**Median**	**Importance**
S1													
S2													
S3													
S4													
S5													
S1: Project management techniques are applied													
S2: Standards are actively used to drive quality of outputs													
S3: Regular and careful progress monitoring													
S4: Pre-project planning is thorough and considered													
S5: Direct and indirect suppliers are aware of project													

Appendix 9 (b): Delphi second-round survey - Product critical success factor

	Ranking for participants												
Product success factor	A	B	C	D	E	F	G	H	I	J	**Mean**	**Median**	**Importance**
P1													
P2													
P3													
P4													
P5													
P1: Value for money													
P2: Improve efficiency of the system													
P3: Satisfactory overall equipment effectiveness													
P4: Minor and major upgrades required to improve reliability													
P5: Unexpected disruptions beyond the control of project management													

Appendix 9 (C): Delphi second round survey- Critical organisational success factor

	Ranking for participants												
Organisational success	A	B	C	D	E	F	G	H	I	J	**Mean**	**Median**	**Importance**
O1													
O2													
O3													
O4													
O1: Business benefits realised													
O2: Strategic benefits realised													
O3: New core competency realised													
O4: New organisational capability realised													

Appendix 10 (a): Delphi third-round survey - Project critical success factor effects in PMBoK

Success factor	Integration	Scope	Time	Cost	Quality	Human	Communications	Risk	Procurement	Total
S1										
S2										
S3										
S4										
S5										
Total										
T test										
S1: Project management techniques are applied										
S2: Standards are actively used to drive quality of outputs										
S3: Regular and careful progress monitoring										
S4: Pre-project planning is thorough and considered										
S5: Direct and indirect suppliers are aware of project										

Appendix 10 (b): Delphi third-round survey - Product critical success factor effects in PMBoK

Success factor	Integration	Scope	Time	Cost	Quality	Human	Communications	Risk	Procurement	Total
F1										
F2										
F3										
F4										
F5										
Total										
T test										

F1: Construction methods by contractors	
F2: Waiting time for approval consultants	
F3: Decision making by owners	
F4: Inappropriate communication	
F5: Material quality	

Appendix 10 (C): Delphi third-round survey - Critical organisational success factor effects on PMBok

Success factor	Integration	Scope	Time	Cost	Quality	Human	Communications	Risk	Procurement	Total
P1										
P2										
P3										
P4										
P5										
Total										
T-total										
P1: Value for money										
P2: Improve efficiency of the system										
P3: Satisfactory overall equipment effectiveness										
P4: Minor and major upgrades required to improve reliability										
P5: Unexpected disruptions beyond the control of project management										