



RESEARCH TOPIC: PROJECT COMPLEXITY AND HOW TO EFFECTIVELY MEASURE COMPLEXITY IN PROJECTS: THE CASE OF A REFUELLING OUTAGE IN A NUCLEAR POWER GENERATING PLANT

Author: N Mabumbulu (Student No: MBMNOX001)

Study supervisor: Ian Jay

Submission date: 2016 August 31

Minor dissertation presented to the Department of Construction Economics and Management under the Faculty of Engineering and Built Environment for MSc in Project Management

The copyright of this thesis vests in the author. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Published by the University of Cape Town (UCT) in terms of the non-exclusive license granted to UCT by the author.

Signed by candidate

ABSTRACT

Background: Projects have become larger, technologically more sophisticated and are organised with a higher number of contractors and partners, compared to 40 years ago. The majority of large, complex capital projects often incur significant cost/budget and schedule overruns. Delays and cost overruns are seemingly, the rule rather than an exception these days. Research shows that one of the reasons for project failure is the increasing complexity of projects or an underestimation of the project complexity. There is therefore a fundamental need to develop a tool or model that will assist project managers to measure complexity within their projects

Research Purpose: To define project complexity, develop a model or tool to measure complexity within projects and to improve the understanding of the dimensions of project complexity.

Research Methodology: The case study methodology was employed, and the unit of analysis was the refuelling outage in a nuclear power generating plant. Focus group was adopted as a technique to gather information. A group of project managers with wealth of knowledge in refuelling outages were assembled. They were given the complexity assessment matrix to assess their respective subprojects, in order to rate the refuelling outage project

Findings: Two main scientific approaches to project complexity, namely; descriptive complexity and perceived complexity were established. Descriptive complexity considers complexity as an intrinsic property of a system. Perceived complexity considers complexity as subjective, since the complexity of a system is understood through the perception of an observer and both approaches can coexist. There are vital layers of complexity such as: social, cultural, operative and cognitive complexity that must be considered when dealing with complexity within projects. A three dimensional model that encompasses the complexity dimensions (origin of project complexity), severity factors (the extent to which complexity dimension will be a problem) and the nature of interdependences (pooled, sequential, and reciprocal) was developed. This model was used to assess complexity of the refuelling outage in a power generating plant. The results of this assessment indicated that this project is a very complex project.

Key words: project complexity, complexity theory, complexity dimensions, severity factors, nature of interdependences, project complexity assessment.

TABLE OF CONTENTS

CHAPTER 1: BACKGROUND INFORMATION	6
1.1 INTRODUCTION	6
1.2 RATIONALE OF THE RESEARCH	9
1.3 PROBLEM STATEMENT	10
1.4 RESEARCH QUESTIONS	10
1.5 RESEARCH OBJECTIVES	10
1.6 IMPORTANCE OF THE RESEARCH	10
1.8 CASE DESCRIPTION	11
1.9 CHAPTER CONCLUSIONS	12
CHAPTER 2: LITERATURE REVIEW	14
2.1 INTRODUCTION	14
2.2 GENERAL COMPLEXITY THEORY	14
2.3 BACKGROUND INFORMATION ON PROJECT COMPLEXITY	14
2.3.1 Current Definitions of Complexity and Project Complexity	16
2.3.2 Types of Complexity	17
2.4 Dimensions and severity of complexity	22
2.5 Chapter Conclusion	30
CHAPTER 3: THEORETICAL FRAMEWORK.....	31
3.1 INTRODUCTION	31
3.2 DEFINITION OF PROJECT COMPLEXITY	31
3.3 MODEL TO MEASURE PROJECT COMPLEXITY	31
3.4 CHAPTER CONCLUSION	36
CHAPTER 4: RESEARCH METHODOLOGY	37
4.1 Research Paradigms	37
4.3 Research Design	38
4.4 Research Instrument	40
4.4.1 Data collection	40
4.5 Data analysis	41
4.6 Analyses Techniques	41
4.7 Data Evaluation Criterial	42
4.8 Research Ethics	43

4.8.1	Participant Consent and Anonymity	43
4.8.2	Safety of the Participants during information gathering	43
4.8.3	Participants profile.....	44
CHAPTER 5: DISCUSSION OF FINDINGS		45
5.1	INTRODUCTION.....	45
5.2	Analyses of Results	49
5.3	Summary of results	53
CHAPTER 6: CONCLUSION AND RECOMMENDATION.....		56
6.1	Future Research.....	57
8.	APPENDIX A: RESEARCH ETHICS INFORMATION	59
8	APPENDIX B: PROJECTS PARTICIPANTS ASSESSMENT.....	63
	Appendix B:1 Moisture separator and reheated heat exchanger sub project.....	63
	Appendix B:2: Maintenance Of The Turbine And Alternator Subproject (P1)	64
	Appendix B:3 Replacement Of The Pirelli Seal (P2): Sub Project	65
	Appendix B:5 Inspection And Repair Of The Essential Cooling Water System Subproject	68

TABLE OF FIGURES

Figure 1:	Systems thinking based approached to describe projects (Vidal <i>et al.</i> , 2011)	15
Figure 2:	Characteristics of Project complexity (Williams, 1999).....	17
Figure 3:	Example of pooled interdependency	21
Figure 4:	Example of sequential Interdependency.....	21
Figure 5:	Example of reciprocal Interdependency	21
Figure 6:	Project complexity framework (Vidal <i>et al.</i> , 2011).....	23
Figure 7:	Project complexity framework: Classification of complexity factors (Marle LA, 2008:1099-1100)	25
Figure 8:	Project complexity framework: Classification of complexity factors (Marle LA, 2008:1099-1100)	25
Figure 9:	Complexity Dimensions (Marle LA, 2008:1099-1100)	28
Figure 10:	Complexity severity factors identified (Note: severity increases the level of complexity).	29
Figure 11:	Pictorial representation of complexity categories: Structural differences between systems Ulrich and Probst (1988) cited by (Marle and Vidal, 2016)	33
Figure 12:	Complexity framework.....	34
Figure 13:	Complexity assessment matrix	35
Figure 14:	Typical outage project structure.....	45
Figure 15:	Revised Complexity Assessment Matrix	48
Figure 16:	Outage 121 Complexity Dimensions.....	55

CHAPTER 1: BACKGROUND INFORMATION

1.1 INTRODUCTION

Projects have become larger, technologically more sophisticated and are organised with a higher number of contractors and partners, compared to 40 years ago, (Marle and Vidal, 2016). The complexity in projects is therefore driven by high and ever changing global forces, rapid technological change, socioeconomic and political influences and or change. Most organizations including the public sector have become more profit driven and with a high pace of technological change, delivering new products and services on time and in budget is the main success or failure criteria of projects.

Complex projects have an unusual degree of uncertainty and unpredictability, which introduce risks in a project. The project manager is often required to make decisions in an environment in which many of the critical factors, or factors with high leverage on the project are outside his direct control. Complex projects are dynamic; their components interact with each other in different ways, (Shane *et al.*, 2015). Furthermore, complex projects contain some level of ambiguity, uncertainty and propagation (Marle and Vidal, 2016).

Project ambiguity is defined as lack of awareness of elements, events and their characteristics due to overall lack of understanding of the project system, particularly when evaluating them. Another aspect to consider is the differences in the perception of the project system by team members notably because of their different cultures, (Marle and Vidal, 2016).

Project uncertainty relates to the inability of the project manager to pre-evaluate project objectives and characteristics of project elements as well as the impact of actions and decisions, (Marle and Vidal, 2016).

Project propagation: Complex projects are complex systems with multiple interdependences and interconnections between their elements (i.e. tasks, resources, processes etc.). As a result uncertainty on a certain parameter can spread through the entire system. Therefore any change in any element of a project may affect other elements in an unpredictable manner due to change propagation.

Static network modelling approaches such as PERT and the critical path method (CPM) and similar methods were developed in the 1950s to assist project managers

to plan, monitor and manage projects effectively. Over the years these models evolved, into allowing risk assessment, resource loading and other specialised applications. It must be noted that these are deterministic models. In deterministic models, the output of the model is fully determined by the parameter values and the initial conditions.

Complex projects have a high level of uncertainty and have numerous emergent properties. Furthermore, in a complex system, the behaviour of the whole is difficult to deduce from understanding the individual parts. That is, when the project management team look at a complex project, while they might know the effects that impacted upon the project and the project outcomes, it can be difficult for them to understand intuitively how the latter came from the former (Williams, 2005). It can thus be concluded that:

- Deterministic models will fail to forecast the outcomes of complex projects,
- The conventional project management approaches, tools and models are inadequate to manage the complexity and uncertainty brought by the rapidly changing business environments. These traditional approaches are more suited to simple environments with low levels of uncertainty, ambiguity and propagation.

Success of projects is measured by the project meeting its objectives. Project success can be measured in quantitative measures or qualitative measures. The objectives normally include time, budget and quality (quantitative measure). Qualitative project success is often difficult to define and measure as it depends on a person's perception and perspective, therefore there is probably no absolute qualitative measure of project success but perceived success (Pretorius *et al.*, 2012).

The majority of large, complex capital projects often incur significant cost/budget and schedule overruns. Morris and Hough (1987) cited by Lyneis *et al.* (2001) studied approximately 3500 projects, and their study revealed that overruns for these projects are normally between 40 and 200 percent. (Roberts, 1993) performed a survey on corporate R&D projects. This survey indicated that less than fifty percent of these projects met their time-to-market and budget objectives. Delays and cost overruns also seem to be the rule rather than the exception in construction, defence, power generation, aerospace, product development software, and other areas, Sterman (2002), cited by Cavaleri and Reed (2008).

(Williams, 2005) indicates that one of the reasons for project failure is the increasing complexity of projects or an underestimation of the project complexity, hence the need to develop a tool or model that will assist project managers to measure complexity within their projects.

South African project's performance is not unique, as the country has been struggling to deliver complex projects on time and in budget. Below is a brief summary of South African mega projects performance:

- *Gautrain*: Overrun its duration by 2 years and cost by 14 billion, Chihuri, and Pretorius (2010) cited by (PMSA, 2014).
- *The 2010 FIFA Soccer World Cup*: Exceeded its baseline budget by approximately R6 billion Philips (2008) cited by (PMSA, 2014).
- *Transnet's multi-product pipeline between Durban and Gauteng* exceeded its baseline budget by R20 billion and duration by more than 3 years, Guern Le (2013) cited by (PMSA, 2014).
- *Medupi Power Station*, the world's 4th largest coal fired power-station, was 30 months delayed and the estimated cost to completion was estimated at R56 billion more than initial estimates, Donnelly (2012), cited by (PMSA, 2014).

These projects probably failed as a result of:

- Poor conceptualisation of project objectives at inception: *Project ambiguity*,
- Inherent weakness in the plan or planning phase: *Deterministic project tools*,
- Inadequate execution: processes, people and technology: *Deterministic project tools*,
- Inability to recognise the changing internal or external factors that have high leverage on a project: *Absence of a measuring tool*
- Inability to recognise their inherent complexity (Prieto, 2015): *Absence of a measuring tool*
- Application and use of traditional project management approaches, tools and models (Williams, 1999): *Deterministic project tools*.
- Inability of the project managers to manage complex projects (Thomas and Mengel, 2008).

It must be noted that there is lack of consensus amongst the researchers on what project complexity really is. Sinha (2001) cited by (Vidal *et al.*, 2011) *indicates that*

there is no single concept of complexity that can adequately capture the human being's intuitive notion of what the word ought to mean. Complexity can be understood in different ways, not only in different fields but has also different connotations within the same field, Morel and Ramanujam (1999) cited by (Vidal *et al.*, 2011). Furthermore, the correlation between project complexity, project risks, and project performance are still unclear in the project management field. Parsons-Hann and Liu (2005) cited by (Vidal *et al.*, 2008) state that: it is apparent that complexity contributes to project failure in organisations, what is not apparent is to what degree does project complexity contributes to project failure. Even if the correlation between project failure and complexity is not clear, complexity appears to be one of the main reasons of the unpredictability of projects, particularly in terms of problems and failures, (Vidal *et al.*, 2008). It is imperative to understand project complexity. (Baccarini, 1996) highlights the following importance/s of project complexity to the project management environment:

- It aids in determination of planning, coordination and control requirements,
- If not properly understood, it hinders the clear identification of goals and objectives of major projects,
- Complexity is an important criteria in the selection of an appropriate project organizational structure,
- Project complexity influences the selection of project inputs, e.g. the expertise and experience requirements of management personnel,
- Complexity is frequently used as a criterion in the selection of a suitable project procurement strategy.

1.2 RATIONALE OF THE RESEARCH

The rapid change in business environment, uncertainty in political and socio-economic environment, requires project management professionals to fully understand complexity within projects and for them to be fully equipped to manage these projects effectively. Complex projects have a high number and wide range of diversity of objects to manage, with a high number and great diversity of parameters that characterise them. The amount and diversity of these interactions are so great that, project's rapidly become unmanageable due to the sole use of classical tools and methods of project management, (Vidal *et al.*, 2008). It is evident that the traditional approaches, models and tools are inadequate to effectively manage complex projects. Literature analysis of past performance of complex projects revealed that the majority of complex capital projects failed to meet their objectives,

see section 1.1 of this report. From this analysis it can be concluded that the complexity of these projects was not properly understood and measured from initiation to implementation project phases, as a result they were not properly managed or the tools or models used to manage them were not suitable to manage such projects.

1.3 PROBLEM STATEMENT

Complexity dimensions and severity factors have been developed to assist project managers to understand and manage complexity within projects. However there is a lack or absence of a tool that can comprehensively measure complexity within projects throughout the project life cycle.

1.4 RESEARCH QUESTIONS

The associated research questions for this study are as follows:

- What is a workable definition of project complexity?
- How can project complexity be measured?

1.5 RESEARCH OBJECTIVES

The objectives of this research are as follows:

- Define project complexity,
- Develop a model or tool to measure complexity within projects ,
- To improve the understanding of the dimensions of project complexity

1.6 IMPORTANCE OF THE RESEARCH

Projects are becoming more complex due to the advancement in technology, speed of change, financial constraints, socioeconomic and political changes. The aforementioned then impose a fundamental requirement to fully understand and be able to measure the factors that influence project complexity as well as their interdependences and interconnectivity. The results of this study will assist corporations, government entities and project management practitioners to understand and measure the factors that drive complexity in order for them to effectively manage complex projects thereby minimising budget and duration overruns.

1.7 Research Limits

This study will not develop or identify a tool or model to effectively manage complex projects. Furthermore it will not determine the correlation between project complexity and project risk.

1.8 CASE DESCRIPTION

This research will use a refuelling outage project in a nuclear power plant as a case study. The energy industry is suffering from increasing project complexity and with the increasing energy demand, this industry's main focus is to improve its project performance, IEA (2006) cited by (Rekvelde *et al.*, 2011). Hence, the decision to use the refuelling outage as a case of study.

For an approximately 1000 megawatts (MWe) nuclear power plant, the core (reactor) contains approximately 75 tonnes of low-enriched uranium(U-235). In the reactor core the U-235 isotope fissions or splits, producing a lot of heat in a continuous process called a chain reaction or fission process. The heat generated from the fission process is used to produce steam that drives a turbine and an electric generator. Each fission process results in the destruction of a fissionable nucleus, therefore there is a gradual depletion of the fuel as the reactor produces power. This process is called fuel burn up. The process also depends on and is controlled by the presence of a moderator such as borated water and control rods (reactivity control). Over a period of time the reactivity effect of the fuel depletion is large, and it ultimately reaches the point where refueling the reactor is required. To maintain efficient reactor performance, about one-third of the spent fuel is removed from the reactor core every 18 months and is replaced with fresh fuel. Maintenance and modifications are also implemented during an outage. The outage philosophy is as follows:

- Refuelling outage: short duration outage typically 35 days as the focus is only on refuelling the reactor and perform non-intrusive maintenance
- Maintenance outage: Medium duration outage typically 58 days to allow the reactor to be refuelled, minor modifications and intrusive maintenance to be performed
- Modification outage: Long duration outage typically 98 days to allow the reactor to be refuelled, major maintenance and modifications to be performed.

Past performance of the refuelling outages has been poor, where outage duration, budget has been exceeded. Below is the summary of previous outage performance:

Outage No.	Planned Duration (days)	Actual Duration (days)	Slip (days)
119	69	72	+3
120	43	48.5	+5.5
218	50	66	+16
219	69	69	0
220	43	57	+14

Table 1: Historic outage performance

It must be understood that when an outage has delayed, the company incurs revenue losses for the days the unit has been shut down for maintenance. These will not be highlighted in this report due to confidentiality concerns. A refuelling outage is conducted in the following sequence:

- Plant shut down,
- Fuel unload
- Maintenance
- Fuel reload
- Plant start up and synchronisation

1.9 CHAPTER CONCLUSIONS

The evidence from literature indicates that the majority of complex projects failed to meet their duration and budget requirements. To improve performance of complex projects, it is important to properly understand the:

- Fundamental principles of project complexity,
- Factors that contribute to project complexity and how these affect project performance.

Furthermore, it is vital to have a tool that will enable project managers to measure project complexity. Conventional project management approaches, tools and models are inadequate to manage the complexity and ambiguity of a rapidly changing business environment. These traditional approaches are more suitable for static environments with low levels of uncertainty, ambiguity and propagation

This study will then focus on developing the fundamental definition of project complexity, develop a model that will assist project managers to measure complexity in their projects, see table below:

Problem statement	Objectives	Research questions	Research methodology
There is a lack or absence of a tool that can comprehensively measure complexity within projects throughout the project life cycle	To define project complexity within projects ,	What is a workable definition of project complexity?	Case study
	To improve the understanding of the dimensions of project complexity	How can project complexity be measured?	
	Develop a model to measure project complexity		

Table 2: Research proposal summary

This study will be conducted following the structure:

Chapter 1: Background Information detailing the problem that this study is to address and the research questions.

Chapter 2: Literature Review: Analyses of the existing literature on project complexity.

Chapter 3: Theoretical framework: that is the framework developed from the literature to address the research questions and the problem statement.

Chapter 4: Research Methodology: Methodology that will be employed to gather data in order to test the developed framework.

Chapter 5: Discussion of findings: Assessment of the information gathered

Chapter 6: Conclusions and recommendations from the findings

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Chapter 1 of this report, indicated that the majority of complex projects failed to meet their budget and time-to-market requirements. Projects are becoming more complex and consequently, traditional deterministic approaches are inadequate to ensure success of these projects

Previous studies on project complexity including Perrow (1965), Stalker (1965), Woodward (1965), have been conducted mainly from a technical perspective but not directly addressing the effects of complexity on project schedule performance (Gidado, 1996). Hence the objectives of this study are to:

- Define project complexity, identify factors that contribute to project complexity,
- Develop a tool or a model to measure project complexity.

The literature review in this chapter is aimed at reviewing and evaluating the current literature on project complexity in order to achieve the objectives.

2.2 GENERAL COMPLEXITY THEORY

There are two characteristics of a complex system namely: large number of interacting elements and emergent properties.

- *Large number of interacting elements:* Complex systems contain a large number of elements that interact with one another. These interactions occur due to the presence of feedback mechanisms in the system. The interactions in a complex system in turn introduce nonlinearities in the dynamics of the system. A complex system can be made up of diverse elements (Morel and Ramanujan, 1999: 279).
- *Emergent properties:* Complex systems also have emergent properties, i.e. the appearance of patterns which are due to the collective behaviour of the elements of the system. An example of an emergent property is pressure and temperature, as these parameters emerge from a number of molecules colliding with each other, emitting heat energy and expanding (Morel and Ramanujan, 1999).

2.3 BACKGROUND INFORMATION ON PROJECT COMPLEXITY

To understand complexity within the project management environment, a project must be viewed as a system. A system can be defined as an object, which, in a given environment, aims at reaching some objectives (teleological aspect) by doing an activity (functional aspect) while its internal structure (ontological aspect) evolves through time (genetic aspect) without losing its own identity (Vidal *et al.*, 2011). A

project exists within a specific environment with certain objectives (teleological aspect). It also has to accomplish a set of activities through application of some methods and methodologies (functional aspect). Furthermore, a project has an internal structure composed of human and material resources, deliverables, tasks, information systems/software, which is the ontological aspect. Finally, a project evolves through different phases, via resource consumption, product delivery, members changes and gain of experience, without losing its own identity which is the genetic aspect, (Vidal *et al.*, 2011). These categorical aspects of projects are illustrated in figure 3.

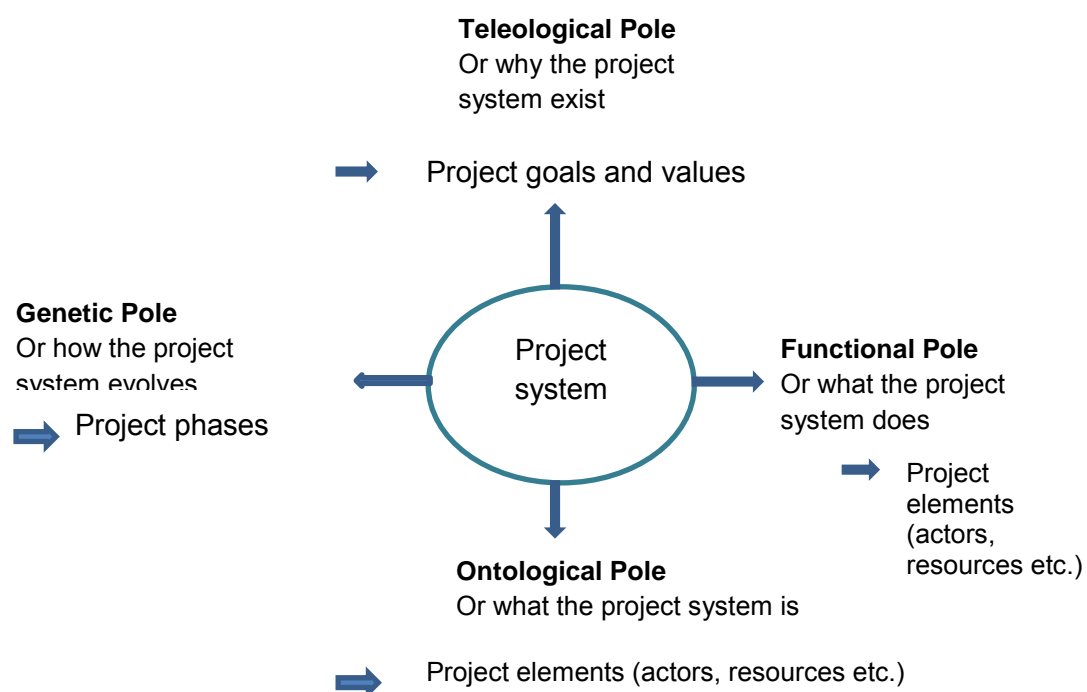


Figure 1: Systems thinking based approached to describe projects (Vidal *et al.*, 2011)

This theory does not factor the perceived (cognitive), social , cultural , operative and complexity.

Two main scientific approaches to project complexity, namely; descriptive complexity and perceived complexity were established. Descriptive complexity considers complexity as an intrinsic property of a system. Perceived complexity considers complexity as subjective, since the complexity of a system is understood through the perception of an observer and both approaches can coexist (Vidal *et al.*, 2011). The difference between what is complex and what is simple is relative and changes with time and perspective, (Remington *et al.*, 2009).

(Brockmann and Girmscheid, 2008) indicate that the current definitions of project complexity are more task specific and do not consider all possible layers of complexity such as: social , cultural , operative and cognitive complexity.

(Brockmann and Girmscheid, 2008) define these layers of complexity as follows:

- *Task complexity* as the density of activities in a given spatial and temporal frame,
- *Social complexity* as the one that emanates from the number and diversity of actors communicating and working with each other,
- *Cultural complexity* as the one encompassing the history, experience, and sense-making processes of the different groups that join their efforts in a megaproject.
- *Operative complexity* as the degree to which organizations of the project are independent when defining their operations to achieve the project goals.
- *Cognitive complexity* emanates from an individual or group level, this involve sense-making processes, the emergence of an identity, or even an organisational culture.

Karsky 1997 cited by (Marle and Vidal, 2016) indicates that complexity has three characteristic that coexist in a project:

- *Spatial complexity*: the structural complexity of a system in terms of a number and variety of elements (e.g. resources, actors, tasks, processes) and their mutual interrelations,
- *Unpredictable complexity*: which refers to chaos, fluctuations and bifurcations considering the behaviour of a system in the essence of unpredictability as it is characterised by nonlinearity,
- *Dynamic complexity*: refers to the interrelations and feedbacks loops which make it more difficult to understand the evolution of a complex system.

2.3.1 Current Definitions of Complexity and Project Complexity

- 1) Cooke-Davies *et al.* (2007) broadly defines complexity theory as the study of how order, structure, pattern, and novelty arise from extremely complicated, apparently chaotic systems and conversely, how complex behaviour and structure emerges from simple underlying rules.
- 2) Baccarini (1996), defines a complex project as a project that consists of many varied interrelated parts/ elements.
- 3) Vidal *et al.* (2011) defines project complexity as the property of a project which makes it difficult to understand, foresee and keep under control its overall

behaviour, even when given reasonably complete information about the project system

- 4) Remington *et al.* (2009) defines a complex project as one that demonstrates a number of characteristics to a degree, or level of severity, that makes it extremely difficult to predict project outcomes, control or manage project
- 5) Gidado (1996) defines project complexity as the measure of difficulty of implementing a planned work flow in relation to any one or a number of quantifiable objectives.

2.3.2 Types of Complexity

Baccarini (1996) categorised project complexity into, differentiation and interdependency. There are two types of project complexity namely, organisational and technological complexity. These complexity types can be described in the context of differentiation and interdependency. It is important to state clearly the category and type of complexity being dealt with, when referring to project complexity (Baccarini, 1996). (Williams, 1999) characterised project complexity into two dimensions namely: structural complexity and uncertainty see figure below:

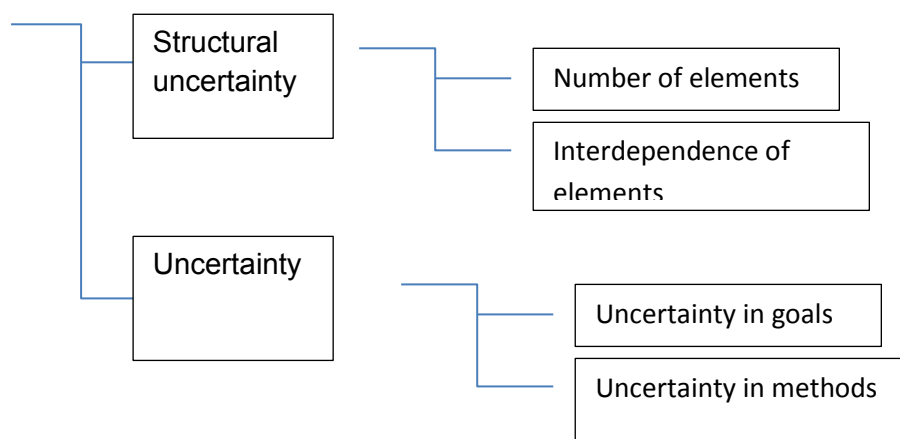


Figure 2: Characteristics of Project complexity (Williams, 1999)

Organisational complexity

Organisational complexity entails the relationships in terms of communication and reporting; allocation of responsibility and authority for decision making; allocation of tasks. Complex projects have several stakeholders or role-players and have diverse organisations. This tends to create a temporal multi organisation to manage typical projects.

Organisational complexity in terms of differentiation is one that contains differentiated parts in such that the greater the differentiation the more complex the organization becomes (Baccarini, 1996).

Differentiation has two dimensions namely:

- Vertical differentiation: This refers to the depth of organizational hierarchical structure, i.e. number of levels,
- Horizontal differentiation: This can be defined in two ways:
 - (i) Organizational units: i.e. the number of formal organizational units, e.g. departments, groups or;
 - (ii) Task structures i.e. the division of tasks e.g. division of labour tasks i.e. tasks that are structured in a manner that non-specialists can perform them, and personal specialization i.e. works to be performed by specialists (Baccarini, 1996).

To bring context to this, organisational complexity would mean the number of hierarchical levels, number of formal organisational units, division of tasks, number of specialisations (Williams, 1999).

Organizational complexity in terms of interdependency is the one that entails a degree of operational interdependencies and interaction between the project organizational elements. This type of complexity can be defined in terms of the following types of interdependencies between organizational units: pooled, sequential and reciprocal (this interdependencies represent the highest level of complexity) (Baccarini, 1996). The Baccarini approach to project complexity also does not consider other layers of complexity such as: cognitive, social and cultural. It is important to consider these layers as they may complicate a project and may lead to schedule and budget overruns. It is also important to consider the softer aspects and influences from the environment as they also influence project complexity (Rekveldt *et al.*, 2011). The softer aspects that contribute to the overall project complexity include the complexity of interaction that normally takes place at the interfaces between people and organizations. It includes aspects like politics, ambiguity and empathy Gerald, (2009) cited by (Rekveldt *et al.*, 2011).

It is also important to understand the sources of complexity and its severity in order to determine the skills and capabilities needed to effectively manage the project (Rekveldt *et al.*, 2011). Antoniadis *et al.* (2011) studied the relationship between socio-organo complexity of interconnections, in particular the processes of selecting team members, structuring project teams and the management style adopted, and

project schedule performance. Interconnections are formed as individuals and teams from different companies work together to deliver the project. Lucas (2000a) cited by (Antoniadis *et al.*, 2011) indicates that these interconnecting structures between the teams contribute to project complexity. Therefore selection of team members is critical in managing the effects of complexity which stem from the organisational and technological complexity.

Technological Complexity

There is no consensus on what technological complexity is. Some authors have operationalised technological complexity in terms of the difficulties of task performance (Baccarini, 1996) and (Williams, 1999). (Gidado, 1996) refers to this type of complexity as inherent complexity that originates from science, technological advances, physical ability, availability of skills required and environmental sources. (Williams, 1999) indicates that complexity is also concerned with the underlying structure of the project which he terms structural complexity. Structural complexity refers to the inherent product or project deliverable complexity. Structural complexity in Baccarini terms refers to the number of subsystems of a product and their inter-relationships, where an inter-relationship can mean, that changes in the design for one subsystem produces cross-impacts and affect the design of the other system (Baccarini, 1996).

Technological complexity in terms of differentiation refers to the variety or diversity of some aspects of tasks, such as:

- Number and diversity of inputs and/or outputs
- Number of separate and different actions or tasks to produce the end product of a project.
- Number of specialities (e.g. subcontractors or trades) (Baccarini, 1996).

Technological complexity in terms of interdependency refers to complexity by interdependency. It encompasses interdependencies between tasks within a network of tasks; between teams; different technologies and inputs, Jones (1993), cited by (Williams, 1999). Complex projects have some non-linearity characteristic which makes the relationship between inputs and outputs unpredictable (Richardson, 2008) cited by (Remington *et al.*, 2009). Non-linearity potentially contributes to structural complexity, which is an emergent behaviour which is from interactions between many interconnected tasks (i.e. variety of tasks) (Remington *et al.*, 2009).

Understanding the degree of interdependencies or the degree of interrelatedness or connectivity between the elements within these tasks is crucial. It is also prudent to distinguish the cause and effect of product type of complexity. If the product to be manufactured or designed is complex, there is a high probability that the project will be a complex one. Product complexity relates to the number of subsystems of a product and their inter-relationships (where an inter-relationship can mean, for example, that changes in the design of one subsystem produces cross-impacts and affect the design of the other system) (Williams, 1999). Product complexity can be measured in:

- *Sequential (product) complexity* i.e. the likely length of a sequence of interactions (i.e. if subsystem *i* affects subsystem *j* which affects subsystem *k*, this is a length of 3);
- *Feedback (product) complexity* i.e. the probability that a change in system *i* eventually affects the whole system (Williams, 1999) These help the project manager to evaluate the impact of requirements changes by a customer.

It is not sufficient to only count the number of interdependencies, understanding the nature of these interdependencies is crucial. Thompson (1976, p.54) cited by (Williams, 1999) analysed interdependencies and identified three types:

- *Pooled*: In pooled interdependent project system or structure each part renders a discrete contribution to the whole and each is supported by the whole (Thompson, 1967, p. 54). An example in construction is the way two specialists share a crane or other major piece of equipment (Shirazi et al., 1996 cited by (L Bankvall *et al.*, 2010). There is not necessarily a direct operational dependence between the parts, but the failure of one part can threaten the whole and the other parts involved, see figure 3.
- *Sequential* i.e. one element's output becomes another's input, see figure 4
- *Reciprocal* i.e. each element's output becomes inputs for other elements, so the actions of each must be modified to the actions of others. This interdependency particularly intensifies complexity, see figure 5.

Diverse inputs e.g. fatigue, experience,

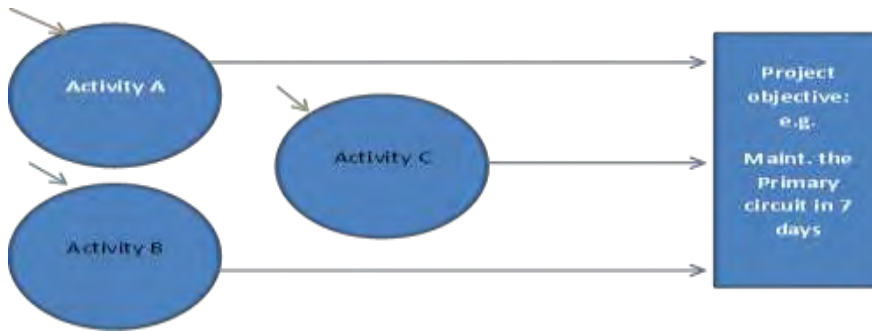


Figure 3: Example of pooled interdependency

Diverse inputs e.g. fatigue, experience,

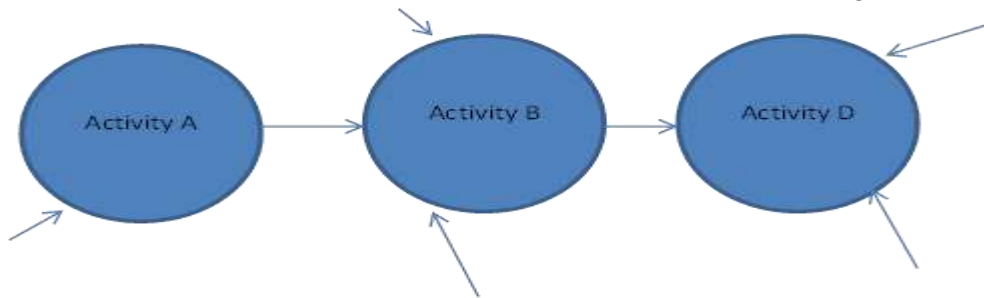


Figure 4: Example of sequential Interdependency

Example of diversity of

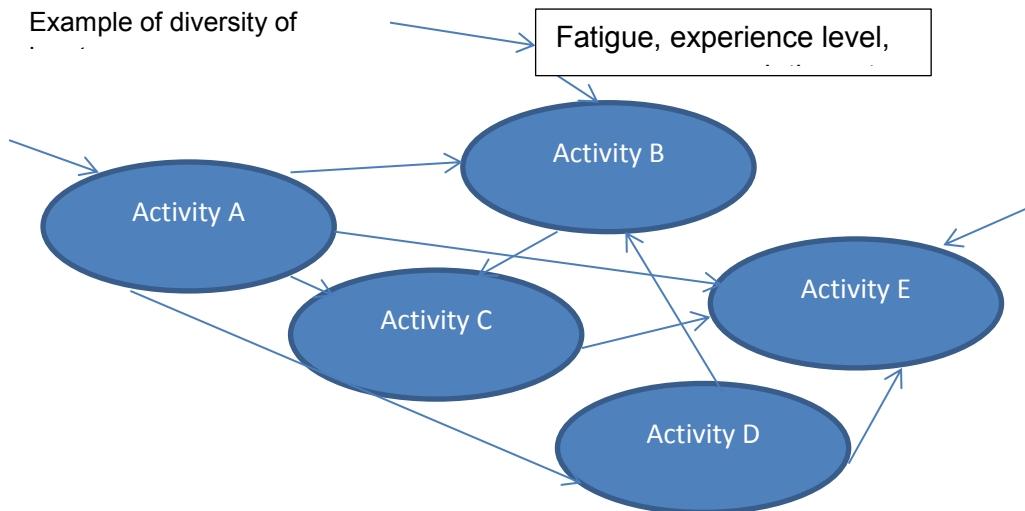


Figure 5: Example of reciprocal Interdependency

2.4 Dimensions and severity of complexity

(Vidal *et al.*, 2011), identified 4 factors (based on a system definition, see section 2.3) that drive complexity:

- **Project size** i.e. the sizes of elementary objects which exist within the project system (Ontological aspect)
- **Project variety** i.e. the diversity of elementary objects which exist within the project system. Diversity relates closely to the number of emergent properties (Ontological aspect)
- **Project interdependence** i.e. the existence of relationships between elementary objects within the project system (Functional aspect). These are likely to be the greatest drivers of project complexity. Traditional project management tools are not sufficient to identify and manage project interdependence.
- **Project context dependence:** i.e. the environment within which a project is undertaken (Teleological aspect). The above factors are further illustrated in figure 6 and 7.

Family	Organisational Complexity (Org)	Technological complexity (Tech)
Project size	Number of stakeholders	
Project system variety	Variety of information systems to be combined	
	Geographic location of the stakeholders (and their mutual disaffection)	
	Variety of interest of the stakeholders	Specifications interdependence
Interdependence with project system	Dependences with the environment	
	Availability of people, material and any resources due to sharing	
	Interdependences between sites, departments and companies	
	Interconnectivity and feedback loops in the task and project networks	
	Team cooperation and communication	
	Dependences between schedules	
	Interdependences of objectives	Environment complexity (networked environment)
	Interdependence of information systems	
	Level of interrelations between phases	
Elements of Context	Cultural configuration and variety	
	Environment complexity (networked environment)	

Figure 6: Project complexity framework (Vidal *et al.*, 2011)

	Project system size	Project system variety	Interdependences within the project system	Elements of context
Organisational complexity	Duration of the project	Diversity of staff (experience, social span etc.)	Availability of people, material and of any resources due to sharing	Competition
	Largeness of capital investment	Geographic location of the stakeholders and their mutual disaffection	Combined transportation	Cultural configuration and variety
	Number of activities	Variety of financial resources	Dependences between schedules	Environment complexity (networked environment)
	Number of companies/ projects sharing their resources	Variety of hierarchical levels within the organisation	Dependences with the environment	Institutional configuration
	Number of decisions to be made	Variety of information systems to be combined	Dynamic and evolving team structure	Local laws and regulations
	Number of deliverables	Variety of organisational interdependences	Interconnectivity and feedback loops in the task and project networks	New laws and regulations
	Number of departments involved	Variety of organisational skills needed	Interdependence between actors	Organisational degree of innovation
	Number of hierarchical levels within the organisation	Variety of project management methods and tools applied	Interdependence between sites, departments and companies	
	Number of information systems to be combined	Variety of interests of stakeholders	Interdependence of information systems	
	Number of investors	Variety of stakeholders	Interdependence of objectives	
	Number of stakeholders		Level of interrelations between project phases	
	Number of structures/groups/ teams to be coordinated		Number of interfaces in the project organisation	
	Staff quantity		Processes interdependence Process interdependence Relations with permanent organisation Stakeholders interrelations Team cooperation and communication	

Figure 7: Project complexity framework: Classification of complexity factors (Marle LA, 2008:1099-1100)

	Project system size	Project system variety	Interdependences within the project system	Elements of context
Technological Complexity	Number and quantity of resources	Variety of resources to be manipulated	Interdependence between the components of the product	Competition
	Largeness of scope (number of components)	Variety of the product components Variety of technological skills needed Variety of the technologies used during the project	Resource and raw material interdependences Specification interdependences Technological processes dependences	Cultural configuration and variety Demand of creativity Environment complexity (networked environment) Institutional configuration Local laws and regulations New laws and regulations Scope for development Significance on public agenda Technological degree of innovation

Figure 8: Project complexity framework: Classification of complexity factors (Marle LA, 2008:1099-1100)

Research, suggests that not all projects are complex in the same way, hence the need to consider complexity dimensions and severity factors. Dimension of complexity, indicates the origin of complexity. It must be noted that complex projects have more than one source of complexity, (Remington *et al.*, 2009). Severity indicates the extent to which the complexity source will be a problem. It is important to note that a severity factor can affect any dimension of complexity and for each dimension of complexity the severity of the complexity is likely to differ. Understanding the source of the complexity and to what degree the resultant difficulties will be played out will help the organisations to determine the skills and capabilities needed to manage complex projects (Remington *et al.*, 2009). It must be noted that the perceived severity in relation to each of the dimensions of complexity depends on:

- The experience level and capability of key personnel in relation to the type and degree of complexity;
- The project organisational structure, and its interfaces with key participating organisations, with respect to communication and governance;
- Existing cultural norms and work practices within and between participating organisations, including project culture;
- Appropriateness of organisational processes, such as procurement practices, (Remington *et al.*, 2009), see figure 9 for severity factors.

Complexity dimension and severity will enable project managers to measure complexity in a project. Once project complexity becomes measurable, acceptable limits can be established as the threshold of complexity (Gidado, 1996).

Below and in figure 8 are the complexity dimensions:

- *Parallelism and concurrency*, influences and intensify project complexity. These approaches are normally adopted to reduce project durations to reduce the time to market of products (Williams, 1999.). (Gidado, 1996) also identified complexity that stems from sequencing operations in a work flow.
- *Uncertainty of the assumptions* upon which the tasks are based. Uncertainty can be considered as one of the negative consequences of project complexity (Vidal *et al.*, 2008). Uncertainty for a project can emanate from ambiguity in goals and/or high uncertainty in how to implement the objectives. The vagueness of the goals might be measurable by how long it would take to establish whether the goals were satisfied; changes in goals could also be measured in terms of contract changes (Williams, 1999) . (Gidado, 1996) indicates that uncertainty can also originate from:
 - Incomplete specification for the activities,
 - Unfamiliarity of the inputs and or environment by management,

- Lack of uniformity e.g. when the roles of the team keeps changing with time and place,
- Unpredictability of the environment

Complex projects are characterised by a degree of disarray, instability, evolving decision-making, non-linear processes, iterative planning and design, uncertainty, irregularity, and randomness. (Geraldi *et al.*, 2011) supports this concept as he stated that dynamics in projects, such as changes in: specifications, goals due to ambiguity, management team, suppliers, etc. contribute to project complexity. Typical changes in a project may lead to high levels of disorder, rework, or inefficiency, when changes are not well communicated or assimilated by the team and others involved. Project complexity is therefore dynamic, i.e. the parts in a system can react or interact with each other in different ways. Some categories of uncertainty with variations involve foreseen and unforeseen uncertainty, and chaos. The following types of uncertainty are to be considered:

- *Aleatoric uncertainty*: relates to the reliability of calculations, this can be alleviated by contingency planning. *Aleatoric uncertainty* can lead to change in project requirements. It must be noted that changes in some of the requirements will require interacting elements also to be changed (see types of interdependences e.g. *reciprocal*), (Williams, 1999) cited by (Remington *et al.*, 2009)
- *Epistemic uncertainty*: originates from lack of knowledge of the project team and leading to project complexity (Williams, 1999). Uncertainty in methods for novel projects is also a contributor to epistemic uncertainty. There is some correlation between technological novelty and technological maturity of the organization, which leads to task uncertainty, Taikonda & Rosenthal (2000) and Pundir *et al.*, (2007) cited by (Remington *et al.*, 2009). There is an understanding in literature that risk is the contributor to uncertainty (Jaafari, 1998). Therefore, risk management throughout the lifecycle of a project becomes more important. (Vidal LA and F, 2008) consider complexity as a source of risks, either directly or indirectly induced by complexity in a project. It must be noted that this aspect of complexity will not be covered in this study.

Citation	Dimension 1 Goals	Dimension 2 Means to achieve goals	Dimension 3 Number and interdependency of elements	Dimension 4 Timescale of projects	Dimension 5 Environment: Market; policy, regulatory
D'Herbemont & Cesar, 1998		Technical Innovation	Number of people Number of stages Number of elements	Timescale of projects	Financial investment Risk in the event of failure
Baccarini, 1996, Williams, 2002			Interdependent elements		
Remington & Pollack, 2007	Directional clarity and agreement on goals and goal paths	Technical: level of technical innovation	Structural: Numbers and interdependence of elements	Temporal: Duration of projects	Temporal: Dynamism of the market, political or regulatory environment
Vidal & Marle, 2008		Variety	Size interdependent		Context dependence

Figure 9: Complexity Dimensions (Marle LA, 2008:1099-1100)

Citation	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9
	Difficulty	Non-linearity	Uncertainty	Uniqueness	Communication	Context dependency	Clarity	Trust	Capability
Turner & Cochrane, 1993						Dynamism	Lack of clarity		
Kallininkos, 1998									
D'Herbement & Cesar, 1998									Human
Luhmann & Boje, 2001 Williams, 2002				Uniqueness	Indirect communication				
Williams, 2002	Difficulty	Interconnected	Uncertainty estimates						
Muller & Gerald, 2007								Lack of trust	
Remington & Pollack, 2007		Non linearity	Uncertainty			Org. culture / work practices/process			PM capability/ sponsor support
Danilovic & Browning, 2007		Interrelations							
Alderman & Ivory, 2007		Interconnectivity							
Pundir, et al., 2007		Interconnectivity				Context and history			
Cooke-Davies et al., 2007		Interconnectivity							
Gerald, 2008	Difficulty	Interconnectivity						Trust	
Aritua et al., 2008		Interconnectivity							
Vidal & Marle, 2008		Interdependent				Context dependent			

Figure 10: Complexity severity factors identified (Note: severity increases the level of complexity).

2.5 Chapter Conclusion

Complexity theory has two fundamental characteristics i.e. large number of interacting elements and emergent properties. All complex system comprises of these characteristics.

To fully comprehend complexity within projects, a project must be viewed as a system. A system operates within a certain environment; its aim is to achieve certain goals or objectives by undertaking certain activities. It is also prudent to consider the layers of complexity such as task, social, cultural, operative and cognitive complexity (large number of interacting elements).

Baccarini (1996) categorize complexity into differentiation and interdependency. Complexity in a project can be introduced by the organizational structures, i.e the number of hierarchical levels organizational units, division of tasks, and number of specialists. Furthermore complexity can emanate from technology. Baccarini (1996) and Williams (1999) operationalised technological complexity in terms of task difficulty. (Gidado, 1996) refers to technological complexity as the one emanating from science, technological advances, availability of skills, etc. Technological complexity in terms of differentiation refers to variety and diversity of tasks, and in terms of interdependency it refers to interdependencies between tasks within a network of tasks and between different technologies. Understanding the nature of interdependences such as pooled, sequential, reciprocal interdependency is vital (interaction between elements). Schedule and budget overruns are emergent properties in a project.

Vidal *et al.* (2011) identified 4 factors that drive complexity (dimensions) in a project, namely: project size, project variety, project interdependencies, project context dependence. Project complexity dimensions and severity have been developed to enable the project managers to measure project complexity. Complexity dimension indicates the source of complexity and the severity indicates the extent to which the complexity will be a problem. Once this parameters are fully determined and understood, the project manager can develop a strategy to effectively manage complexity within his/her project. These parameters are not integrated into a three dimensional model, to enable the project managers to holistically assess complexity in their projects.

CHAPTER 3: THEORETICAL FRAMEWORK

3.1 INTRODUCTION

Chapter 2 of this report reviewed literature on complexity and project complexity i.e. the categories of complexity, factors that influence complexity, complexity dimensions and severity factors. This chapter will address the following research questions, using the information detailed in chapter 2 (Literature Survey):

- I. What is a workable definition of project complexity?
- II. How can project complexity be measured?

3.2 DEFINITION OF PROJECT COMPLEXITY

The five definitions for project complexity sampled in the literature survey all have the following similar components:

- Difficulty or extremely complicated systems, (Cooke-Davies *et al.*, 2007), (Vidal *et al.*, 2011), (Remington *et al.*, 2009), (Gidado, 1996)
- Varied interrelated parts (Baccarini, 1996) and (Remington *et al.*, 2009)

Proposed project complexity definition: A complex project is the one that is complicated, containing many interrelated parts making it difficult to predict its outcomes and response to changes and therefore difficult to manage and control it.

3.3 MODEL TO MEASURE PROJECT COMPLEXITY

Complexity dimensions aid in the understanding of the origin or factors that drive complexity in projects. These are: project size, project variety, project interdependences and project context dependence.

Project Size: The sizes of elementary objects which exist within the project system. This can be assessed using quantitative measures such as time scales or cardinal measures Marle and Vidal (2016).

Project variety: The diversity of elementary objects which exist within the project system. Diversity relates to the number of emergent properties (Marle and Vidal, 2016 83).

Project interdependency: The existence of relationships between elementary objects within the projects i.e. each element depends and influence other elements in the project system (Marle and Vidal, 2016).

Project Context: The environment within which a project is undertaken (Marle and Vidal, 2016).

Difficulty, non-linearity, uncertainty, uniqueness, communication, context dependence, clarity, trust and capability have been identified as complexity severity factors (Remington *et al.*, 2009). However of these nine severity factors, two most prevalent ones, namely difficulty and uncertainty, have been selected for this study. It is crucial to also consider the nature of interdependency such as pooled, sequential and reciprocal. To properly measure project complexity it is of outmost importance to integrate all factors that influence or contribute to project complexity. In the proposed complexity measurement model, the complexity dimensions, severity factors and interdependences have been integrated into a three dimensional matrix (see figure 12). This model can be systematically used to measure complexity of a project throughout the phases of a project (initiation, planning and scheduling, execution, control and monitoring, close out). This complexity measurement matrix will be used to assess a refueling outage project that is currently in the planning and scheduling phase.

(Marle and Vidal, 2016) differentiate complicated and complex systems. Complicated systems can be understood and kept under control through the work of the experts and efficient use of lessons learned and advanced computational tools. The final classification of the project will be simple, complicated, complex and very complex systems, see figure 11.

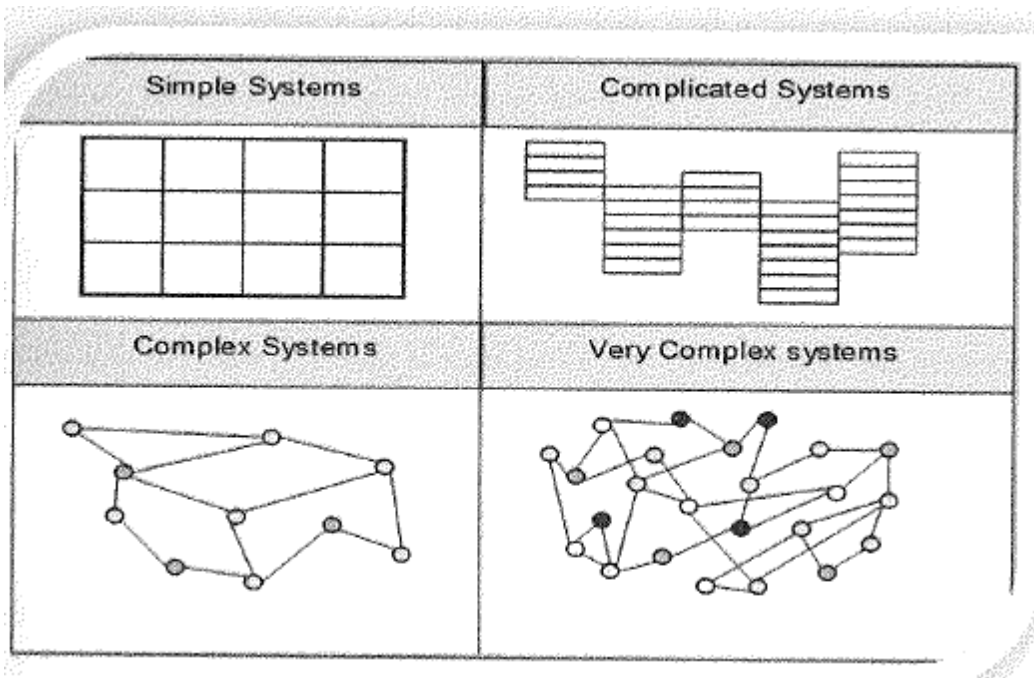


Figure 11: Pictorial representation of complexity categories: Structural differences between systems Ulrich and Probst (1988) cited by (Marle and Vidal, 2016)

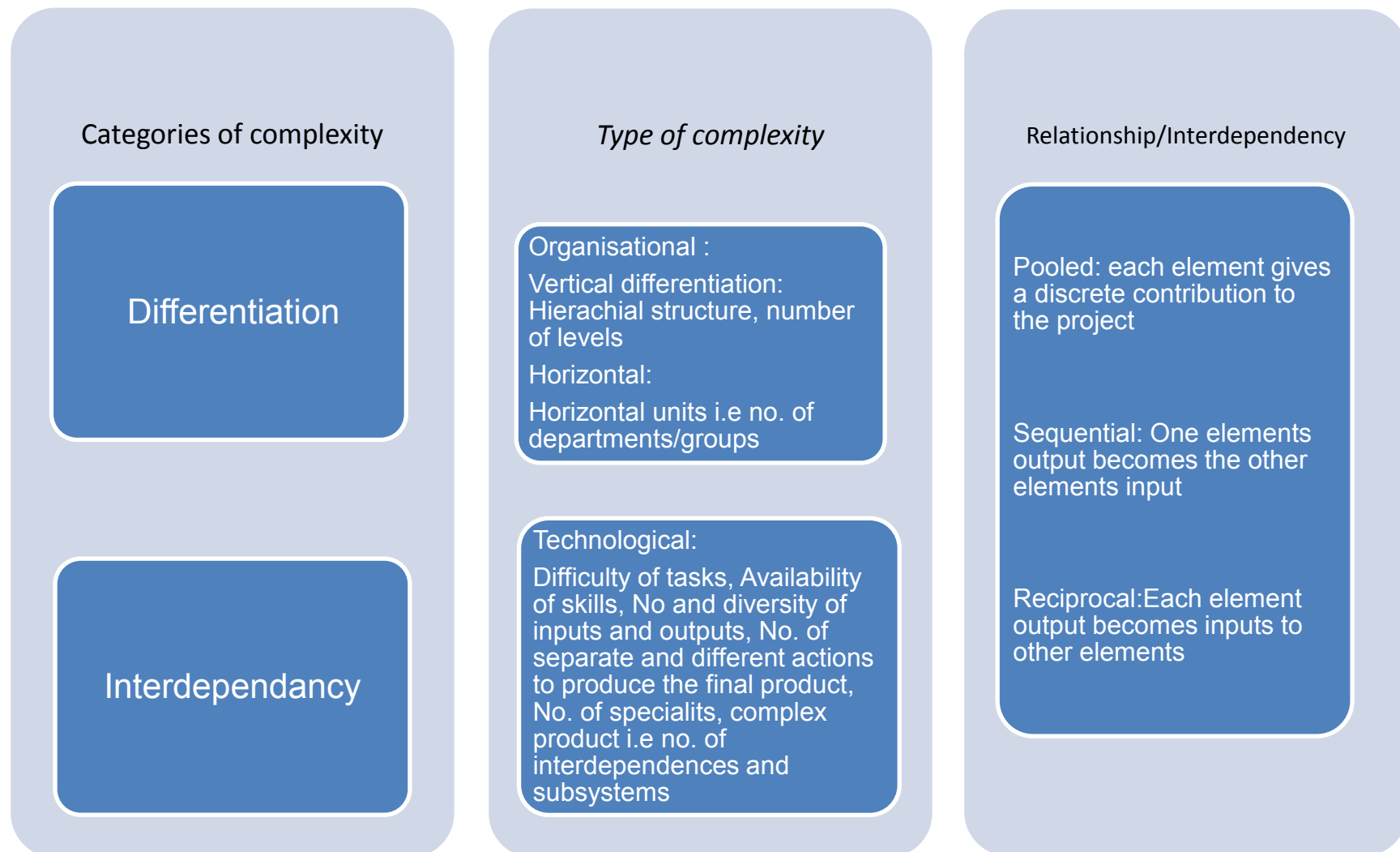


Figure 12: Complexity framework

SEVERITY FACTORS	Difficulty	Non-linearity	Uncertainty	Uniqueness	Communication	Clarity	Trust	Capability		
COMPLEXITY DIMENSIONS									Legend:	
Number of Interdependences:									<i>Interdependency</i>	P: Pooled
Availability of people and tools due to sharing	S	S	S	S	S	S	S	S		S: Sequential
Parallelism/ concurrency	P/R	P/R	P/R	P/R	S	S	S	S	<i>Complexity Rating</i>	R: Reciprocal
Dependences between schedules	P/R	P/R	P/R	P/R	S	S	S	S		Simple
Dependences within the environment	S	S	S	S	S	S	S	S		Complicated
Dynamic and evolving team structure	P/R	P/R	P/R	P/R	S	S	S	S		Complex
Interconnectivity and feedback loops and project networks	P/R	P/R	P/R	P/R	S	S	S	S		Very complex
Interdependences between actors	P/R	P/R	P/R	P/R	S	S	S	S		
Interdependency of information systems	P/R	P/R	P/R	P/R	S	S	S	S		
Process interdependency	P/R	P/R	P/R	P/R	S	S	S	S		
Level of interrelations between project phases	S	S	S	S	S	S	S	S		
Stakeholder relations	S	S	S	S	S	S	S	S		
Interdependency between the components of the product	P/R	P/R	P/R	P/R	S	S	S	S		
Specification interdependences	P/R	P/R	P/R	P/R	S	S	S	S		
Technological process dependences	P/R	P/R	P/R	P/R	S	S	S	S		
Project Size										
Project duration (>6M)	S	S	S	S	S	S	S	S		
Capital investment amount										
Number of activities	S	S	S	S	S	S	S	S		
Number of companies and departments involved	S	S	S	S	S	S	S	S		
Number of decisions to be made	S	P/R	S	S	S	S	S	S		
Number of hierarchical levels	S	S	S	S	S	S	S	S		
Number of stakeholders	S	S	S	S	S	S	S	S		
Number of structures, teams to be coordinated	S	S	S	S	S	S	S	S		
Staff quantity	S	S	S	S	S	S	S	S		
Number and diversity of inputs, outputs, tasks or specialities	P/R	P/R	P/R	P/R	S	S	S	S		
Project Variety:										
Diversity of staff (experience, cultural, religion, etc.)	S	S	S	S	S	S	S	S		
Variety of organizational interdependences	S	S	S	S	S	S	S	S		
Variety of organizational skills	S	S	S	S	S	S	S	S		
Variety of the interest of the stakeholders	S	S	S	S	S	S	S	S		
Project context:	S	S	S	S						
Competition										
Ambiguity/ vagueness of goals or project objectives	P/R	P/R	P/R	P/R	S	S	S	S		
Environment complexity	S	S	S	S						
Laws and regulations	S	S	S	S						
Significance on public agenda	S	S	S	S						
Organisational degree of innovation	S	S	S	S						

Figure 13: Complexity assessment matrix

3.4 CHAPTER CONCLUSION

A Theoretical base was established by analysing the fundamental principles of complexity theory and project complexity. From the rudiments of these theories the following definition has been proposed:

“A complex project is the one that is complicated, containing many interrelated parts making it difficult to predict its outcomes and response to changes and therefore difficult to manage and control it”.

From project complexity theory it was deduced that 3 parameters influence complexity in a project. These are: complexity dimension (origin of complexity), severity factors (the extent to which the complexity source will be a problem), and interdependency (pooled, reciprocal, sequential).

CHAPTER 4: RESEARCH METHODOLOGY

The case study approach will be used as a research strategy for this research. The case is a refuelling outage project in a power generating plant. Case-study research allows investigators to retain the holistic and meaningful characteristics of real-life events, such as individual life cycles, organisational and managerial processes, international relations, among other reasons. (Yin, 2003). However, case studies have been viewed as less desirable than experiments or surveys, due to their lack of rigor. Case-study research provides little basis for scientific generalisation; however, this can be overcome by the use of multiple case studies. Some case study researchers have been criticised for the length of time involved and the resultant massive and undesirable documentation. (Yin, 2003) emphasises that case-study researchers must be competent to conduct case-study research, or this might jeopardise the study. He further acknowledges that the problem is that the skills required to conduct good case-study research have not yet been identified.

4.1 Research Paradigms

There are three principle paradigms, namely positivism, social constructivism, advocacy or participatory. These are paradigms are briefly described below:

Postpositivism

This paradigm involves a research that is engaged in qualitative research using a belief system grounded in postpositivism taking a scientific approach to research. The approach has the elements of being reductionistic, logical, an emphasis on empirical data collection, cause-and-effect oriented, and deterministic based on a priori theories. Postpositivist researchers are likely view inquiry as a series of logically related steps, believe in multiple perspectives from participants rather than a single reality, and espouse rigorous methods of qualitative data collection and analysis. They will use multiple levels of data analysis for rigor, employ computer programs to assist in their analysis, encourage the use of validity approaches, and write their qualitative studies in the form of scientific reports, with a structure resembling quantitative approaches (e.g., problem, questions, data collection, results, conclusions) (Creswell, 2007).

Social Constructivism

In this worldview, the researcher seeks an understanding of the world in which they live and work. He/she develops subjective meanings of their experiences or meanings directed toward certain objects or things. These meanings are varied and

multiple, leading the researcher to look for the complexity of views rather than narrow the meanings into a few categories or ideas. The goal of research, then, is to rely as much as possible on the participants' views of the situation (Creswell, 2007)

Advocacy/Participatory

The basic principle of this worldview is that the research should contain an action agenda for reform that may change the lives of participants, the institutions in which they live and work, or even the researchers' lives. The issues facing these marginalised groups are of paramount importance to study, issues such as oppression, domination, suppression, alienation, and hegemony (Creswell, 2007).

The research paradigm adopted for this study is postpositivism.

4.2 Research Philosophy

The research methodology adopted for this study is that of the case study. Yin (2003:19) defines research design as the logical sequence that links the data to be collected and the conclusions to be drawn to the initial question of a study. Case-study research is normally adopted: when the research questions are “how”? or “why?”; when the researcher has little control over events; or when the focus is a contemporary phenomenon (Yin, 2003). Schramm (1971), cited by (Yin, 2003), identified the central tendency among all types of case studies as the attempt to illuminate a decision or set of decisions by indicating: why they were taken, how they were implemented, and what the results were. The purpose of this case study is to demonstrate and verify the applicability of the introduced framework in chapter 3, in order to measure the complexity of the refuelling outage project in a power generating plant.

4.3 Research Design

(Yin, 2003) describes five components of research design:

- The research question
- Its proposition – paying direct attention to something that should be examined within the scope of the study
- Its units of analysis – the fundamental problem of defining what the “case” is. The challenge in constructing a case-study research design is to ensure that the study questions are relevant to the selected unit of analysis. The selection of an appropriate unit of analysis occurs when the primary research question is accurately

specified. The unit of analysis for this study is project complexity and how to effectively measure complexity in projects: the case of a refuelling outage project in a power generating plant. Research may be categorised into two distinct types namely:

- *Qualitative*: concentrates on words and observations to express reality and attempts to describe people in natural situations.
- *Quantitative*: Places considerable trust on in numbers that presents opinions or concepts. (Amaratunga et al., 2002). Table 1 illustrates the strengths and weaknesses of each category.

Research Category	Strengths	Weaknesses
Quantitative	Ability to provide a wide coverage of the range of situations	Methods used tends to be rather inflexible and artificial
	Fast and economical	They are not very effective in understanding process or the significance that people attach to actions
	Where statistics are aggregated from large samples they may be of considerable relevance to policy decisions	Not effective in establishing theories
		Because they focus on what is or what has been recently they make it hard for policy makers to infer what changes and actions should take place in the future
Qualitative	Data gathering method seems more as natural than artificial	Data collection can be tedious and require more resources
	Ability to look at change processes over time	Analyses and interpretation of data may be more difficult
	Ability to understand peoples meaning	Harder to control the pace, progress and end points of research process
	Ability to adjust to new issues and ideas as they emerge	Policy makers give low credibility to results from qualitative approach
	Contribute to theory generation	

Table 3: Comparison between quantitative and qualitative research studies (Amaratunga et al., 2002)

The objective of this study is to develop a model to measure project complexity. This model will be implemented on a refuelling outage project to measure the complexity of this project. Categorical classification such as very complex, complex, complicated, or simple will be used, therefore, this study will adopt the qualitative research category. Qualitative research is normally conducted through an intense and/or prolonged contact with a field or life situation. A well collected qualitative data focuses on naturally occurring, ordinary events in natural settings so that there is view on what real life is like. Qualitative data offers a strong rich and holistic data, with strong potential for revealing complexity (Amaratunga *et al.*, 2002).

4.4 Research Instrument

Qualitative research will be conducted using the following tools interviews, participant observations, tracers studies, case studies (Amaratunga *et al.*, 2002).

4.4.1 Data collection

Data can be collected in various ways for case study research. There are six sources of information for case study research (Yin, 2003):

- Documentation – This source is regarded to be relevant to every case study topic. Documentation includes letters, memoranda, agendas, administrative documents, formal studies and articles. The investigator must critically interpret the information from these sources and corroborate and augment it with evidence from other sources. The challenge associated with this source of information is that access is sometimes blocked or limited. For this case study, the outage 122 plan.
- Archival records – This source of information includes computer files and records. Archives include service records, organisational records, survey data, maps and charts. With this source of information, accessibility is a problem due to privacy issues. For this case study the previous outage plans and previous outages performance analysis reports were used.
- Interview – This source of information is the essential source in case-study research. Most commonly, case-study interviews are of an open-ended nature, i.e. an investigator can ask key respondents about the facts of a matter as well as about their opinions about these events. The second type of interview is a focused interview whereby a respondent is interviewed for a short period of time.

However, the third type of interview entails questions of a more structured nature, along the lines of a survey.

- Direct observation – Information is gathered by visiting case-study sites and doing observations. These observations can range from formal to casual data collection.
- Participant observations – In this source, an investigator may assume roles within a case study situation and participate in the events being studied. The problem with participant observation is the possibility of an investigator becoming biased.
- Physical artefacts – This source of information includes technological devices, tools and instruments or some other physical evidence.
- Focus groups – Where a group of individuals with experience in the research field are assembled. In this case study, 16 project leaders participated, see appendix A. They were first given fundamental principles of project complexity in a form of a presentation. Following the presentation the project complexity assessment model was introduced to them, and they were shown how to use it to assess complexity in their projects.

4.5 Data analysis

Data analysis consists of examining, categorising, tabulating, testing or re-combining both quantitative and qualitative evidence to address the research question (Yin, 2003: 109). (Yin, 2003) strongly suggests that an analytical strategy must be chosen to treat the evidence fairly, produce a compelling analytical conclusion and to rule out alternative interpretations. These strategies are:

- Relying on theoretical propositions – Where theoretical propositions that led to the case study are followed.
- Thinking about rival explanations – Where rivals explanations are defined and tested. However, this strategy is relevant even in the absence of theoretical propositions and is useful for doing case study evaluations.
- Developing a case description – Where a descriptive framework for organising the case study is drawn up.

4.6 Analyses Techniques

Analyses and interpretation of research findings forms a major part of a research. Defining an analytical method is of paramount importance to any research. The analytical strategy would determine the limits of data collection and dissemination of

results. Below are the qualitative data analyses techniques (Amaratunga *et al.*, 2002):

Explanation building: This is a special type of pattern matching. The objective of this technique is to analyse the qualitative data by building an explanation about the situation. Explaining the situation means explaining the causal links about it (Amaratunga *et al.*, 2002).

Time series analyses: This strategy involves conducting a time series analyses, directly analogous to the time series analysis conducted in experiments and quasi experiments. The underlying logic of a time series analyses is the match between trends of data points compared with a theoretically significant trend specified before the onset of investigation. When interpreting data the following steps are recommended (Amaratunga *et al.*, 2002):

- **Identify patterns of agreement:** across data points, by mediating variables with literature and experience (Amaratunga *et al.*, 2002)
- **Identify contradictions:** Across data sources, by mediating variables with literature and experience (Amaratunga *et al.*, 2002)
- **Try to resolve contradictions:** through alternative plausible explanations for a finding, by re-examining the data, by collecting a specific data to test an alternative hypothesis (Amaratunga *et al.*, 2002).
- **Identification of the important findings,** by ranking and organising them
- **Simple presentation of the findings** through charts and tables, etc. (Amaratunga *et al.*, 2002)

4.7 Data Evaluation Criterial

An evaluation is often focused on measures to counteract the weaknesses inherent in the chosen research strategy, Then (1996) cited by (Amaratunga *et al.*, 2002). The value of any research stems from the validity of its results and the extent of its contribution to the body of knowledge. Data evaluation often includes validity, reliability and generalisability.

- **Validity:** Determines how good an answer provided by the research is. Meaning that a theory, model or concept describes reality with good fit. The measure of validity is often considered either under internal or external validity. Internal validity refers to whether or not what has been identified as the causes actually produce what has been interpreted as “effect” or “responses” and checks whether

the right cause and effect has been established. External validity refers to the extent to which any research findings can be generalised beyond the immediate research sample. External validity can be achieved from theoretical relationships (Amaratunga *et al.*, 2002).

- Reliability: The extent to which a test or procedure produces similar results under constant conditions in all circumstances, i.e. if another researcher followed the same procedure, the same findings and conclusions would result. The goal of reliability is to minimise errors and biases in a study (Amaratunga *et al.*, 2002).

4.8 Research Ethics

The methodology for collecting research data made use of living people within the power generating organisation. The population of participants was selected based on their experience in project management, mainly the refuelling outages. Human beings were only used to gather the technical information on the case study. As mentioned on section 4.4.1, the technique used to gather data was a focus groups or a workshop.

4.8.1 Participant Consent and Anonymity

Prior to information gathering, all the participants were informed that participation is completely voluntary and that information gathered will be treated with high anonymity. Furthermore, participants were informed not to share information they deem confidential, and were informed that their personal details are not required for the research. Participants were also given an option to withdraw at a later stage if they felt that there is a need to do so or felt uncomfortable to continue participating. A consent form with all these details was developed and each participant requested to sign, see appendix A for a sample.

4.8.2 Safety of the Participants during information gathering

This research did not require any physical experiments and thus there was no harm or danger to the participants. The participants were only given the project complexity model to use or apply to measure complexity in their respective subprojects.

4.8.3 Participants profile

The table below summarises the profile of the participants:

Title	Brief job description	Number of participants
Outage execution manager	Ensure outage schedule adherence, manage risk, prioritize daily activities, manage the critical path plan, conduct outage performance assessment	2
Outage planning manager	Quantify outage scope, quantify outage duration, develop outage plan, optimize the plan, resource load the plan,	2
Operating outage manager	Ensure that nuclear safety parameters are factored in the plan during planning phases in accordance with operating technical specification, ensure that the operating safety envelop is not compromised during execution, manage plant isolations and system/component requalification	1
Project managers	Develop their project plans, resource load the plans, conduct readiness meetings, execute their plans, update plans when required	5
Project leaders	They assist project managers during planning and during execution they coordinate activities	5
Licensed reactor operator	Performs scope review to ensure that the nuclear safety operating envelop is not challenged, develop isolation plans, etc.8	1
Operating commissioning engineers	Isolate the plan and commission the systems after maintenance	2

Table 4: Participants profile

CHAPTER 5: DISCUSSION OF FINDINGS

5.1 INTRODUCTION

The objective of outage 122 is to refuel reactor number 1 and to perform non-intrusive maintenance and statutory tests in 30.5 days without the buffer and in 35 days with the buffer. To better manage the outage project, it was broken down into subprojects, see figure below for a typical project structure. Every subproject has its own project structure, a project manager, project leaders and the line groups that are performing the work. There are high interdependences between the structures as well as between the processes used or followed to perform work. Therefore, there is an inherent organisational complexity in terms of differentiation as well as in terms of interdependences. Furthermore, this project has a significant input from structural or technological complexity, as it has numerous systems that are interrelated where a delay or quality issue on one system will definitely have a cross impact on other systems.

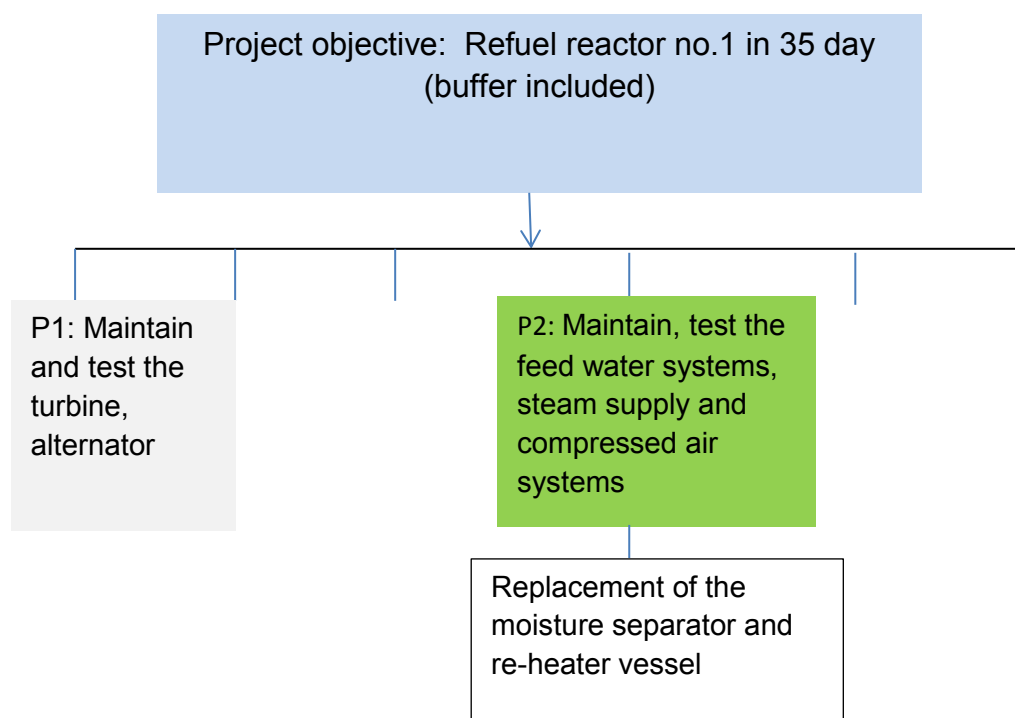


Figure 14: Typical outage project structure

Project Code	Objective
P1	Maintain and test the turbine, alternator and their respective auxiliary systems in 15 days
P2	Maintain, test the feed water systems, steam supply and compressed air systems in 15 days
P3	Maintain, test the electrical supply systems, cooling water systems and reactor protection system in 15 days
P4	Maintain, test containment building ventilation systems, reactor pressure vessel inspection, in 15 days
P5	Maintain and test the primary systems and perform containment local leak rate tests in 15 days
P6	Maintain and test steam generators and feed water control system in 15 days
Plant shutdown	Safely shut down the reactor in 72 hours for fuel unload and reload in 72 hours
Plant start up	Safely start up the plant and synchronize the generator to the grid in 10 days

Table 5: Outage Subprojects breakdowns

A meeting was scheduled with the experienced Project Managers with wealth of experience in reactor refueling outages. The attendees were given project complexity background information in an effort to help them to use the tool to assess complexity in their respective projects. The original tool (see figure 12) was complicated for them to use and it had to be revised. The complexity dimensions and severity factors that are not relevant to reactor refueling outages were removed and only left the ones that are applicable, see figure 14. The final rating to determine whether the subproject is complex or not was based on the following criteria:

1. *If there are greater than 5 complexity dimensions and greater than 1 severity factor and the interdependency relationship is reciprocal, pooled and sequential, the project will be very complex.*
2. *If there are greater than 5 complexity dimensions and greater than 1 severity factor and the interdependency relationship is pooled and sequential the project will be complex.*
3. *If there are less than 5 complexity dimensions and 0 severity factor and the interdependency relationship is pooled the project will be complicated*

4. *If there are less than 5 complexity dimensions, 0 severity factor/s and the interdependency relationship is sequential, the project will be simple. See figure 10 for the system view of all the categories.*

Five subprojects were evaluated to decide on the final rating for the outage. The assessment results from the project managers are contained in Appendix B. A conservative approach was applied on the final rating of the refueling outage project, i.e. those projects with highest complexity rating were used to rate the overall outage project.

	Severity Factors	Type of Intedependency			Project Code				
		Difficulty (Task)	Uncertainty	Pooled		Reciprocal	Sequential		
COMPLEXITY DIMENSIONS (i.e Origion of complexity)	Applicability								
Number of Interdependences:									
Resource (peaple and tools,etc) sharing (between tasks or other projects)									
Parallelism/ concurrency									
Dependences between schedules									
Dynamic and evolving team structure									
Interdependences between actors									
Interdependency of information systems									
Process interdependency									
Project Size (No interdependency assessemment is required)									
Project duration (>50% total outage duration = yes)		N/A							
Number of activities (>500 at the order level= yes)									
Number of companies and departments involved (>10=yes)									
Number of hierarchical levels (>5=y)		N/A							
Number of structures, teams to be coordinated (>5 = yes))									
Number and diversity of inputs, outputs, tasks or specialities (>5=yes)									
Project Variety: (No interdependency assessment is required)									
Diversity of staff (experience, cultural, religion, etc.) (>5=yes)									
Variety of organizational skills (>5 = yes)									
Variety of the interest of the stakeholders (>5 = yes)									
Project context: (No interdependency assessemment is required)									
Ambiguity/ vagueness of goals or project objectives									
Laws and regulations									

Figure 15: Revised Complexity Assessment Matrix

5.2 Analyses of Results

Replacement of moisture separator and steam re-heater vessel sub project

The replacement of the moisture separator and steam re-heater vessel was assessed. This activity is one of the critical activities. These heat exchanger units are designed to remove moisture from the saturated high pressure exhaust steam to reduce the risk of erosion on the low pressure turbine blades and to reheat the steam to improve the thermodynamic cycle efficiency. These heat exchangers are of tube type design. The unit that is currently installed has reached its end of life and also has exceeded the tube plugging limit of 12%, and it needs to be replaced. This is a multidisciplinary project that requires extensive logistics planning as well as coordination.

The following complexity dimensions were highlighted:

- Resource (people and tools, etc.) sharing (between tasks or other projects)
- Parallelism/ concurrency
- Dependences between schedules
- Dynamic and evolving team structure
- Interdependences between actors
- Interdependency of information systems
- Process interdependency
- Number and diversity of inputs, outputs, tasks or specialties
- Diversity of staff (experience, cultural, religion, etc.)
- Variety of the interest of the stakeholders
- Laws and regulations

This subproject is rated as difficult with some uncertainty (severity factors). Furthermore it contains all three interdependencies, namely pooled, sequential and reciprocal, see appendix B: 1. Applying the criteria in section 5.1, criteria no.1 is applicable and therefore this subproject is very complex.

Maintenance Of The Turbine And Alternator Subproject (P1)

The following complexity dimensions were highlighted

- Resource (people and tools, etc.) sharing (between tasks or other projects)
- Parallelism/ concurrency

- Dependences between schedules
- Interdependences between actors
- Interdependency of information systems
- Process interdependency
- Project duration
- Number of activities
- Number of structures, teams to be coordinated
- Number and diversity of inputs, outputs, tasks or specialties
- Diversity of staff (experience, cultural, religion, etc.)
- Variety of organizational skills
- Variety of the interest of the stakeholders
- Laws and regulations

This subproject is also rated as difficult with some uncertainty (severity factors). It contains two interdependencies, namely pooled, sequential, see appendix B:2. Applying the criteria in section 5.1, criteria no.2 is applicable and therefore this subproject is complex

Replacement of the Pirelli Seal (P2) Sub Project

The replacement of the Pirelli seal sub-project was analysed as it was one of critical activities under P2 project. Pirelli seal is used in the condenser to prevent oxygen ingress into the secondary feed water. The secondary feed water is highly purified and its conductivity is kept minimal to prevent corrosion, stress corrosion cracking, etc. on the steam generator tubes.

- Resource (people and tools, etc.) sharing (between tasks or other projects)
- Parallelism/ concurrency
- Dependences between schedules
- Dynamic and evolving team structure
- Interdependences between actors
- Interdependency of information systems
- Process interdependency
- Number of activities
- Number of hierarchical levels
- Number of structures, teams to be coordinated
- Number of structures, teams to be coordinated

- Number and diversity of inputs, outputs, tasks or specialties
- Diversity of staff (experience, cultural, religion, etc.)
- Variety of organizational skills
- Laws and regulations

This subproject is also rated as difficult with some uncertainty (severity factors). It contains two interdependencies, namely pooled, sequential, see appendix B:3 . Applying the criteria in section 5.1, criteria no.2 is applicable and therefore this subproject is complex.

Plant Shutdown and Start Up Phase Sub Project

Safety test of the steam isolation valves

During plant shutdown and startup phase, various tests are conducted to ensure safe plant shutdown and start up and also to identify defective components so that they can be repaired or replaced during the maintenance window. One of the tests conducted is a safety test on the main steam isolation valves. Once the reactor has reached hot shutdown conditions i.e. primary circuit pressure at 15.4 MPa, primary circuit average temperature at 286 °C and heat sink is the steam generators, the main steam isolation valves are tested to confirm that the set point pressures are within the specified design criteria.

The main steam system transports saturated steam from the steam generators to the turbine-generator set where the thermal energy is converted to mechanical energy and electrical energy. The plant is of 3 loop design, i.e. 1 reactor vessel has 3 similar cooling loops connected parallel to the reactor vessel consisting of reactor coolant pump, steam generator and pipes. Each steam generator has 3 main steam isolation valves and associated bypass valves. Main steam isolation valves are designed to isolate steam from the steam generators in an event of an accident to prevent radioactive release to the atmosphere and for reactivity control.

The following complexity dimensions were highlighted:

- Resource (people and tools, etc.) sharing (between tasks or other projects)
- Parallelism/ concurrency
- Dependences between schedules
- Dynamic and evolving team structure
- Interdependences between actors
- Interdependency of information systems

- Process interdependency
- Number of companies and departments involved
- Number of hierarchical levels
- Number of structures, teams to be coordinated
- Number and diversity of inputs, outputs, tasks or specialties
- Diversity of staff (experience, cultural, religion, etc.)
- Variety of organizational skills
- Variety of the interest of the stakeholders
- Laws and regulations

This subproject is also rated as difficult with some uncertainty (severity factors). Furthermore it contains all three interdependencies, namely pooled, sequential and reciprocal, see appendix B:4 (a). Applying the criteria in section 5.1, criteria no.1 is applicable and therefore this subproject is very complex.

Safety injection test

Every outage during unit start up, the safety injection system is tested to confirm its operability before the reactor can be taken critical. The assessment of this subproject using the complexity assessment model revealed the following:

Complexity dimensions

- Resource (people and tools, etc.) sharing (between tasks or other projects)
- Parallelism/ concurrency
- Dependences between schedules
- Dynamic and evolving team structure
- Interdependences between actors
- Interdependency of information systems
- Process interdependency
- Number of hierarchical levels
- Number of structures, teams to be coordinated
- Number and diversity of inputs, outputs, tasks or specialties
- Diversity of staff (experience, cultural, religion, etc.)
- Variety of organizational skills
- Variety of the interest of the stakeholders
- Laws and regulations

This subproject is also rated as difficult with some uncertainty (severity factors). Furthermore it contains all three interdependencies, namely pooled, sequential and reciprocal, see appendix B:4(b). Applying the criteria in section 5.1, criteria no.1 is applicable and therefore this subproject is very complex.

Inspection and Repair of the Essential Cooling Water System Subproject

Inspection and civil repair of the essential cooling water system was evaluated using the proposed model. The following complexity dimensions were identified:

- Resource (people and tools, etc.) sharing (between tasks or other projects)
- Parallelism/ concurrency
- Dependences between schedules
- Dynamic and evolving team structure
- Interdependences between actors
- Interdependency of information systems
- Process interdependency
- Number of companies and departments involved
- Number of hierarchical levels
- Number of structures, teams to be coordinated
- Number and diversity of inputs, outputs, tasks or specialties
- Diversity of staff (experience, cultural, religion, etc.)
- Variety of organizational skills
- Variety of the interest of the stakeholders
- Laws and regulations

Some of the complexity dimensions were highlighted to have a probability of introducing uncertainty in this subproject, which will intensify complexity to a certain degree. Both pooled and reciprocal interdependencies were also observed, see appendix B:5. Applying the criteria in section 5.1, criteria no.1 this subproject is graded as a very complex project.

5.3 Summary of results

Six subprojects were assessed using the model and the results indicate that there are 10 major complexity contributors for this project, (see figure 14):

- Dependences between schedules
- Diversity of staff (experience, cultural, religion, etc.)
- Interdependences between actors

- Interdependency of information systems
- Laws and regulations
- Number and diversity of inputs, outputs, tasks or specialties
- Number of structures, teams to be coordinated
- Parallelism/ concurrency
- Process interdependency
- Resource (people and tools, etc.) sharing (between tasks or other project
- Variety of organizational skills
- Variety of the interest of the stakeholders

Both severity factors namely difficulty and uncertainty have been identified and all 3 interdependences namely; pooled, reciprocal and sequential have been identified. Therefore refueling outage 121 is a very complex project. Care must be taken when resourcing the subprojects that were graded as very complex. Effective management strategies must be developed to manage these projects to minimise schedule overruns.

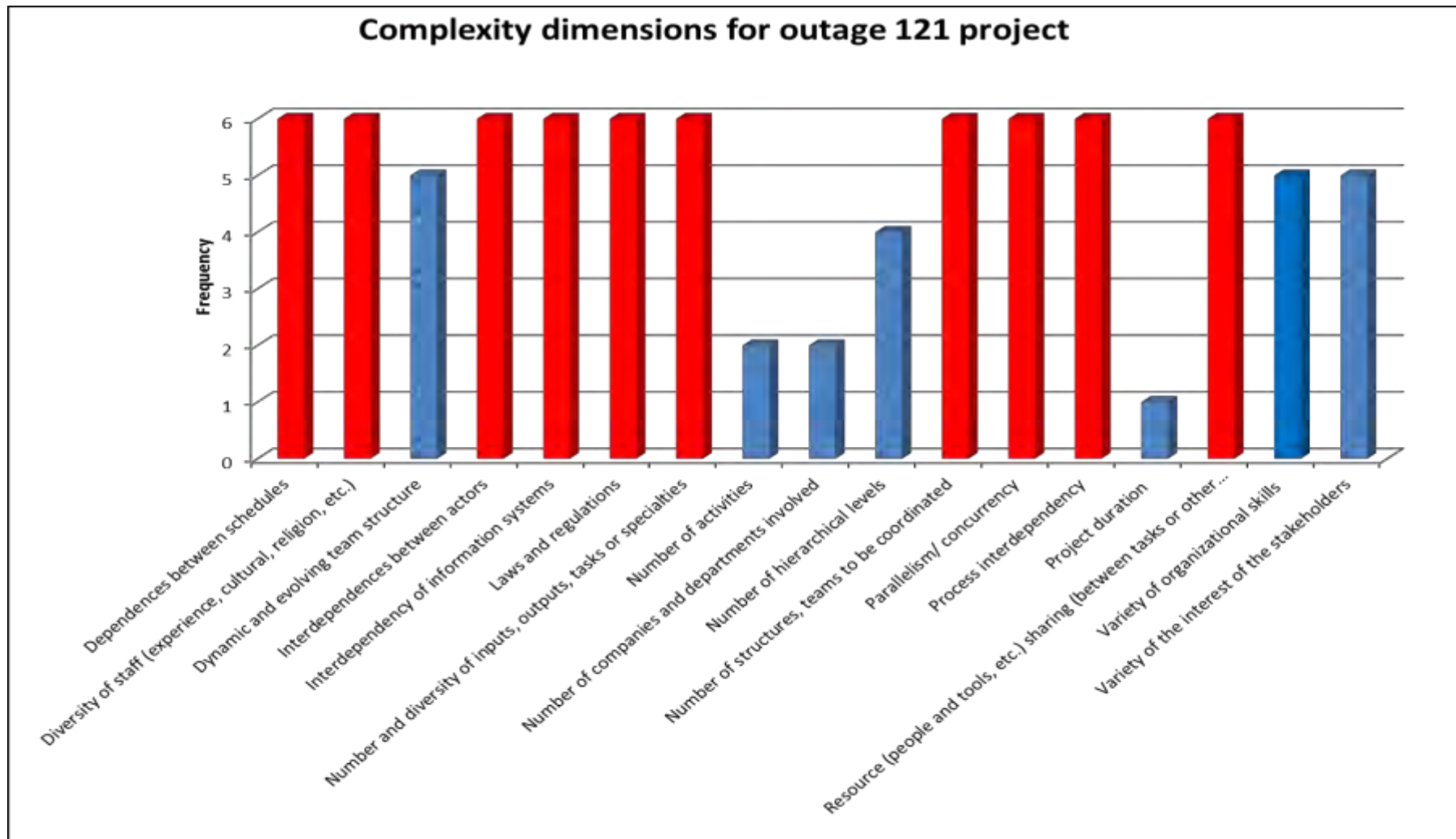


Figure 16: Outage 121 Complexity Dimensions

CHAPTER 6: CONCLUSION AND RECOMMENDATION

The literature indicates that the majority of complex projects failed to meet their duration and budget requirements. To improve performance of complex projects, it is important to properly understand the: fundamental principles of project complexity, factors that contribute to project complexity and how these affect project performance, have ability to measure project complexity. Conventional project management approaches, tools and models are inadequate to manage the complexity and ambiguity of rapidly changing business environment. These traditional approaches are more suitable for static environments with low levels of uncertainty, ambiguity and propagation.

This study then focused on developing the fundamental definition of project complexity and on developing a model that will assist project managers to measure complexity in their projects.

To fully comprehend complexity within projects, a project must be viewed as a system. A system operates within a certain environment; it is aimed to achieve certain goal/ objectives by doing certain activities. It is prudent to consider the layers of complexity such as task, social, cultural, operative and cognitive complexity.

(Baccarini, 1996) categorised complexity into differentiation and interdependency. Complexity in a project can be introduced by the organizational structures, i.e. the number of hierarchical levels organizational units, division of tasks, and number of specialists.

Furthermore complexity can emanate from technology. (Baccarini, 1996) and (Williams, 1999) operationalised technological complexity in terms of task difficulty. (Gidado, 1996) refers to technological complexity as the one emanating from science, technological advances, availability of skills, etc. Technological complexity in terms of differentiation refers to variety and diversity of tasks, and in terms of interdependency it refers to interdependencies between tasks within a network of tasks and between different technologies. Understanding the nature of interdependences such as pooled, sequential, reciprocal interdependency is vital.

(Vidal *et al.*, 2011) identified 4 factors that drive complexity (dimensions) in a project, namely: project size, project variety, project interdependencies, project context dependence. Project complexity dimensions and severity have been developed to

enable the project managers to measure project complexity. Complexity dimension indicates the source of complexity and the severity indicates the extent to which the complexity will be a problem. Once these parameters are fully determined and understood, the project manager can develop a strategy to effectively manage complexity within his/her project.

This study then proposed the following project complexity definition: A complex project is the one that is complicated, containing many interrelated parts making it difficult to predict its outcomes and response to changes and therefore difficult to manage and control it.

The complexity assessment model or matrix integrated the complexity dimensions, severity factors and nature of interdependences, see figure 14. The intent was to develop a three dimensional model that will allow project managers to holistically measure project complexity of projects. This model will assist them in understanding the factors that drive complexity in their projects, in order for them to develop strategies to manage these factors to prevent schedule and budget overruns while ensuring that quality is maintained.

This model was used to assess the complexity of the refueling outage in a power generating plant. The results indicated that this project is a very complex project. The majority of complexity dimensions stems from project interdependences, project variety, project size and project context. This project has activities that are deemed difficult with some uncertainty. Furthermore it has all three interdependences namely, pooled, reciprocal and sequential.

6.1 Future Research

- There is a fundamental need for efficient complexity modelling in order to identify, quantify and assess complexity induced risks. It is therefore prudent to understand how complexity induced risk affect performance in a project
- A study is required to understand whether the current conventional project management models allow for effective management of complex projects?
- Furthermore, it is prudent to determine how should the existing conventional project management models be adapted to appropriately manage complex projects?

- This tool was only tested/ applied in a refuelling outage project plan. To get a more representative sample to validate it. It is proposed that it be used/ tested in different projects to validate it.

8. APPENDIX A: RESEARCH ETHICS INFORMATION

INFORMATION SHEET & CONSENT FORM

RESEARCH TOPIC: PROJECT COMPLEXITY AND HOW TO EFFECTIVELY MEASURE PROJECT COMPLEXITY: THE CASE A REFUELLING OUTAGE IN A NUCLEA POWER GENERATING PLANT

To whom it may concern,

My name is Noxolo Mabumbulu and I am conducting research towards Masters in Project Management. My research is on project complexity i.e. developing an assessment tool to assist project managers to identify complexity factors in their project in order for them to manage their projects effectively to ensure project success. I would like to invite you to participate in this research.

Research has revealed that more than 80% of complex project failed to meet their budget, time to market and quality requirements. Academics have concluded that the reason why projects fail is the increasing complexity and complexity underestimation. Understanding the factors that have high leverage on project complexity is paramount throughout the project life cycle. It is therefore prudent that project managers identify the existence of these factors within their projects in order for them to develop effective management strategies. This will therefore contribute to the reduction of complex project failures.

Please understand that you are not obliged to participate therefore your participation is voluntary. If you choose to participate, but wish to withdraw at a later stage time, you will be free to do so without negative consequence. However, I would really appreciate your participation on this study.

You will be requested to the participate on the focus meeting where the complexity measurement tool will be employed as part of the research study.

Information gathered will be made available for possible use in strategic planning by the Koeberg Power Station management and project managers/leaders to successfully manage complex projects.

Please note that all information gathered will be treated with high anonymity and confidentiality. If you feel that the information required is sensitive and confidential, please feel free to indicate so and not to share it.

All information gathered will be treated with high anonymity. However, the intended workshop will require all participants to be on the same venue and share ideas and knowledge. The sequence of the received ideas or information will be changed for the workshop so to achieve the anonymity of the source of the information gathered.

Participant Initials S. NJTO YANTO ... Date

Signature of participant ... **Signed**

INFORMATION SHEET & CONSENT FORM

RESEARCH TOPIC: PROJECT COMPLEXITY AND HOW TO EFFECTIVELY MEASURE PROJECT COMPLEXITY: THE CASE A REFUELLING OUTAGE IN A NUCLEA POWER GENERATING PLANT

To whom it may concern,

My name is Noxolo Mabumbulu and I am conducting research towards Masters in Project Management. My research is on project complexity i.e. developing an assessment tool to assist project managers to identify complexity factors in their project in order for them to manage their projects effectively to ensure project success. I would like to invite you to participate in this research.

Research has revealed that more than 80% of complex project failed to meet their budget, time to market and quality requirements. Academics have concluded that the reason why projects fail is the increasing complexity and complexity underestimation. Understanding the factors that have high leverage on project complexity is paramount throughout the project life cycle. It is therefore prudent that project managers identify the existence of these factors within their projects in order for them to develop effective management strategies. This will therefore contribute to the reduction of complex project failures.

Please understand that you are not obliged to participate therefore your participation is voluntary. If you choose to participate, but wish to withdraw at a later stage time, you will be free to do so without negative consequence. However, I would really appreciate your participation on this study.

You will be requested to participate on the focus meeting where the complexity measurement tool will be employed as part of the research study.

Information gathered will be made available for possible use in strategic planning by the Koeberg Power Station management and project managers/leaders to successfully manage complex projects.

Please note that all information gathered will be treated with high anonymity and confidentiality. If you feel that the information required is sensitive and confidential, please feel free to indicate so and not to share it.

All information gathered will be treated with high anonymity. However, the intended workshop will require all participants to be on the same venue and share ideas and knowledge. The sequence of the received ideas or information will be changed for the workshop so to achieve the anonymity of the source of the information gathered.

Participant Initials *N.N* Date

Signature of participant **Signed**

INFORMATION SHEET & CONSENT FORM

RESEARCH TOPIC: PROJECT COMPLEXITY AND HOW TO EFFECTIVELY MEASURE PROJECT COMPLEXITY: THE CASE A REFUELLING OUTAGE IN A NUCLEA POWER GENERATING PLANT

To whom it may concern,

My name is Noxolo Mabumbulu and I am conducting research towards Masters in Project Management. My research is on project complexity i.e. developing an assessment tool to assist project managers to identify complexity factors in their project in order for them to manage their projects effectively to ensure project success. I would like to invite you to participate in this research.

Research has revealed that more than 80% of complex project failed to meet their budget, time to market and quality requirements. Academics have concluded that the reason why projects fail is the increasing complexity and complexity underestimation. Understanding the factors that have high leverage on project complexity is paramount throughout the project life cycle. It is therefore prudent that project managers identify the existence of these factors within their projects in order for them to develop effective management strategies. This will therefore contribute to the reduction of complex project failures.

Please understand that you are not obliged to participate therefore your participation is voluntary. If you choose to participate, but wish to withdraw at a later stage time, you will be free to do so without negative consequence. However, I would really appreciate your participation on this study.

You will be requested to the participate on the focus meeting where the complexity measurement tool will be employed as part of the research study.

Information gathered will be made available for possible use in strategic planning by the Koeberg Power Station management and project managers/leaders to successfully manage complex projects.

Please note that all information gathered will be treated with high anonymity and confidentiality. If you feel that the information required is sensitive and confidential, please feel free to indicate so and not to share it.

All information gathered will be treated with high anonymity. However, the intended workshop will require all participants to be on the same venue and share ideas and knowledge. The sequence of the received ideas or information will be changed for the workshop so to achieve the anonymity of the source of the information gathered.

Participant Initials *C.D. Fredericks* Date

Signature of participant **Signed**

Application for Approval of Ethics in Research (EIR) Projects
Faculty of Engineering and the Built Environment, University of Cape Town

APPLICATION FORM



Please Note:

Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form. <http://www.ebe.uct.ac.za/ugr/ebe/researchethics.pdf>

APPLICANT'S DETAILS	
Name of principal researcher, student or external applicant	N Mabumbulu
Department	Construction economics and management
Preferred email address of applicant:	Mabumbn@eekom.co.za
If a Student	Your Degree: e.g., MSc, PhD, etc.,
	Name of Supervisor (if supervised):
If this is a research contract, indicate the source of funding/sponsorship	
Project Title	PROJECT COMPLEXITY ASSESSMENT: THE CASE OF A TEAM GENERATOR REPLACEMENT IN A NUCLEAR POWER STATION PROJECT

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

SIGNED BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Noxolo Mabumbulu		05/08/2016 Click here to enter a date.
APPLICATION APPROVED BY	Full name		Date
Supervisor (where applicable)	Ian Jay		07/06/2016 Click here to enter a date.
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section 1, and for all Undergraduate research (Including Honours).	Abimbola Windapo Click here to enter text.		05 August 2016 Click here to enter a date.
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.	Click here to enter text.		Click here to enter a date.

8 APPENDIX B: PROJECTS PARTICIPANTS ASSESSMENT

Appendix B:1 Moisture separator and reheated heat exchanger sub project

GSS 10022 Tube Bundle Replacement

COMPLEXITY DIMENSIONS (i.e. Origin of complexity)	applicability	Severity Factors		Type of Interdependency		
		Difficulty (Task)	Uncertainty	Pooled	Reciprocal	Sequential
Number of interdependencies						
Resource (people and tools, etc.) sharing (between tasks or other projects)	✓		✓		✓	
Parallelism/ concurrency	✓	✓			✓	
Dependencies between schedules	✓	✓			✓	
Dynamic and evolving team structure	✓	✓				✓
Interdependences between actors	✓		✓	✓		
Interdependency of information systems	✓	✓			✓	
Process interdependency	✓	✓			✓	
Project Size (No interdependency assessment is required)						
Project duration (>50% total outage duration = yes)	N		N/A			
Number of activities (>500 at the order level= yes)	N	✓				
Number of companies and departments involved (>10=yes)	N				N/A	
Number of hierarchical levels (>5=y)	N		N/A			
Number of structures, teams to be coordinated (>5 = yes))	Y					
Number and diversity of inputs, outputs, tasks or specialities (>5=yes)	Y	✓			✓	
Project Variety (No interdependency assessment is required)						
Diversity of staff (experience, cultural, religion, etc.) (>5=yes)	Y					
Variety of organizational skills (>5 = yes)	N					
Variety of the interest of the stakeholders (>5 = yes)	Y					
Project context (No interdependency assessment is required)						
Ambiguity/ vagueness of goals or project objectives	N		N/A			N/A
Laws and regulations	Y					

Appendix B:2: Maintenance Of The Turbine And Alternator Subproject (P1)

	Severity Factors		Type of Interdependency			Project Code	
	Difficulty (Task)	Uncertainty	Pooled	Reciprocal	Sequential		
COMPLEXITY DIMENSIONS (i.e. Origin of complexity)	Applicability						
Number of Interdependences:							
Resource (people and tools, etc.) sharing (between tasks or other projects)	Y	N	Y	N/A	Y	N/A	P1
Parallelism/ concurrency	Y	Y	Y	Y	N/A	N/A	P1
Dependences between schedules	Y	Y	Y	N/A	N/A	Y	P1
Dynamic and evolving team structure	N/A	N	N	N/A	N/A	N/A	P1
Interdependences between actors	Y	N	N	N	N	Y	P1
Interdependency of information systems	Y	N	Y	N	Y	N	P1
Process interdependency	Y	Y	Y	Y	N	N	P1
Project Size (No interdependency assessment is required)							
Project duration (>50% total outage duration = yes)	Y	N/A		N/A			P1
Number of activities (>500 at the order level= yes)	Y						P1
Number of companies and departments involved (>10=yes)	N	N/A					P1
Number of hierarchical levels (>5=y)	N						P1
Number of structures, teams to be coordinated (>5 = yes))	Y						P1
Number and diversity of inputs, outputs, tasks or specialities (>5=yes)	Y						P1
Project Variety: (No interdependency assessment is required)							
Diversity of staff (experience, cultural, religion, etc.) (>5=yes)	Y	N/A			N/A		P1
Variety of organizational skills (>5 = yes)	Y						P1
Variety of the interest of the stakeholders (>5 = yes)	Y						P1
Project context: (No interdependency assessment is required)							
Ambiguity/ vagueness of goals or project objectives	N						P1
Laws and regulations	Y						P1

Appendix B:3 Replacement Of The Pirelli Seal (P2): Sub Project

	Severity Factors	Type of Interdependency			Project Code		
		Difficulty (Task)	Uncertainty	Pooled		Reciprocal	Sequential
COMPLEXITY DIMENSIONS (i.e. Origin of complexity)	Applicability						
Number of Interdependences:							
Resource (people and tools, etc.) sharing (between tasks or other projects)	Y	Y	Y	Y	N/A	N/A	P2
Parallelism / concurrency	Y	Y	Y	Y	N/A	N/A	P2
Dependences between schedules	Y	Y	Y	Y	N/A	N/A	P2
Dynamic and evolving team structure	Y	Y	Y	Y	N/A	N/A	P2
Interdependences between actors	Y	Y	N	Y	N/A	N/A	P2
Interdependency of information systems	Y	N	N	N	N	Y	P2
Process interdependency	Y	Y	N	Y	N/A	N/A	P2
Project Size (No interdependency assessment is required)							
Project duration (>50% total outage duration = yes)	N	N/A					P2
Number of activities (>500 at the order level= yes)	Y						P2
Number of companies and departments involved (>10=yes)	N						P2
Number of hierarchical levels (>5=y)	Y	N/A					P2
Number of structures, teams to be coordinated (>5 = yes))	Y						P2
Number and diversity of inputs, outputs, tasks or specialities (>5=yes)	Y						P2
Project Variety: (No interdependency assessment is required)							
Diversity of staff (experience, cultural, religion, etc.) (>5=yes)	Y						P2
Variety of organizational skills (>5 = yes)	Y						P2
Variety of the interest of the stakeholders (>5 = yes)	N						P2
Project context: (No interdependency assessment is required)							
Ambiguity/vagueness of goals or project objectives	N						P2
Laws and regulations	Y						P2

Appendix B:4 (a) Plant Shutdown And Start Up Phase Sub Project

COMPLEXITY DIMENSIONS (i.e. Origin of complexity)	Applicability	Severity Factors		Type of Interdependency			Project Code
		Difficulty (Task)	Uncertainty	Pooled	Reciprocal	Sequential	
Number of Interdependences:							
Resource (people and tools, etc.) sharing (between tasks or other projects)	Y	Y			Y		
Parallelism/ concurrency	Y		Y	Y			
Dependences between schedules	Y	Y				Y	
Dynamic and evolving team structure	Y	Y				Y	
Interdependences between actors	Y		Y		Y		
Interdependency of information systems	Y	Y			Y		
Process interdependency	Y		Y		Y		
Project Size (No interdependency assessment is required)							
Project duration (>50% total outage duration = yes)	N	N/A		N/A			
Number of activities (>500 at the order level= yes)	N						
Number of companies and departments involved (>10=yes)	Y	N/A					
Number of hierarchical levels (>5=y)	Y						
Number of structures, teams to be coordinated (>5 = yes))	Y				Y		
Number and diversity of inputs, outputs, tasks or specialities (>5=yes)	Y	Y			Y		
Project Variety: (No interdependency assessment is required)							
Diversity of staff (experience, cultural, religion, etc.) (>5=yes)	Y	N/A		N/A			
Variety of organizational skills (>5 = yes)	Y						
Variety of the interest of the stakeholders (>5 = yes)	Y						
Project context: (No interdependency assessment is required)							
Ambiguity/ vagueness of goals or project objectives	N						
Laws and regulations	Y						

Appendix B:4 (b) Plant Shutdown And Start Up Phase Sub Project

	Applicability	Severity Factors		Type of Interdependency			Project Code
		Difficulty (Task)	Uncertainty	Pooled	Reciprocal	Sequential	
COMPLEXITY DIMENSIONS (i.e. Origin of complexity)							
Number of Interdependences:	Y	Y	Y	Y	Y	Y	RIS016P
Resource (people and tools, etc.) sharing (between tasks or other projects)	Y	Y	Y	N	Y	Y	
Parallelism/ concurrency	Y	Y	Y	Y	Y	Y	
Dependences between schedules	Y	Y	Y	Y	Y	Y	
Dynamic and evolving team structure	Y	Y	Y	Y	Y	Y	
Interdependences between actors	Y	Y	Y	Y	Y	Y	
Interdependency of information systems	Y	Y	Y	Y	Y	Y	
Process interdependency	Y	Y	N	Y	Y	N/A	
Project Size (No interdependency assessment is required)	N	Y	Y	Y	Y	N/A	
Project duration (>50% total outage duration = yes)	N	N/A		N/A			
Number of activities (>500 at the order level= yes)	N	Y	Y				
Number of companies and departments involved (>10=yes)	N	N/A					
Number of hierarchical levels (>5=y)	Y						
Number of structures, teams to be coordinated (>5 = yes))	Y	N/A		N	N		
Number and diversity of inputs, outputs, tasks or specialities (>5=yes)	Y			Y	Y	Y	Y
Project Variety: (No interdependency assessment is required)	Y	Y	Y	Y	Y		
Diversity of staff (experience, cultural, religion, etc.) (>5=yes)	Y	N/A		N/A			
Variety of organizational skills (>5 = yes)	Y						
Variety of the interest of the stakeholders (>5 = yes)	Y						
Project context: (No interdependency assessment is required)	Y	N/A		N/A			
Ambiguity/ vagueness of goals or project objectives	Y						
	Y						

Appendix B:5 Inspection And Repair Of The Essential Cooling Water System Subproject

	Severity Factors		Type of Interdependency			Project Code
	Difficulty (Task)	Uncertainty	Pooled	Reciprocal	Sequential	
COMPLEXITY DIMENSIONS (i.e. Origin of complexity)	Applicability					
Number of Interdependences:						P3
Resource (people and tools, etc.) sharing (between tasks or other projects)	Y	N	N	Y		P3
Parallelism/ concurrency	Y	N	Y	Y	Y	P3
Dependences between schedules	Y	N	Y	Y		P3
Dynamic and evolving team structure	Y	N	Y	N/A	N/A	P3
Interdependences between actors	Y	N	Y	Y		P3
Interdependency of information systems	Y	N	Y	N/A	N/A	P3
Process interdependency	Y	Y	Y	Y	Y	P3
Project Size (No interdependency assessment is required)						P3
Project duration (>50% total outage duration = yes)	N	N/A		N/A		P3
Number of activities (>500 at the order level= yes)	N					P3
Number of companies and departments involved (>10=yes)	Y	N/A				P3
Number of hierarchical levels (>5=yes)	Y					P3
Number of structures, teams to be coordinated (>5 = yes))	Y					P3
Number and diversity of inputs, outputs, tasks or specialities (>5=yes)	Y	N	Y	Y		P3
Project Variety: (No interdependency assessment is required)						P3
Diversity of staff (experience, cultural, religion, etc.) (>5=yes)	Y	N/A		N/A		P3
Variety of organizational skills (>5 = yes)	Y					P3
Variety of the interest of the stakeholders (>5 = yes)	Y					P3
Project context: (No interdependency assessment is required)						P3
Ambiguity/ vagueness of goals or project objectives	N					P3
Laws and regulations	Y					P3