

Minimising engineering delivery cycle time variability on similar projects: An Eskom Case Study

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DECLARATION

I Thoka Godfrey Mocheke, hereby declare that this thesis is my own unaided work. It is being submitted in fulfilment of the requirements for the Doctor of Philosophy in Engineering with Development and Management Engineering at the North-West University. This thesis has not been submitted for any degree or any examination at any other university or institute. Acknowledgements of other researchers are captured in citation and the list of references.

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ABSTRACT

Eskom Generation is experiencing high levels of cycle times variabilities on the delivery of similar engineering deliverables within similar project phases and similar plant areas across different power stations. These variabilities of cycle times deprive Eskom power stations the benefit of effective utilisation of information from previous and current similar projects for the purpose of similar projects schedules estimations and reduction of similar projects engineering deliverables delivery risk.

This research investigates factors contributing to cycle time variability on similar engineering deliverables focusing on the impact of **variability** of both **activities and activities durations** for **similar engineering deliverables, application of engineering processes and, intra-organisational knowledge transfer** on **cycle time variability**. The ultimate deliverable of the research is the **framework model for minimising cycle time variability on similar projects**.

The research is a progressive development of the **framework model for minimising cycle time variability on similar projects** in which the **initial conceptual framework** is further developed and updated as the research progresses up to the development of the framework model. Both primary and secondary data were used for the research. The primary data was obtained by means of questionnaire surveys consisting of 20 different questions while the secondary data was obtained from a combination of sampled power stations' projects schedules with similar engineering deliverables.

The research revealed that **inconsistent and inadequate intra-organisational knowledge transfer, inconsistent application of engineering processes, variability of activities, and variability of activities durations** result in increased **project cycle time variability**. Evidence of the **mediation** role played by both **variability of activities** and **variability of activities duration** on (1) **intra-organisational knowledge transfer** and **cycle time variability** and (2) **application of engineering processes** and **cycle time variability** was observed.

Consistent knowledge transfer and **consistent utilisation of engineering processes** were identified as the leading variables while **clearly defined consistent activities** and **consistent activities durations** were identified as the lagging variables for **minimising cycle time variability**. The research is concluded by the development of a framework model for minimising cycle time variability for similar engineering deliverables. The model can serve as a building block for minimising cycle time variability for similar projects in related industries and academic research.

KEY WORDS: Similar, Deliverables, Cycle Time Variability, Intra-Organisational Knowledge Transfer, Engineering Processes, Power Stations, Activity Duration, Activity, Activities Attributes, Conceptual Framework and Framework Model.

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LIST OF KEY ABBREVIATIONS

Abbreviation	Explanation
BRA	Benefit Realisation Approval
CRA	Concept Release Approval
DRA	Definition Release Approval
ERA	Execution Release Approval
EMAP	Engineering Management Plan
FRA	Finalisation Release Approval
IDR	Internal Design Review
GCIMC	Group Capital Investment & Monitoring Committee
HOA	Hand Over Approval
LV	Low Voltage
MV	Medium Voltage
MDR	Multidisciplinary Design Review
ROC	Required Operation Capability
PDRA	Project Definition Readiness Assessment
PLCM	Project Life Cycle Model
SRD	Stakeholder Requirement Definition

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CHAPTER 1

1 RESEARCH BACKGROUND

1.1 Introduction

The construction of Eskom's new power stations and major refurbishment of existing power stations resulted in Eskom engineering division being put under tremendous pressure to deliver project engineering deliverables faster than ever before. The pressure to deliver engineering deliverables was exacerbated by the concurrent execution of new power stations projects and existing power stations' major refurbishment projects.

Engineering processes were not adequately compiled within the project management context during the early years of managing existing power stations. The focus of managing these power stations was mainly technical with more emphasis on operating and maintenance. This made it difficult for engineering to function optimally within the project management space in later years of managing existing power stations.

Later years of managing existing power stations required major refurbishments projects of critical plant components, necessitating a structured approach of executing these projects and further management of the power stations' remaining life. The structured approach came in the form of developing the Engineering Management Framework that included the Engineering Operating Model.

The Engineering Management Framework was only launched for the first time on the 12th of September 2012. It should be appreciated that for an organisation as large as Eskom, the Engineering Management Framework was relatively young at the time of this research and still had a long way to maturity and organisational cultural change.

This research focuses on Eskom coal fired power stations' refurbishment projects with particular interest on the engineering deliverables during the project development phases and stages.

The Eskom context of project engineering deliverables delivery includes all engineering activities carried out during the project life cycle as per the Eskom project life cycle model. The Eskom project life cycle model is divided into six phases namely: Pre-Project Planning, Concept, Definition, Execution, Finalisation and Post Project phase. Each phase has at least one stage and a governance approval gate. Figure 1 below indicates major components of the Eskom project life cycle model.

MAJOR COMPONENTS OF ESKOM GENERATION PROJECT LIFE CYCLE MODEL.

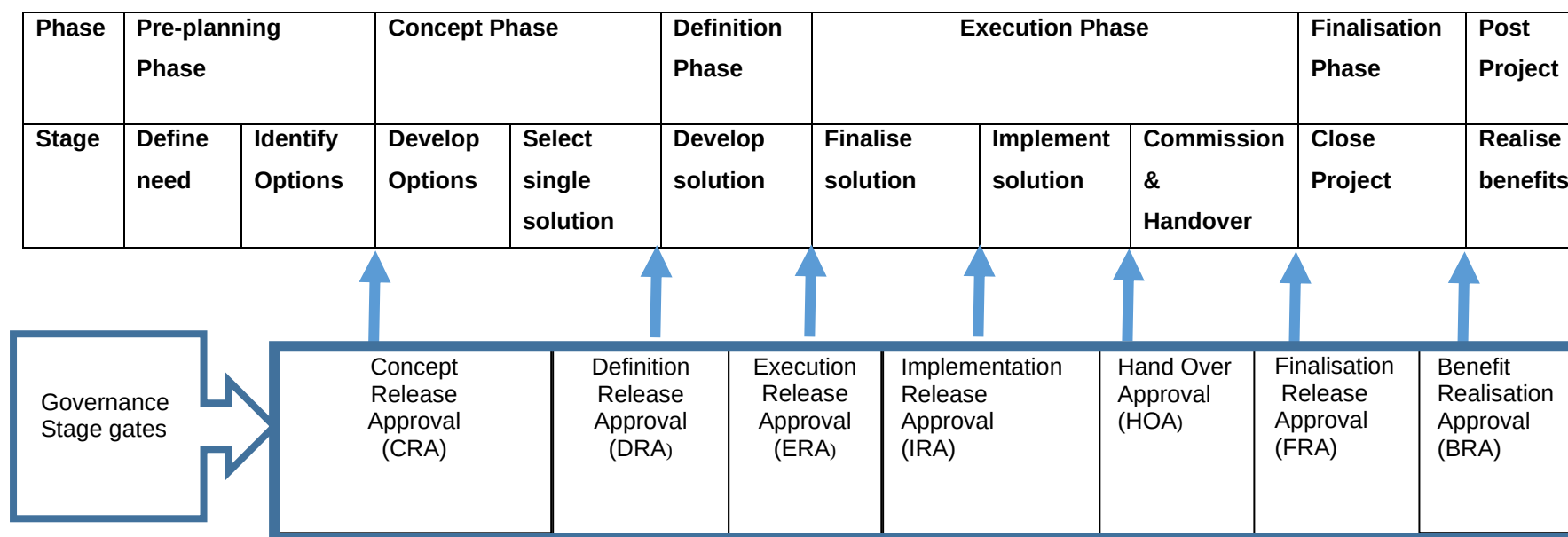


Figure 1: Major Components of Eskom Generation Project Life Cycle Model. (PLCM)

Source: Generation PLCM Framework

The success or failure to deliver on engineering deliverables depends mainly on factors interacting with engineering effort deployed. These factors relate to the project context and influence the cycle time of engineering deliverables.

The general practice by Eskom project engineers is that, work in progress for the delivery of engineering activities that could not be included in the project master schedules due to the detail level of schedule requirements, get monitored within engineering disciplines and this reduces visibility of project engineering activities.

The schedule levels of detail are quantified by single digit numeric values ranging from 1 to 5. The smaller the digit the more summarised the schedule is and the larger the digit the more detailed the schedule becomes. According to Association for the Advancement of Cost Engineering Recommended Practice No.37R-06, level 3 is a more suitable level of detail for overall project control as it is neither over-summarised nor too detailed.

The reduced visibility of engineering activities inherently contributes to the reduced cross-functional influence within the project thus contributing to the reduced **cross-functional learning** by the project team members and often contributes to **inconsistent application of engineering processes**.

This reduced visibility is not only limited to cross-functional teams of the same projects but also of team members of similar projects having similar project engineering deliverables that are executed on similar plant areas.

The practice of storing detailed information within engineering disciplines and not availing information to other relevant projects team members by having a central storage place, further contributes to the reduced visibility.

Inconsistent application of engineering processes and limited cross-functional learning, are not only attributed to the reduced visibility of engineering activities but are also attributed to other additional factors that also cause high levels of variability of activities, variability of activities durations and variability of cycle times of similar engineering deliverables.

1.2 The research problem and its significance

Variabilities of cycle times for similar engineering deliverables within similar project phases across different projects executed on similar plant areas are prevalent in Eskom power stations' similar projects. These variabilities of cycle times make it difficult to utilise information from previous and current similar projects for the purpose of similar project schedule estimation and reduction of similar projects engineering deliverables delivery risk, leading to possible schedule overruns.

Factors contributing to cycle time variability for similar projects are not apparent, as there is no structured approach of determining them within Eskom power stations projects environment. It is critical to structure the research problem statement in a way that allows relevant factors contributing to cycle time variability to be included in the research studies. The study of these factors extends to understanding how they relate to each other and how they can assist in the development of the framework for minimising cycle time variability.

The research problem statement for this research is defined as: *To minimise cycle time variability on similar engineering deliverables within similar project phases and similar plant areas across different power stations.*

Figure 2 below provides a visual illustration of cycle time variability of similar engineering deliverables within similar project phases and plant areas across different power stations. The illustration is based on actual information from power stations' project schedules.

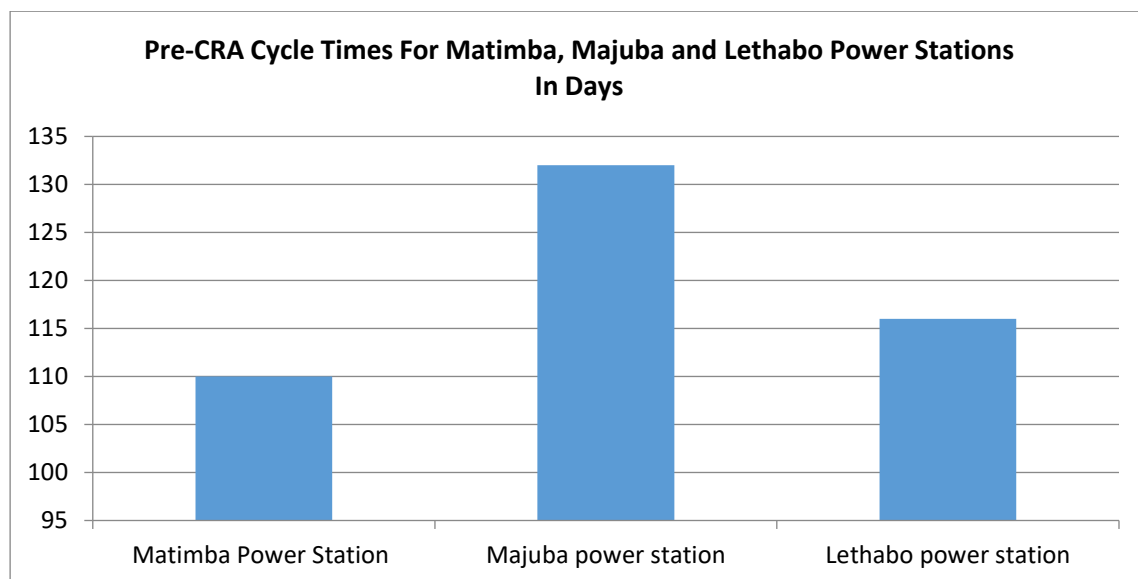


Figure 2: Illustration of Cycle Time Variability of Similar Engineering Projects

Source: Eskom Project Schedules

Figure 2 indicates cycle times variability (**110,132 and 116 days** respectively) of similar engineering deliverables (**pre-CRA work**) that are at a similar project phase (**pre-CRA phase**) executed in similar plant areas (**Medium and Low Voltage Switch gear**) across different power stations (**Matimba, Majuba and Lethabo**)

1.3 Purpose of the research

The purpose of the study is to:

- Study factors contributing to cycle time variability on engineering delivery cycle time.
- Study the impact of factors contributing to cycle time variability on similar engineering deliverables.
- Identify areas of focus for minimising engineering cycle time variability on similar projects.
- Develop the framework model for minimising cycle time variability on similar projects.

1.4 Key research objective

The key research objective is to:

- Set a base for minimising cycle time variability of similar engineering deliverables.
- Contribute towards project engineering related bodies of knowledge.

1.5 Anticipated benefits of the research

The anticipated benefits of the research are:

- Increased consistency in schedule estimation of similar projects engineering deliverables.
- Reduced project engineering delivery risk for similar projects engineering deliverables.

1.6 Main deliverable for the research

The main deliverables of the research are:

- Identification of focus areas for minimising cycle time variability on similar projects engineering deliverables.
- The development of the framework model for minimising engineering delivery cycle time variability on similar projects.

1.7 The Research question, investigative questions and hypothesis

The research explores factors contributing to cycle time variability on similar engineering deliverables and identifies focus areas for minimising cycle time variability on similar projects in order to answer the research question formulated as follows:

How can cycle time variability of similar engineering deliverables within similar project phases and similar plant areas across different power stations be minimised.

In order to answer the research question comprehensively, it is necessary to break down the research question into manageable focused investigative questions. The investigative questions are as follows:

- Is there a direct relationship between variability of activities for similar engineering deliverables and cycle times of similar projects.
- Is there a direct relationship between variability of time durations for similar activities of similar engineering deliverables and cycle times of similar projects.
- Does application of engineering processes have direct impact on the engineering delivery cycle time of similar projects.
- Does intra-organisational knowledge transfer have a direct impact on engineering delivery cycle time of similar projects.

The investigative questions are further translated into hypotheses to enable statistical quantification (hypothesis tests) of responses from the research questionnaire questions. Below are the related formulated hypotheses:

The hypothesis tests consist of the null hypothesis test and alternative hypothesis test. The null hypothesis is a statement indicating that no difference exists between the parameters while the alternative hypothesis indicates a difference (Emory and Cooper, (1995). In this research H_a represent the alternative hypothesis and H_o represent the null hypothesis.

Below are the formulated hypotheses for the research:

- H_{a1} :
 - There is a direct relationship between variability of activities for similar engineering deliverables and cycle times of similar projects.
- H_{o1}
 - There is no direct relationship between variability of activities for similar engineering deliverables and cycle times of similar projects.
- H_{a2} :
 - There is a direct relationship between variability of time durations for similar activities of similar engineering deliverables and cycle times of similar projects.
- H_{o2} :

- There is no direct relationship between variability of time durations for similar activities of similar engineering deliverables and cycle times of similar projects.
- H_{a3} :
 - Implementation of engineering processes has a direct impact on the engineering delivery cycle time of similar projects.
- H_{o3} :
 - Implementation of engineering processes has no direct impact on the engineering delivery cycle time of similar projects.
- H_{a4} :
 - Intra-organisational knowledge transfer has a direct impact on engineering delivery cycle time of similar projects.
- H_{o4} :
 - Intra-organisational knowledge transfer has a direct impact on engineering delivery cycle time of similar projects.

1.8 Contribution to the body of knowledge

The study contributes to the project engineering related bodies of knowledge by identifying key areas of focus for minimising cycle time variability of similar projects within the typical power generation space and related industries by providing a framework for cycle time minimisation on similar project engineering deliverables within the same space.

1.9 Research methodology

The researcher opted to collect both primary and secondary data for the research. The primary data was collected by means of questionnaire surveys consisting of 20 different questions, which were based on the formulated investigative questions while the secondary data was obtained from a combination of sampled power stations' projects schedules with similar engineering deliverables.

The target population for primary data was at least 60 personnel consisting of Eskom project engineering managers, construction managers, project engineers, engineering discipline managers and project managers working in Eskom power plant new built and major refurbishment projects. The corresponding target sample was 21 personnel.

The target population for secondary data consisted of project schedules from Eskom major refurbishment projects for the running power stations and the corresponding target samples were as follows:

- Basic design schedules from Eskom Matimba Power Station and Lethabo Power Station control and instrumentation projects.
- Pre-concept design schedules from Eskom Matimba Power Station, Lethabo Power Station, and Majuba Power Station medium voltage and Low voltage (MV/LV) switchgear projects.
- Concept design schedules for Lethabo and Kendal power stations' High frequency transformers (HFT) projects.

1.10 Limitations of the research and assumptions

The main research assumptions and associated identified limitations were as follows:

- The research would receive good participation from the targeted sample.
 - This assumption was based on normal business as usual and could not have considered limitations imposed by the covid-19 national lockdowns.
- The questionnaire survey design was adequate to pull relevant information from participants.
 - The questionnaire survey questions were based on the researcher's understanding of the research environment and the formulated investigative questions emanating from the studied literature.
- The available obtainable secondary data was sufficient to provide relevant information for the research.
 - Although Eskom power stations execute many similar projects on similar plant areas, the information is not always well organised as different project names are likely to be given to projects with similar activities and main deliverables.
- The critical path method was the dominant means of determining the activities and major deliverables durations.
 - The researcher took into consideration that the critical path does not include all activities of the deliverables but only those found in the longest path. This makes it difficult to evaluate similar activities and activities durations from other similar projects as there might be inconsistencies of activities on the critical path across similar projects. It should also be taken into consideration that the critical path can change during the execution of the project.

- The research focused on the activities and activities durations and did not consider the logical relationships of activities in the secondary data.

1.11 Chapter and content analysis

CHAPTER 1: Scope of the research

In this chapter, the research context, the research problem and its significance, the research question, the investigative questions, the research purpose, the research objective, and the main research deliverables are explained. The research process and the research design methodology are briefly elaborated upon, and the limitations of the research explained.

CHAPTER 2: Literature review

In this chapter, the **initial conceptual framework** is introduced, and literature review is presented on the following:

- Factors contributing to variability of cycle times.
- Key focus areas for cycle time variability minimisation

The chapter is concluded by providing the **updated conceptual framework** emanating from the literature review.

CHAPTER 3: Research Methods

In this chapter, the research process is elaborated upon. The approach to data collection is provided, the targeted population and the targeted sample defined. The measuring scales for the research are explained in detail and a brief explanation on the framework model for minimising cycle time is provided. The details of the framework model are provided in detail in Chapter 5.

CHAPTER 4: Results Presentation, Analysis and Discussion

In this chapter, data coming from the research is presented, analysed and discussed in detail. The results from both primary data and secondary data are compared with outcomes from the literature review and the formulated investigative questions. Salient points of the analysis from the primary and secondary data analysis are provided in the same chapter.

The chapter is concluded by the **latest conceptual framework** based on the literature review, analysis of both the primary and secondary results taking salient points into consideration.

CHAPTER 5: Development of Framework Model for Minimising Cycle Time Variability of Similar Engineering Deliverables

In this chapter, the developed framework model is presented. The development of the framework model was done progressively based on the information from the previous chapters.

The validation of the framework model and the related scoring tool are provided. The limitations and key success factors of the model are elaborated upon.

CHAPTER 6: Conclusion and Recommendations

In this chapter, the research is concluded and the purpose of the study, the key research objectives, the main deliverables of the research, the anticipated benefits of the research processes, the research limitations and assumptions are revisited, and the challenges of the research are elaborated upon.

The chapter provide recommendations on the framework model emanating from the key success factors, the recommended areas of further research, and the researcher's view of the research.

1.12 Conclusion

This chapter provided the background of the research, introduced the research problem and its significance. The research objectives, the anticipated benefits and contribution of the research were elaborated upon. A brief explanation on the research methodology was explained, the assumptions and limitations before the research was undertaken were explained, and the contents of the thesis chapters were provided. In the next chapter, the literature review is presented.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Introduction

In this chapter, the literature review is conducted for the research and factors influencing cycle time variability are studied. The initial conceptual framework is explained and expanded as the literature review unfolds and then, refined at the end of the literature review.

2.1.1 Definition of cycle time and cycle time variability

There are several definitions for cycle time in the literature. These definitions include the following:

- The Lean Enterprise Institute defines cycle time as the amount of time required to produce a product or process as timed by actual measurement. <https://www.lean.org/lexicon-terms/cycle-time>
- The International Institute of Lean Six Sigma defines cycle time as the actual time spent working on producing an item or providing a service, measured from the start of the first task to the end of the last task. <https://www.isixsigma.com/dictionary/cycle-time>.
- Merriam- Webster dictionary define cycle time as the time required to complete a cycle.
- PMBOK seventh edition (2021) define cycle time as follows:
 - “Cycle time is related to lead time; cycle time indicates the amount of time it takes the project team to complete a task. Shorter times indicate a more productive project team. A consistent time helps predict the possible rate of work in the future”.

Lonnie Turpin Jr (2018), in the article “A note on understanding cycle time” also observed that cycle time has several definitions and listed a long list of definitions of which most of them were from the production, manufacturing and operations environment and had to mention the applicable definition for the article.

Similarly, to the definition of cycle time, cycle time is expressed in different ways. The following are common expressions of cycle time from various literature:

- Cycle time = Processing time + inspection time + wait time + move time. Koskela (1992)
- Average waiting time = $\frac{\text{Average number of items in a queuing system}}{\text{Average arrival rate of items to the system}}$

Above equation is called Little's Law. OPERATIONS RESEARCH (INFORMS) Vol. 59, No. 3, May–June 2011, pp. 536–549.

- Process lead-time = $\frac{\text{Number of things in process}}{\text{Completed per hour}}$ this is an extension of Little's law.

OPERATIONS RESEARCH (INFORMS) Vol. 59, No. 3, May–June 2011, pp. 536–549.

- Cycle time = duration of deliverable = Sum of activities on the critical path. PMBOK sixth edition (2017)

From the cycle time definition above and how it is expressed, cycle time involves **activities** and **activities durations**. The general agreement in defining cycle time is that cycle time is the time taken, period, or duration to complete a function or task or activity or job or operation.

According to Anderson and Carmichael (2016), cycle time definition can be ambiguous unless given context.

In the context of this research, cycle time definition includes the following:

- Time planned or taken to complete a major activity.
- Time planned or taken to complete a project work package.
- The duration of an identified milestone or deliverable.
- The time required to complete a task.

Cycle time **variability** for similar engineering deliverables means, time taken or planned to complete above major activities or project work packages or milestones or deliverables or task, is **inconsistent for similar engineering deliverables**.

It should be noted that there is a major difference between **project deliverables cycle time variability** and **similar projects deliverables cycle time variability**. The major difference is that:

- Project deliverables cycle time variability refers to the difference between **Actual durations** and **Planned durations** of activities, milestones, or work packages, or tasks within the **same project**.
- Similar projects deliverables cycle times variability refers to the difference of **both the planned and actual durations** of activities, milestones, or work packages **among similar projects**. (i.e.) comparing planned durations of a project with planned durations of other similar project deliverables and similarly with actual durations.

In the context of this research, Identification of cycle time variability for similar engineering deliverables can be achieved by comparing time taken or planned to complete similar deliverables in similar projects. Inconsistencies of time taken or planned to complete similar deliverables are considered to be cycle time **variabilities for similar deliverables**. This can be expressed as plots of profiles from graphs drawn on the same set of axes or can be expressed mathematically using tools such as Euclidian distance measure or conducting statistical variance analysis.

In this research unless otherwise stated, cycle time variability **does not** refer to the **difference** between **actual duration** and **planned duration**.

2.1.2 Existing knowledge on minimising engineering delivery cycle time variability for similar projects engineering deliverables and limitations.

From literature review conducted, it was evident that the term **cycle time variability** is not as popular in the project engineering or project management disciplines as it is in and not limited to the manufacturing, operations, production, and new product development disciplines. Variability of cycle times is popular in the manufacturing, operations and production disciplines and mostly refers to variations experienced within the same system unless comparison is required among different systems producing similar products or using similar processes.

These variations could manifest as process variations or product variations. Whereas this research involves variability of cycle times for similar project engineering deliverables in different project management contexts.

The science or art of identifying and establishing relationships of generic factors contributing to cycle time variability for similar deliverables is well established and well organised in the manufacturing, production, new product development, and operations disciplines and was difficult to observe for project engineering and project management disciplines during literature search.

As indicated that the term cycle time variability is not popular in the project management or project engineering space, the literature is consequently limited in this space. The implication of limited literature for cycle time variability within the project management or project engineering space is that the use of available literature on cycle time variability cannot be applied directly into this research. Although a lot can be learned from various disciplines with

regards to cycle time variability, there seems to be a gap in finding suitable framework models for minimising cycle time variability of similar engineering deliverables or similar models.

2.1.3 Development of conceptual framework for minimising cycle time variability of similar engineering deliverables

As indicated in Chapter 1 the investigative questions are formulated as follows:

- Does application of engineering processes have direct impact on the engineering delivery cycle time of similar projects?
- Does intra-organisational knowledge transfer have a direct impact on engineering delivery cycle time of similar projects?
- Is there a direct relationship between variability of activities for similar engineering deliverables and cycle times of similar projects?
- Is there a direct relationship between variability of time durations for similar activities of similar engineering deliverables and cycle times of similar projects?

The initial conceptual framework for addressing the above investigative questions is illustrated in figure 3 below:

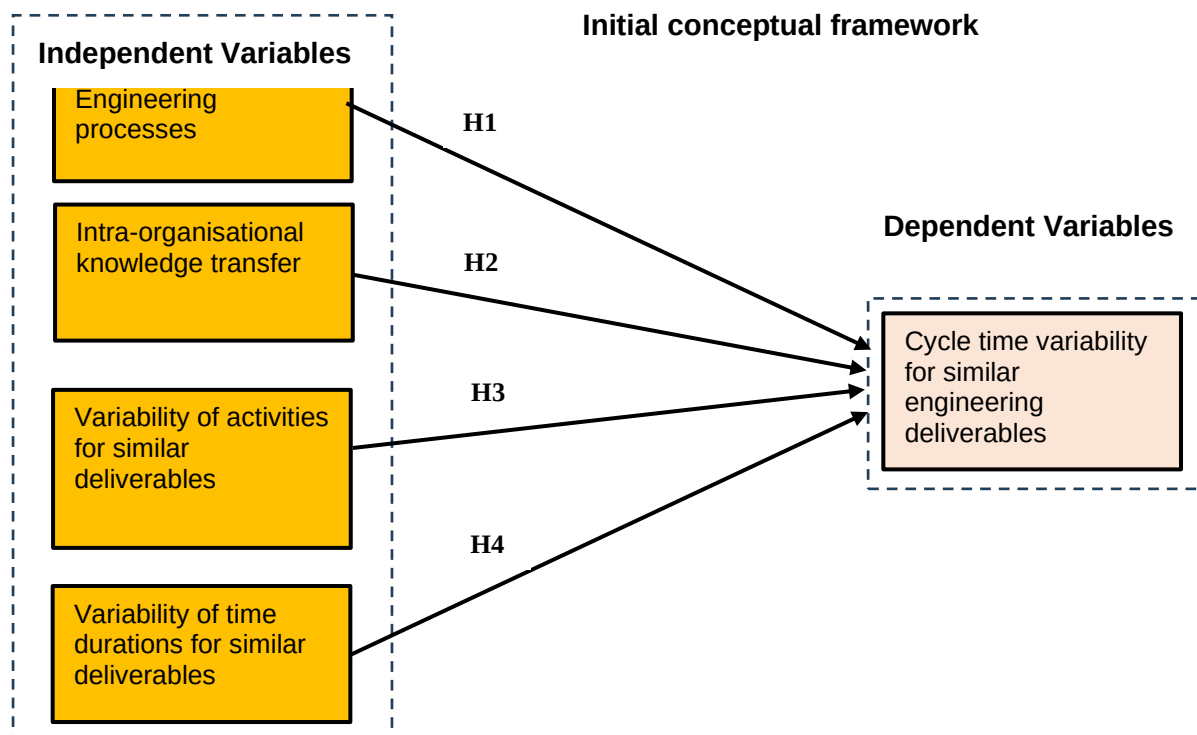


Figure 3: Initial Conceptual Framework for Cycle Time Variability Minimisation for Similar Engineering Deliverables

Source: Author

Figure 3 above summarises the initial conceptual framework of the research. The framework illustrates both the basic independent and dependent variables necessary for the literature review.

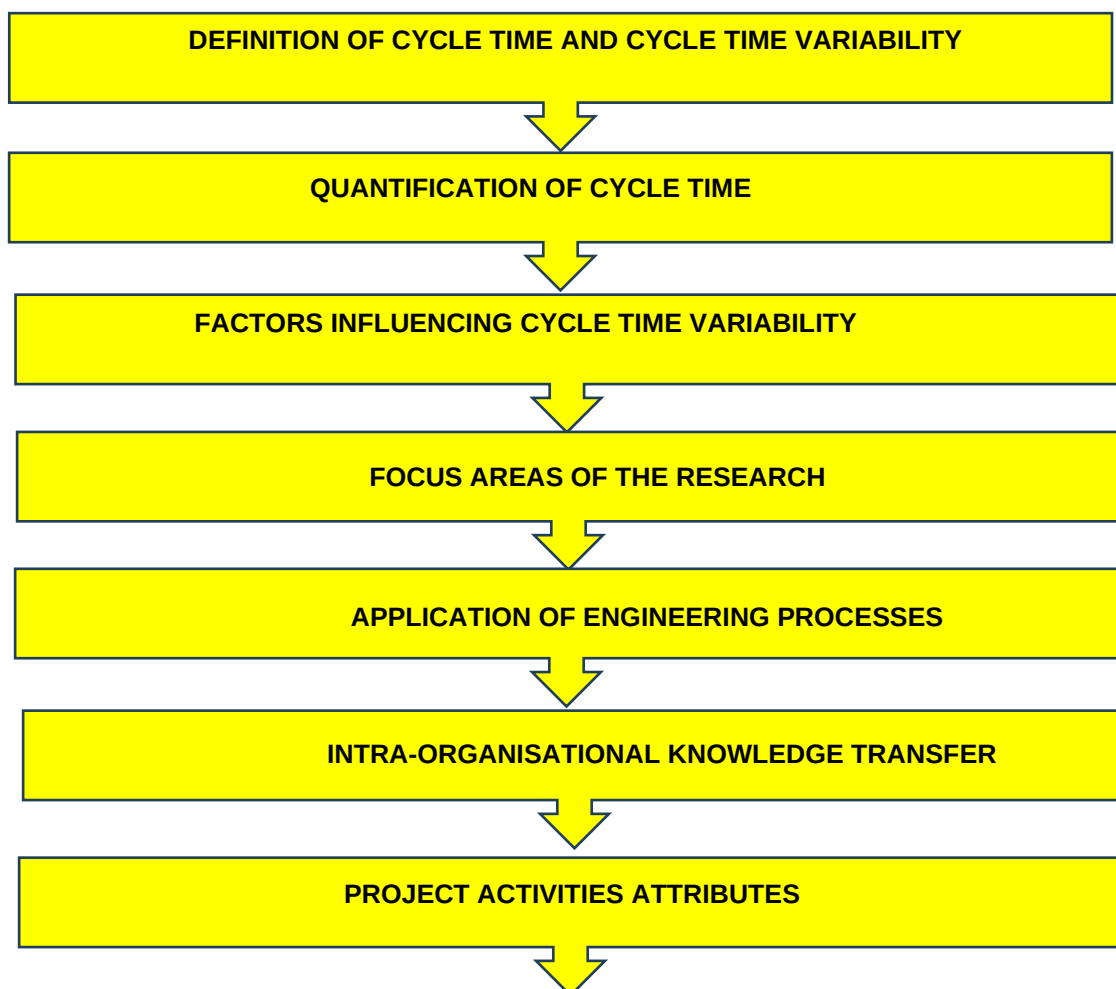
The **independent variables** are identified as:

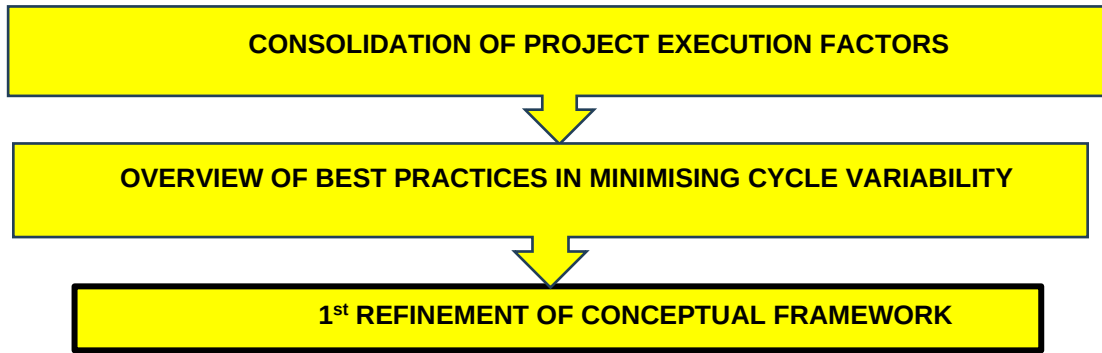
- Variability of activities for similar deliverables
- Variability of activities durations for similar deliverables
- Intra-organisational Knowledge transfer
- Application of engineering processes

While cycle time variability for similar engineering deliverables is identified as the **dependent variable**.

Below figure illustrates the flow of how the literature review was conducted to further develop the initial conceptual framework.

Flow diagram for further development of conceptual framework





Source: Author

2.2 Cycle time quantification

2.2.1 Estimation of activity duration in project management

According to PMBOK sixth edition (2017), there are at least eight activity duration estimation tools available in practice. They include the following:

- **Analogous Estimating**

An analogy of similar project activities previously performed is undertaken and estimation information is sourced from actual work completed. Activity duration estimation is achieved by adjusting parameter to suit the current project environment. This estimation tool can be applied to a total project or some parts of the project and may be used in conjunction with other tools. PMBOK sixth edition (2017). The reliability of the tool is dependent on the extend of similarities of previous activities' attributes and the expertise of project team members conducting the analysis. PMBOK sixth edition (2017)

- **Parametric Estimating**

The work is drilled down into specific units of work per time. For example, pouring time per cubic meter of concrete. This estimate is not as accurate as the first one, but it is considered to provide close enough estimates. PMBOK sixth edition (2017)

- **Expert Judgment**

This estimation relies heavily on the expert judgement. The expert could be professional estimator or experienced personnel in the field of work. PMBOK sixth edition (2017)

- **Three-Point Estimating**

This estimate is based on three estimates namely:

- Optimistic estimate

- Most likely estimate.
- Pessimistic estimate

The activity duration is estimated by means of an equation namely the Performance Evaluation and Review Technique (PERT) equation. The PERT equation is a weighted average in which the most likely estimate is weighted four times more than the optimistic and the pessimistic estimates. The equation is expressed as follows:

- $T_e = (T_o + 4T_m + T_p)/6$ where T_o , T_m and T_p represent optimistic, most likely and pessimistic estimates respectively.

This estimate is inherently probabilistic in nature, and it is useful in large projects where there are high levels of uncertainties. This tool is often used together with the Critical Path Method (CPM) that identify the critical path of the project network. The critical path is considered to be the duration of the project. PMBOK sixth edition (2017)

- Group Decision Making

This estimating tool attempts to eliminate individual biases by utilising collective wisdom from different individuals. It utilises other tools such as:

- Consensus Decision Making
Requires agreement on an estimate by the majority and a consensus will be reached on a specific estimate. PMBOK sixth edition (2017)
- Weighted Vote
Different estimates are presented and then a voting is undertaken, an estimate that gained more votes is chosen. PMBOK sixth edition (2017)
- Delphi Method.
Individual group members present estimates independently without the knowledge of others and then results are presented to the group. Efforts to converge to a single estimate are made. PMBOK sixth edition (2017)

- Reserve Analysis

This estimate technique takes into consideration possible risks, consolidates as a single overall task, and includes it in the schedule. PMBOK sixth edition (2017)

- Bottom-Up Estimating

Bottom-up estimating is a method of estimating project duration or cost by aggregating the estimates of the lower-level components of the WBS. When an activity's duration cannot be estimated with a reasonable degree of confidence, the work within the activity is decomposed

into more details and the detail durations are estimated. These estimates are aggregated into a total quantity for each of the activities' durations. Activities may or may not have dependencies among them that can affect the application and use of resources. If there are dependencies, the pattern of resource usage is reflected and documented in the estimated requirements of the activity. PMBOK sixth edition (2017)

- **Data Analysis**

Data analysis techniques that can be used for this process include alternatives analysis. Alternatives analysis is used to compare various levels of resource capability or skills; scheduling compression techniques; different tools (manual versus automated); and make, rent, or buy decisions regarding the resources. This allows the team to weigh resource, cost, and duration variables to determine an optimal approach for accomplishing project work. PMBOK sixth edition (2017)

- **Meetings**

The project team may hold meetings to estimate activity durations. The team breaks down user stories to low-level tasks, with estimates in hours, and then validates that the estimates are achievable based on team capacity over the duration (iteration). The outcome of the meeting includes an iteration backlog, as well as assumptions, concerns, risks, dependencies, decisions, and actions. PMBOK sixth edition (2017)

2.2.2 Estimation of project deliverable duration

Estimation of project deliverable duration cannot logically take place before activity duration estimation take place. A project deliverable consists of a group of activities arranged logically to achieve the objective of the project.

The most basic tool for estimating project deliverable duration is the Bar Chart in which activities durations are represented by bars the length equivalent to the time required to complete the activities. The Bar Chart is limited in terms of assisting in controlling project activities.

The most utilised method of determining the project delivery durations estimates is the Critical Path Method (CPM). The project duration estimate is achieved by streamlining activities durations in a project network and analysing the longest duration. The path with the longest duration is considered to be the critical path. PMBOK sixth edition (2017)

2.3 Factors influencing cycle time variability.

Factors influencing cycle time variability are inevitably embedded in factors influencing cycle time and factors influencing cycle time are embedded in the means and management practices of producing desired products or services.

In this research, the means and management practices of producing desired products or services are referred to as factors influencing cycle time. The premise of this research is that cycle time related variabilities experienced within a particular project, are likely to be experienced in other similar projects.

Over the years, researchers have been making efforts of identifying and grouping factors influencing cycle time into manageable clusters or dimensions in order to gain more understanding and to obtain basis for continuous improvement in best practices. Kahn et.al. (2012). Griffin (2002).

The identification of these factors and how they fit into their clusters is not consistently applied in the literature except in areas where bodies of knowledge such as the Product Development and Management Association (PDMA) are mentioned. It is common to observe some clusters being mentioned as factors and factors as clusters by different researchers.

The contribution by researchers from a variety of study fields within the product development area, led to more structured approach into best practices and bodies of knowledge such as PDMA were formed. (Kahn et al., 2012) (Eckert et al., 2017) (Lee & Markham, 2016)

Benefits derived from the formation of these bodies of knowledge are not only limited to the development of products but can also be enjoyed in the project engineering and project management space as they cover aspects from inception of the product up to commercialisation.

The PDMA developed the new product development practices, which are characterised across the following dimensions:

- Strategy,
- Process,
- Research,
- Project climate,
- Company culture,

- Metrics and performance measurement, and
- Commercialisation.

Factors influencing cycle time are likely to be embedded in some or all of above dimensions. Below table indicates typical PDMA dimensions (clusters) and associated factors.

Table 1: Typical PDMA dimensions (clusters) and associated factors.

Dimension (cluster)	Factors
Strategy	○ Clarity on organisational goals and objectives ○ Clarity on organisational strategic direction ○ Alignment with common purpose
Process	○ Clarity on Pre-defined Go/no-go criteria for each review gate. ○ Adaptability of processes to meet the needs, size, and risk of individual projects. ○ Visibility of process and documentation. ○ Storage and accessibility of project knowledge.
Research	Market research, Product demand analysis.
Project climate	○ Existence of cross- functional team and turnover ○ Existence of a clearly identifiable project leader ○ Team rewards and recognition ○ Use of formal and informal communication
Company culture	○ Top management supports of the new product development process. ○ Involvement of customers in developing solutions ○ Rewards and recognition by Management entrepreneurship.
Metrics and performance measurement	○ Application of best practices.
Commercialization	○ Composition of launch team. ○ Amount of decision making by cross-functional team in key aspects. ○ Holding of Post-mortem meeting.

Source: (Kahn et al., 2012) (Eckert et al., 2017), (Lee and Markham, 2016)

Although bodies of knowledge such as the PDMA provide good basis for reference and continuous improvement, they do not necessarily supersede current and earlier contributions by individuals or teams of researchers in the related fields. The literature review identified researchers who conducted focused studies with similar dimensions to the ones identified in the PDMA. This does not come as a surprise as some of the individuals or teams of researchers are likely to have contributed to the development of the PDMA and continue to contribute. Below is an extract from focused studies by Owens and Davies on the importance of new product development process.

Table 2: New product development process.

Subject (Cluster)	Characteristics (Factor)
Systematic process for progressing new products.	Stage-Gate Model. Close monitoring & Evaluation at each stage.
Early involvement of all relevant functions.	Bring key perspectives into the process early enough to influence design and prepare for downstream problems. Early detection of problems leads to less rework.
Overlapping/Parallel Working.	Concurrent or simultaneous engineering to aid faster development whilst retaining cross-functional involvement.
Appropriate project management structures.	Choice of structure – e.g., matrix/line/project/heavyweight project management – to suit conditions and task.
Cross-Functional team working	Involvement of different perspectives, use of team-building approaches to ensure effective team working and develop capabilities in flexible problem solving.
Advanced support tools	Use of tools – such as CAD, rapid prototyping, computer-supported co-operative work aids (e.g., Lotus Notes) – to assist with quality and speed of development.
Learning and Continuous Improvement.	Carrying forward lessons learned, via post-project audits etc. Development of continuous improvement culture.

Source: Owens and Davies (2000)

Griffin (2001) below focuses on the impact of project strategy, development process, firm characteristic, and organisational characteristics on cycle time.

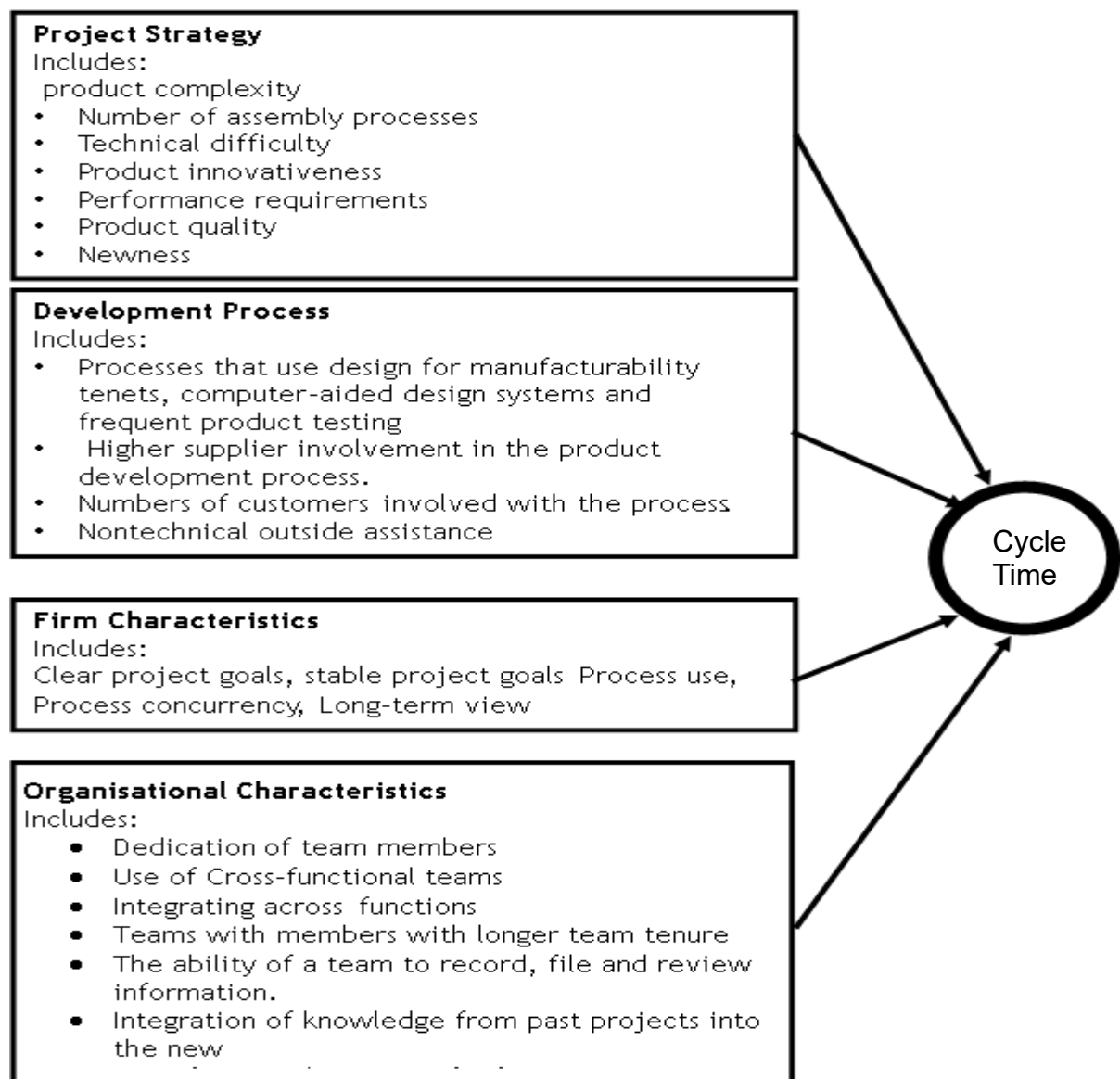


Figure 4: Impact of Project Strategy, Development Process, Firm and Organisational Characteristics

Source: Griffin (2001)

Lebeir (2011) in his article “Impact of Project Complexity Factors on New Product Development Cycle Time” indicates product complexity as one of the two main contributors to project complexity. The other main contributor is innovation. He further divides product complexity into product size and product interconnectivity while Innovation is divided into product newness and project uncertainty. Below is the schematic illustration by Lebeir (2011).

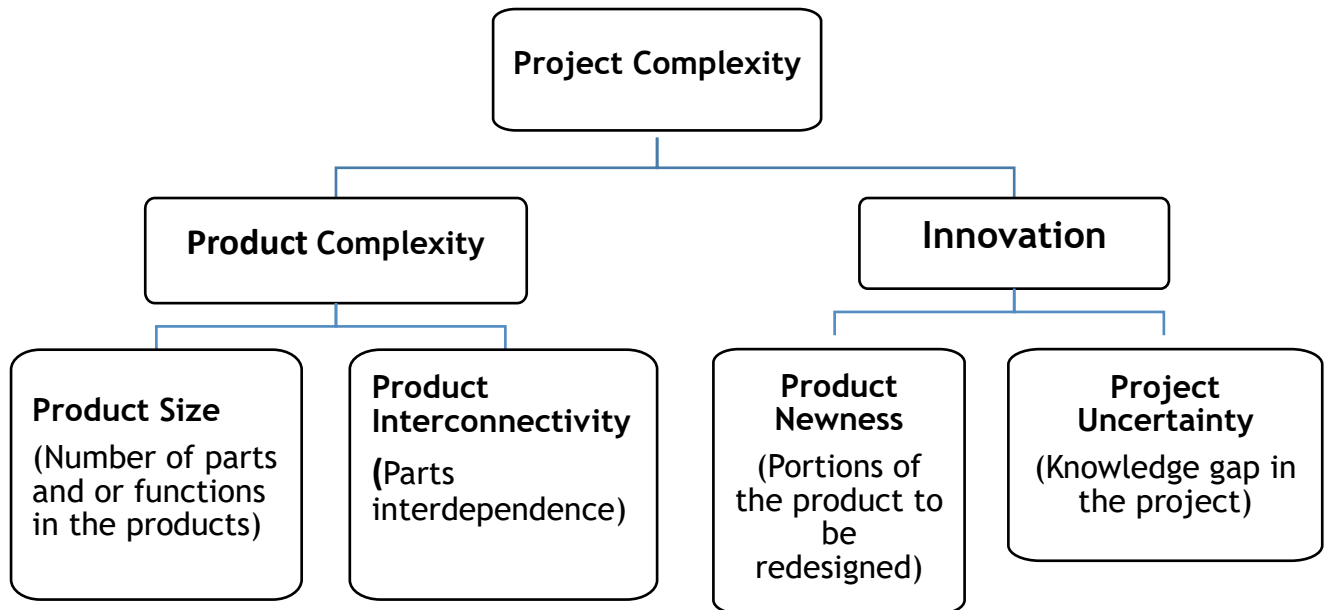


Figure 5: Project Complexity

Source: Lebeir (2011)

Lebcir and Choudrie (2011) later developed an equivalent model to Lebeir's model that focused on project complexity in construction in the article "A Dynamic Model of the Effects of Project Complexity on Time to Complete Construction Projects".

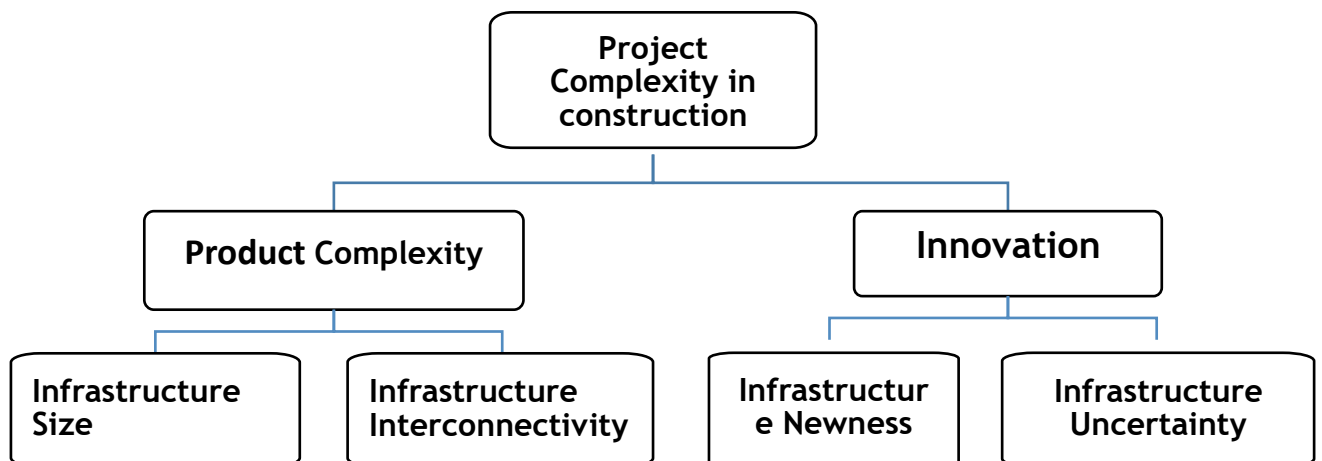


Figure 6: Project Complexity in construction

Source: Lebcir and Choudrie (2011)

Griffin (1997) in the article "The effect of Project and Process Characteristics on Product Development Cycle Time" includes **product newness**, **product complexity**, **use of formal processes** and **use of cross-functional team** as factors influencing cycle time.

The article asserts that using cross-functional teams is more associated with cycle time reduction in new product development while the use of formal processes is more associated with cycle time reduction in product complexity. Below is the associated structure of project, process, and cycle time relationships.

STRUCTURE OF PROJECT, PROCESS, AND CYCLE TIME RELATIONSHIPS.

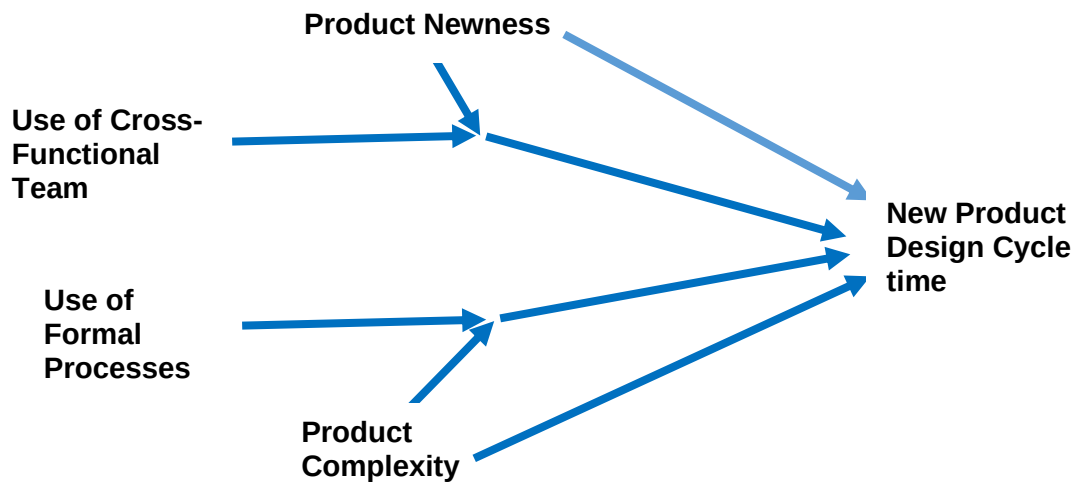


Figure 7: Structure of Project, Process, and Cycle Time Relationships

Source: Griffin (1997)

The figure above illustrates the influence of product newness and product complexity on new products cycle time variability.

Clift and Vandebosch (1999) also associate reduction in cycle time with the application of formal processes but discourage a blanket approach to the adherence of the structure and formality of standardised processes that does not consider the level of complexity.

Their study revealed that the level of formalisation of processes should be tailored for varying degrees of project complexity. The tailoring effort includes the leadership style, the amount of flexibility required and the timing of involving senior leadership and customers.

2.4 Focus areas of research

Above presented factors, can be further categorised as follows:

2.4.1 Factors having inherent organisational strategy.

These factors include:

- Organisation operating model
- Organisational goals and objectives
- Organisational strategic direction
- Company culture

Due to the nature of these factors, it is difficult to achieve optimisation by attempting to adjust the factors' parameters as they might require adjustments to be done at strategic level of the organisation.

2.4.2 Factors having inherent project/product characteristics.

These factors include:

- Product newness
- Product complexity
- Project uncertainty
- Infrastructure newness
- Infrastructure interconnectivity
- Infrastructure size

Adjustment of these factors' parameters to influence cycle time variability is limited, as the parameters might characterise the product or project. An attempt to change or adjust might not take place without changing the nature of the product or project.

2.4.3 Project execution factors

These factors include:

- Use of formal processes
- Use of cross-functional team.
- Project activities attributes
- Dedication of team members
- Integration across functions
- The ability of a team to record, file, and review information.

- Integration of knowledge from past projects into the new
- Use of external sources of information
- Accessibility of processes and documentation
- Storage and accessibility of project knowledge
- Clarity on Pre-defined criteria for each review gate
- Adaptability of processes to meet the needs, size, and risk of individual projects.
- Learning and Continuous Improvement
- Early involvement of all relevant functions
- Project communication protocol
- Project team knowledge gap
- Project Management Structure

It is more feasible to adjust these parameters at the project level without the need to go through organisational structural changes and without affecting the nature of the product or project.

It is for above reason that the researcher opted to focus the studies on the **project execution factors**.

These project execution factors are re-grouped into three main study categories that are relevant to the research studies as follows:

- Application of formal processes
- Intra-organisational knowledge transfer
- Project activities attributes.

The influence of factors having inherent **organisational strategy** and factors having inherent **project/product characteristics** is inevitably embedded in the **use of formal processes**, **Intra-organisational knowledge transfer** and **project activities attributes factors** as they form part of the project management context.

2.5 Application of formal Processes

Project engineering delivery in Eskom operates within the Engineering Management framework under the Manage Engineering Projects mandate. See below.

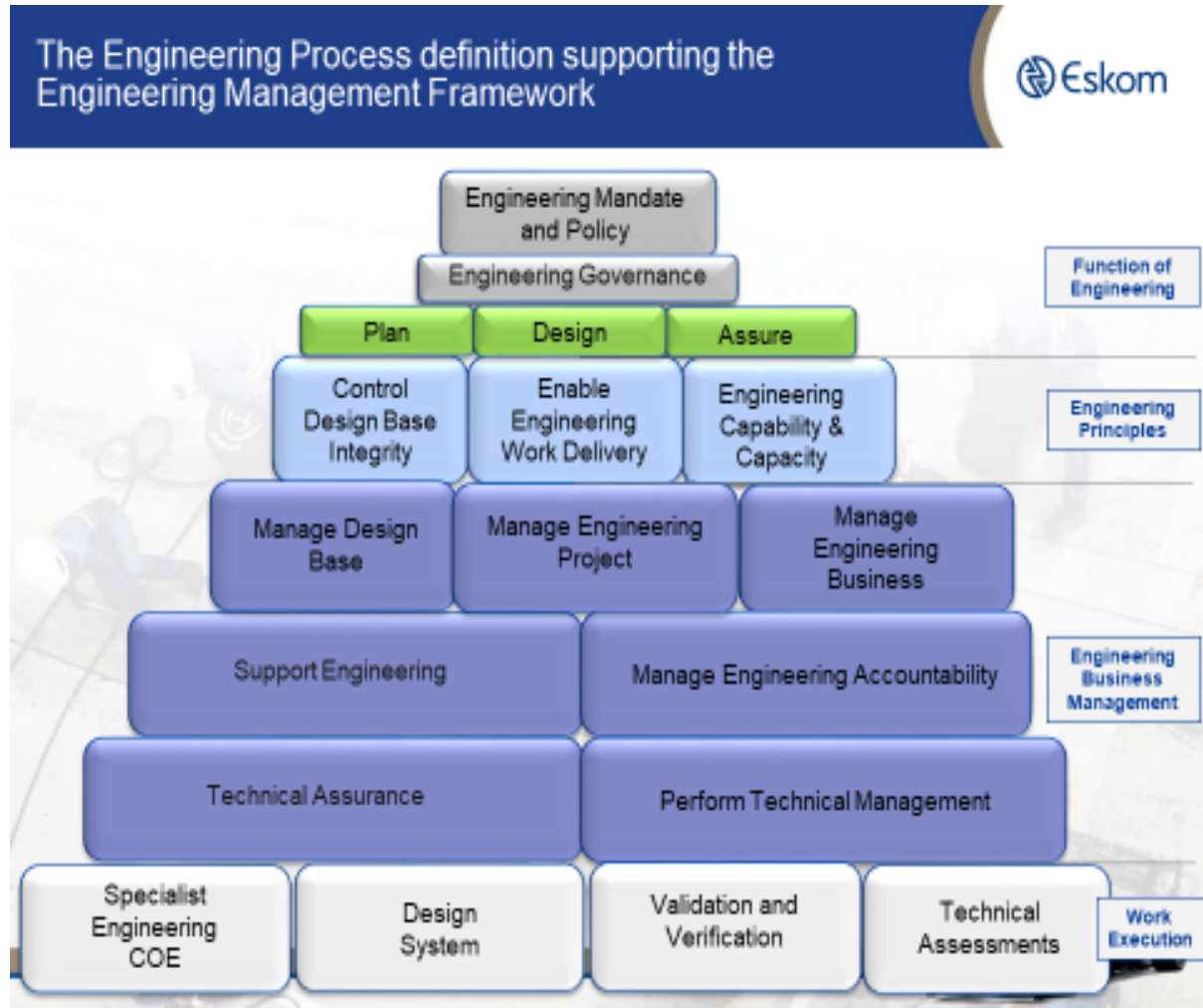


Figure 8: Eskom Engineering Management Framework

Source: Eskom Engineering Management Framework launch (2012)

As indicated in the introduction in Chapter 1, the Eskom context of project engineering deliverables includes all engineering activities carried out during the project life cycle as per the Eskom project life cycle model. The project life cycle model is central to the context of project engineering processes within Eskom.

The literature review revealed that Eskom engineering processes within the project management context are not significantly different from processes found in other disciplines including product development. The differences are mainly due to the main deliverables whereas the conceptual project lifecycle models remain relatively similar.

2.5.1 Project Life Cycle Models

Below is a comparison of Eskom project life cycle model with other selected life cycle models to illustrate relative similarities referred to by the researcher:

2.5.1.1 Generic Project Life Cycle Model

The typical generic project life cycle model consists of Initial Phase, Intermediate Phases and Final Phase. See figure 9 below:

PHASES	INITIAL	INTERMEDIATE			FINAL	
PROJECT MANAGEMENT OUTPUT	Project Charter Scope Statement	Baseline Plan	Acceptance	Approval	implementation	Handover
PROJECT DELIVERABLE						Product

Figure 9: Generic Project Life Cycle Model

Source : (PMBOK sixth edition (2017))

How the project phases are broken down marks the varieties found in different industries and literature. The braking down of project phases determines the nature and number of project stage gates.

2.5.1.2 Example from Textbook “Project Management A Multi-Disciplinary Approach Second, Revised Edition by Herman Steyn and Co-authors)

MILESTONES(Gates)	Gate 1		Gate 2		Gate 3		Gate 4		Gate 5	
PHASE (Stage)	1 Determine need or opportunity	2 Concept exploration	3 Definition of deliverables (e.g., detail design)	4 Implementation	5 Close-out					
DELIVERABLES	- Charter - Detail Plan for Phase 2	- Specification - Detail Plan for Phase 3	- Detail design - Detail plan for phase 4 and 5	- Project deliverables - Preliminary Product support plan	- Final product support plan - Formal acceptance - Report on lessons learned					

Figure 10: Steyn et al, Project Life Cycle Model by Steyn et al. (2010)

Source: Steyn et.al, (2010)

2.5.1.3 Cooper's Product life cycle model

Cooper's Product life cycle model emphasising on the need to involve customers very early in the process.

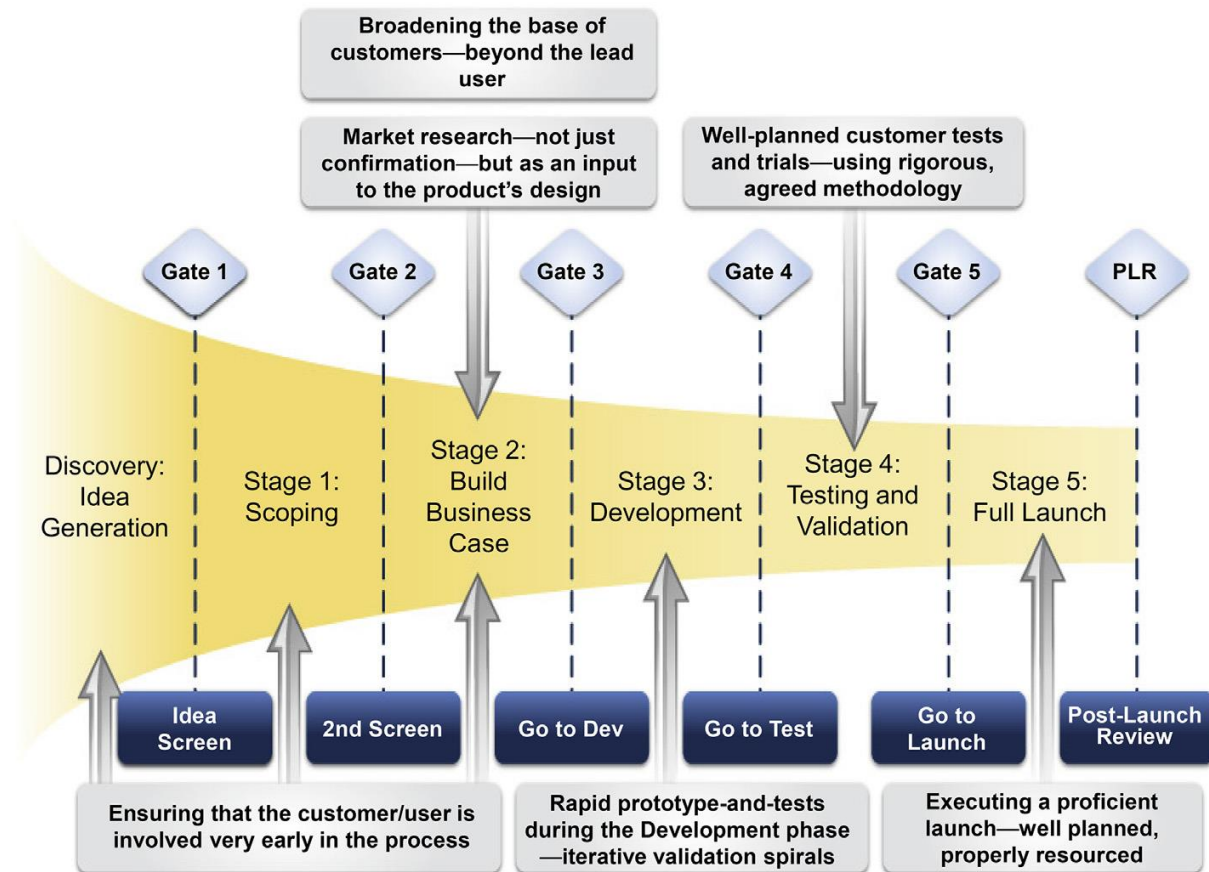


Figure 11: Cooper Project Life Cycle Model

Source: Cooper (2018)

2.5.1.4 The Eskom life cycle model

As indicated in Chapter 1, the Eskom project life cycle model is divided into six phases namely: Pre-Project Planning, Concept, Definition, Execution, Finalisation and Post Project phase. Each phase has at least one stage and a governance approval gate.

Figure 12 below indicates major components of the Eskom project life cycle model.

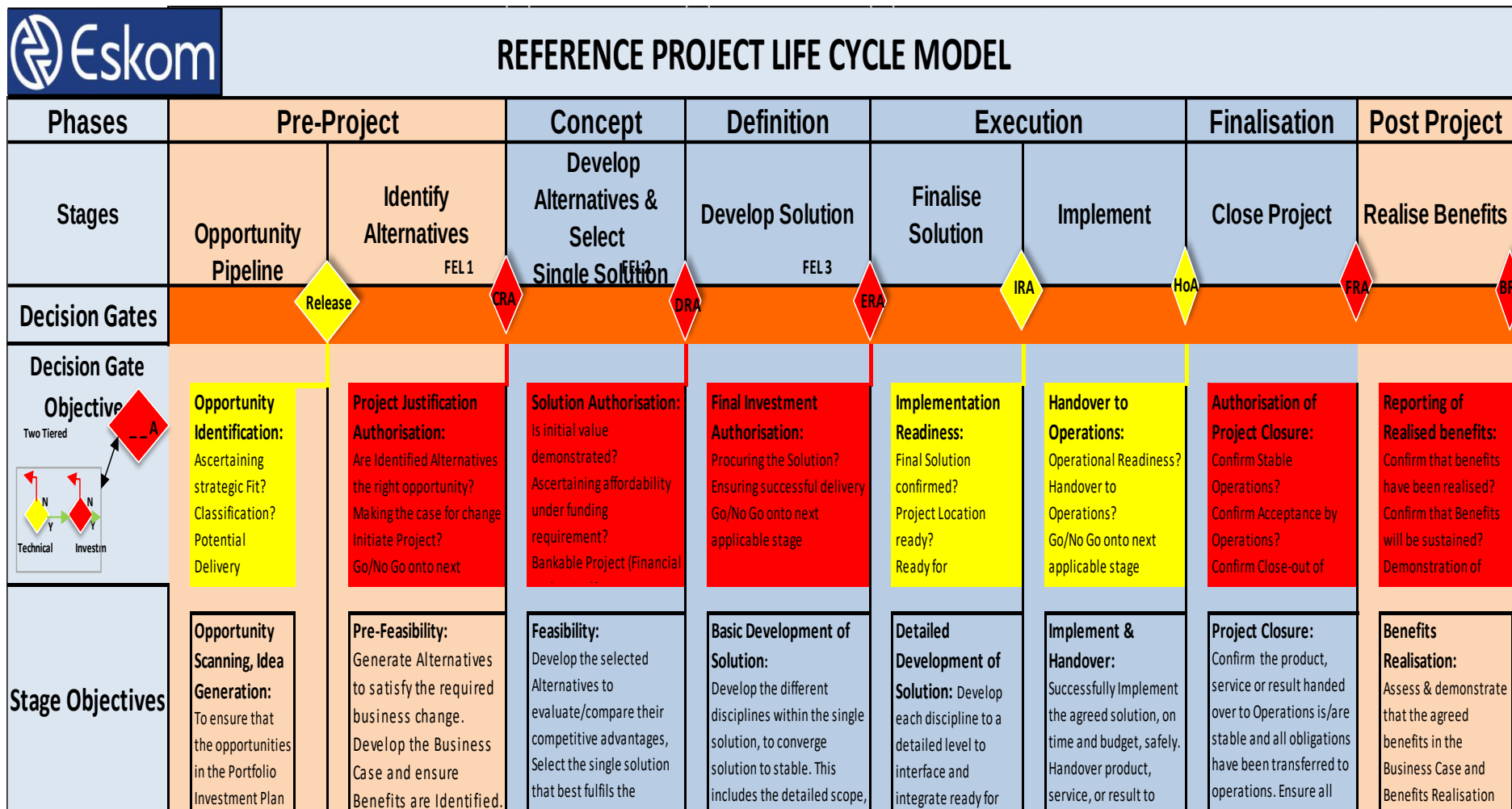


Figure: 12 The Eskom Life Cycle Model

Source: Eskom Life Cycle Model (2021)

The Eskom PLCM combines both the stage gate approach and the project management approach to deliver its projects. The stage gate approach is robustly applied in the early phases of the project and the project management approach serves as an overarching. Management process of the project. The challenge of combining these approaches is that over analysis of risks tends to take place at the latter stages of the project leading to expensive delays.

Jetter et.al. (2016) assert that if the stage gate and the project management approaches are not clearly differentiated, they can lead to either a rigid stage gate that is too strongly influenced by project monitoring and control, leading to unwanted rigidities and overheads, or result in projects that are less rigorously managed and over- documented.

Qureshia et.al. (2014) in their paper **“Stages in product lifecycle: Trans-disciplinary design context”** conclude that life cycle models across disciplines exhibited similarities in the mist of different organisational context regarding the process stages and design stages. They attributed the similarities to the lifecycle centric approach. Eskom project life cycle model is not an exception to this observation.

Below table indicates typical activities for engineering deliverables within the Eskom Project Life Cycle Model (PLCM).

Table 3: Typical activities for engineering deliverables

Activity Name	Activity Description	Deliverables
Identified Design Alternatives	To conduct a pre-feasibility study and generate a list of recommended design alternatives that satisfies need as indicated in the Business Case. These design alternatives are evaluated in more detail to determine the optimal solution.	List of Identified Design Alternatives in Concept Design Report
Concept Design	The concept (design) for the preferred solution is developed and completed to ensure that the preferred solution is achievable from an Engineering / technical perspective.	Concept Design Report Design Review Team Minutes
Basic Design	The concept is now developed further by dividing the project into its different disciplines and developing each discipline up to the point where the solution has been stabilised, ready for finalising the design.	Approved Basic Design Report
Detail Design	The Basic Design is detailed further by fully developing the different disciplines within the solution to enable design integration to the lowest level of the design work breakdown structure.	Approved Detail Design Report

Identify Equipment and Material	Equipment and materials to be utilised during the execution phase are identified and analysed concerning suitability, availability, pricing and ordering and manufacturing lead times.	List of Equipment and Materials needed
As Built Data	All final data and drawings produced for the product of the project are updated, signed-off and handed over to the owner / operator. These are inclusive of drawings, diagrams, manuals, operating procedures, and test certificates defining the 'As Built' baseline status of the product.	Confirmation of updated As Built data in the system

Source: Eskom Generation PLCM (2021)

The processes to deliver above deliverables are captured in the process control manuals (PCM's) arranged to achieve specific project delivery objectives. The key engineering deliverables such as engineering designs goes through the design review process that is governed by the design review procedure. (Generation design review procedure 240-53113685)

Below is a list of typical Eskom engineering processes control manuals (PCM) related to the delivery of engineering deliverables. These PCM's are used in conjunction with other project management related PCM's from other Eskom disciplines such as Project Management, Finance and Procurement.

Table 4: Eskom Engineering PCM's

PCM Number	Engineering Processes	Objective
240-149587314	Perform Project Front End Planning	To ensure that all upfront planning is conducted in order to minimise project delivery risk.
240-44443156	Assign Engineering Accountability	Reduced liability and professional risk through professional accountability
240-44271204	Manage Engineering Delivery	- Effective project management and delivery from planning through to commissioning and handover. - Ensure proper understanding of and compliance to the Design Output requirements
240-44509520	Define Requirements	Enhance requirements development and control reducing project failure
240-44509543	Design System	Translates requirements into a design solution that fulfils the specific goals of the respective Project Life Cycle Model design phase.

240-46977482	Perform Technical Assessment	• Ensure proper understanding of and compliance to the Design Output requirements
240-46953552	Plan Technical Effort	• Accurate, relevant, complete and timely establishment of all the technical planning to obtain an effective and compliant sustainable engineering system design
240-43898151	Perform Verification and Validation	• Ensures that Engineering Work performed is in compliance with design and development input requirements and stakeholder requirements
32-1286	Manage Item Configuration	• Controlled changes to baseline and alignment of documented and physical characteristics of plant or components
240-46977030	Manage Requirements	• Improvement in quality, customer satisfaction and productivity
240-46977377	Manage Interfaces	• Improves multi-discipline integration and arrangement design
32-1216	Manage Documents and Records	• Easy retrieval and traceability meaningful documents. Compliance to ISO9001
240-44682850	Provide Engineering during Project Sourcing	• Ensuring sourcing of project technical services and equipment is within defined specifications.
240-44682832	Provide Engineering during Manufacturing	• Ensuring manufacturing of technical equipment are manufactured within the defined design parameters.
240-44682816	Provide Engineering during Construction	• Ensuring construction work is done within the designed constructability parameters and meeting the defined design parameters.
240-44682732	Provide Engineering during Commissioning	• Ensuring the commissioning activities are within the set parameters and that they meet the required acceptance tests.

Source: Eskom Generation Engineering Management Framework (2023)

The engineering deliverables are mostly needed in the early stages of the project life cycle as they form part of the basis for other deliverables within the project life cycle. The need and influence of engineering effort diminishes in latter phases of the project life cycle and engineering team's participation in the project life cycle gradually translate into playing supportive roles in areas such as and not limited to project sourcing, manufacturing, construction and commissioning. Eskom Engineering PCM's extends to above supportive roles. See the last four PCM's in table 4 above.

The figure below indicates the design resource profile as the PLCM phases progresses.

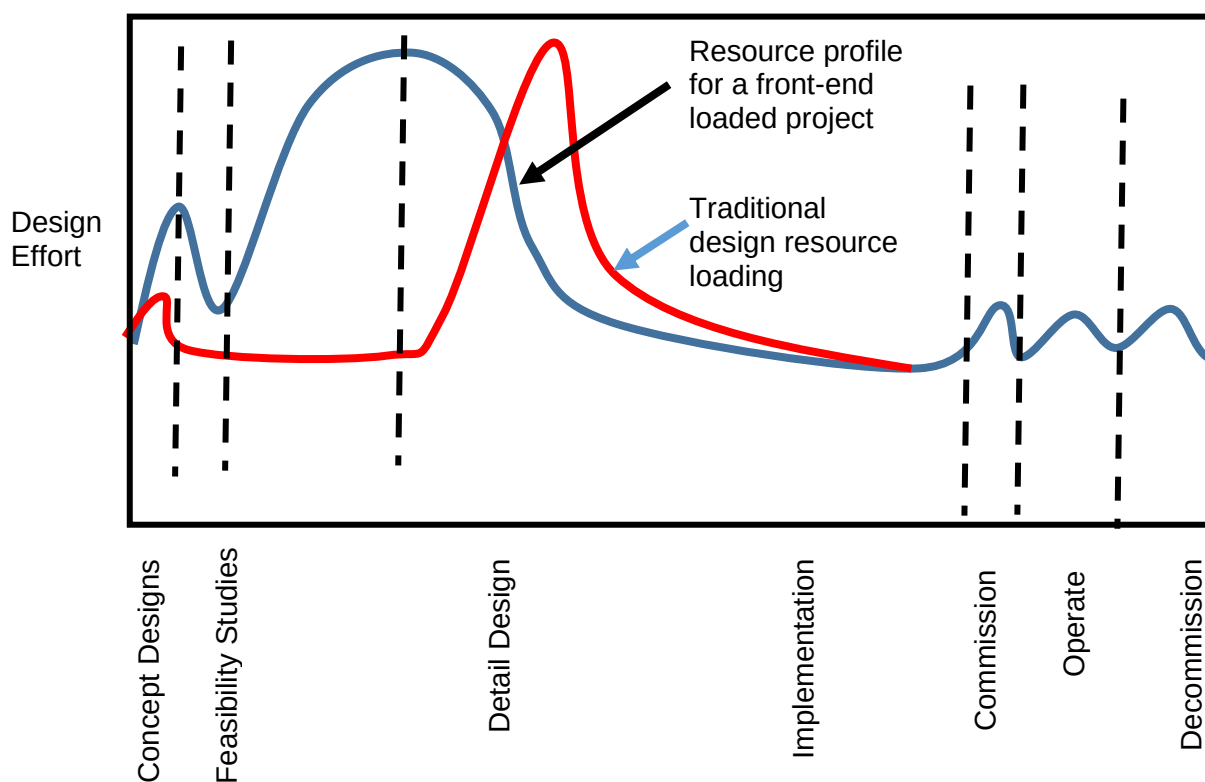


Figure 13: The design resource profile for project with front-end loading

Source: Smith (1998)

As can be seen in the figure the design effort diminishes as the phases progresses. The figure also reveals that in front-end loaded projects, the engineering effort picks much earlier than in traditional design resource loading.

The premise of the Eskom project life cycle model (PLCM) is front-end loading which emphasises robust upfront planning and development in the early phases and stages of the project. The related PCM is captured in the list of PCM's above. It is the first one in the list.

As can be observed above, Eskom project life cycle model and related processes are comparable with those found in the literature. The way these processes are carried out inherently influences activities and their related cycle times.

Consistent application of similar PCM's on similar deliverables is likely to minimise variability of activities and contribute towards reduced cycle times variability while inconsistent application of similar PCM's on similar deliverables is likely to increase variability of activities. Kahn et al, (2012) assert that best-performing companies use common, formal processes with clearly defined phases and stage gates that are visible and well documented.

2.6 Intra-organisational knowledge transfer

To achieve consistent application of engineering processes, it is critical to ensure that consistent relevant knowledge is available and accessible by the project team or the practicing communities. Tsai (2001) argues that better performance can be achieved if central networks are set up to provide access to new knowledge developed by others.

2.6.1 Knowledge Management Process

The management of knowledge in an organisation requires that knowledge must be created, organised, distributed, and applied. Below figure indicates the typical knowledge management process cycle indicating knowledge creation, knowledge organisation, knowledge distribution and knowledge application.

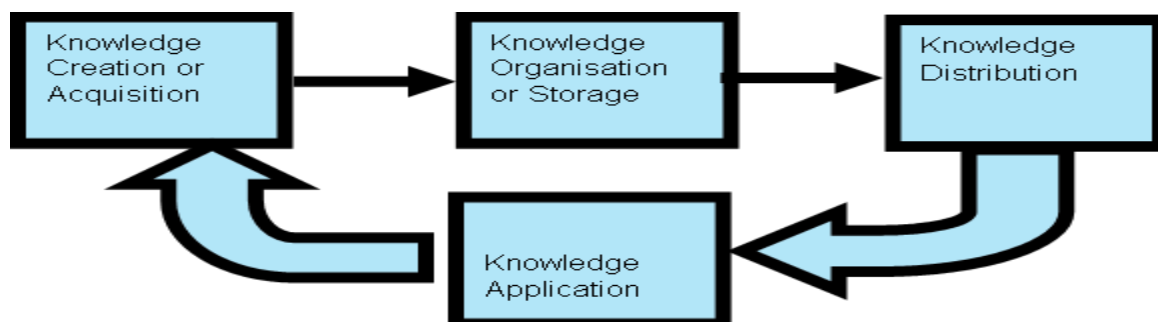


Figure 14: Knowledge Management Process

Source: Dahlan et.al. (2005)

2.6.2 Knowledge transfer mechanisms

Literature review indicates that Knowledge can be divided into Explicit and Tacit Knowledge. Nonaka and Takeuchi (1995)

- Explicit Knowledge
 - This is knowledge that is coded and stored in devices, archives, books etc. and can be retrieved mechanically or electronically without directly involving the provider of knowledge. PMBOK seventh edition (2021)
 - It is relatively easier to retrieve explicit knowledge.
- Tacit Knowledge
 - This is knowledge that is stored in individuals or individual entities.
 - It is difficult to retrieve without directly involving the source.
 - Although it is difficult to retrieve, it is considered to be the most effective form of knowledge yet the most ignored. Dahlan et, al (2005)
 - Tacit knowledge is transferred by connecting the people who need the knowledge with people who have the knowledge via networking, interviews, job shadowing, discussion forums and any other form that allow human to human engagement. PMBOK seventh edition (2021)

Nonaka and Takeuchi (1995) based on their Socialisation, Externalisation, Combination and Internalisation Model (**SECI Model**) assert that there are four modes of knowledge conversions, which are:

- Socialisation (from tacit to tacit)
 - Where sharing experiences and thereby creating tacit knowledge. Knowledge is passed on through practice, guidance, imitation, and observation.
- Externalization (from tacit to explicit)
 - Where articulating tacit knowledge into explicit knowledge in the form of documenting, codifying and packaging knowledge in documents, manuals, procedures, etc. This conversion is considered difficult, as the knowledge provider cannot convey further internalised knowledge that could be embedded in human expressions and illustrations.
- Combination (from explicit to explicit)
 - A combination creates new knowledge by combining different types of explicit knowledge and re-organising existing information into different categories. This is a much simpler conversion of knowledge.

- Internalization (from explicit to tacit).
 - Absorption and storage of knowledge by individuals. Explicit knowledge is internalised and adds into residual knowledge.

Figure 15 below is an illustration of the SECI Model.

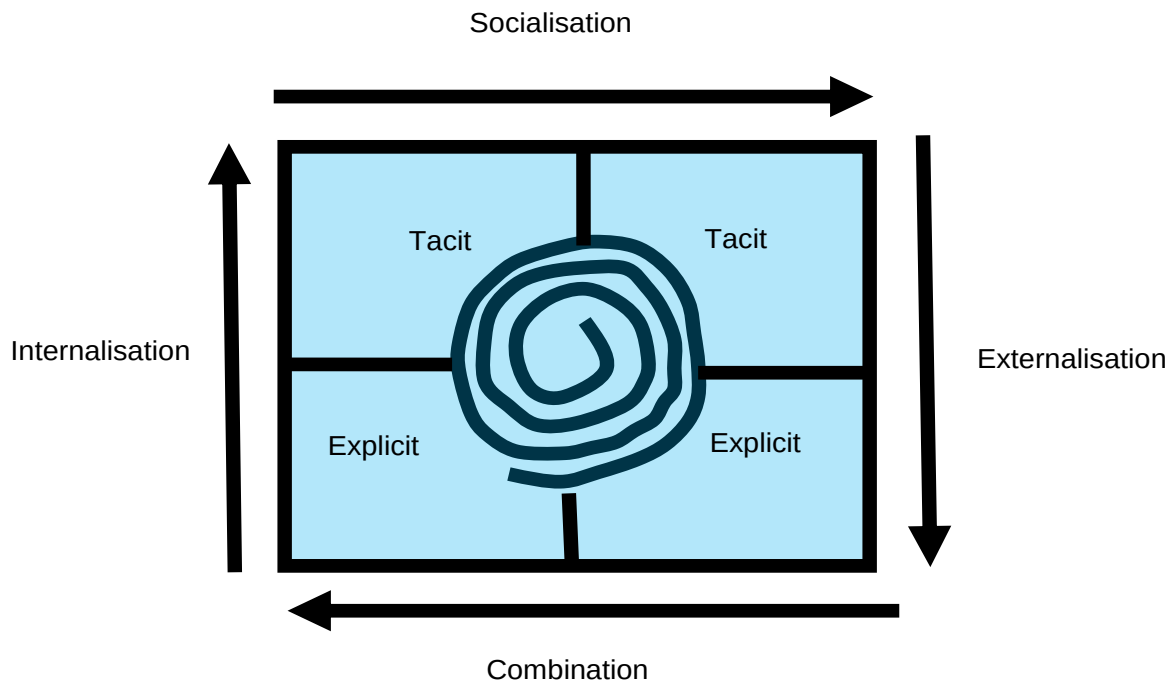


Figure 15: The SECI Model

Source: Nonaka and Takeuchi (1995)

In the project environment, tacit knowledge is uncoded knowledge that is **embedded** in the individual personnel participating in the execution of the project or experts supporting the project while explicit knowledge is coded knowledge that is embedded in documentations such as processes, policies, directives, regulations, reports, etc. Glisby and Holden (2003)

Boisot and Li (2007) confirm that tacit knowledge is difficult to disseminate and tends to stay localised within the agents of knowledge. They developed a model that demonstrates the migration of knowledge from tacit to explicit captured as the three **Different Knowledge Regimes in the I-Space**. The migration involves the move from **concrete to abstract**, from **uncoded to coded** and from **undiffused to diffused knowledge**. This migration is a journey from uncoded embodied concrete knowledge towards coded abstract knowledge. They further confirm that explicit knowledge is easier to disseminate by indicating that diffusion of knowledge takes place much easier with abstract coded knowledge. See figure 16 below. E stands for embodied, N for narrative and A for abstract.

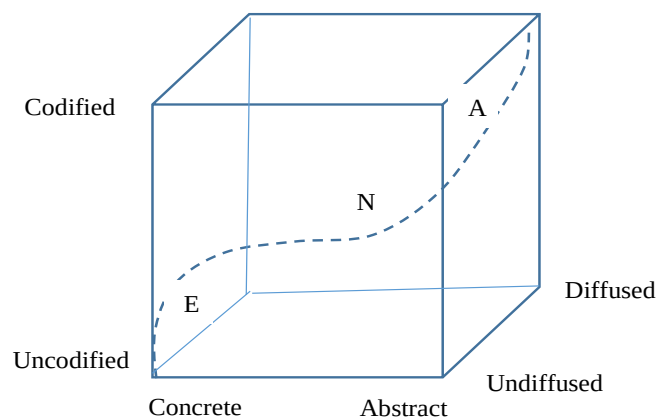


Figure 16: The Three Different Knowledge Regimes in the I-Space

Source: Boisot and Li (2007)

The diffusion of knowledge does not reflect the level of knowledge internalisation since internalisation requires sharing of codes and context. Boisot and Li (2007).

The uniqueness of tacit knowledge requires the formation of **cross-functional teams** and the communities of practice for its externalisation. Mohamed et, al. (2005). The use of cross-functional teams cannot be separated from **intra-organisation knowledge transfer** and Cross-functionality cannot be effective without sharing knowledge among team members. Mohamed et al. (2005).

Knowledge transfer requires **networks** to reach the intended recipients and it is facilitated by intensive **social interactions** of organisational participants. Tsang and Inkpen (2005).

Ferrer-Serrano et, al. (2022) having conducted a systematic review of the literature published between 2000–2020 assert that there is a consensus that **social relations play a relevant role in the exchange of knowledge** and that the sustainability of collaborative networks requires strong links to facilitate the knowledge flow. Literature coined the social relations and social interactions with networks as the **social capacity**.

Social capacity is the embedded resources within the network of relationships of individuals or organisations. Tsang and Inkpen (2005). Below are the three main dimensions of social capacity developed by Tsang and Inkpen:

The structural

- Involves the pattern of relationships between the network actors.
- The Cognitive
 - Represents the resources providing shared meaning and understanding between the network members. This includes common and shared organisational culture.
- The Relational
 - Focus on the role of direct tie between network members.

Cummings and Teng (2003) based on knowledge transfer research from the technology transfer and strategic management field broke down the transfer mechanism into three main components, which are:

- **The knowledge context**

This relates to the source of knowledge and includes:

- The embeddedness – where is the knowledge concentrated?
- Articulability – can knowledge be shared with ease?

Boisot (2007) assert that knowledge that can be articulated diffuses faster and extensively within a given population of agents than knowledge that cannot be articulated. This relates to Explicit and Tacit knowledge. Nonaka and Takeuchi (1995)

- **The relational context.**

This relates to the social interactions of the knowledge transfer participants and includes:

- The physical distance – Are the network members sharing the same physical space?
- Knowledge distance – Are the network members at the same level of understanding the knowledge?
- Norm distance- Do the network members share the same norms and values?

- **The recipient context**

This relates to the absorptive capacity of the recipients and includes:

- The learning culture – how willing and able are the recipients of knowledge to absorb the knowledge?
- Priorities – How important is the knowledge to the recipient.

Ali et.al. (2018) assert that knowledge governance and knowledge sharing are important input variables for improving the absorption capacity within the project.

Argote et al. (2022) highlight the interaction of social networks, routines, search, organisational design, and mobility with knowledge characteristics, context characteristics and source & recipient characteristics. These interactions are consistent with above factors by Cummings and Teng (2003). The additional benefit derived from Argote et al. (2022) is that their work is very recent and has incorporated the latest studies on knowledge transfer mechanisms. See table 5 below.

Table 5: Framework of Transfer Mechanism and knowledge Transfer Components

	SOCIAL NETWORKS	ROUTINES	SEARCH	ORGANISATIONAL DESIGN	MOBILITY
CHARACTERISTICS OF KNOWLEDGE	Knowledge characteristics influence social ties characteristics.	Characteristics of routines as knowledge repositories can influence likelihood of transfer	Characteristics of knowledge can influence its utilisation and subsequent transfer	Characteristics of knowledge can interact with organisational design to influence processes of knowledge transfer	Characteristics of knowledge held by individuals influence the likelihood of transfer
CHARACTERISTICS OF CONTEXT	Characteristics of context can influence network tie formation and subsequently transfer of knowledge	Routines can shape the context in which knowledge transfers and how workers interact	Knowledge repositories can create a context. Which enables knowledge to transfer knowledge	Design elements such as (team, proximity) create context within which transfer occurs	Entry and exit of organisational members can create context to stimulate transfer
CHARACTERISTICS OF SOURCE/RECIPIENT	Characteristics of network actors influence transfer of knowledge	Characteristics of sending and receiving units influence routines	Senders and receivers may vary in their expertise and categorical similarity which predicts transfer	Organisational design methods can influence how sender/receivers transfer	Senders and recipients of movers influence the knowledge that is transferred

Source: Argote et al. (2022)

The frequency of engagement among the network members, the ability to disseminate knowledge, the ability to absorb knowledge and the degree of uniformity of the organisational culture, influence the **quality and rate of knowledge transfer**. Inkpen and Tsang (2005).

Effective intra-organisational knowledge transfer can only be achieved if and when formal and informal conducive environments are deliberately provided, acknowledging that knowledge transfer involves human beings with human tendencies. Having appreciated above statement, the transfer mechanisms and strategies should be well structured to be able to measure and track progress for continuous improvement.

One of the roles played by organisational design include creation of context within which knowledge transfer takes place and creation of teams or layouts that facilitate proximity of organisational knowledge participants. This increases the frequency of engagement among the organisational participants leading to increased knowledge transfer. Argote et.al. (2022).

2.6.2 Knowledge Transfer Networks

Inkpen and Tsang (2005) agree with Tsai (2001) on the importance of network structure in the process of knowledge transfer. Below is how Inkpen and Tsang structured the network structures.

- Intra-corporate network
 - A group of organisational divisions operating under one corporate identification or legal entity.
 - There is a clear link between head office and organisational divisions and the influence of head office varies along dimensions such as centralisation or decentralisation of power.
 - The physical and cultural distances among divisions can add to variabilities in knowledge transfer.
- Industrial District network and
 - A network of independent firms operating in the same market space.
- Strategic Alliance network
 - Firms entering in agreements for knowledge transfer.

The applicable network for this research is the intra-corporate network as the study focuses on the intra-organisation knowledge transfer and it is characteristic to the Engineering Management Framework. Figure 17 below illustrates decentralisation of power within the Eskom engineering space.

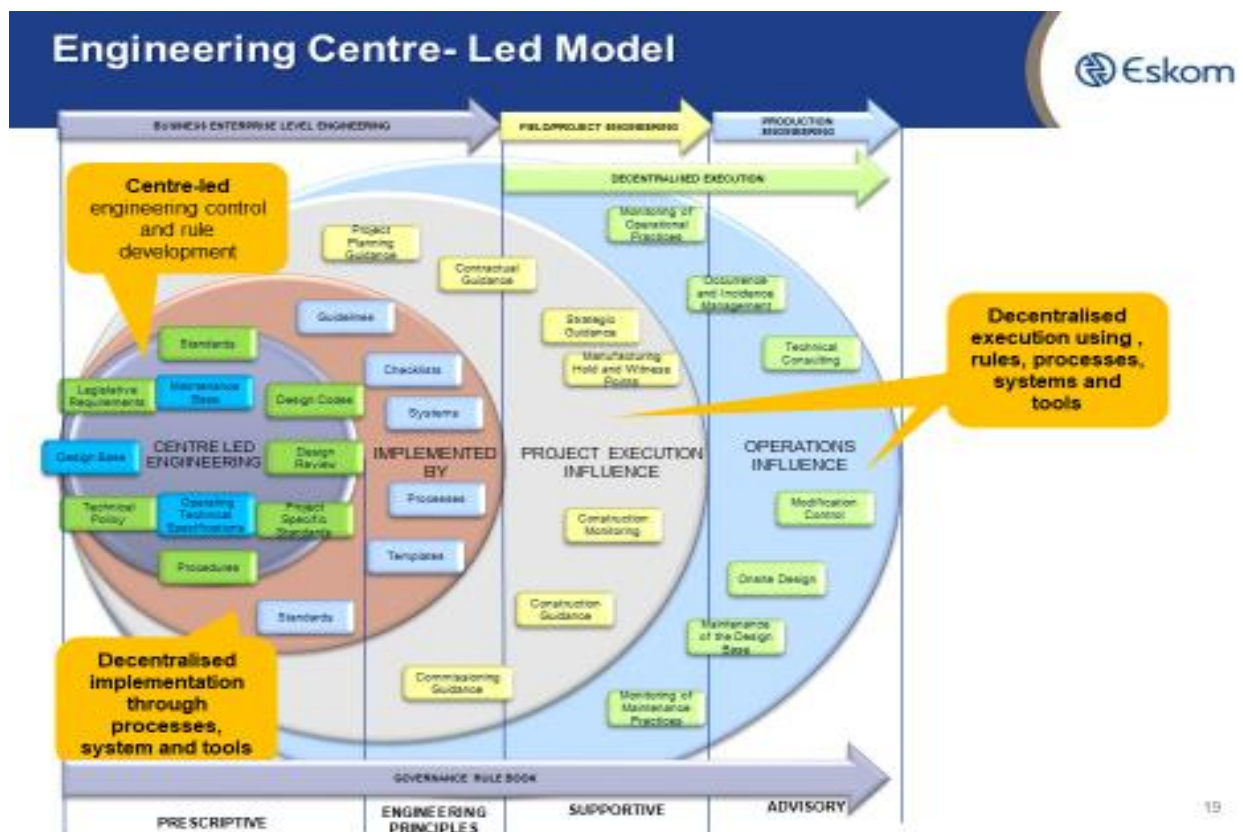


Figure 17: Engineering Centre Led Model

Source: Eskom Engineering operating model launch (2012)

Figure 17 above indicates how Eskom can carry out its engineering mandate across its divisions by decentralising the execution of its projects through its centre-led processes.

As can be seen in the model, the fundamental organisational structural network within Eskom is well established.

Although the nature of Eskom's organisational structure is set up to be more conducive for formal information flow, it should be appreciated that the size and diversity of the organisation is likely to pose a challenge in terms of transferring consistent knowledge on similar projects that are executed at different geographical areas with diverse localised cultures and social networks.

Inkpen and Tsang (2005) confirm above statement by indicating that the physical and cultural distances among divisions can add to variabilities in knowledge transfer.

Howells (2002) asserts that, knowledge is centred on knowing self and it is influenced in its human development, its cognitive, social, cultural, and economic circumstances that in turn are influenced by its geographical environment.

Lucas's (2006) studies on **how reputations, culture, and incentives influence knowledge transfer**, confirm that knowledge transfer is not a socially neutral process but is a social activity occurring within a social context.

The major challenge in knowledge transfer within Eskom Generation projects does not seem to be heavily embedded in the organisational structure but in **social interactions within the network**.

The **social networks** and **interactions** between individuals are critical component of knowledge management system. Ali et.al. (2018)

Serrano et al, (2022) in their article named "Examining knowledge transfer and networks: an overview of the last twenty years", suggest four stages for implementing dynamic knowledge management system. These stages are chronologically as follows:

1. Assessment of the current state of knowledge management strategies.
2. Identification of goals and objectives by establishing an inventory of available resources and capacity by involving leadership.
3. The development of a change management strategy by determining its processes and building an implementation roadmap.
4. Periodically evaluating its effectiveness and making continuous improvement.

2.7 Project activities attributes

PMBOK's description of activity attributes includes the multiple components associated with each activity. This includes the activity name, activity description, activity duration, the type of effort involved, the logical relationship with other activities and the required resources for the activity. PMBOK sixth edition (2017)

The durations of similar projects activities are seldom the same due to several variations taking place during the execution of activities Fachrurrazi et al. (2018.). Variables such as the production rate per day (PRPD) and variations of other activity attributes including:

- Variations in the resource characteristics such as demographics, experience, skills, capability, and capacity. (**Intra-organisational knowledge transfer**) Fachrurrazi et al. (2018).
- Different approaches and methodologies in performing similar activities. (**Inconsistent application of processes**). (Fachrurrazi et al. (2018)

The relationships between the **activities attributes** and both the **intra-organisational knowledge transfer** and **application of processes** are immediately observed in above bullet points (highlighted in **bold**.)

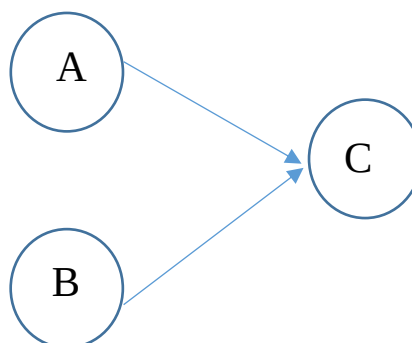
Variability of activities attributes can be introduced as early as at the project duration estimation stage, starting with the project duration estimation tools up to and not limited to the resources deployed to execute the project.

As indicated in 2.2.1 above, the most common tools used in Eskom major projects schedule development are Performance Evaluation and Review Technique (PERT) and the Critical Path Method. The project duration is determined by the longest path of the PERT/CPM project network. Since the inception of these tools, there has been several studies conducted on the advantages and disadvantages of using them.

For the purpose of this research, the focus will be on the areas affecting cycle time variability. Below are some of the problems of using the PERT/CPM tools identified by Pittman (1994) as cited in the Theory of Constraints Handbook (2010)

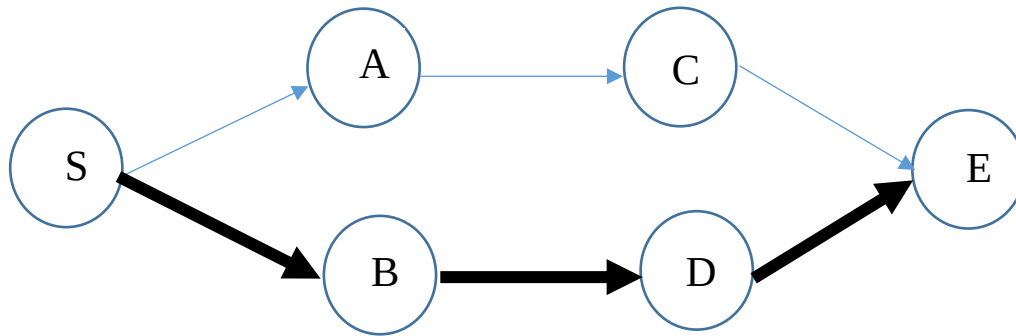
*Please note that variability of durations on the PERT/CPM illustrations below, refers to the difference between the **actual duration** and the **planned duration** of the same project.*

- **Variability of activity duration and point of convergence.** Below network applies to the explanation:



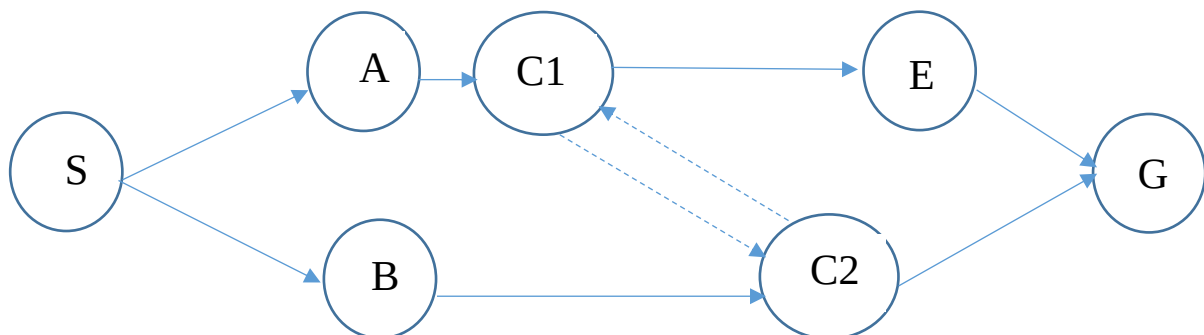
Since the Network conventions require that all paths converge to one end node, the delay of activity C, can be caused by the intersection of activities A and B convergent point when activity duration variability exists.

- **High variability on non-critical path.** Below network applies to the explanation:



Considering the above network, if path S-B-D-E is a critical path and path S-A-C-E is non-critical path, the delay can be caused at E when high activity duration variability exists since the Network conventions require that all paths converge to one end node.

- **Variability of activity duration, convergence point, and resource contention.**



Activity duration variability worsen resource contention at the point of delivery leading to delays. C1 and C2 illustrate the contention of resources due to variability of activity durations.

According to Acebes et al, (2016) an **increase** in **activity duration variability** (actual vs planned duration) leads to an **increase** in the **expected duration**. Acebes et al, (2016) assert that their study concurs with Schonberger's Investigative question on the same topic which states that an increase in the variability of task durations will result in an increase of the expected project duration. In the same article Acebes et.al, (2016) indicate that **Criticality**

index and **Cruciality index** of the project activities can both be used as a measure of the influence of the duration of each activity on the duration of the entire project.

The **Criticality index** of an activity is the probability that such activity lies on at least one critical path of the project. The **Cruciality Index** of an activity is the correlation between the activity and the duration of the entire project. Acebes et.al, (2016) indicate that both indexes provide complementary information to make decisions.

Koskela (1992) asserts that variability, especially of activity duration, **increases the volume of non-value-adding activities** and recommends the standardisation of activities by implementation of **standard procedures to reduce variability**.

The problem with non-value-adding activities in the project management space is that such activities are often allocated time and they distort the real picture of activities durations, and this is a breeding ground for **Parkinson's law** which states that work will expand to fill the allocated time. Parkinson.C.N (1957). Non value-adding activities are wasteful as they consume time and resources without any value added. Koskela (1992).

Delp et al, assert that reduced variability in the system keeps the cycle time low and that the rate at which the cycle time increases is dependent on the system's variability. See figure 18 below.

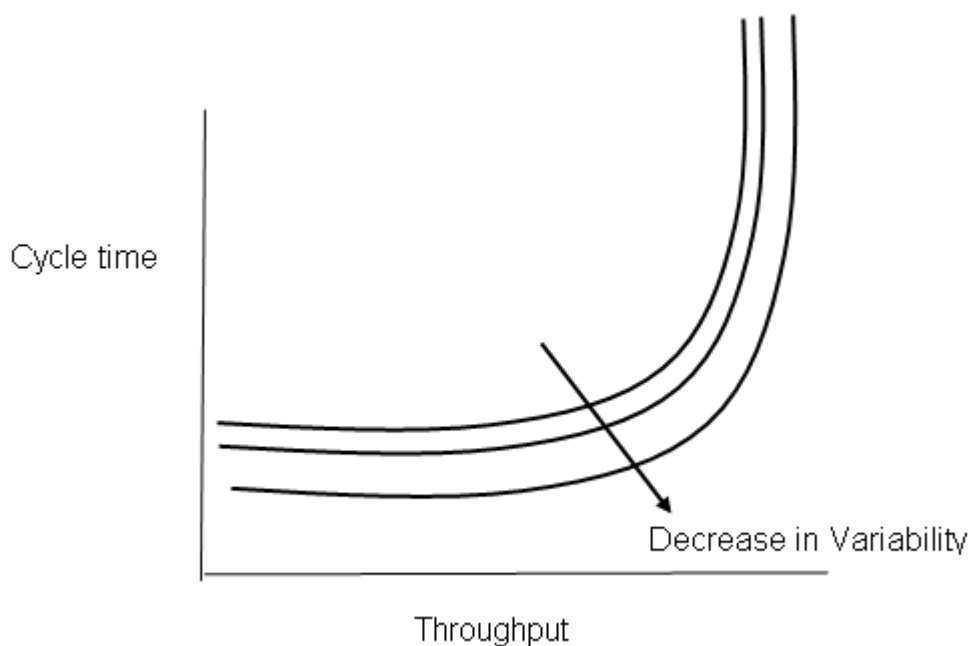


Figure 18: Effect of variability on cycle time

Source: Delp et al, (2006)

Figure 18 shows a cycle time performance curve with a decrease in variability thus shifting the curve downward for a higher throughput rate at a lower cycle time. Their recommendations in terms of reducing cycle time include the following:

- Cross training maintenance personnel.
- Cross training operators.
- Use of Just in time (JIT) principle to lower the work in progress (WIP)
- Use of Theory of constraints by identifying the system bottleneck and focusing resources on the bottleneck to ensure timeous delivery.

Although above illustration relates to the production, manufacturing or operating environment, the principle can be applicable in the project engineering or project management space. The INCOSE-TP Systems Engineering and System Definitions (2019) asserts that physical and conceptual systems can be considered to be structurally ontologically the same at the level of parts & relationship and it is what allows the modelling of physical systems with the use of conceptual systems.

AGI-Goldratt Institute (2010) in the article “Translating Lean Six sigma into Project Management “assert that at the end of each project completion, the team should perform an analysis of Variabilities identified before execution versus the actual variability after execution. The activities should be categorised in order to protect against variability of next projects.

Salient points from literature on activities attributes

- The variance between the actual duration of activities and the planned duration of the same project can lead to increased duration of the project. Pittman (1994) (Acebes et al, (2016).
- When an activity is delayed at a certain point during execution, it can impact on the planned resources at the next points leading to resource contentions and ultimately delays of the project due to waiting. Pittman (1994)
- The variance between the actual and planned duration on the critical path at a certain point can lead to delays and resulting in non-critical path activities being prioritised due to waiting and this will further exacerbate delays of the project. Pittman (1994)
- Reduced variability within the system ‘reduces cycle time. Delp et al, (2006)

Based on salient points above, it can be deduced that the variabilities experienced by individual deliverables within a project are **likely** to be inconsistent due to many factors influencing them

and this contributes to cycle time variabilities when compared to similar deliverables of similar projects.

It can therefore be concluded that **variabilities** experienced by **individual deliverables** within a project contribute to **variability of similar deliverables** among similar projects. That being the case, this could mean that if we want to minimise variability of similar deliverables among similar projects, we can target **individual deliverables or projects**. The targeting of individual deliverables needs to look at the **context of the individual projects**, the drivers of variabilities and the context of the drivers of variability.

A similar approach to above thinking from the manufacturing and operations environment is found in Khalil et, al. (2008) in which the collected strategies for minimising variabilities included:

- Reducing the levels of variation from individual causes, e.g., through lean-based waste reduction techniques.
- Combining sources of variation, i.e., through variability pooling and buffering. Then applying strategies to reduce variability.

Khalil et, al. assert that knowledge of **time variability inherent in individual work tasks**, the impact of **inherent work tasks variabilities** on **workstation variability**, how they **affect resource** allocation and utilisations of individual workstations are critical for ensuring effective reduction of variabilities.

In this research the drivers and the context of drivers are presented under factors influencing cycle time variability which include Application of Engineering Processes, Intra-organisational knowledge transfer and activities attributes.

2.8 Overview of best practices in minimising cycle time variability

It is important to note that effective minimisation of cycle time variability cannot take place in isolation of best practices in the related disciplines and practices. Several approaches can contribute towards minimising cycle time variability. These approaches include the following:

2.8.1 Adoption of tools from other related disciplines

Goldratt Institute AGI (2010) assert that traditional project management will need some refinements to become Lean thus allowing more projects to reduce cycle time. Below is an example of adaptation of lean principles relevant in the project engineering and project management space AGI-Goldratt Institute (2010):

- Address variability at the earliest point in the project.
 - Plan how you desire to do the project.
 - Do not commit to alternative solutions to work before impact analysis is conducted.
 - Template best project practices into network diagram and use for similar projects.
 - Apply project-based risk management to the project prior to commencing the project.
 - Monitor “actual to plan” for what causes project cycle time to expand or contract.
- and reduce all sources of variation.

Throughout literature review conducted, variability has been associated with an increase in cycle time. This includes variability of operations, methods, activities, and their durations. As mentioned earlier in the literature, the art and science of dealing with variabilities in the operations, manufacturing, production, and new product development seemed to be more advanced than in the project engineering or project management disciplines.

Below Khalil et, al. (2008) present some of the collected strategies within the manufacturing operations environment that can be adopted in the project engineering and project management disciplines:

- Effective allocation of tasks to workstations during the line balancing procedure.
- Effective sequencing of work items
- Adoption of an optimum mechanism for controlling material flows
- Removing the causes of variation, e.g., through setup reduction and total quality management activities.
- Reducing the levels of variation from individual causes, e.g., through lean-based waste reduction techniques.
- Combining sources of variation, i.e., through variability pooling and buffering; making use of flexible resources to off-set the effects of variability.

. All above points can be translated into the project engineering or project management environment.

Literature review revealed that project management undertaking in the engineering space cannot be effective without the integration of modern tools and disciplines such as and not limited to six sigma, lean, systems engineering, system dynamics and knowledge management.

This is confirmed by the following observations:

- A growing appetite of combining the six sigma, lean and systems engineering methodologies. Sreeram and Thondiyath. (2015).
- A drive to combine best components from tools or methodologies such as theory of constraints, lean and six sigma coined as TLS methodologies. Blackstone assert that companies that apply TLS deliver projects at reduced costs.
- A growing appetite in systems thinking tools such as the System Dynamics Modelling in the project management environment. This is a result of appreciating that project management undertakings are not as simple and linear in nature as might be perceived. Project management problems can be complex and non-linear requiring tools such as systems dynamics models to assist in solving them. System dynamics is a modelling approach that has the ability to represent dynamic behaviour of complex systems. It can be used in the context of managing projects. Van Heijnsbergen (2022). Rodrigues and Williams (1998)
- The integration of knowledge management in the PMBOK sixth edition also an indication of appreciation of the need to integrate other disciplines in project management.

2.8.2 Integration and Process simplification

Process simplification is one of the key benefits emanating from continuous improvement of best practices. Below Koskela (1992) provides some of the fundamental process simplification technics that can be deployed in minimising cycle time and cycle time variability if applied consistently:

- Consolidation of activities as much as possible.
- Minimising the amount of control information as much as possible.
- Reduction of the number of steps in information flow
- Eliminating non-value-adding activities
- Timeous execution of activities
- Increasing process transparency by making the process directly observable by availing schedule performance measurements and display of activities information during execution.

- Re-arranging the sequence of activities and identification of activities that can be executed in parallel.
- Isolating the main value-adding sequence from support work.

Gaurav et al. (2018) argues that in order to achieve process simplification, it is critical to identify and remove redundant elements within the organisational upstream processes for effectiveness and efficiency.

Duplication of processes and procedures is one of the main challenges in Eskom. The duplication comes in the form of translating Eskom corporate procedures into divisional procedures and processes and further translation is done at business units' level. These translations increase discrepancies in the content of processes and procedures thus contributing to inconsistent application of processes.

2.9 Consolidation of project execution factors

The consolidation of project execution factors is summarised in figure 19 below.

The project execution factors initially mentioned in 2.4.3 are expanded with the inclusion of other related factors from the literature review. The consolidation still maintains the same key factors namely:

- Application of formal processes
- Intra-organisational knowledge transfer
- Project activities attributes.

Consolidation of project execution factors

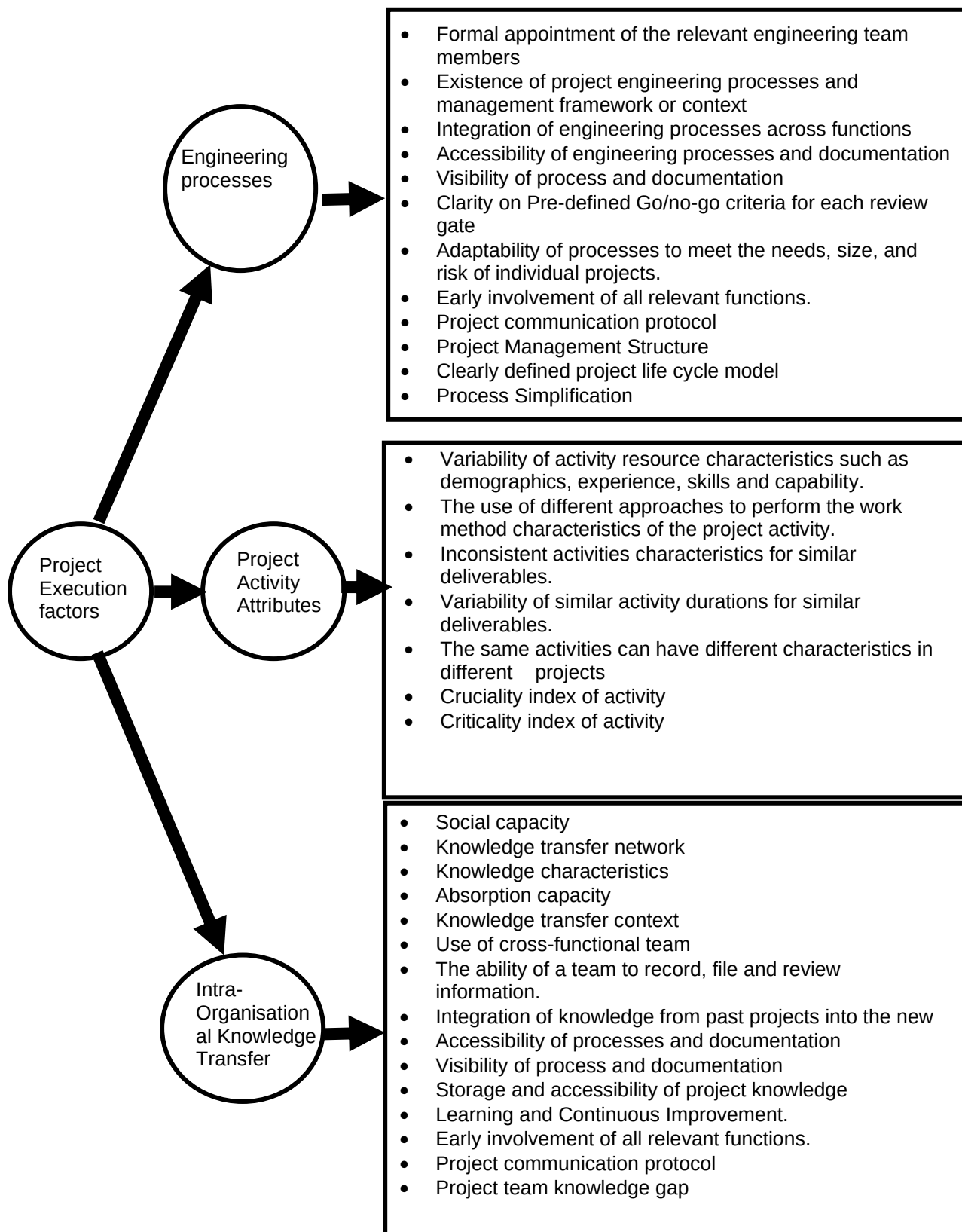


Figure 19: Project Execution Factors

Source: Remodelled by The Author

The researcher's observation of above project execution factors is that they are equivalents of the leading variables in the Balanced Score Card (BSC) considering specific project management or project engineering space.

The Balanced score card has four perspectives namely: (1) Financial perspective, (2) Customer perspective, (3) Internal business process perspective, and (4) Learning and growth perspective. Kaplan and Norton (1996). The last two perspectives are the leading variables followed by the customer perspective and then the Outcome lagging variable is the financial perspective, which is considered the bottom line.

The observed equivalence is in the last two BSC perspectives (i.e.) internal business process, Learning, and growth. Having **Internal Business Processes**, being equivalent to **Application of Engineering Processes**, Learning, and Growth being equivalent to **Intra-Organisational Knowledge Transfer** and the Activity Attributes are implied in both perspectives.

2.10 1st Refinement of the conceptual framework model

Figure 20 below indicates a refined conceptual framework model based on the conducted literature review. The refined conceptual framework includes the following changes and additions:

- Introduction of key antecedent variables to the independent variables. These antecedent variables are the key inputs to the independent variables.
- Introduction of moderating variables for the application of engineering processes and intra-organisational knowledge transfer.

The moderating variable is a variable that influences the direction and the strength of the relationship between the independent variable and the dependent variable. Baron and Kenny (1986)

- Introduction of the control variable for the dependent variable. The control variable is the variable that must be kept constant to minimise disturbances during the research studies.

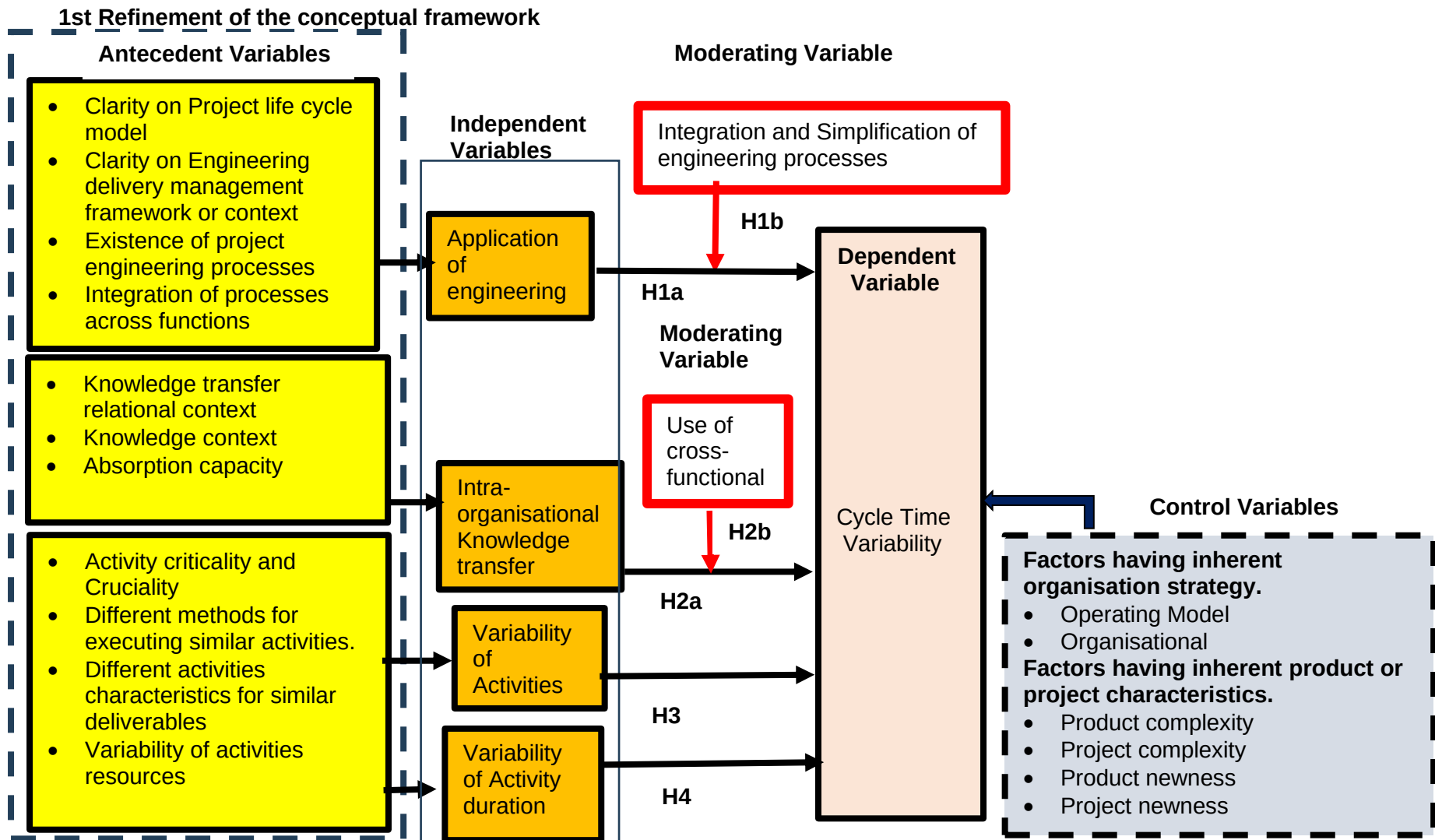


Figure 20: 1st Refinement of Conceptual Framework for Cycle Time Variability Minimisation of Similar Engineering Deliverables

Source: Author

2.11 Conclusion

In this chapter, the **initial conceptual framework** was introduced, and literature review presented on the following:

- Factors contributing to variability of cycle times.
- Key focus areas for cycle time variability minimisation.

The **updated conceptual framework** emanating from the literature review was presented. In the next chapter the research methodology is presented.

CHAPTER 3

3 RESEARCH METHODOLOGY

3.1 Introduction

In this chapter, the research process is elaborated upon. The approach to data collection is provided, the targeted population and the targeted sample defined. The measuring scales for the research are explained in detail and a brief explanation on the framework model for minimising cycle time is provided. The details of the framework model are provided in detail in Chapter 5.

3.2 Research philosophy

The researcher's adopted philosophy stems from a **pragmatism** point of view in which both the qualitative and quantitative methods are accommodated as the research involved gathering a mixture of both quantitative and qualitative data in the form of survey questions and project schedules activities and activities durations. According to Saunders et.al, (2006) the contention to choose either the positivist philosophy or the Interpretivism philosophy is often observed. Drawing largely from Tashakkori and Teddlie, (1998) Saunders et al, (2006) assert that studies should be done in what interest the researcher and deemed appropriate, and the results should be used to bring about positive consequence within the value system.

3.3 Research approach

The nature of this research is a **mixed approach** with more inclination into the **inductive approach** as it involves an attempt to build a theory from data analysis and a combination of relevant models in the field of study. Synthesising data analyses from research surveys and relevant models in the field of study will lead to the development of the conceptual framework and ultimately a development of theory in further research.

Saunders et.al, assert that in using the inductive approach, the theory follow data rather than in the deductive approach. The inductive approach is more appropriate and realistic in research that involve human interactions. (Saunders et al. 2006)

3.4 Research strategy

Aligned with the inductive approach, the strategy for this research involves conducting research surveys to obtain opinions on specific formulated research questions, gathering secondary data from power stations' schedules, analysing and synthesising the results, updating conceptual framework, and developing the framework model from the conceptual

framework and synthesised results. Figure 21 below indicates a schematic illustration of the chosen research philosophy, research approach and strategy and their context.

The research Onion

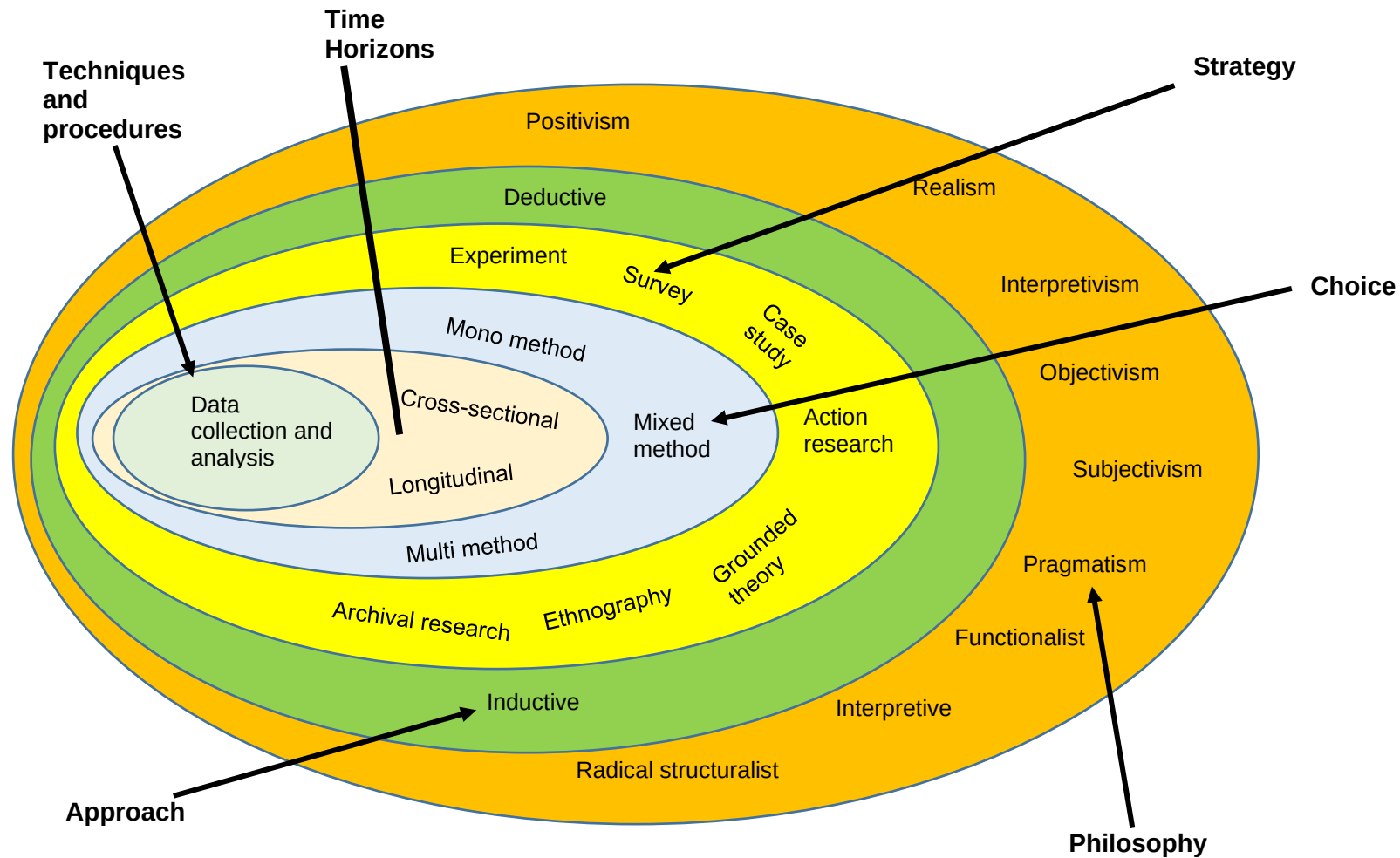
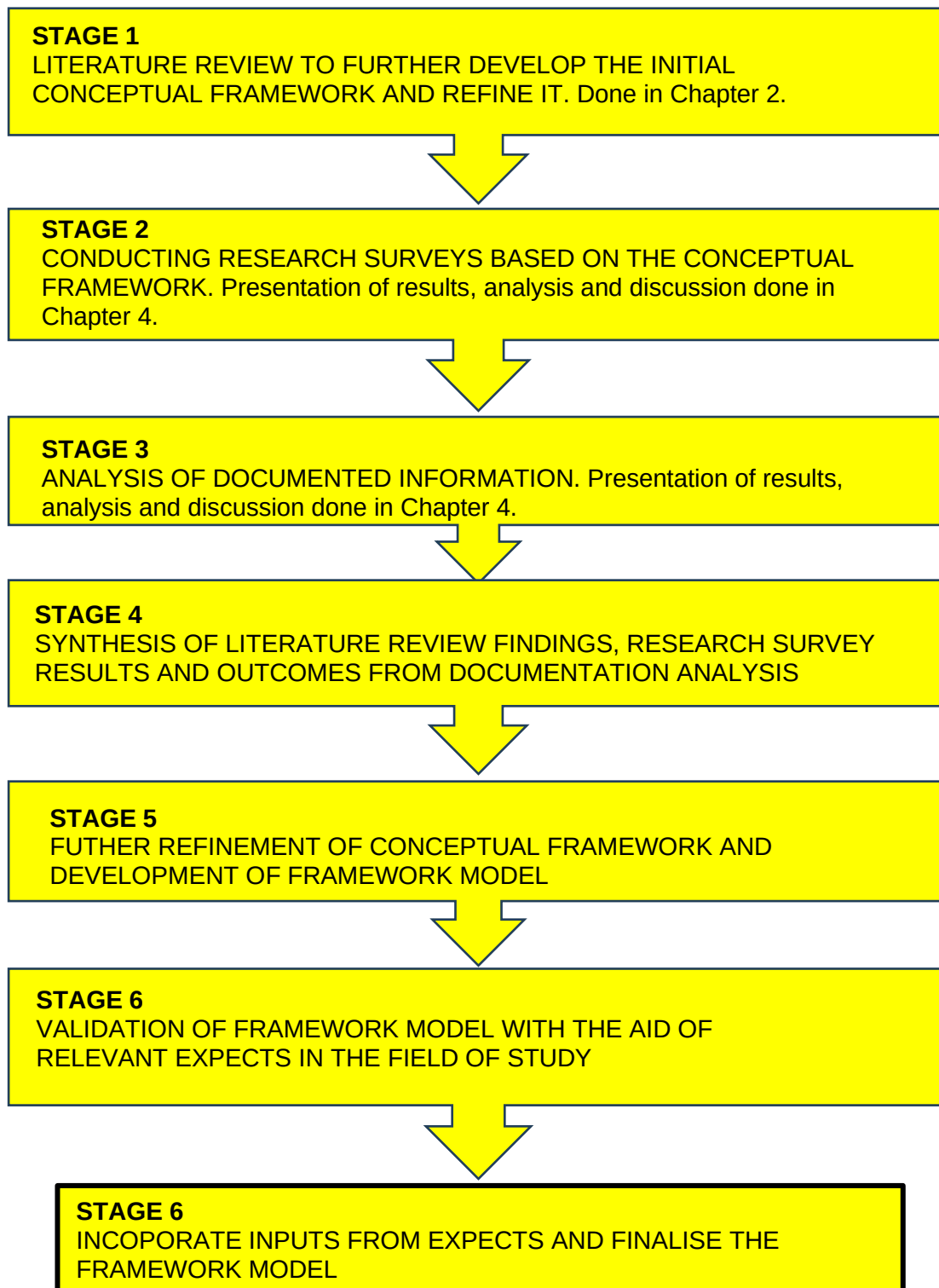


Figure 21: The Research Onion

Source: Mark Saunders, Philip Lewis and Adrian Thornhill 2006

3.5 Research Design

The research design is exploratory in nature. Below figure illustrates steps taken in conducting the research



Source: Author

3.6 Data Collection methods

3.6.1 Primary Data

3.6.1.1 Target population

A population of at least 60 personnel consisting of Eskom project engineering managers, construction managers, project engineers, engineering discipline managers, and project managers working on Eskom power plant new built and major refurbishment projects.

3.6.1.2 Target sample

The sample size was aimed at a third of the target population (at least 20 participants) to get as much representation as practically possible.

3.6.2 Secondary Data

3.6.2.1 Target population

The target population consisted of project schedules from Eskom major refurbishment projects from running stations.

3.6.2.2 Target sample

Below are the target samples and the reasons for choosing them:

- Basic design project schedules from Eskom Matimba Power Station and Lethabo Power Station control and instrumentation projects. These project schedules activities and activities durations were chosen for the following reasons:
 - They were coming from the top two performing generation plants in Eskom with comparable amount of energy generated.
 - There was an attempt to optimise engineering resources by having cross roles between engineering design leads within the two projects. (i.e.) the engineering design lead for Matimba power station would also play a role of Lethabo C&I design engineer and vice versa.
 - The researcher anticipated to see some pattern reflecting the impact of crossing the roles.
 - They include a variety of engineering disciplines and plants areas such as: Boiler Plant, Bulk Materials Handling plant, Heating and Ventilation (HVAC), chemical plant engineering, Electrical plant engineering, civil engineering and Turbine plant engineering.

- Pre- concept design (pre-CRA phase) schedules activities and activities durations from Eskom Matimba Power Station, Lethabo Power Station and Majuba Power Station medium voltage (MV) projects.

These projects schedule activities and activities durations were chosen for the following reasons:

- They demonstrate the initiation stage of Eskom engineering project development activities.
- Concept Designs (CRA phase) schedules activities and activities durations for Lethabo and Kendal High frequency transformers (HFT)
- These projects schedule activities and activities durations were chosen for the following reasons:
- They represent projects schedules activities and durations of projects that are involved in the change of technology.
 - The HFT technology was new in Eskom. Kendal and Lethabo power station were the first stations selected to implement these projects.

3.7 Research Ethics

The ethics of the research was managed through the Northwest University research ethics process in which the researcher had to obtain a research ethics clearance before the research could be conducted. The research clearance included submission of:

- Research proposal
- Research questionnaire questions for scrutiny by the research ethics committee
- Research consent form to be distributed to the candidates.
- Proof of attending the relevant research ethics courses and being declared competent.
- Permission to conduct research in Eskom.

The research questionnaire questions were forwarded together with the consent forms and permission to conduct research in Eskom was provided by the relevant authorities.

3.8 Research design

3.8.1 Primary Data

The researcher opted to group the research questionnaire questions according to the main topics to gather:

- Information on candidates' profiles.
- Opinion on existing systems used to minimise cycle time variability and alignment with project management processes.
- Opinion on benefits of minimising cycle time variability.
- Opinions on research questions **based on the 1st refined conceptual framework**. (The main factors of focus)

3.8.1.1 Measurement scales

- A 4-point Likert scale was utilised on the research survey questions to obtain opinion from participants. The researcher opted to use the 4-point Likert scale to mitigate the risk of not obtaining opinion on some questions from participants considering the sample size.
- A 4-point Likert scale does not provide an option for a neutral opinion implying that participants are forced to provide an opinion on the questionnaire question statement.
- The researcher's confidence to use the 4-point Likert scale emanated from the fact that the sample comes from a targeted population within the specialised project management environment.

Below is a typical example of obtaining opinion concerning the alignment of Eskom engineering processes with the project management processes.

- Eskom engineering processes are aligned with the project management processes.

Strongly Agree	Agree	Disagree	Strongly Disagree
-------------------	-------	----------	----------------------

Strongly agree relates to 4 points, agree relates to 3 points, disagree relates to 2 points and strongly disagree relates to 1 point.

3.8.2 Secondary Data

The researcher opted to make use of sampled power stations' project schedules as explained in targeted sample above.

3.8.2.1 Measurement scales

A comparison among activities and activities durations from sampled projects schedules, mentioned in 3.6.2.2 above was used as a measuring scale. The comparison was achieved by plotting similar projects activities durations on the same set of axes in order to observe the variations on the activities and activities durations profiles.

3.9 Reliability and validity

3.9.1 Reliability

Reliability indicates the accuracy of the research instrument and the extent of consistent measurement across the various items in the instruments. Leedy and Ormrod (2001), Mohajan (2017).

In this research, the Linkert scale is used as a measuring instrument for primary data.

The researcher opted to use the Cronbach alpha reliability test for its simplicity to use on the Likert scale instrument. This test was conducted on the post survey questionnaires questions for the main factors. The Cronbach alpha is expressed as follows:

$$\alpha = \left(\frac{k}{k-1} \right) \frac{(s_y^2 - \sum s_i^2)}{s_y^2}$$

Where k is the number of questions. The value criteria for α is generally accepted as 0.7. Mohajan (2017). Value above 0.7 are consider acceptable thus indicating acceptable levels of reliability. The alpha value for the main factors of this research = **0.75** which is deemed acceptable. There was no need to assess the reliability of the secondary data as it was extracted from Eskom database with Eskom's permission.

3.9.2 Validity

Validity involves the soundness and effectiveness of the measuring instruments as it attempts to identify exactly what the test should measure and whether it measures what it is meant to measure. Robson (2011). Leedy and Ormrod (2001).

Mohajan (2017) suggest the following to increase the validity of the measuring instruments:

- To ensure goals and objectives are clearly defined and operationalised.
- To match the assessment measure to the goals and objectives of research.
- To look for troublesome wording and ambiguity and correct accordingly.
- Where possible to compare the measure with other measures, or available data.

In this research, to minimise the risk of misunderstanding by participants, the researcher forwarded the pilot survey questions to three different participants with diverse roles in the project management space and requested a face-to-face interview with them in order to engage on the quality of the research questionnaires and ease of understanding. The engagement resulted in minor comments and the comments were incorporated in the research questionnaire questions.

Validation of the measuring tool was only required for primary data since it involved questionnaire surveys questions which relied on the participants opinions thus increasing the likelihood of misunderstanding the research survey questions either due to a poorly constructed research survey question or relevance.

The secondary data was extracted from Eskom database with Eskom's permission and was deemed accurate enough for the purpose of the research. Since secondary data also dealt with similar key factors to the primary data, it also served as a further validation component of the primary data and vice versa.

3.10 Presentation of results and analysis

The presentation of results for the primary data was achieved by plotting bar graphs that visually indicated the number of participants agreeing or disagreeing with relevant research questionnaire statements; while the presentation of the secondary data results was achieved by means of plotted graphs of similar projects schedules activities and activities durations on the same set of axes.

The analysis of primary data results was achieved by consolidating opinions as per the questionnaire design main topics grouping. The Likert scale analysis was conducted by comparing the results against the 4-point Likert scale criteria. The **T-test** was used to test the hypothesis on the key factors' results.

The results were compared with the research investigative questions and the literature review. Similarly, the analysis of secondary data was achieved by identifying representative graphs and analysis of the graph profile. Inference of the graph profiles on the focus areas of the research was done and comparison of the results with the research investigative questions was conducted.

3.11 Development of framework model

The development of the framework model for minimising cycle time variability was done progressively as the research information unfolds from initial literature review up to model validation by experts in the field of study.

The researcher captured the progressive development of the framework by updating the conceptual framework after major changes are observed from emerging information. The sources of emerging information were:

- The Literature review.
- The secondary data from the sampled project schedules
- The research survey results.
- The input from experts in the field of study.

3.11.1 Validation by experts in the field of study

Phase 1

The following steps were followed during the model validation by experts in the field of study:

- Identification of relevant experts in the engineering projects development area.
The identified experts consisted of:
 - Manager Complex Projects from Eskom Project Development Department
 - Chief Advisor Project Development from Project Development Department
 - 2 Middle Managers Project from Project Development Department
 - Senior Advisor Capital Efficiency from Capital Efficiency Strategy Department
- Invite experts to attend the validation meeting and provide background information for the meeting.
 - The model and basic background was forwarded to the experts before the meeting.

- Facilitate the engagement meeting and receive feedback from different experts on the usefulness and relevance of the model in the engineering project development area.
 - Experts confirmed that the model was relevant and could be more useful if it is operationalised with simplicity.

Phase 2

The researcher forwarded questionnaires with regards to the model links requesting experts to provide their independent opinion on the levels of influence of variables contributing to cycle time variability and to provide the weighting on the key independent variables.

The model and the relevant validation information is captured in detail in Chapter 5 of this research.

3.12 Conclusion

In this chapter, the research process was elaborated upon. The approach to data collection provided, the targeted population and the targeted sample defined. The measuring scales for the research were explained in detail and a brief explanation on the framework model for minimising cycle time was provided. In the next chapter the presentation, the analysis and discussion of results are presented.

CHAPTER 4

4 PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

4.1 Introduction

In this chapter the presentation, analysis and discussion on both the primary and secondary data for the research are done and the salient points extracted. The presentation, analysis and discussions for the primary data are grouped per main topics, while the presentation for secondary data is grouped per sampled power station project schedules and the analysis and discussions are grouped per identified representative project schedules from the presented secondary data.

The chapter concludes with the latest updated conceptual framework.

4.2 Presentation and analysis of primary data

The primary data was collected by means of questionnaire surveys consisting of 20 different questions, which were based on the formulated investigative questions, the research objectives, and the purpose of the research.

As indicated in Chapter 3 under the research design heading, the research questionnaire questions are grouped according to the main topics for consolidated opinions. Below table indicates the main topics and related questionnaire survey questions.

Table 6: Main topics and Research survey Questions

MAIN TOPIC	RESEARCH SURVEY QUESTIONS
Candidates Profiles	Question 1 and 2
Existing systems and practices	Question 3,4,5,6 and 9, 10
benefits of minimising cycle time variability for similar engineering deliverables	Question 19 and 20
Research questions based on the 1st refined conceptual framework. (Key Factors of focus)	Questions 7, 8, 12, 15, 16, and 17 relates to H1a, H1b, H2b, H2a, H3 and H4 respectively.

4.2.1 Response rate for Questionnaire surveys

Table 7: Response rate for Questionnaire surveys

Number of research surveys sent	Targeted Sample	Number of returned research surveys	Percentage Response based on Target Sample	Percentage Response based on Actual number of surveys forwarded
26	21	15	71%	58%

4.2.1.1 Discussion on the response rate

The research took place during national shutdown in which it was difficult to reach candidates for following up, to mitigate the risk poor response, the researcher opted to forward 5 questionnaires more that the targeted sample.

4.2.2 Candidate profiles

Question 1 and Question 2

Table 8: Response to questions 1 and 2

Question 1 Candidates Role in the Eskom power generation project environment	Question 2 Candidates Experience in the Eskom power generation project environment.
Project Engineers	1 candidate with 2 to 5 years' experience 7 candidates with more than 10 years' experience. Total number of candidates: 8
Project Managers	1 candidate with 5 to 10 years' experience 4 candidates with more than 10 years' experience. Total number of candidates: 5
Engineering Managers	2 candidates with more than 10 years' experience. Total number of candidates: 2

4.2.2.1 Discussion on candidates' profiles

The candidates who participated in the survey were well experienced in the project engineering and project management space. The majority of candidates had more than 10 years' experience in the project management space.

4.2.3 Summary of results based on the Likert scale.

As indicated in the measuring instruments in Chapter 3, the measuring scale used for primary data is the 4-point Likert scale in which 1 indicates strongly disagree, 2 indicates disagree, 3 indicates agree and 4 indicates strongly agree. To be able to determine the results, the 4-points are divided into 4 equal intervals as follows:

Strongly Agree is between 3.25 and 4

Agree is between 2.5 and 3.25

Disagree is between 1.75 and 2.5

Strongly disagree is between 1 and 1.75.

The average score of responses to questionnaire questions are used to determine the results and are compared against the pre-determined intervals. The mode is also calculated to provide some form of assurance that there are no major errors in calculations and serving as some form of validation. Below table indicates the summary of results based on the Likert scale.

Summary of results based on the Likert scale.

Respondent	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	Mode	Results
Question 3	2	2	2	2	3	3	3	3	2	3	1	2	2	3	1	2.3	2	Disagree
Question 4	2	3	2	2	3	2	2	3	2	2	1	3	3	3	2	2.3	2	Disagree
Question 5	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	2.9	3	Agree
Question 6	3	3	4	4	2	1	2	2	2	2	1	2	3	3	4	2.5	2	Agree
Question 7	4	3	4	2	4	4	3	3	2	3	4	3	3	3	4	3.2	3	Strongly Agree
Question 8	4	4	4	4	2	4	3	3	3	3	2	3	4	3	4	3.3	4	Strongly Agree
Question 9	3	2	2	2	3	3	2	3	3	1	1	3	2	2	1	2.2	3	Disagree
Question 10	2	2	1	2	4	4	3	3	3	2	3	3	3	3	1	2.6	3	Agree
Question 11	2	3	1	2	2	3	2	3	3	2	2	3	3	3	1	2.3	3	Disagree
Question 12	3	4	4	4	4	4	3	4	3	4	4	3	4	4	4	3.7	4	Strongly Agree
Question 13	2	2	1	2	2	2	2	4	3	2	3	2	2	2	1	2.1	2	Disagree
Question 14	2	4	4	2	2	3	2	3	2	3	2	3	2	2	2	2.5	2	Agree
Question 15	3	4	4	3	3	4	3	3	2	3	3	3	3	3	3	3.1	3	Agree
Question 16	4	3	4	4	3	4	3	3	3	3	3	3	3	3	4	3.3	3	Strongly Agree
Question 17	4	4	4	4	3	4	3	3	3	3	3	3	3	3	3	3.3	3	Strong Agree
Question 18	3	3	1	3	2	2	3	4	3	2	3	3	3	4	4	2.8	3	Agree
Question 19	3	4	4	4	3	4	3	3	3	3	3	4	3	4	4	3.4	3	Strongly Agree
Question 20	3	4	4	4	3	4	3	3	3	3	3	4	3	4	3	3.4	3	Strongly Agree

Table 9: Summary of research survey results

Benefits

Key factors

Existing systems
and practices

4.2.4 Presentation and Analysis on Existing Systems and Practices

Below is the presentation and analysis on existing systems relating to questionnaire Questions 3, 4, 5, 6, 9, 10, 11, 13, 14, and 18.

Question 3

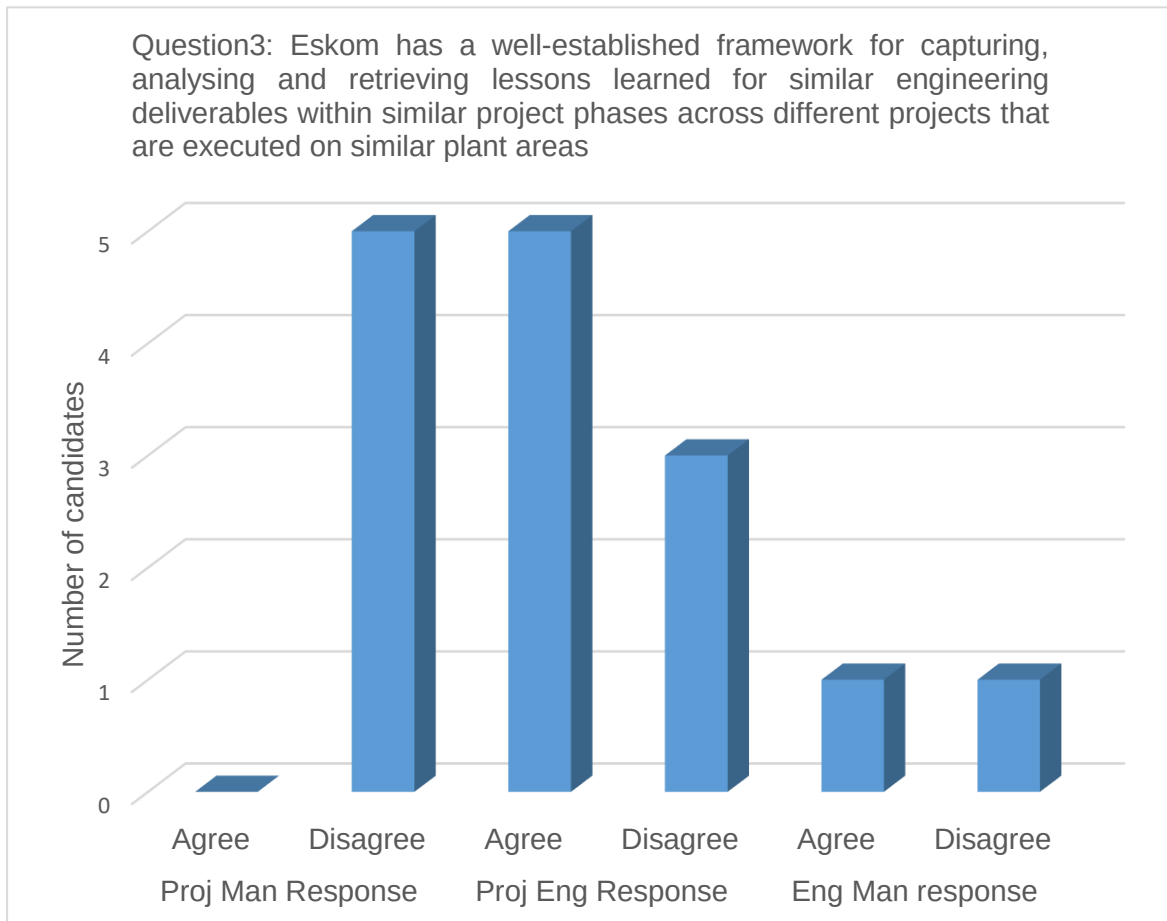


Figure 22: Response to Question 3

The results in figure 22 indicate that 6 out of 15 (40%) candidates agree that Eskom has a well-established framework for capturing, analysing, and retrieving lessons learned for similar engineering deliverables within similar project phases across different projects that are executed on similar plant areas.

Project engineers forms the majority of those who agree (i.e.) 5 out of 8 (62, 5%) of project engineers' candidates and the other candidate was 1 out of 2 (50%) of engineering manager candidates. All 5 out 5 (100%) project managers disagree and the balance of those who disagree constitute 3 out of 8 project engineers (37,5%) and 1 out of 2 (50%) engineering manager.

Question 4

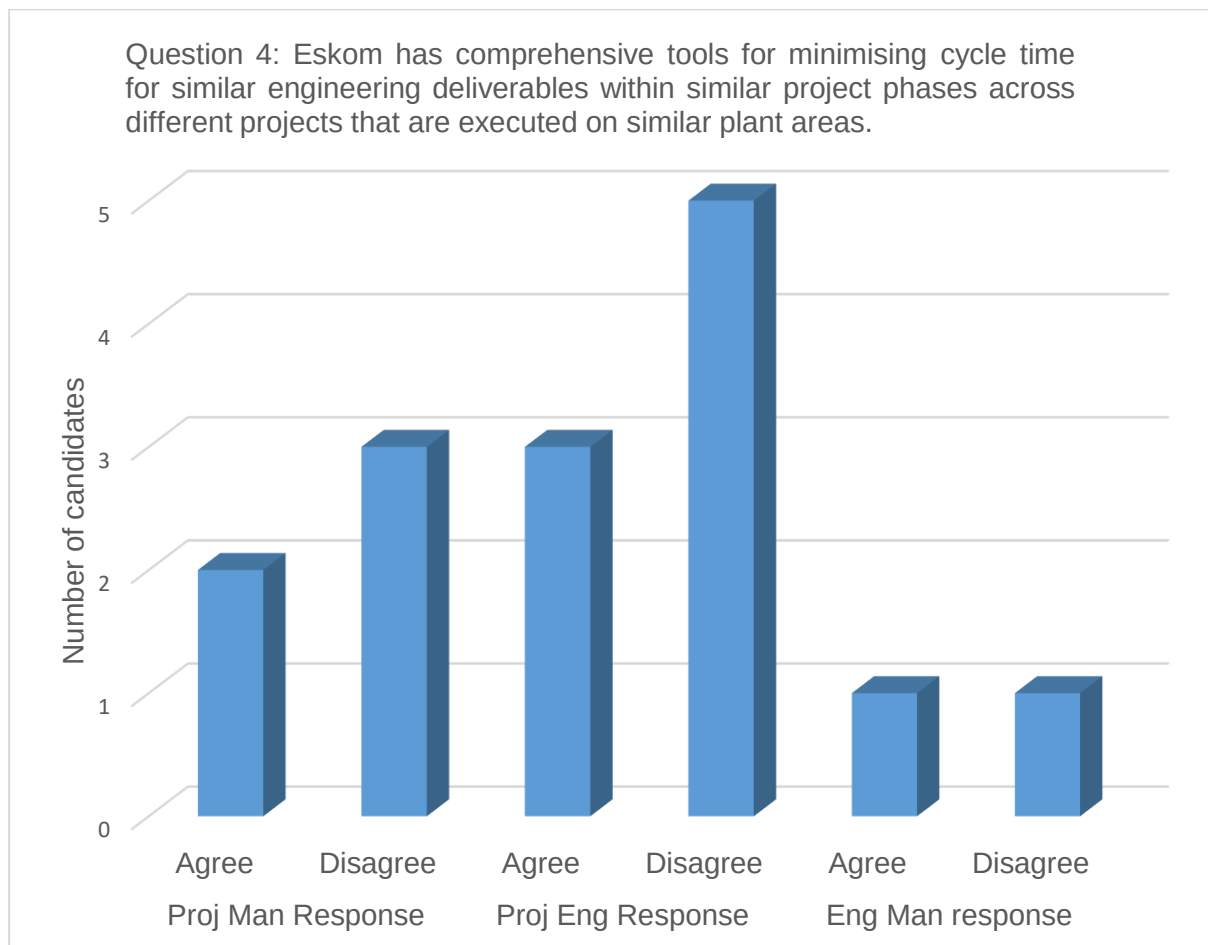


Figure 23: Response to Question 4

The results in figure 23 indicate that 6 out of 15 (40 %) of candidates agree that Eskom has comprehensive tools for minimising cycle time for similar engineering deliverables within similar project phases across different projects that are executed on similar plant areas.

Project engineers forms the majority of those who agree (i.e.) 3 out of 8 (37.5%) of project engineers candidates and the other candidates were 1 out of 2 (50%) engineering manager candidates and 2 out of 5 (40%) project managers. Project engineers also forms the majority of those who disagree (i.e.) 5 out of 8 (62,25%) project engineers candidates and the balance of those who disagree constitute 3 out of 5 (60%) project managers and 1 out of 2 (50%) engineering manager candidate.

Question 5

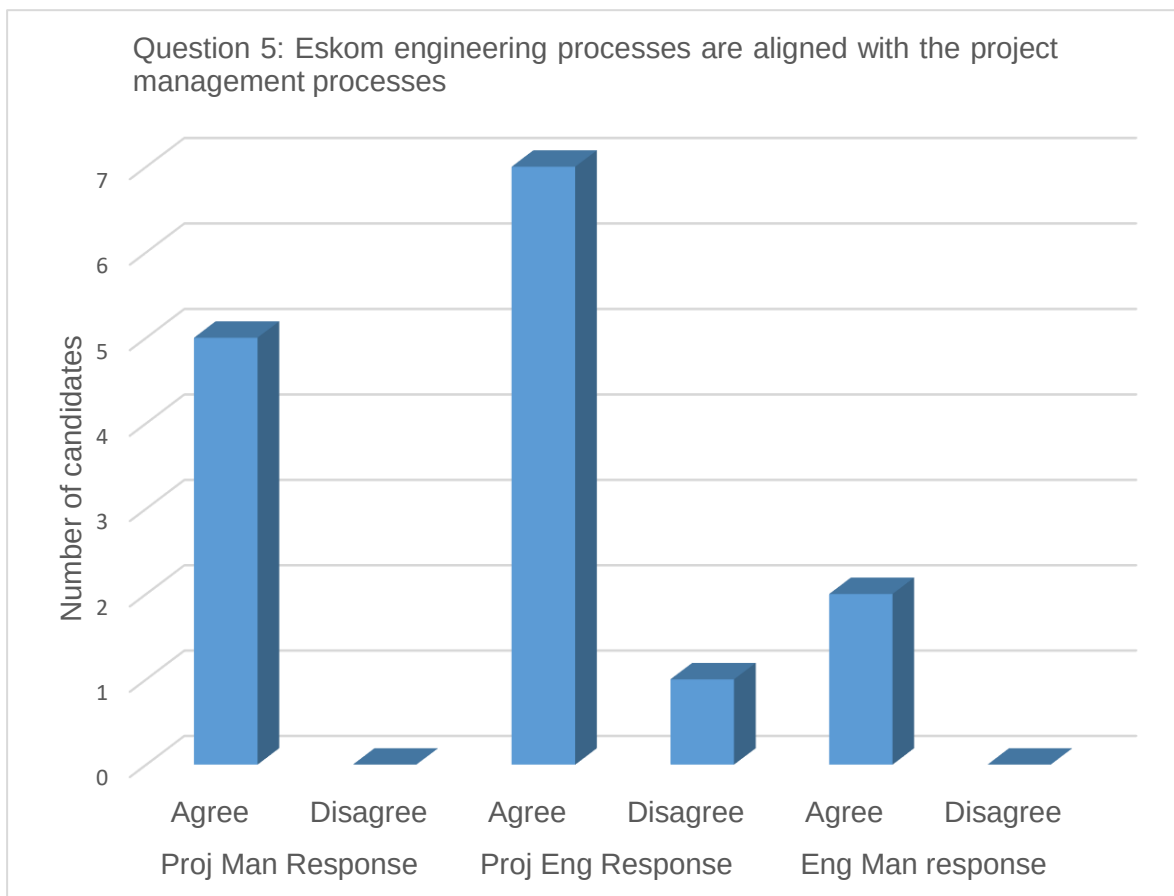


Figure 24: Response to question 5

The results in Figure 24 indicate that 14 out of 15 (93%) candidates agree that Eskom engineering processes are aligned with the project management processes. Only one candidate disagrees, and the disagreeing candidate is the project engineer.

Question 6

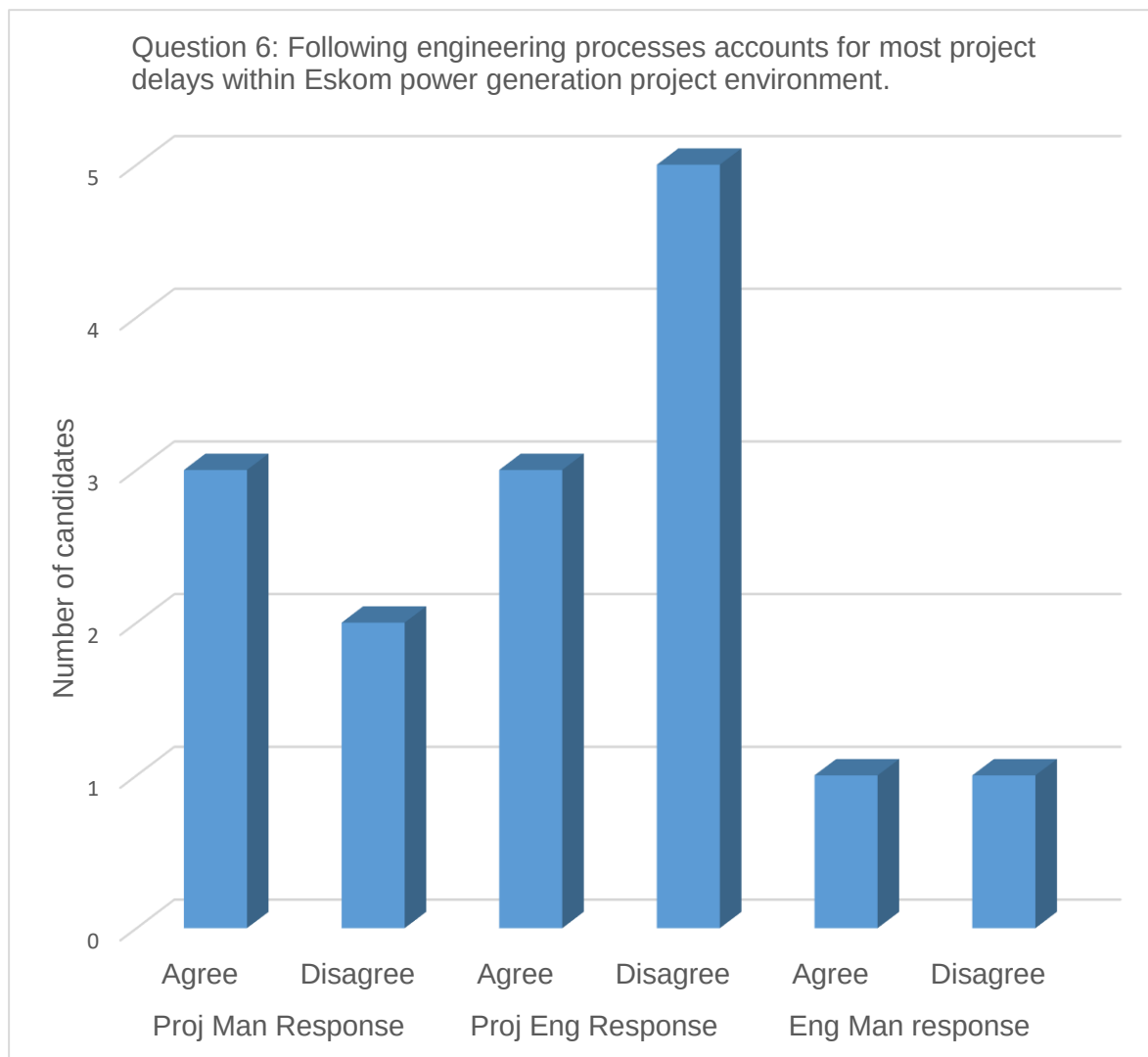


Figure 25: Response to question 6

The results in figure 25 indicate that 7 out of 15 (46.6%) of candidates agree that following engineering processes accounts for most project delays within Eskom power generation project environment.

Project managers forms the majority of those who agree (i.e.) 3 out of 5 (60%) project managers and the other candidates were 3 out of 8 (37.5%) project engineers and 1 out of 2 (50%) engineering manager. Project engineers forms the majority of those who disagree (i.e.) 5 out of 8 (62.5 %) project engineers and 1 out of 2 (50%) engineering manager also disagreed.

Question 9

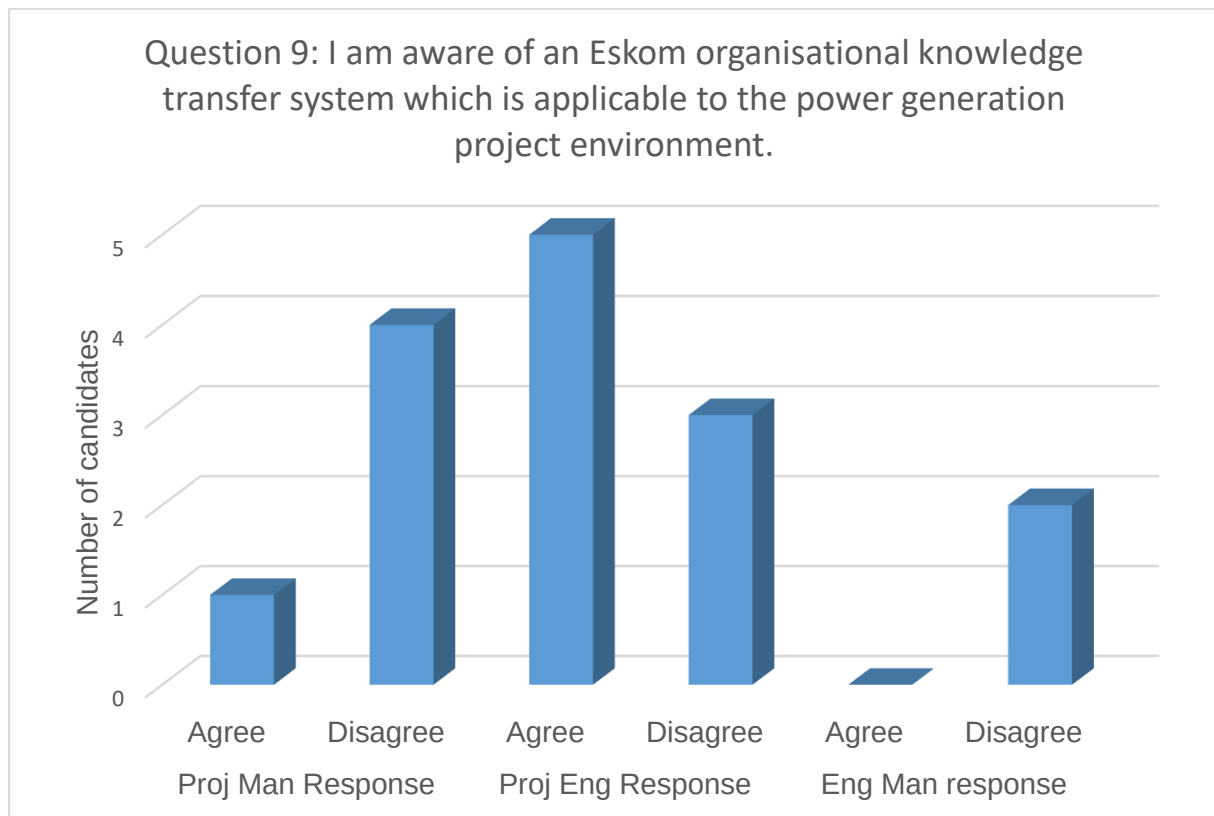


Figure 26: Response to Question 9

The results in figure 26 indicate that 6 out of 15 (40%) of candidates agree that they are aware of an Eskom organisational knowledge transfer system which is applicable to the power generation project environment.

The candidates who agree consist of 5 out of 8 (62.5%) Project engineers and 1 project manager. 4 out of 5 (80%) of project managers and all (100%) engineering managers disagree.

Question 10

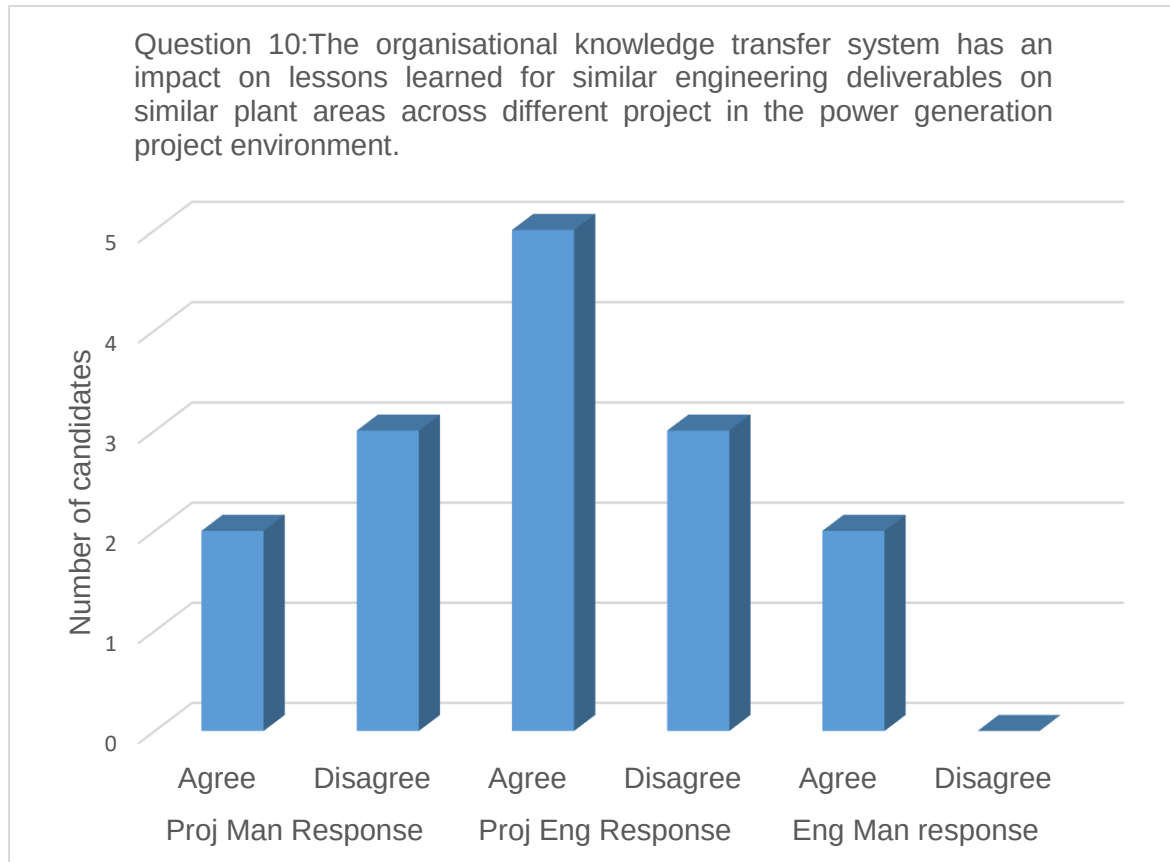


Figure 27: Response to Question 10

The results in figure 27 indicate that 9 out of 15 (60%) candidates agree that the organisational knowledge transfer system has an impact on lessons learned for similar engineering deliverables on similar plant areas across different projects in the power generation project environment. Project engineers forms the majority of those who agree (i.e.) 5 out of 8 project (62.5 %) engineers and the other candidates were all (100%) engineering managers and 2 out of 5 (40%) project managers. Project managers forms the majority of those who disagree in percentage (i.e.) 3 out of 5 (60%) project managers and the balance of those who disagree constitute of 3 out of 8 (37.5%) project engineers.

Question 11

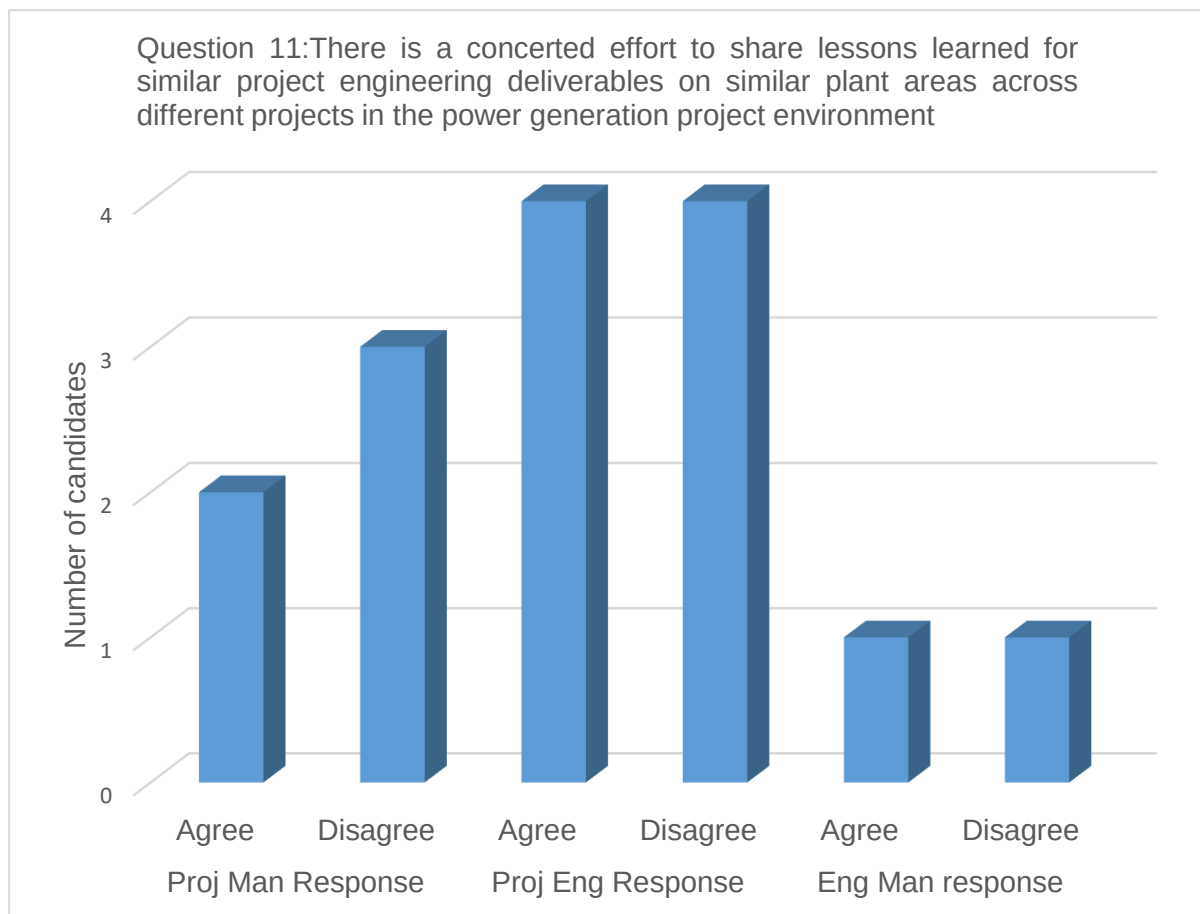


Figure 28: Response to Question 11

Figure 28 indicates that 7 out of 15 (46.6%) of candidates agree that there is a concerted effort to share lessons learned for similar project engineering deliverables on similar plant areas across different projects in the power generation project environment.

Project engineers forms the majority of those who agree (i.e.) 4 out of 8 (50%) project engineers and the other candidates were 2 of 5 (40%) project managers and 1 out of 2 engineering managers. The candidates disagreeing consist of 2 out of 5 (40%) project managers, 4 out of 8 (50%) Project engineers and 1 out of 2 (50%) engineering manager.

Question 13

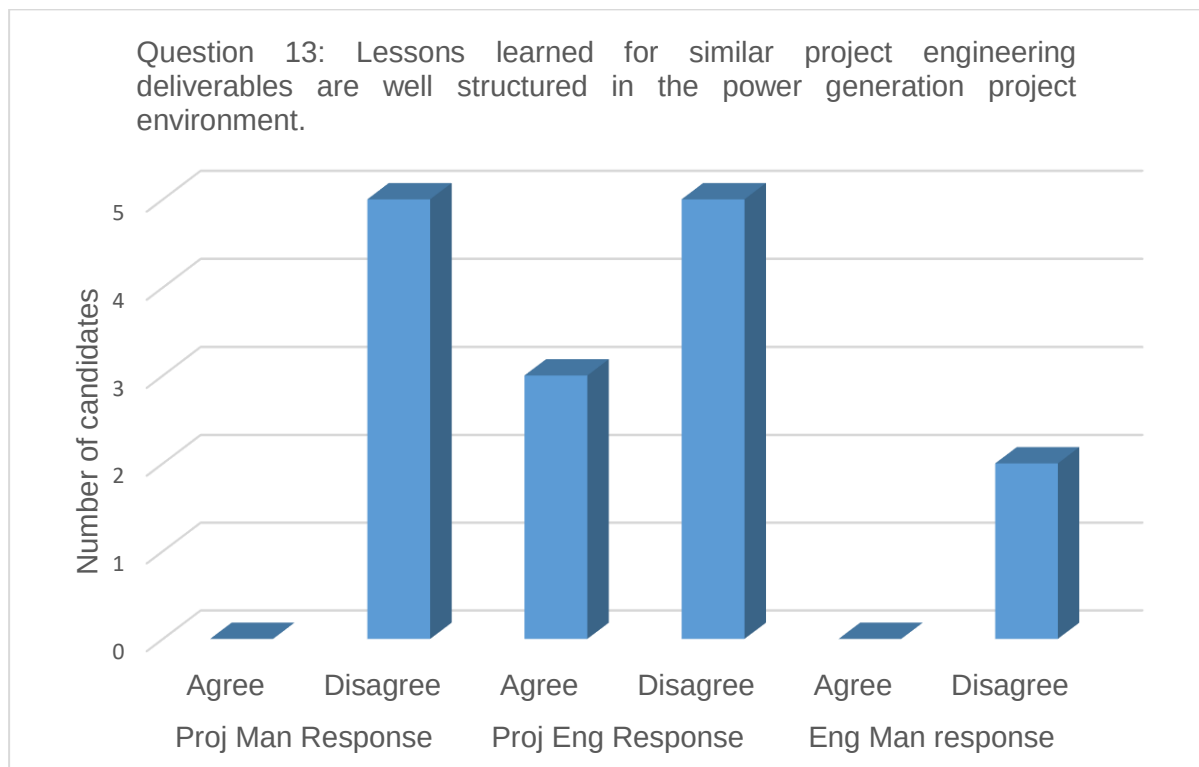


Figure 29: Response to Question 13

Figure 29 indicates that 3 out of 15 (20%) of candidates agree that lessons learned for similar project engineering deliverables are well structured in the power generation project environment. The candidates who agree consist of Project engineers only (i.e.) 3 out of 8 (37.5 %) Project engineers.

Question 14

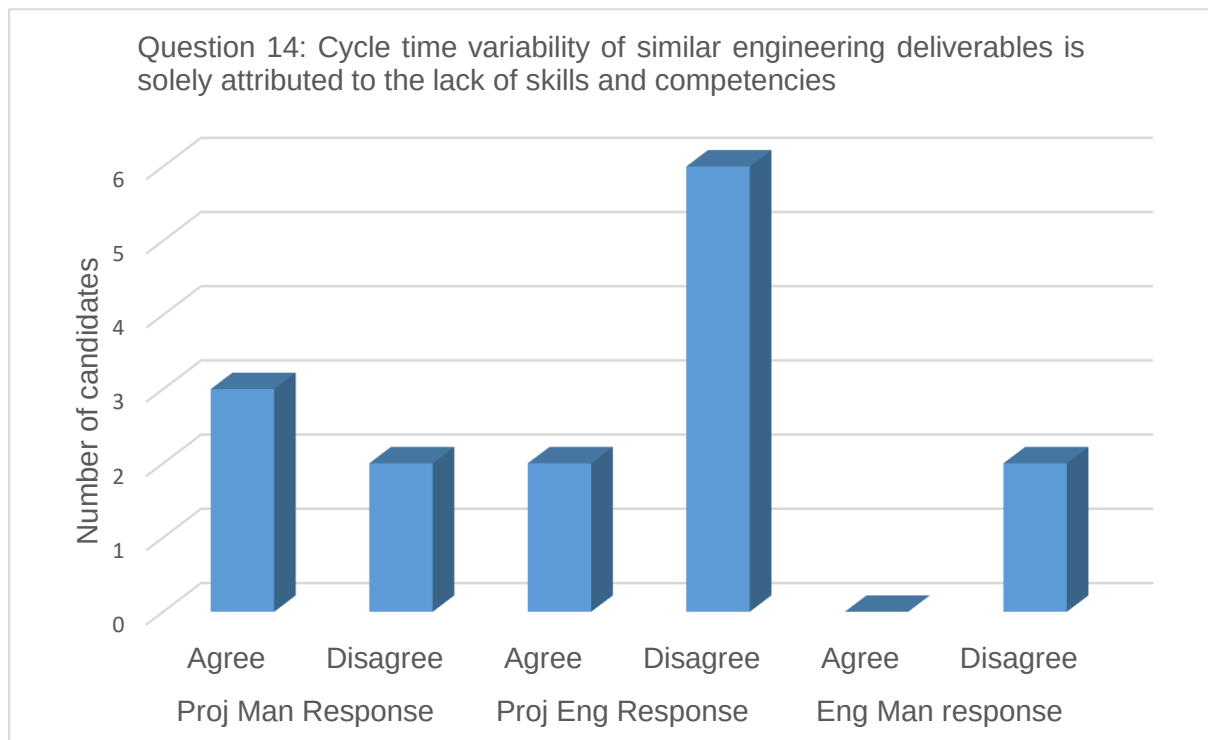


Figure 30: Response to Question 14

The results in Figure 30 indicate that 5 out of 15 (33%) of candidates agree that Cycle time variability of similar engineering deliverables is solely attributed to the lack of skills and competencies.

Project managers formed the majority of those who agree (i.e.) 3 out of 5 (60%) project managers and the other candidates were 2 out of 8 (25 %) project engineers. The candidates disagreeing consist of all (100%) engineering managers, 6 out of 8 (75%) Project engineers and 2 out of 5 (25%) project manager.

Question 18

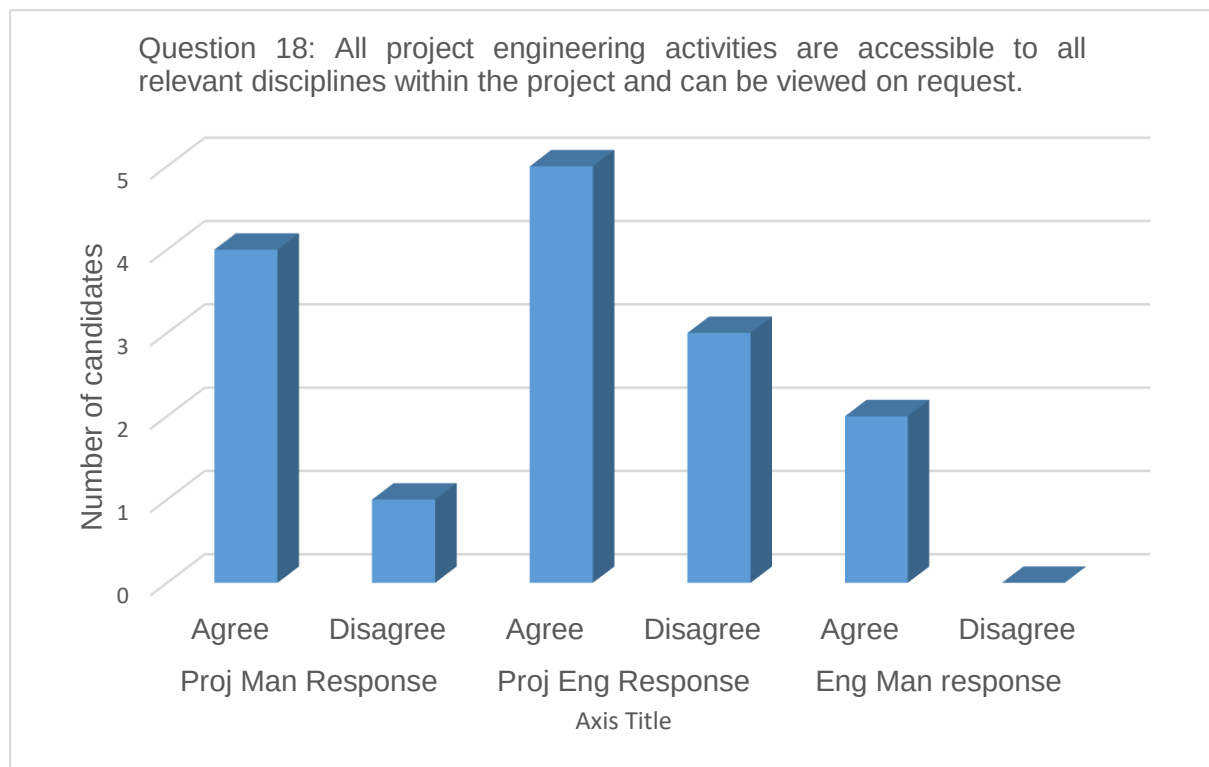


Figure 31: Response to Question 18

The results in Figure 31 indicate that 11 out of 15 (73%) of candidates agree that all project engineering activities are accessible to all relevant disciplines within the project and can be viewed on request.

The results shows that 4 out of 5 (80%) of project managers, all (100%) engineering managers and 5 out of 8 (62.5 %) project engineers formed part of those who agree while 1 out of 5 (20%) project managers and 3 out of 8 (37.75%) project engineers disagreed.

4.2.4.1 Discussion on Existing systems and practices

Discussion on question 3 results

The dominant opinion from the research survey conducted is that:

Eskom does not have well-established framework for capturing, analysing, and retrieving lessons learned for similar engineering deliverables within similar project phases across different projects that are executed on similar plant areas.

Having most participants indicating that Eskom does not have well-established framework for capturing, analysing, and retrieving lessons learned for similar engineering deliverables, is a serious concern for the following reasons:

- Based on Eskom's nature of the product it produces, it has many similar plant areas, which are likely to have similar problems or challenges. The lack of well-established framework discussed above would mean that, access to useful lessons learned from similar plant areas would be limited thus resulting in expensive repeats of similar mistakes.
- The limited flow of knowledge result in increased cycle time variability due to inconsistent integration of lessons learned in the subsequent projects.
- The lack of a well-established framework discussed above deprive new similar deliverables advantage of information for better planning and better project delivery risk management.

Lessons learned and project post-mortems form part of intra-organisational knowledge transfer they should feedback into new knowledge creation. A well -established framework can serve as a consistent means of feeding new created knowledge into the knowledge management process of the relevant community of practice.

Below figure 32 illustrates how the framework for capturing, analysing and retrieving lessons learned for similar engineering deliverables can feed into the knowledge management process. Analysed lessons learned can create new knowledge and should be stored in easily accessible repositories.

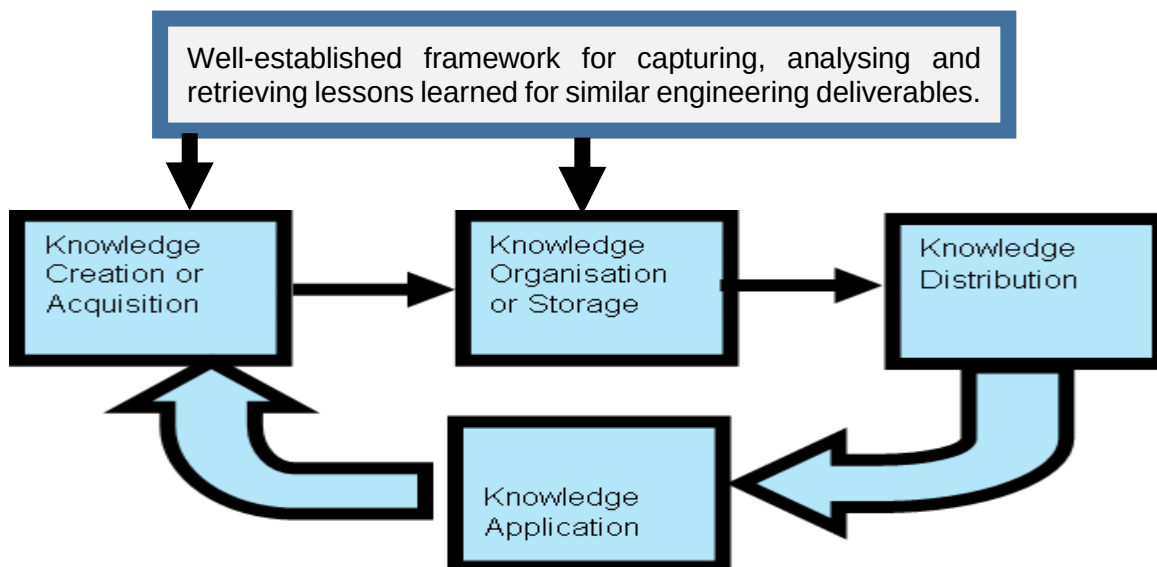


Figure 32: Adapted Knowledge Management Process

Original Source: Dahlan et.al (2005)

Adapted by: Author.

Tsai (2001) argues that better performance can be achieved if central networks are set up to provide access to new knowledge developed by others. It should be appreciated that lessons learned, and project post-mortems could be areas where new knowledge is created and should be fed back into the knowledge management processes in order to benefit the communities of practice and any other relevant entity.

Discussion on question 4 responses

The implication of having most participants indicating that Eskom does not have comprehensive tools for minimising cycle time for similar deliverables, is that efforts of minimising cycle time variability on similar engineering deliverables are likely to be minimal, unstructured and inconsistent. Inconsistent approach to minimising cycle time will lead to variability of cycle times of similar subsequent engineering deliverables as there would be no consistent basis to work with.

Above analysis clearly exposes a gap in the existing systems, which is the lack of or inadequate structured approach for minimising cycle time variability. This gap further reinforces the need for a framework that will assist in minimising cycle time variability for similar engineering deliverables.

Discussion on question 5 responses

The dominant opinion is that Eskom engineering processes are aligned with the project management processes.

The alignment of Eskom engineering processes with the project management processes is critical for the delivery of engineering deliverables. This dominant opinion is a good indication of the effects of the launched Eskom Engineering Operating Model that took place in 2012.

Discussion on question 6 responses

There seems to be a strong split between the project managers and the project engineers on the delays caused by following engineering processes, this is expected especially if engineering processes are not provided for in the schedules by project managers and are not simplified enough for ease of execution by engineers and their managers.

Discussion on Question 9 responses

The dominant opinion on question 9 statement is that candidates are not aware of an Eskom organisational knowledge transfer system that is applicable to the power generation project environment; this could be because the systems are not structured as indicated in question 3 and 4 response discussion.

Discussion on question 10 responses

The dominant response is that the organisational knowledge transfer system has an impact on lessons learned for similar engineering deliverables on similar plant areas across different projects in the power generation space, this further reinforce the need for structured systems that will assist in sustainable transfer of knowledge.

Discussion on question 11 responses

The dominant response to question 11 statement is that there is no concerted effort to share lessons learned for similar project engineering deliverables on similar plant areas across different projects in the power generation project space environment, this could be due to the inadequate systems of knowledge transfer or visibility of such systems.

Discussion on question 13 responses

The dominant response is that lessons learned for similar project engineering deliverables are not well structured in the power generation environment; this is consistent with responses in question 3 and 4.

Discussion on question 14 responses

The response is almost split like the response in question 6 in which the project managers' opinions were very strong on attributing engineering processes on project delays and engineers and engineering managers having a contrary view. To put the whole weight of cycle time variability on the lack of skills or competencies of individuals, is refusing to acknowledge the impact of knowledge transfer systems and application of engineering processes on the individual's ability to perform his or her duties.

4.2.4.2 Conclusion on existing systems and practices

The overall perception on existing systems is that:

- There is no framework nor adequate tools for minimising cycle time variability.
- There is no concerted effort to share lessons learned and the intra-organisational knowledge transfer is unstructured with minimal awareness of its existence.
- There is a strong agreement that Eskom engineering processes are aligned with the project management processes.

The main gaps are found in intra-organisational knowledge transfer.

4.2.5 Presentation and Analysis on the Benefits of minimising cycle time variability

Below is the presentation, analysis and discussion on the Benefits of minimising cycle time variability relating to questionnaire Questions 19 and 20.

Question 19

Response to Question 19

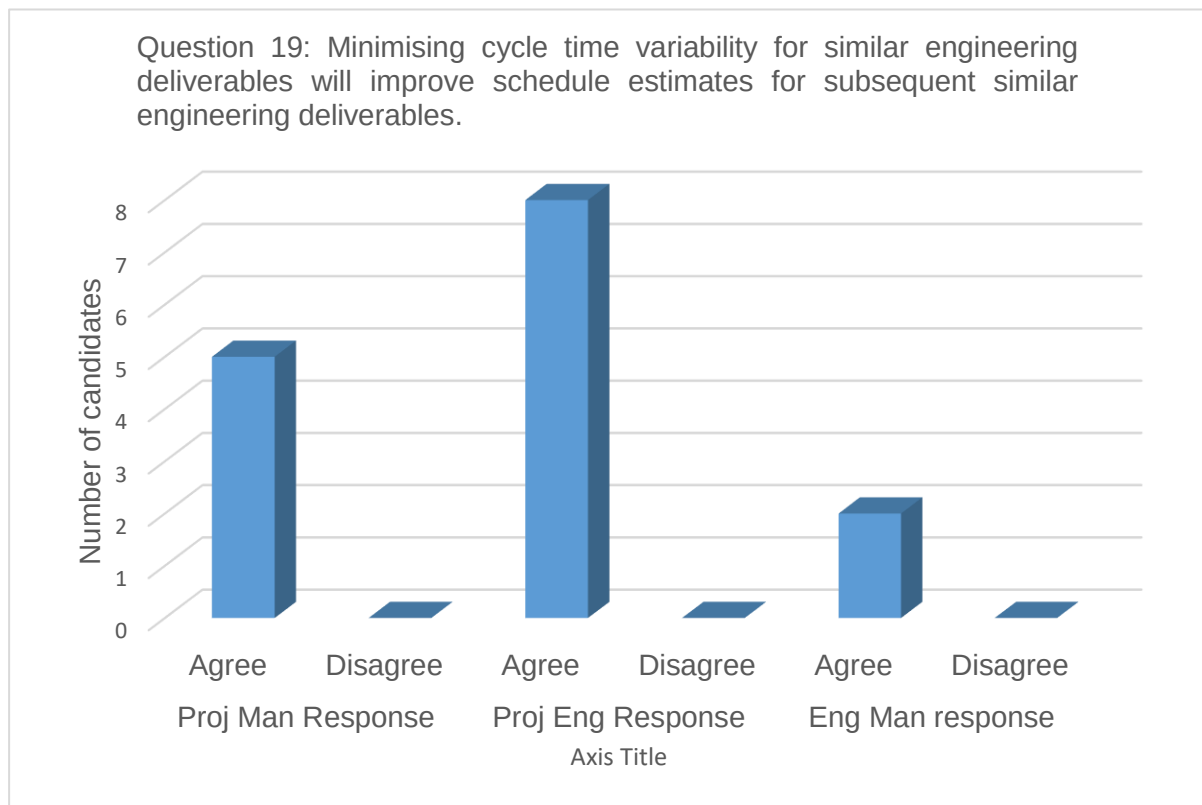


Figure 33: Response to Question 19

The results in Figure 33 indicate that all participants (100%) of candidates agree that minimising cycle time variability for similar engineering deliverables will improve schedule estimates for subsequent similar engineering deliverables.

Question 20

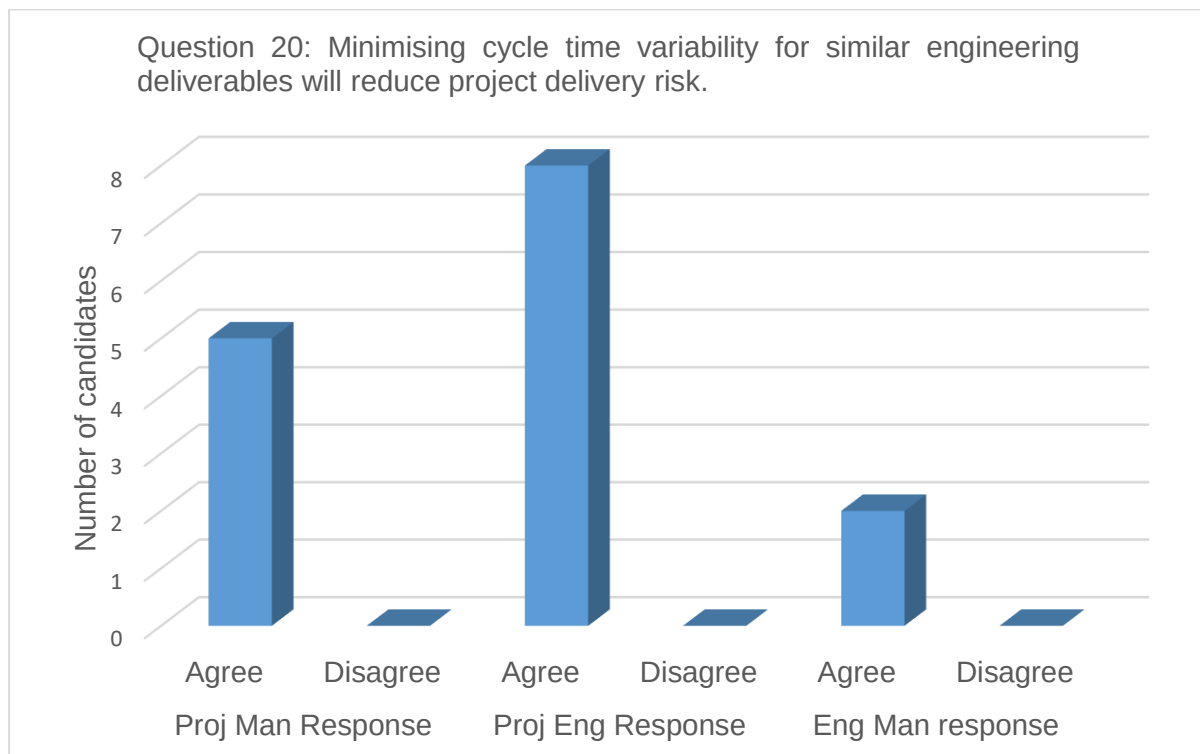


Figure 34: Response to Question 20

The results in Figure 34 indicate that all participants (100%) of candidates agree that minimising cycle time variability for similar engineering deliverables will reduce project delivery risk.

4.2.5.1 Discussion on Benefits of Minimising Cycle Time Variability

Discussion on question 19 responses

Since all agree that minimising cycle time variability for similar engineering deliverables improves schedule estimates for subsequent similar engineering deliverables, there are no gaps to discuss. The implication of this finding is that there will be increased buy-in in implementing solutions for minimising cycle time variability because of the awareness of the benefit derived.

Discussion on question 20 responses

Since all agree that minimising cycle time variability for similar engineering deliverables reduces project delivery risk, there are no gaps to discuss. The implication of this finding is that there will be increased buy-in in implementing solutions of minimising cycle time variability because of the awareness of the benefit derived.

4.2.5.2 Conclusion on Benefits of Minimising Cycle Time Variability

The overall perception is that minimising cycle time will be beneficial for the reduction of schedule risks and improvement of schedule estimation of subsequent similar engineering deliverables.

4.2.6 Presentation and Analysis of research questions based on the 1st refined conceptual framework. (Key Factors of focus)

This part is the backbone of this research as it is directly linked to the main deliverables of the research (i.e.) the conceptual framework and the framework model for cycle time minimisation of similar engineering deliverables.

Below is the presentation and analysis on the opinions on research questions based on the 1st refined conceptual framework relating to questionnaire questions 7, 8,12,15,16, and 17.

Question 7

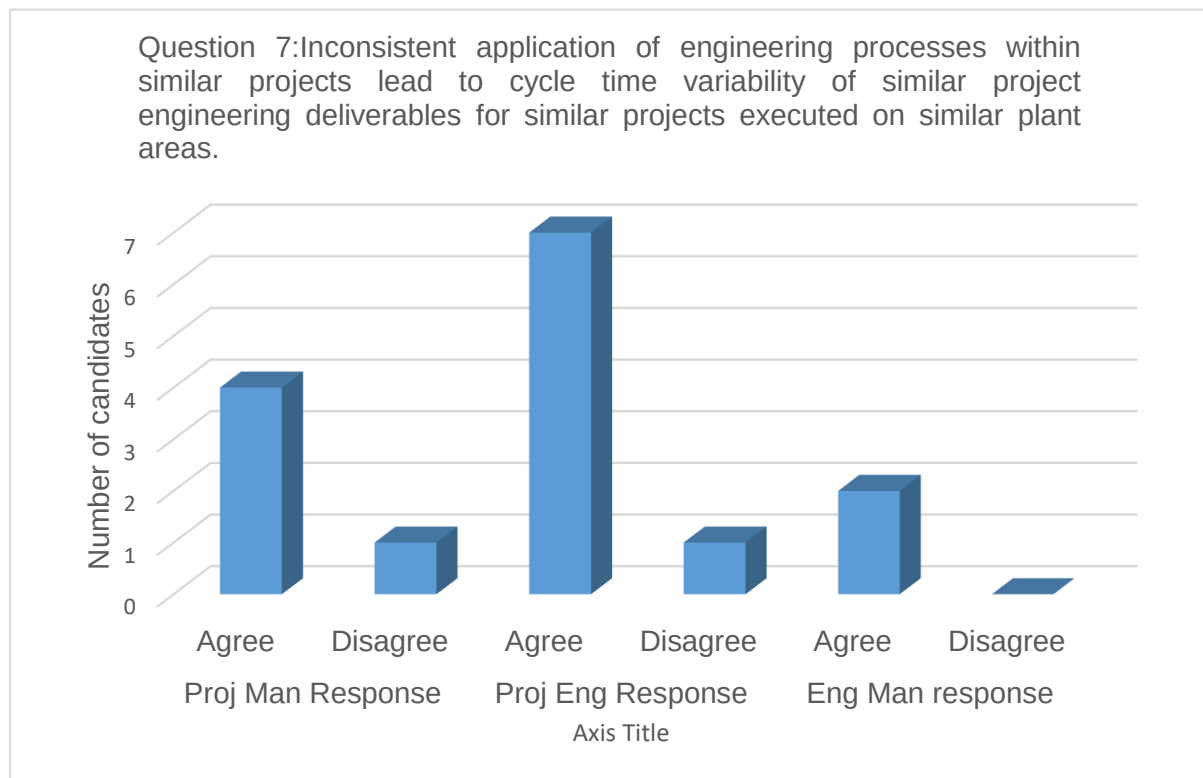


Figure 35: Response to Question 7

The results in figure 35 indicates that 13 out of 15 (88.6%) of candidates agree that Inconsistent application of engineering processes within similar projects lead to cycle time variability of similar project engineering deliverables for similar projects executed on similar plant areas.

Project engineers forms the majority of those who agree (i.e.) 7 out of 8 (87.5%) project engineers and the other candidates were all (100%) engineering managers and 4 out of 5 (80%) project managers. 1 out of 8 (12.5%) Project engineers and 1 out of 5 (20%) project manager disagreed.

Question 8

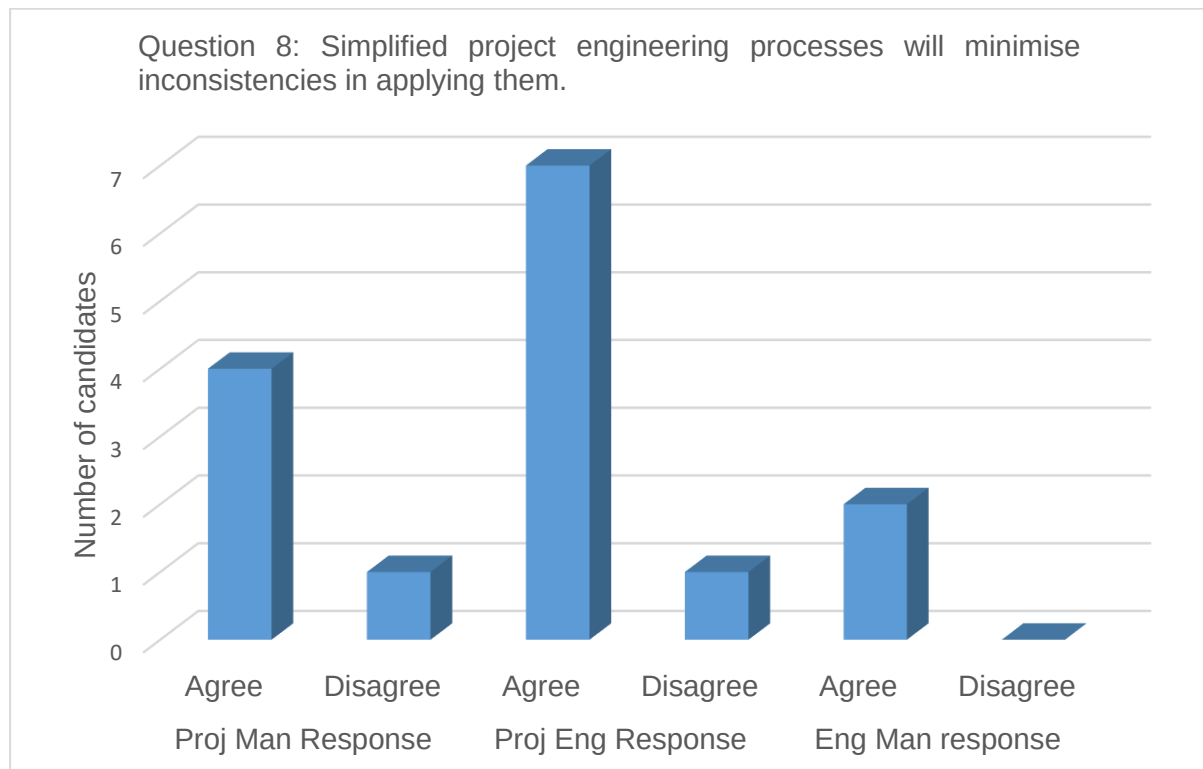


Figure 36: Response to Question 8

The results in figure 36 indicate that 13 out of 15 (86.6%) of candidates agree that simplified project engineering processes will minimise inconsistencies in applying them.

Project engineers forms the majority of those who agree (i.e.) 7 out of 8 (87.5%) project engineers and the other candidates was all (100%) engineering managers and 4 out of 5 (80%) project managers. 1 out of 8 (12.5%) Project engineers and 1 out of 5 (20%) project manager disagreed.

Question 12

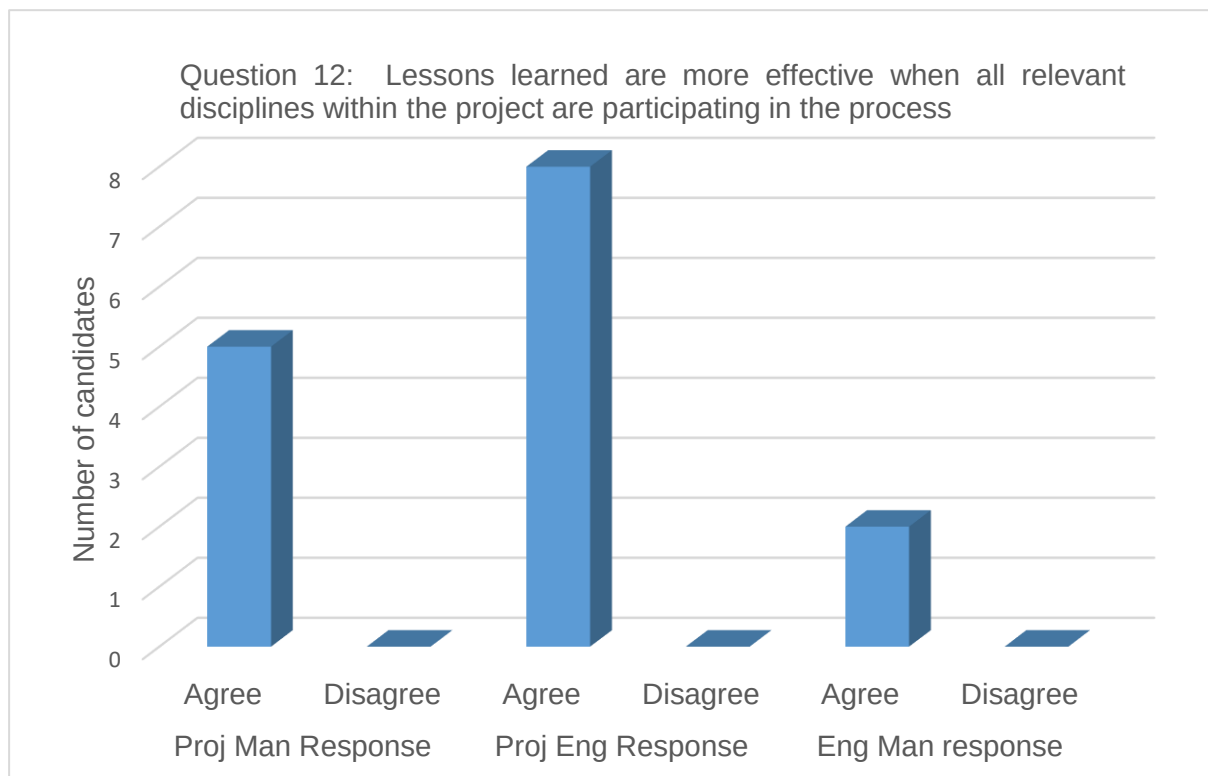


Figure 37: Response to Question 12

The results in Figure 37 indicate that all participants (100%) of candidates agree that Lessons learned are more effective when all relevant disciplines within the project are participating in the process.

Question 15

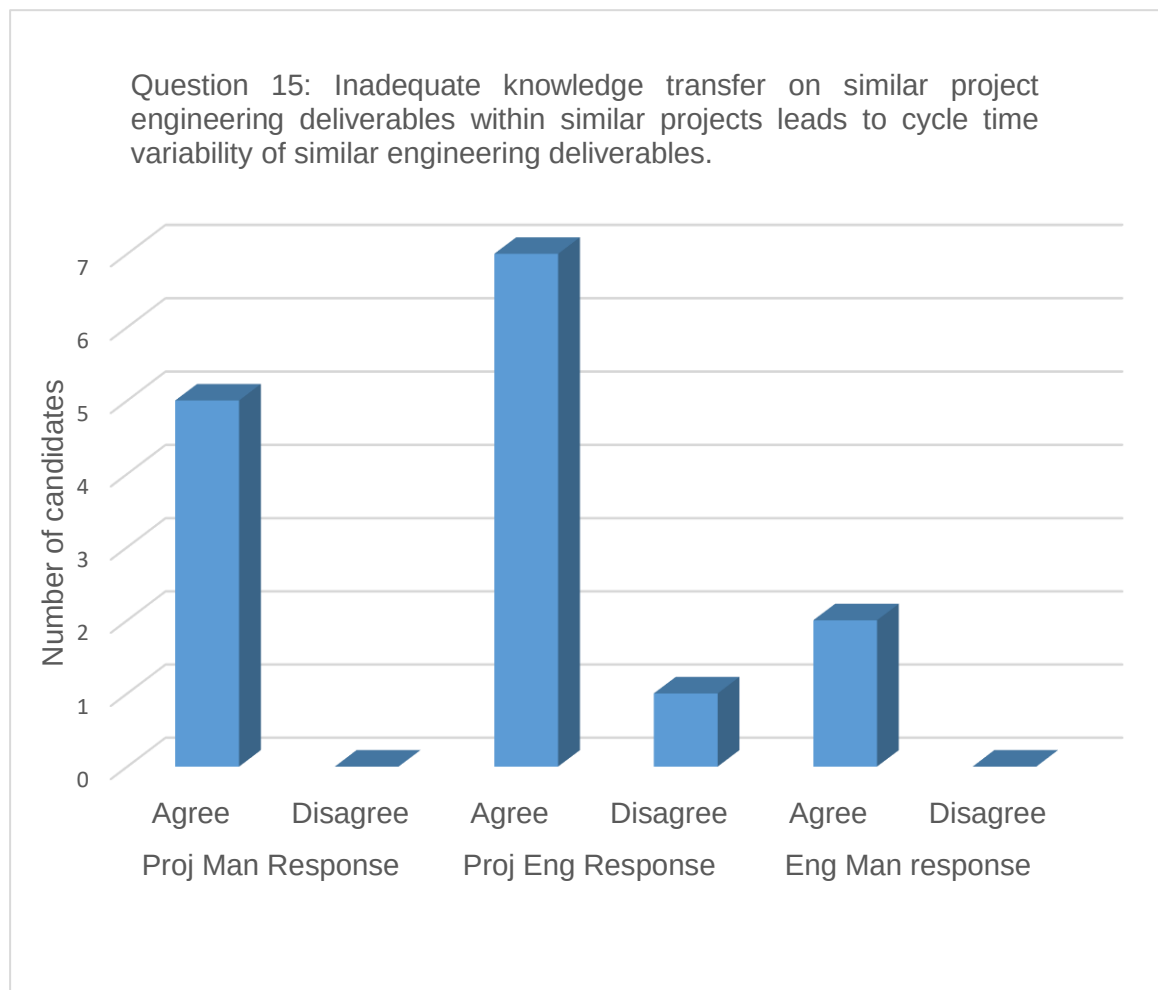


Figure 38: Response to Question 15

The results in Figure 38 indicate that 14 out of 15 (93.3%) of candidates agree that Inadequate knowledge transfer on similar project engineering deliverables within similar projects leads to cycle time variability of similar engineering deliverables.

All (100%) project managers, all (100%) engineering managers and 7 out of 8 (87.5%) project engineers formed part of those who agree. Only 1 out of 8 (12.5%) project engineer disagreed.

Question 16

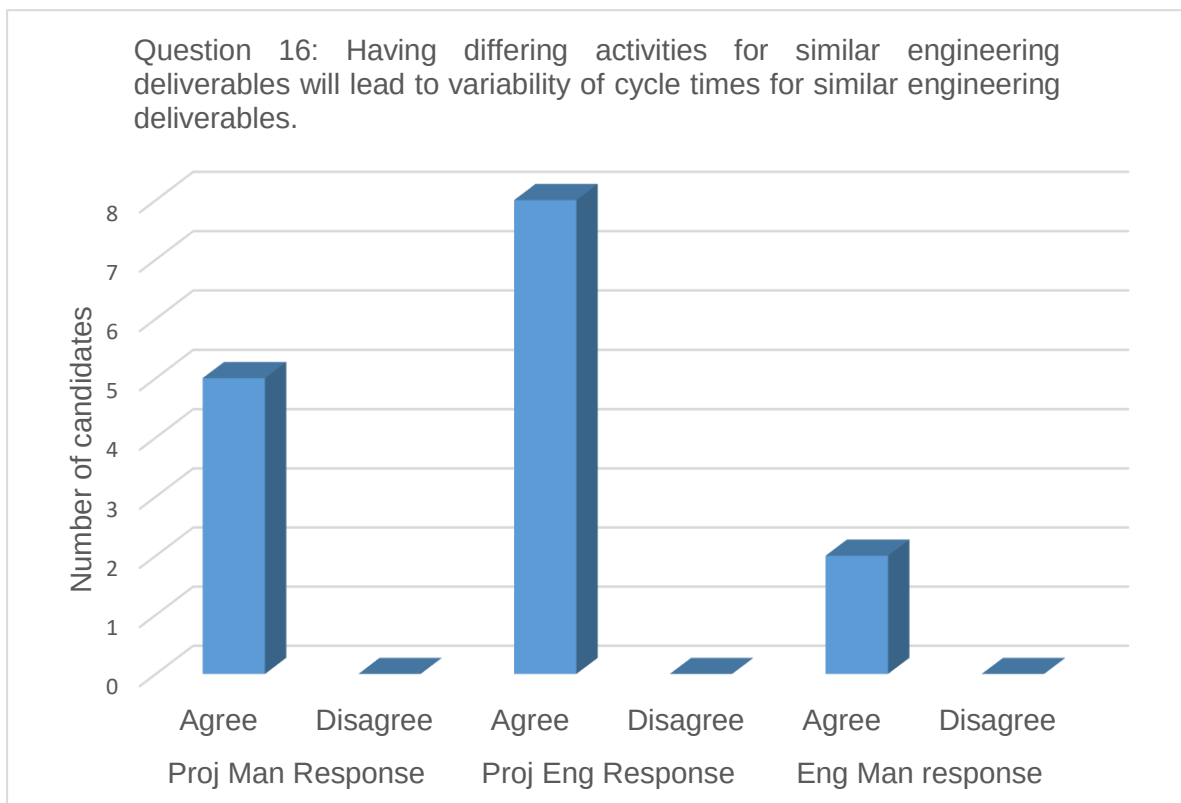


Figure 39: Response to Question 16

The results in Figure 39 indicate that all participants (100%) of candidates agree that having differing activities for similar engineering deliverables will lead to variability of cycle times for similar engineering deliverables.

Question 17

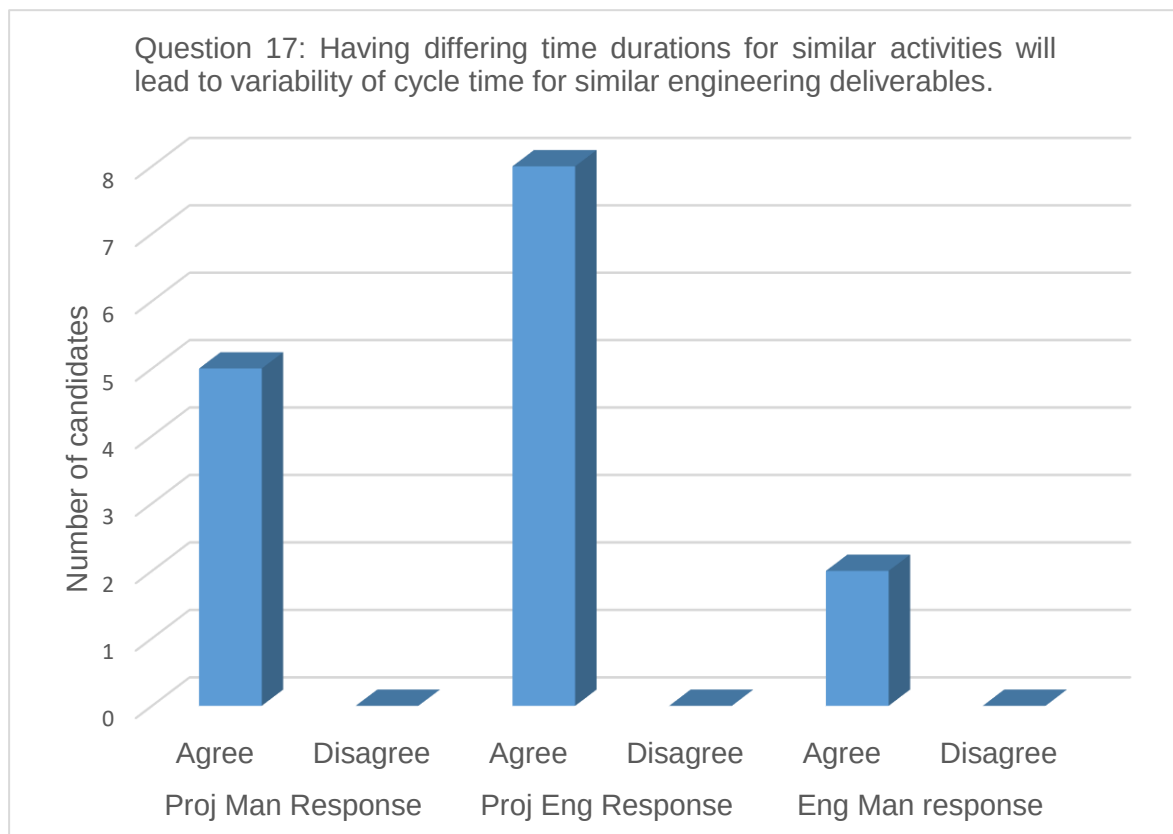


Figure 40: Response to Question 17

The results in Figure 40 indicate that all participants (100%) of candidates agree that having differing time durations for similar activities will lead to variability of cycle time for similar engineering deliverables.

4.2.6.1 Cronbach Alpha Analysis and Hypotheses Analysis on Research Questionnaire Questions Results Based on the 1st Refined Conceptual Framework.

The analysis on this part includes the Cronbach alpha analysis on above relevant questionnaire questions to confirm reliability of the research instrument used and hypothesis testing as per 1st refined conceptual framework.

Table 10 below provides the Likert scale **scores** for the opinions on research questions based on the 1st refined conceptual framework **used** for the Cronbach alpha analysis and hypothesis testing. This is the same information highlighted in green in table 9 above.

Opinions Results on research questions based on the 1st refined conceptual framework.

Table 10: Opinions Results on research questions based on the 1st refined conceptual framework.

Respondent	Question7	Question8	Question12	Question15	Question16	Question17
1	4	4	3	3	4	4
2	3	4	4	4	3	4
3	4	4	4	4	4	4
4	2	4	4	3	4	4
5	4	2	4	3	3	3
6	4	4	4	4	4	4
7	3	3	3	3	3	3
8	3	3	4	3	3	3
9	2	3	3	2	3	3
10	3	3	4	3	3	3
11	4	2	4	3	3	3
12	3	3	3	3	3	3
13	3	4	4	3	3	3
14	3	3	4	3	3	3
15	4	4	4	3	4	3

Cronbach alpha analysis

The Cronbach alpha analysis is expressed as follows:

$$\alpha = \left(\frac{k}{k-1} \right) \frac{(s_y^2 - \sum s_i^2)}{s_y^2} \quad \text{Where } k = \text{number of questions}$$

The calculated value for α is 0.75. Which is deemed acceptable based on the criteria. The criteria uses 0.70 as the reference. If the calculated value of α is more than 0.7 it is deemed acceptable.

Hypothesis Testing

The relevant hypothesis test for above opinions results is the T-Test and the expected value is the minimum value of the agreement interval of the Likert scale, which is 2.5. The null hypothesis is represented by H_{1a0} : $M = 2.5$. The null hypothesis $H_{1a0} = 2.5$ means that there is no difference or impact.

Table 11 below indicates the conducted hypothesis testing on above opinion results.

Hypothesis Testing for Opinions Results on research questions based on the 1st refined conceptual framework.

Table: 11: Hypothesis Testing for Opinions Results on research questions based on the 1st refined conceptual framework.

	Null Hypothesis	Alternative hypothesis	Values of p and t	Hypothesis Results	Likert Scale Results
Question 7	H1a ₀ : M = 2.5	H1 _{ALT} : M > 2.5	t=4.2193 p< 0.000429 significant at p<0.05	H1a ₀ is rejected. Application of engineering processes has direct relationship with cycle time variability	Strongly Agree
Question 15	H2a ₀ : M = 2.5	H2 _{ALT} : M > 2.5	t=4.75 p <0.000155 significant at p<0.05	H2a ₀ is rejected. Intra-organisational knowledge transfer has direct relationship with cycle time variability.	Agree
Question 16	H3 ₀ : M = 2.5	H3 _{ALT} : M > 2.5	t=6.614 p <0.00001 significant at p<0.05	H3 ₀ is rejected. Variability of activities has direct relationship with cycle time variability.	Strongly Agree
Question 17	H4 ₀ : M = 2.5	H4 _{ALT} : M > 2.5	t=6.614 p<00001	H4 ₀ is rejected.	Strong Agree

			significant at $p < 0.05$	Variability of activities durations has direct relationship with cycle time variability	
Question 8	H1b ₀ : M = 2.5	H5 _{ALT} : M > 2.5	t=4.4594 $p < 0.0027$ significant at $p < 0.05$	H1b ₀ is rejected. Simplification of engineering processes has effect on application of engineering processes	Strongly Agree
Question 12	H2b ₀ : M = 2.5	H6 _{ALT} : M > 2.5	t=10.43 $p < 0.00001$ significant at $p < 0.05$	H2b ₀ is rejected. Use of cross-functional teams has effect on knowledge transfer	Strongly Agree

4.2.6.2 Discussion on opinions on research questions based on the 1st refined conceptual framework.

This part is the backbone of this research as it is directly linked to the main deliverables of the research (i.e.) the conceptual framework and the framework model for cycle time minimisation of similar engineering deliverables.

Discussion on question 7 responses

The dominant response is that inconsistent application of engineering processes within similar projects leads to cycle time variability of similar project engineering deliverables for similar projects executed on similar plant areas. This is supported by the conducted hypothesis on the research questionnaire question 7 results in which the **null hypothesis** was **rejected**.

Literature review conducted in Chapter 2 under the heading **factors influencing cycle time and application of engineering** processes, also supports the results from the research questionnaire question 7.

The implication of this finding is that Eskom will have to increase focus on the application of engineering processes in order to minimise variabilities in cycle times of similar engineering deliverables.

Discussion on question 8 responses

The dominant opinion is that simplified project engineering processes will minimise inconsistencies in applying them. Question 8 is a moderating question for question 7 as indicated in the 1st refined conceptual framework in **figure 20** above. The response is supported by the conducted hypothesis on the research questionnaire question 8 results in which the **null hypothesis** was **rejected**.

This response is consistent with literature in Chapter 2 under the heading **overview of best practices in minimising cycle time variability**. The implication to Eskom is similar to the one in question 7.

Discussion on question 12 responses

All candidates agree that lessons learned are more effective when all relevant disciplines within the project participate in the process. The response is supported by the conducted hypothesis on the research questionnaire question 12 results in which the **null hypothesis** was **rejected**.

This response is consistent with literature in Chapter 2 under the heading **intra-organisational knowledge transfer**.

The implication to Eskom is that Eskom should create an environment in which cross-functional teams are encouraged to participate in order to enable the transfer of knowledge.

Discussion on question 15 responses

The dominant opinion is that inadequate knowledge transfer on similar project engineering deliverables within similar projects leads to cycle time variability of similar engineering deliverables. The response is supported by the conducted hypothesis on the research questionnaire question 15 results in which the **null hypothesis** was **rejected**.

This response is consistent with literature in Chapter 2 under the heading **intra-organisational knowledge transfer**.

As revealed by findings in question 3 above, in which it was found that Eskom does not have well-established framework for capturing, analysing, and retrieving lessons learned for similar engineering deliverables within similar project phases across different projects that are executed on similar plant areas. The implication to this finding is that Eskom should establish relevant systems and culture to ensure adequate intra-organisation knowledge transfer.

Discussion on question 16 responses

All candidates agree that having differing activities for similar engineering deliverables leads to variability of cycle times for similar engineering deliverables. The response is supported by the conducted hypothesis on the research questionnaire question 15 results in which the **null hypothesis** was **rejected**.

This response is consistent with literature in Chapter 2 under the heading **activities attributes**.

The implication of this finding is that Eskom needs to establish guidelines or standards on the naming of similar activities of similar deliverables. This can be a challenge if the communities of practice are not involved in the development of guidelines. It will be critical that such endeavour involve the relevant communities of practice in the development of the guidelines so that they can bring in their experiences and challenges in the development.

Discussion on Question 17 responses

All candidates agree that having differing time durations for similar activities will lead to variability of cycle time for similar engineering deliverables. The response is supported by the conducted hypothesis on the research questionnaire question 15 results in which the **null hypothesis** was **rejected**.

This response is consistent with literature in Chapter 2 under the heading **activities attributes**.

The implication of this finding includes one in question 16. As discussed in the literature review the source of differing cycles times for similar engineering deliverables includes inconsistent naming of activities of similar deliverable, inconsistent consolidation or decomposition of similar activities. By increasing consistency in the naming, consolidating and decomposition of similar activities, cycle time variability will be minimised. Eskom will have to make effort in standardising the naming, consolidation and decomposition of similar activities for similar deliverables.

4.2.6.3 Conclusion on research questions based on the 1st refined conceptual framework. (Key Factors of focus)

The overall perception on the application of engineering processes, intra-organisational knowledge transfer, activities durations and activities, is that they have influence on the cycle time variability and inconsistent application of engineering processes and intra-organisational knowledge transfer leads to cycle time variability. Similarly, inconsistent activities and inconsistent activities durations of similar engineering deliverables leads to cycle time variability.

4.3 Presentation of Secondary Data Results

The secondary data was obtained from a combination of paired sampled power stations' projects schedules with similar engineering deliverables. The rationale of choosing the research sample is explained in detail in Chapter 3 above. Below are the paired sampled projects schedules with similar engineering deliverables:

- Matimba Power Station, Lethabo Power Station and Majuba Power Station medium voltage and low voltage (MV/LV) pre-concept designs schedules.
- Matimba Power Station and Lethabo Power Station control and instrumentation (C&I) Basic designs schedules.
- Lethabo and Kendal power stations' High frequency transformers (HFT) concept designs schedules.

4.3.1 Matimba, Lethabo and Majuba Power Stations' medium voltage (MV/LV) pre-concept designs schedules.

Figure 41 below indicates pre-concept designs common activities durations for Matimba, Lethabo and Majuba power stations' MV projects.

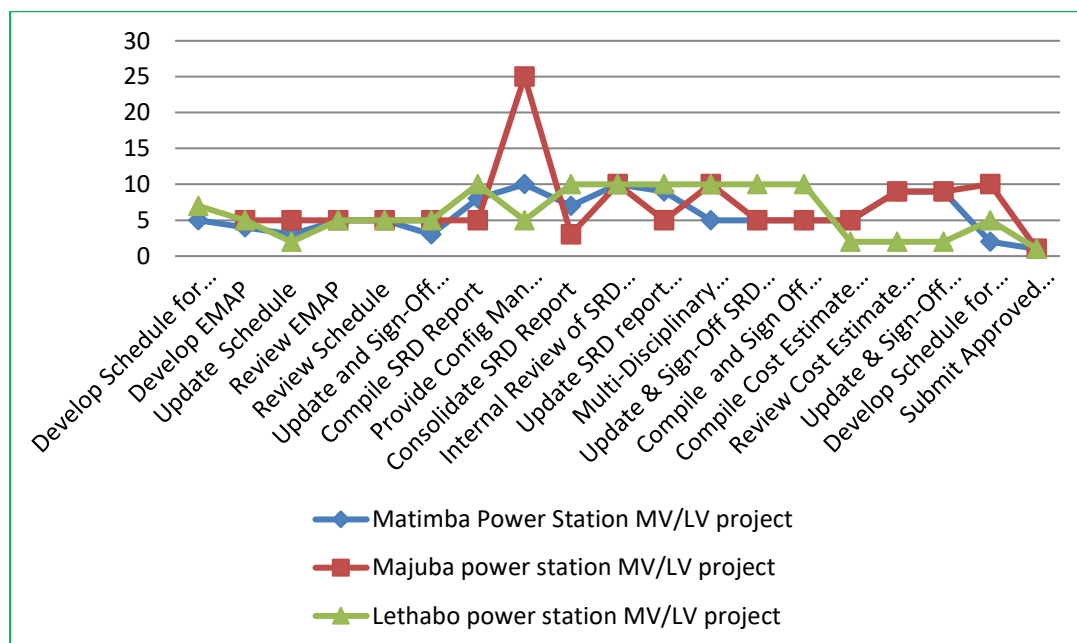


Figure 41: Matimba, Lethabo and Majuba power stations' MV projects pre- concept designs common activities durations.

The graphs on Figure 41 shows major variability on activities durations.

4.3.2 Matimba and Lethabo Power Stations' control and instrumentation (C&I) Projects Basic designs schedules.

Figures 42 to 58 below indicate activities for similar deliverables for Matimba and Lethabo Power Stations' control and instrumentation (C&I) Projects Basic designs activities and activity durations.

Turbine Primary deliverables

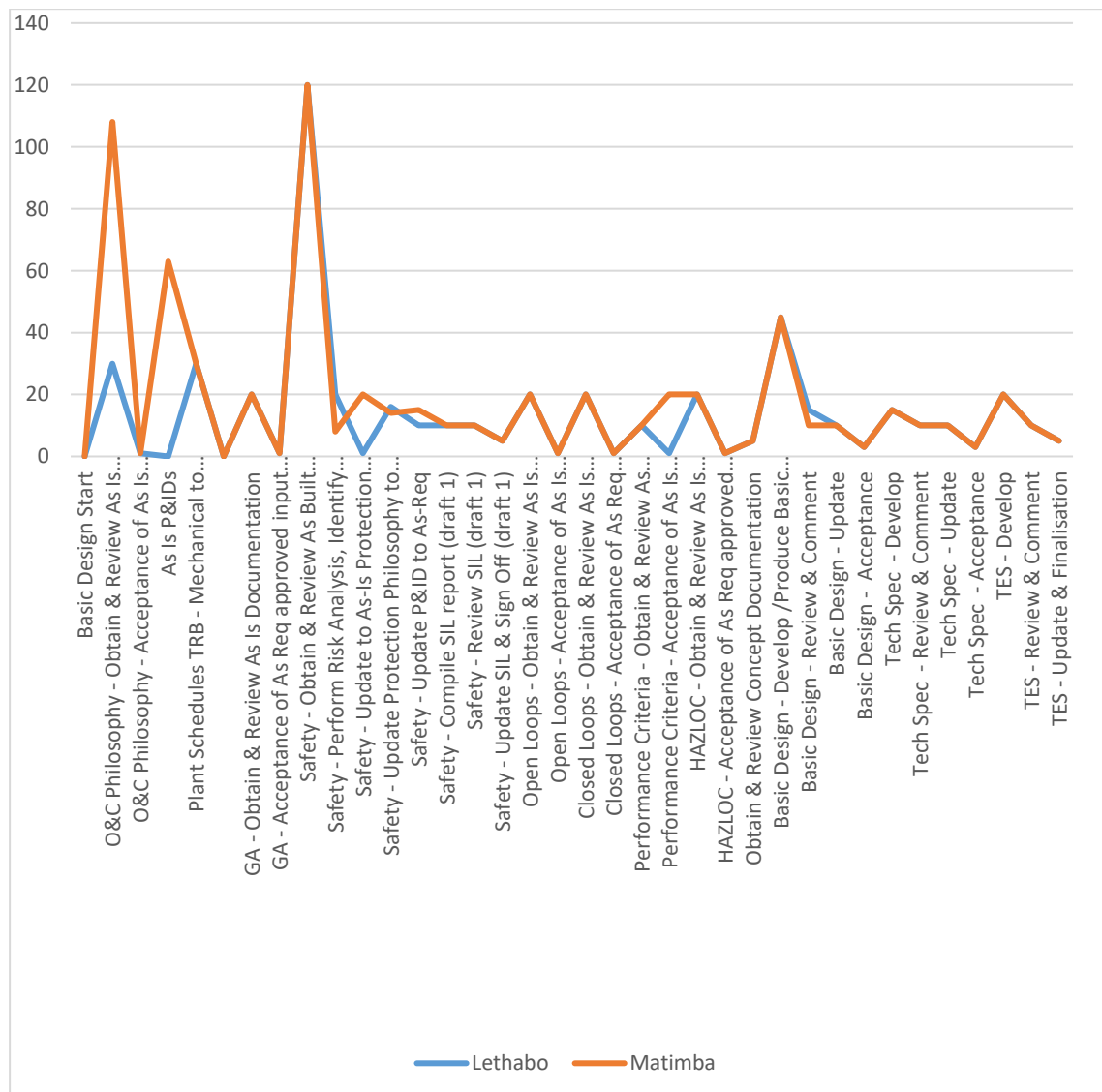


Figure 42: Turbine Primary activities and activity durations

The graphs in Figure 42 show minor variability on Turbine Primary activities durations.

Boiler Auxiliaries (Primary) deliverables

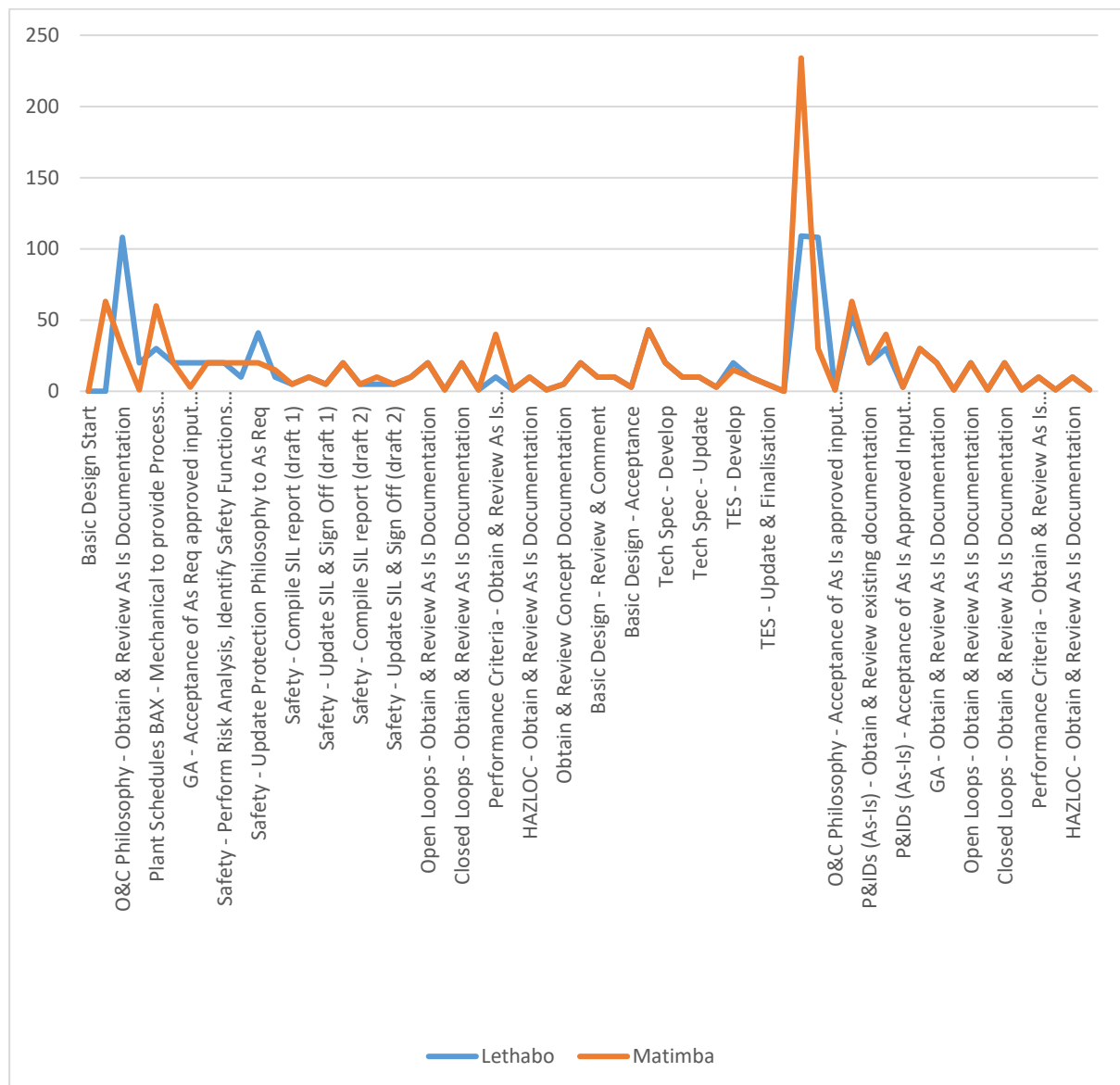


Figure 43: Boiler Auxiliaries (Primary) activities and activity durations

The graphs in Figure 43 show minor discrepancies on Boiler Auxiliaries (Primary) activities and activity durations.

Heating, Ventilation and Air Conditioning (HVAC) deliverables

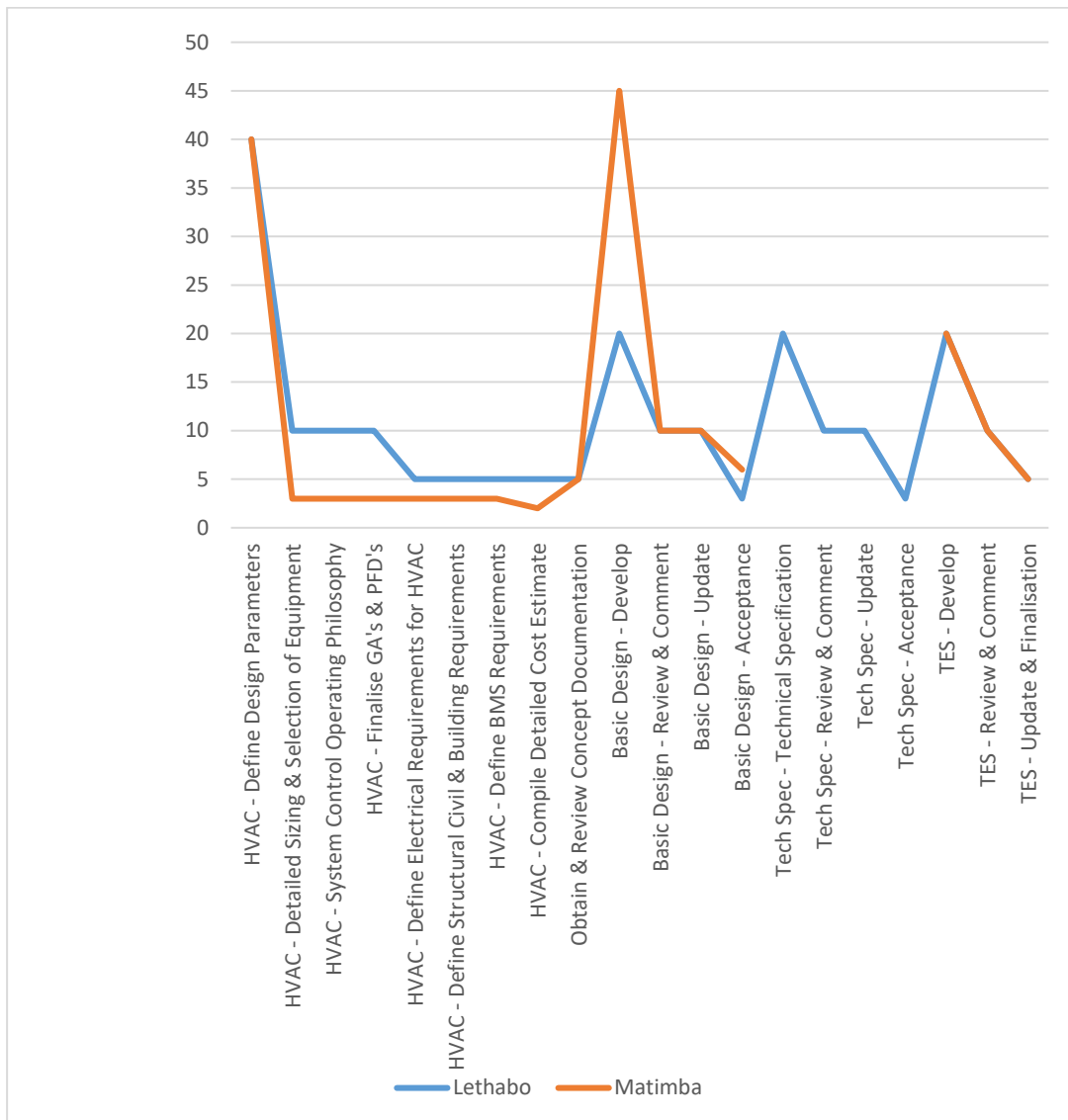


Figure 44: HVAC activities and activity durations

The graphs in Figure 44 show major discrepancies on Heating, Ventilation and Air Conditioning (HVAC) deliverables activities durations.

Chemical Secondary deliverables

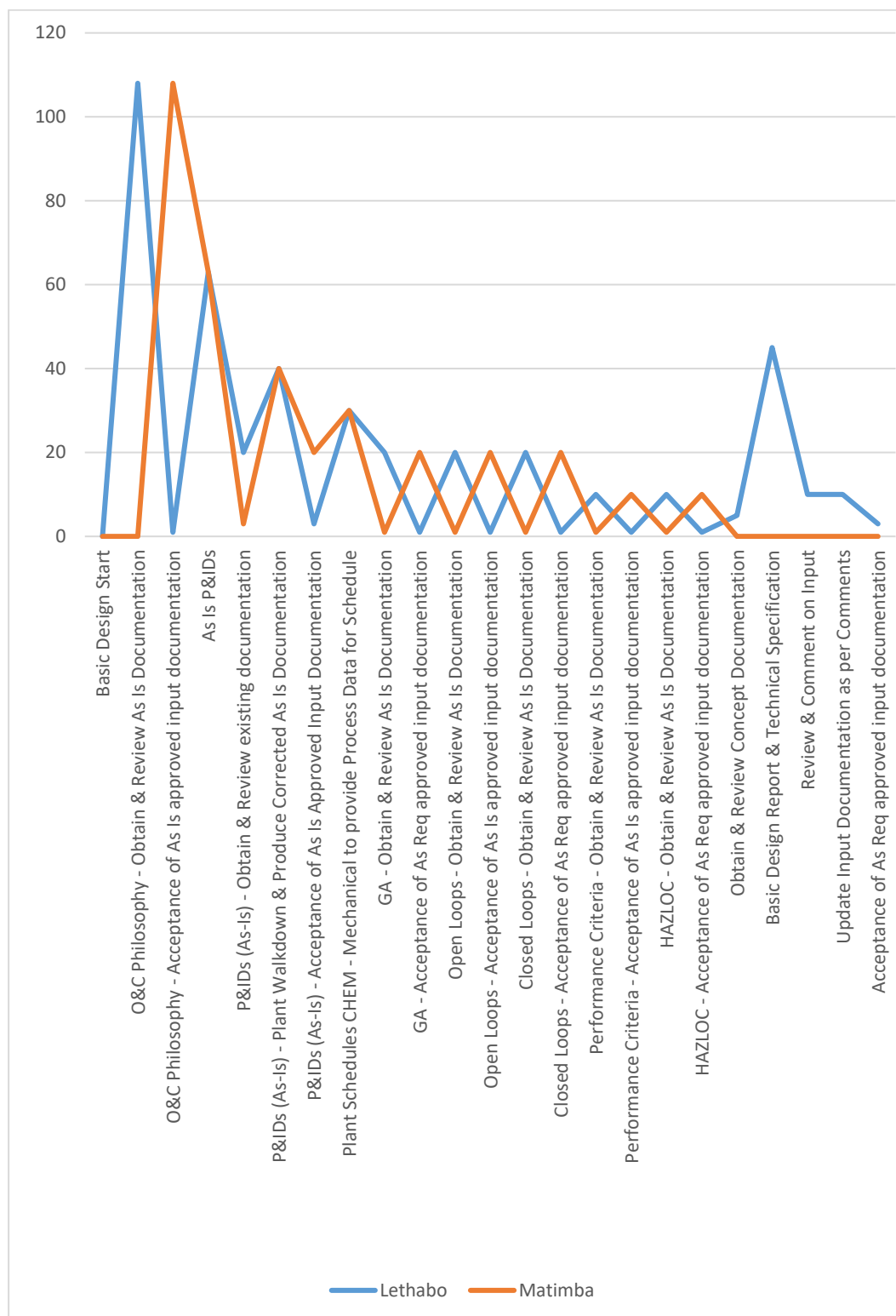


Figure 45: Chemical Secondary activities and activity durations

The graphs in Figure 45 show major discrepancies on Chemical Secondary deliverables activities durations.

Boiler Pressure Parts (Primary) activities and activity durations

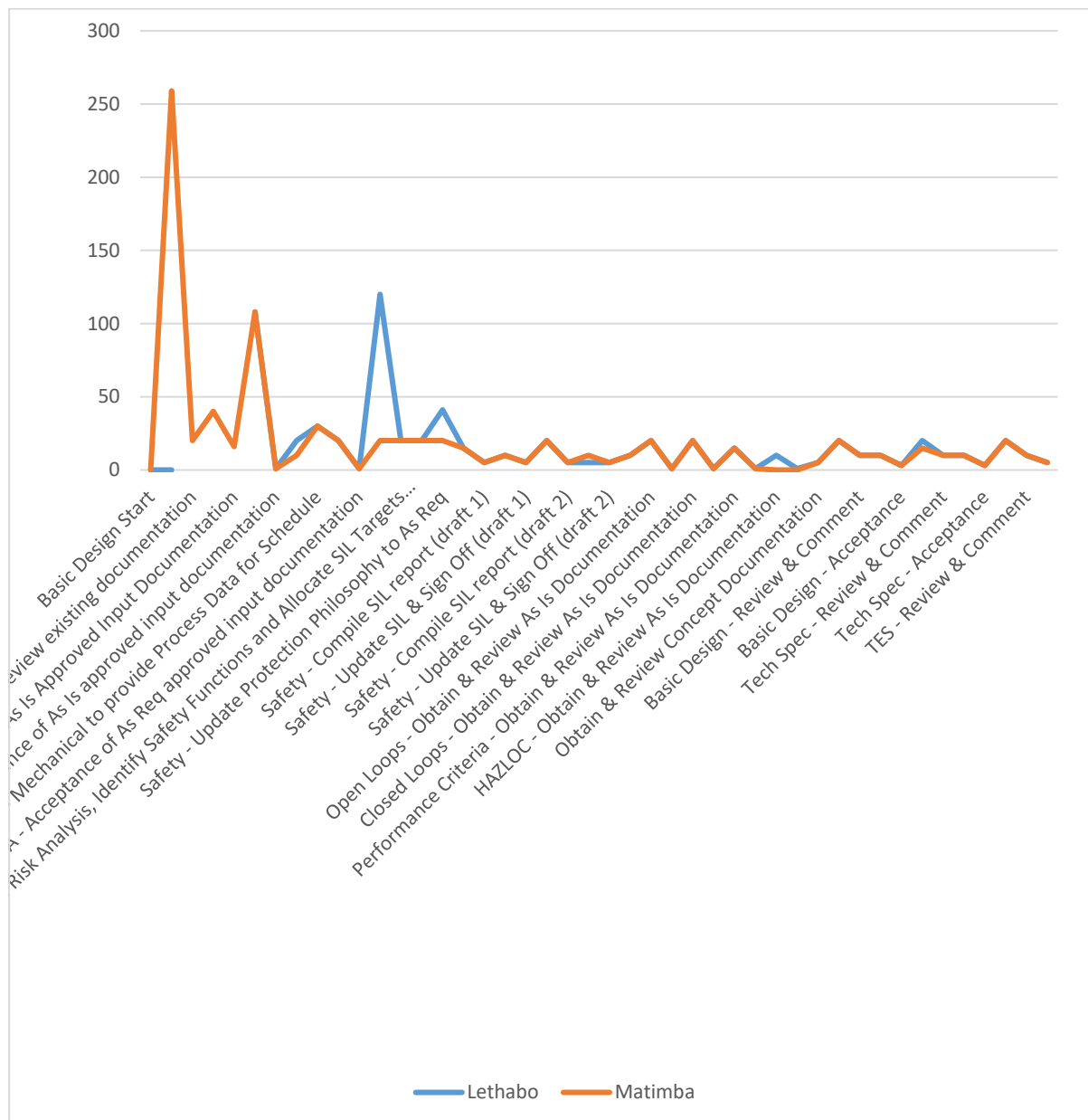


Figure 46: Boiler Pressure Parts (Primary) activities and activity durations

The graphs in Figure 46 show minor discrepancies on Boiler Pressure Parts (Primary) deliverables activities durations.

BMH (Secondary) activities and activity durations

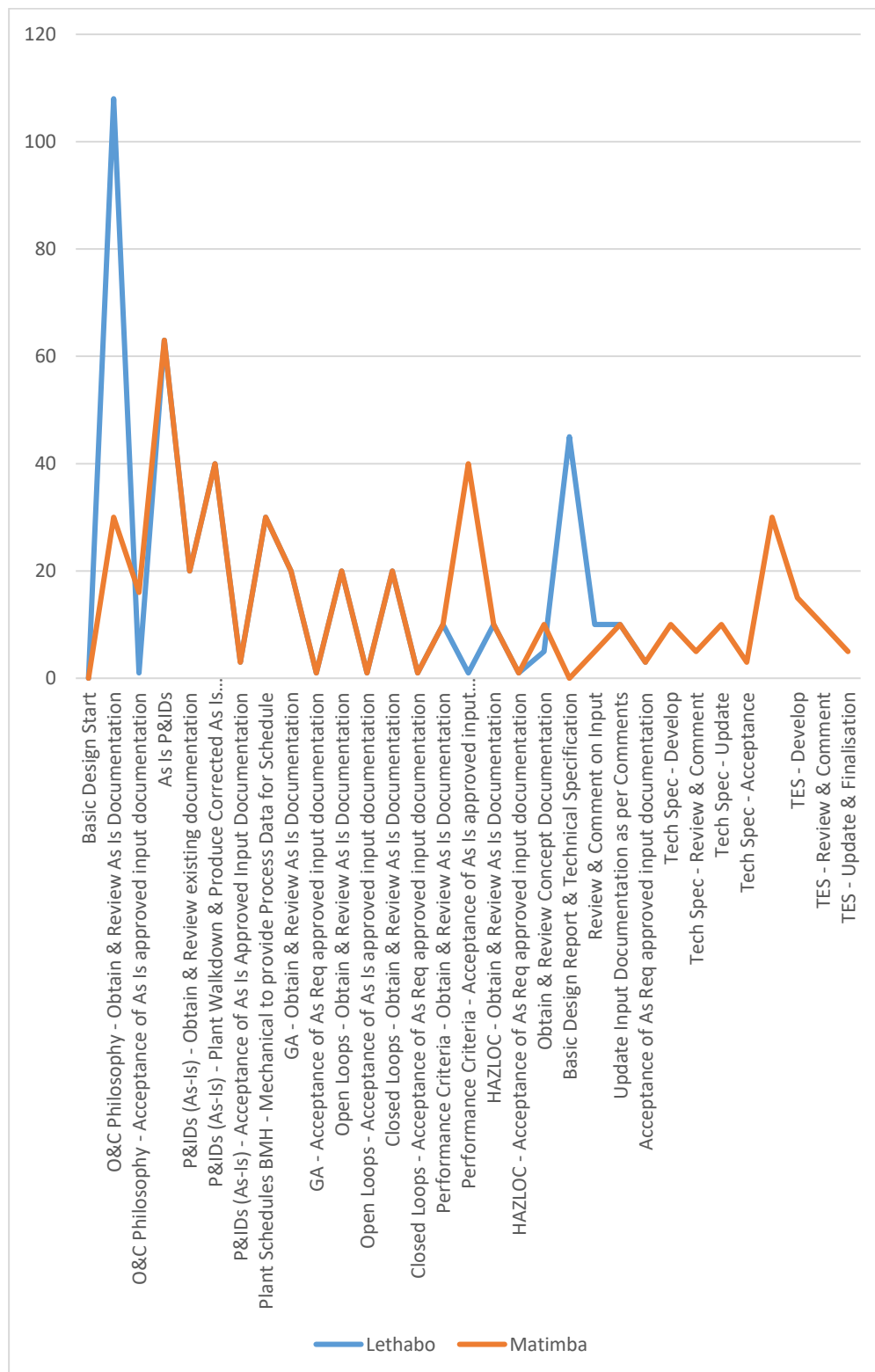


Figure 47: BMH (Secondary) activities and activity durations

The graphs in Figure 47 show minor discrepancies on Bulk Materials Handling (BMH) (Secondary) deliverable activities durations.

Electrical (Tertiary) activities and activity durations

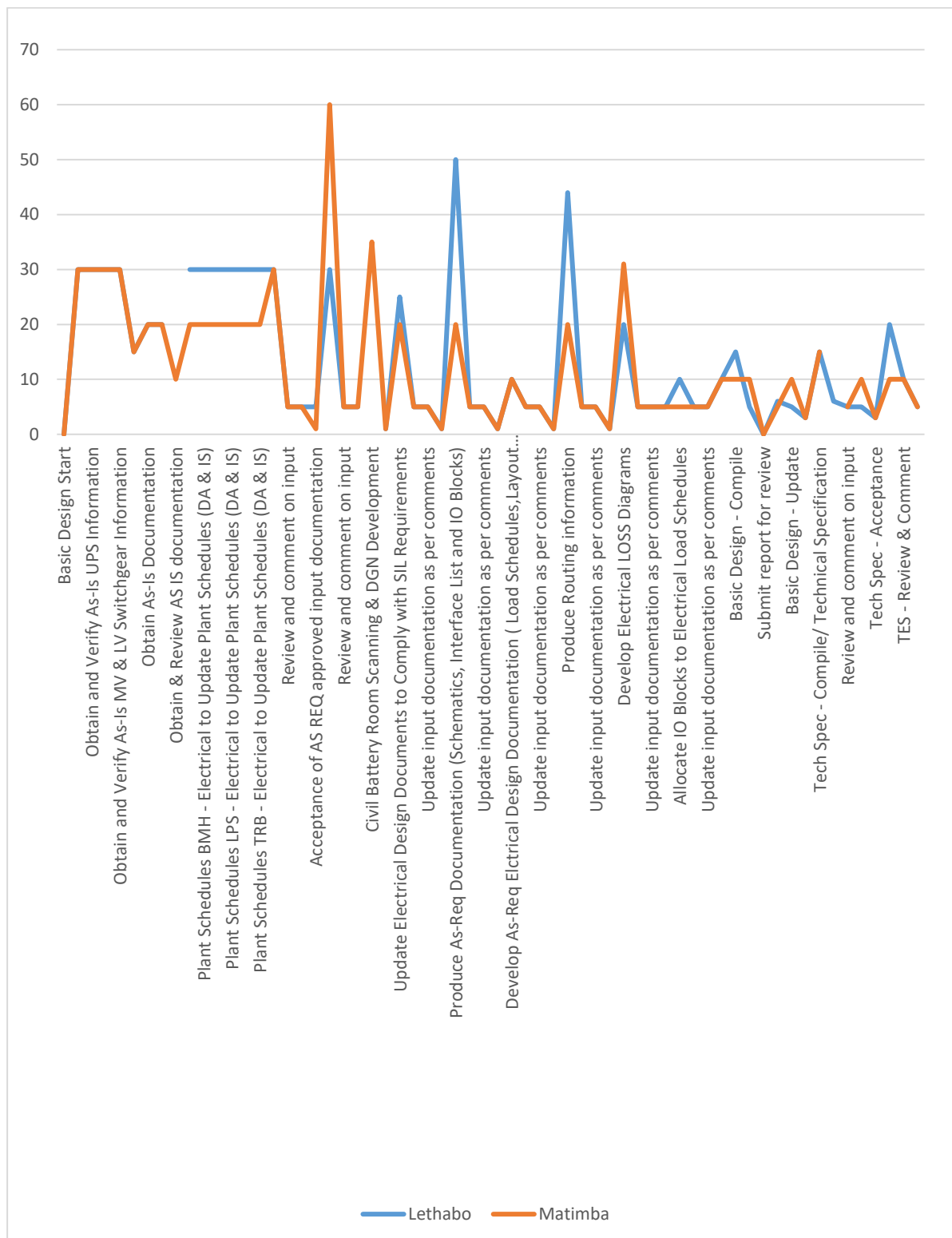


Figure 48: Electrical (Tertiary) activities and activity durations

The graphs in Figure 48 show major discrepancies on Electrical (Tertiary) deliverables activities and activity durations.

Civil (Tertiary) activities and activity durations

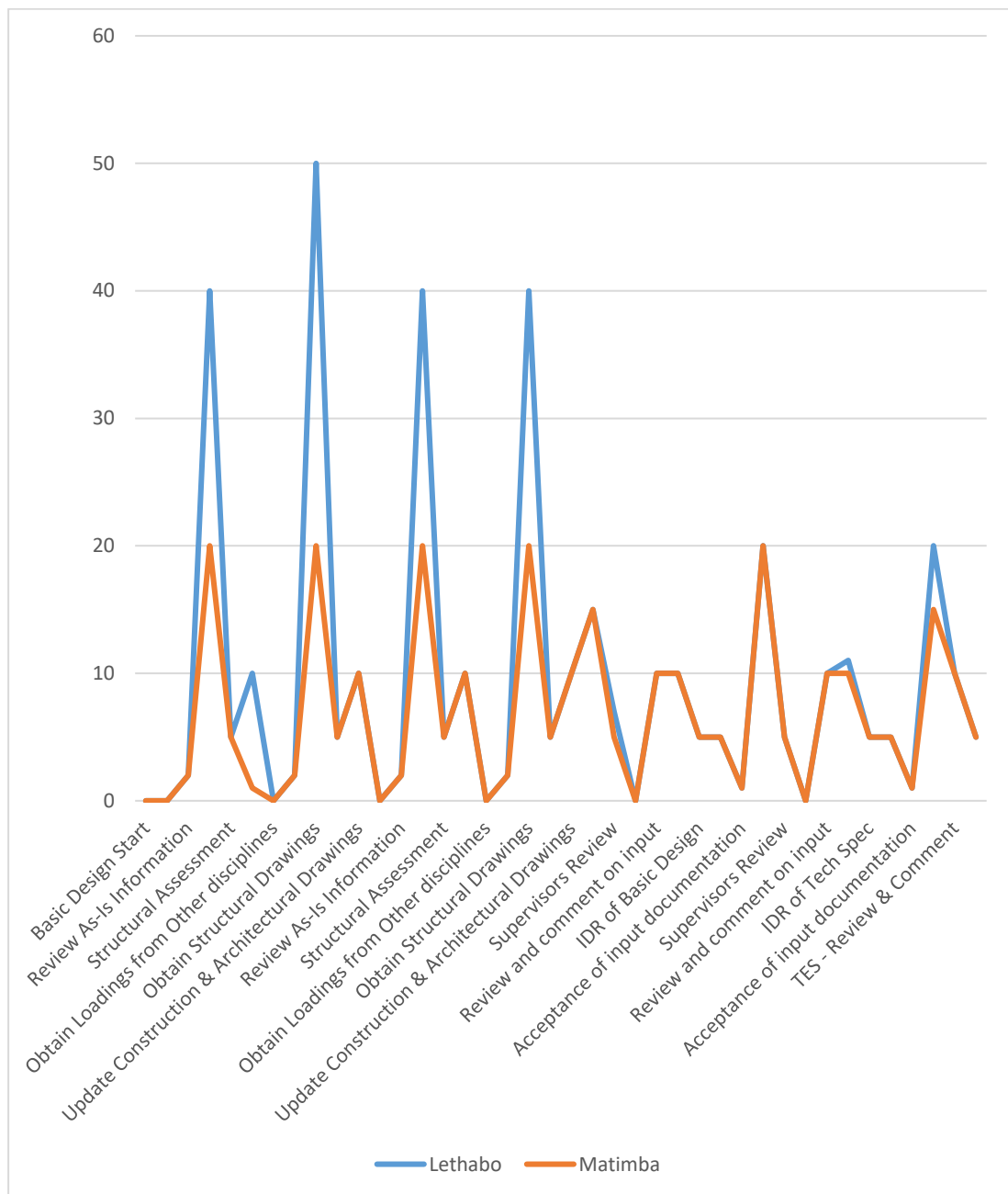


Figure 49: Civil (Tertiary) activities and activity durations

The graphs in Figure 49 show major discrepancies on Civil (Tertiary) deliverables activities durations.

Plant Schedules – Turbine activities and activity durations

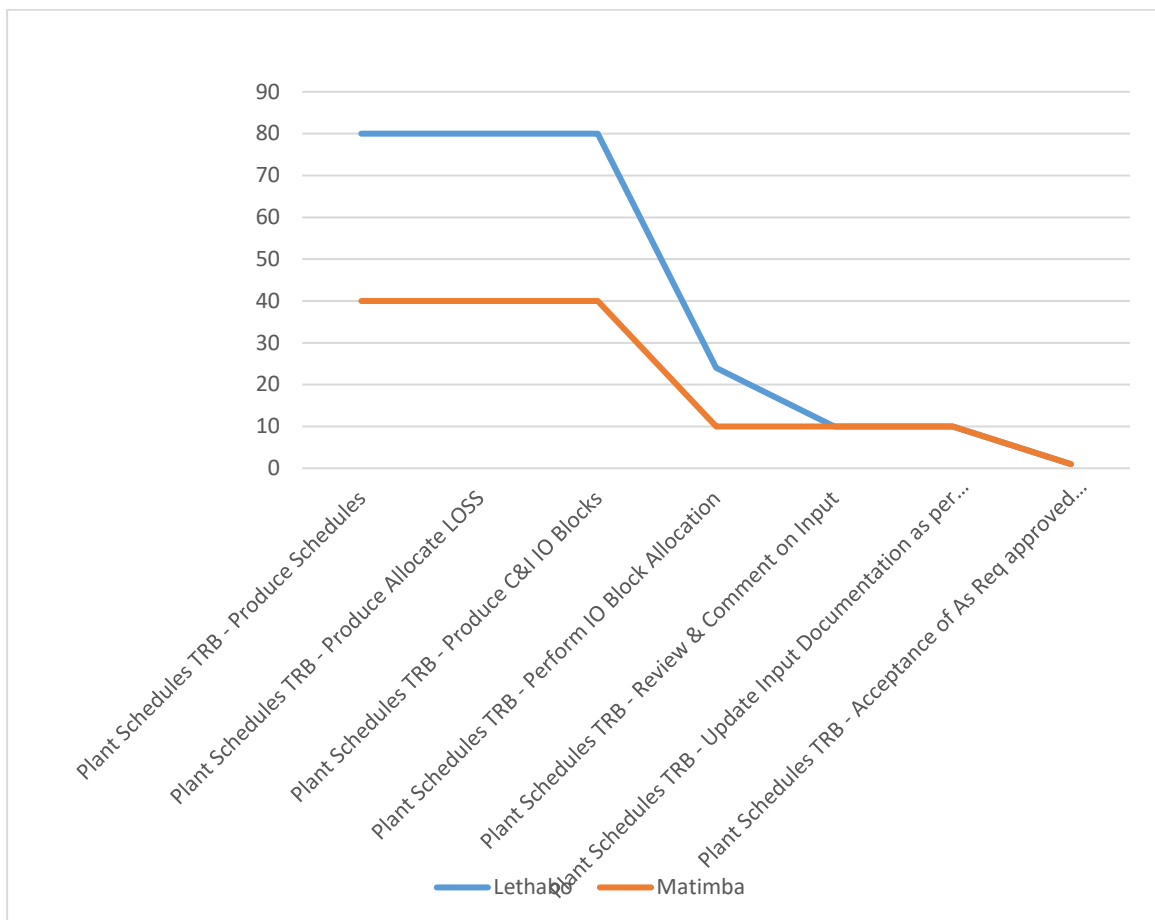


Figure 50: Plant Schedules – Turbine activities and activity durations

The graphs in Figure 50 shows major discrepancies on Plant Schedules – Turbine deliverables activities and activity durations.

Plant Schedules – Boiler Auxiliaries activities and activity durations

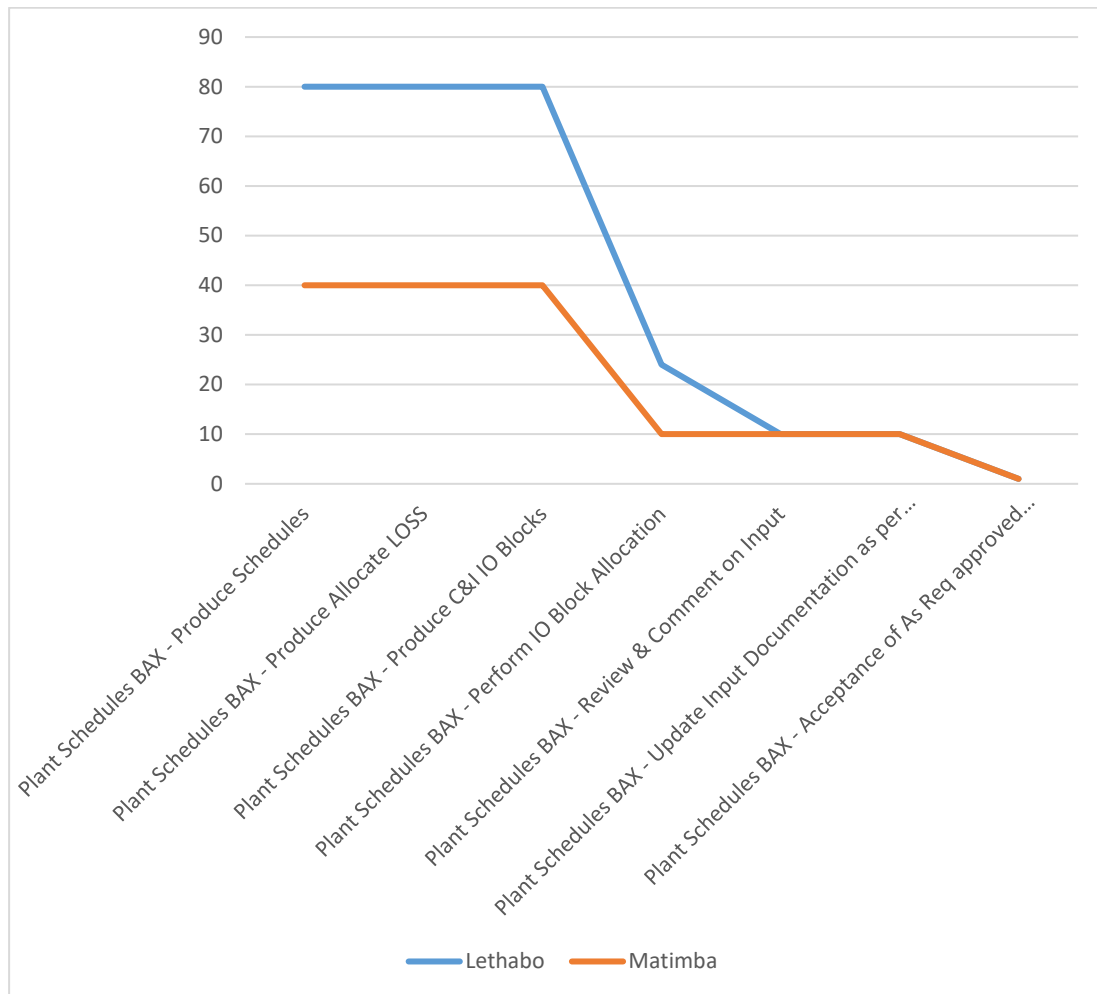


Figure 51: Plant Schedules – Boiler Auxiliaries activities and activity durations

The graphs in Figure 51 show major discrepancies on Plant Schedules – Boiler Auxiliaries deliverables activities durations.

Plant Schedules – Boiler Pressure parts activities and activity durations

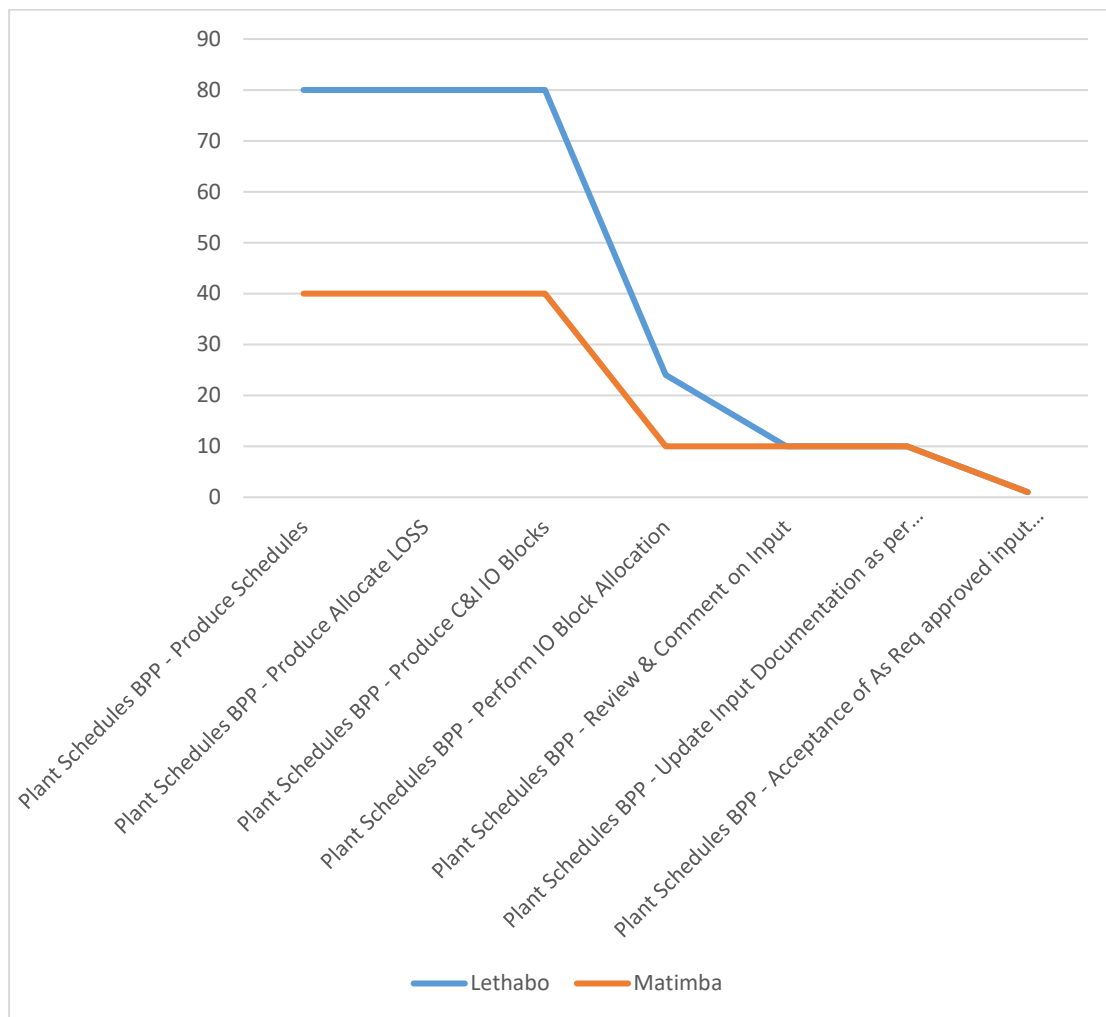


Figure 52: Plant Schedules – Boiler Pressure parts activities and activity durations

The graphs in Figure 52 show major discrepancies on Plant Schedules – Boiler Pressure parts deliverables activities durations.

Plant Schedules - BMH deliverables

Plant Schedule - BMH activities and activity durations

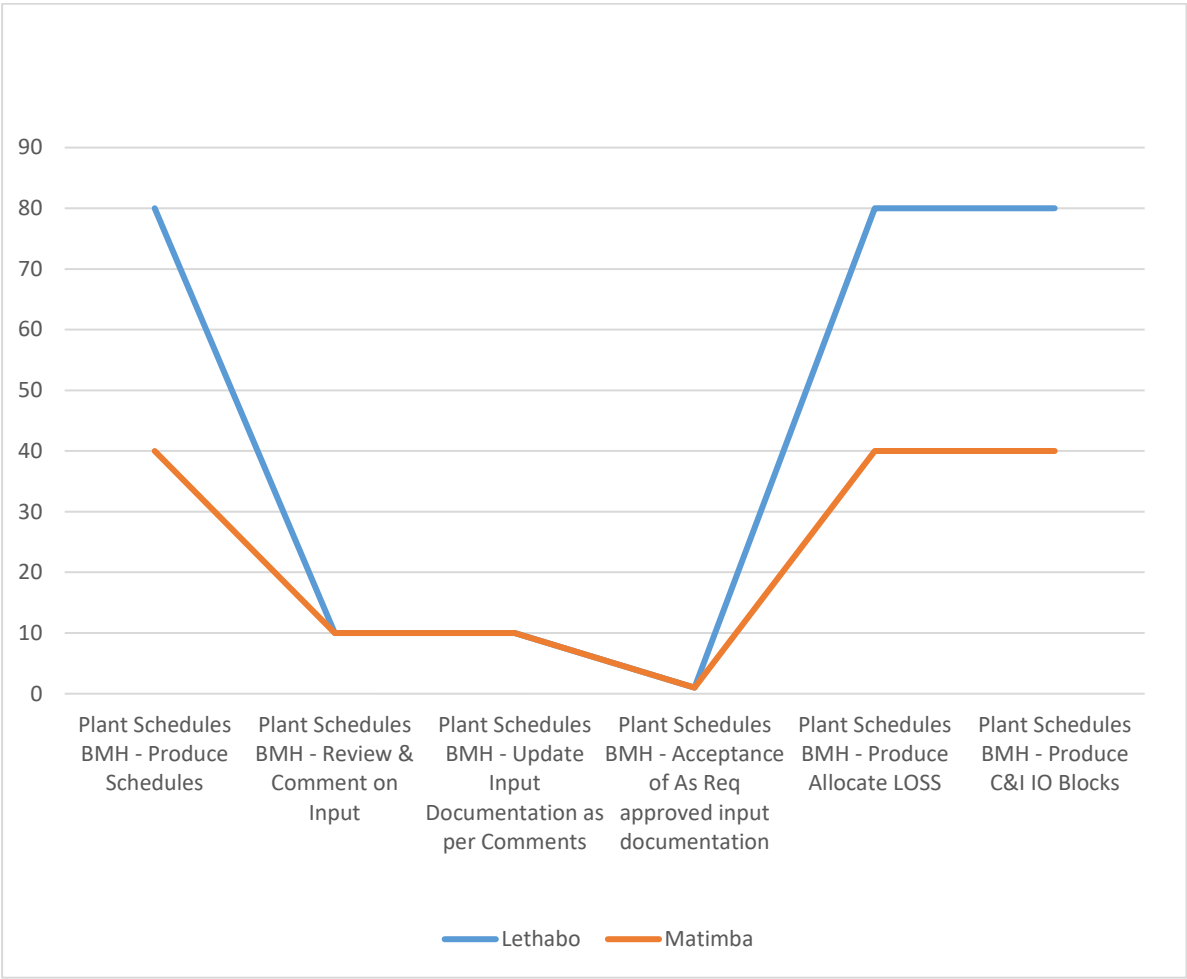


Figure 53: Plant Schedule - BMH activities and activity durations

The graphs in figure 53 show major discrepancies on Plant Schedule - BMH deliverables activity and activities durations.

C&I Equipment Schedules deliverables

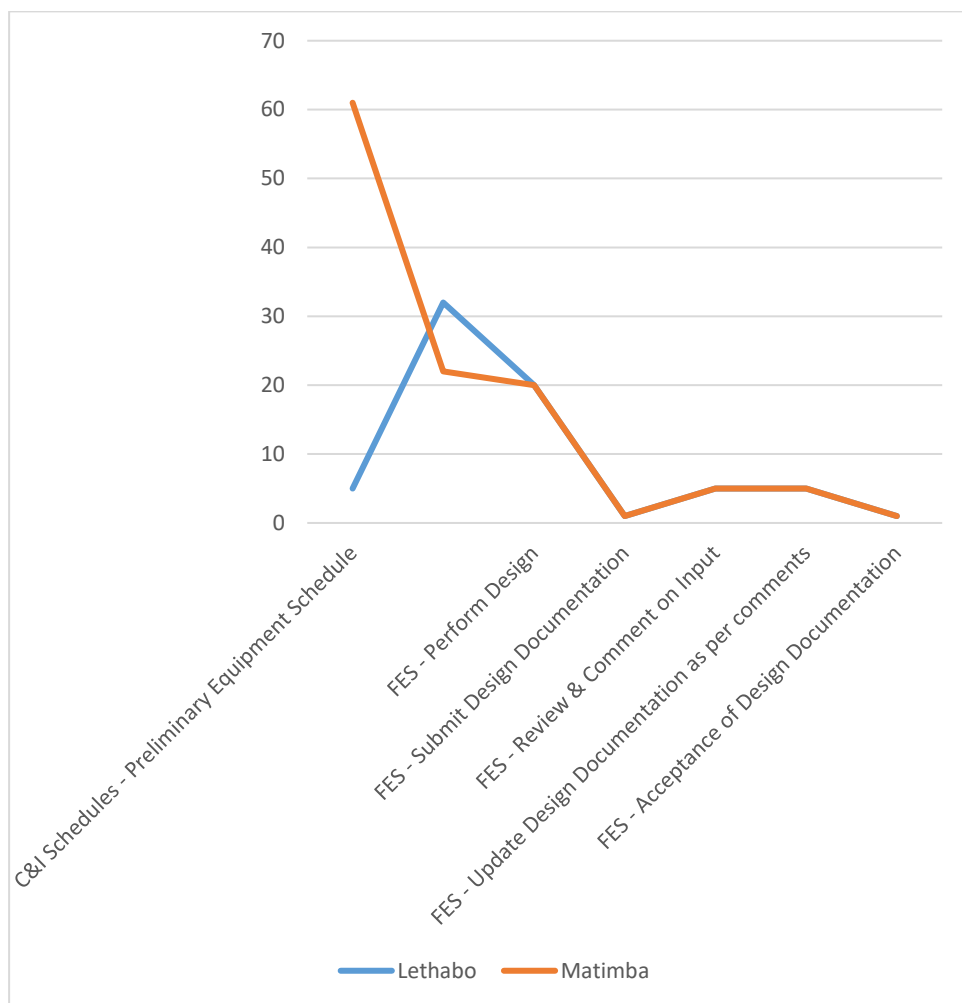


Figure 54: C&I Equipment Schedules activities and activity durations

The graphs show minor discrepancies on C&I Equipment Schedules deliverables activities durations.

Power Distribution Specifications deliverables

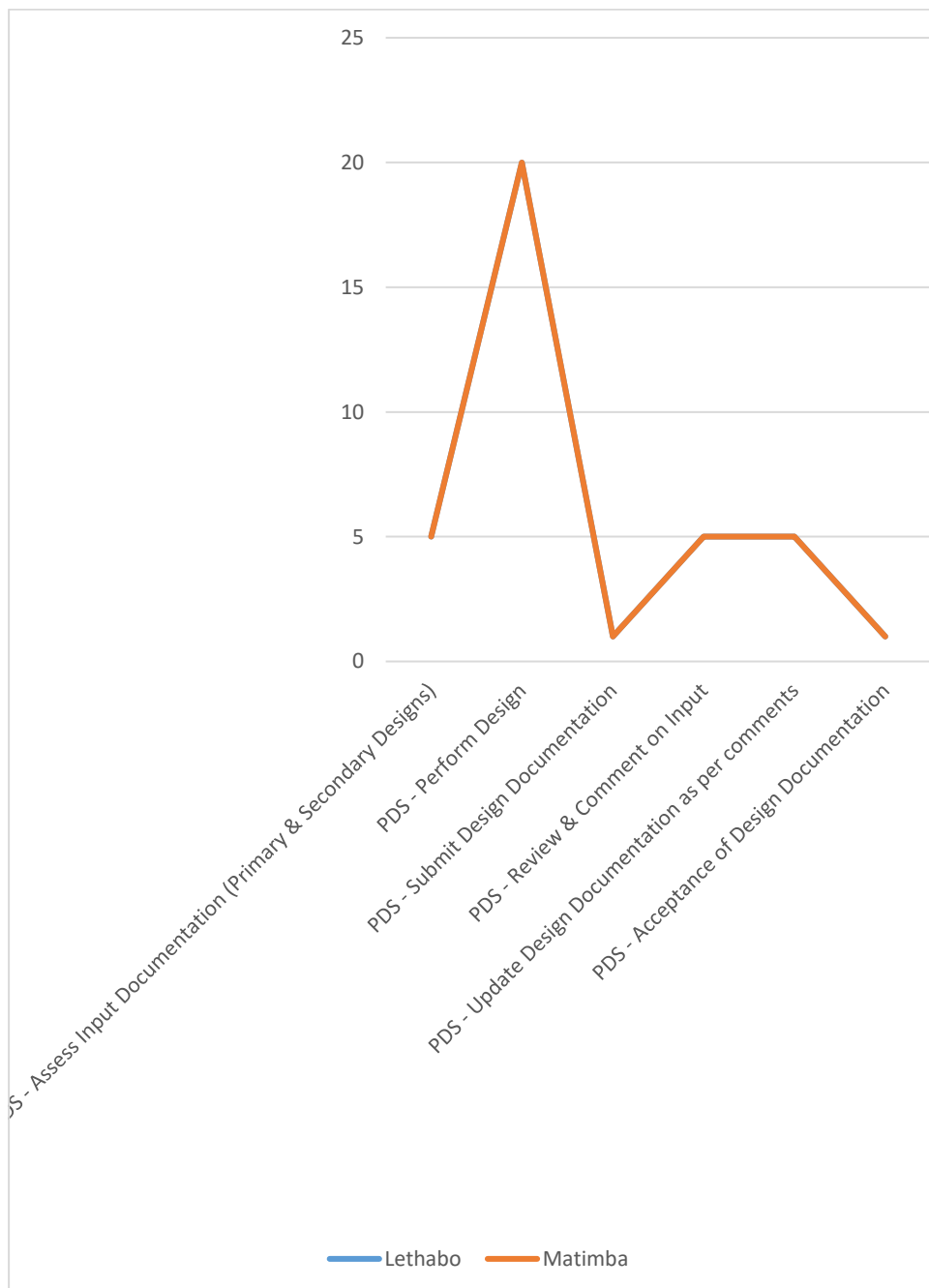


Figure 55: Power Distribution Specifications activities and activity durations

The graphs in Figure 55 show perfect alignment of activities and activity durations on Power Distribution Specifications deliverables.

Management Systems deliverables

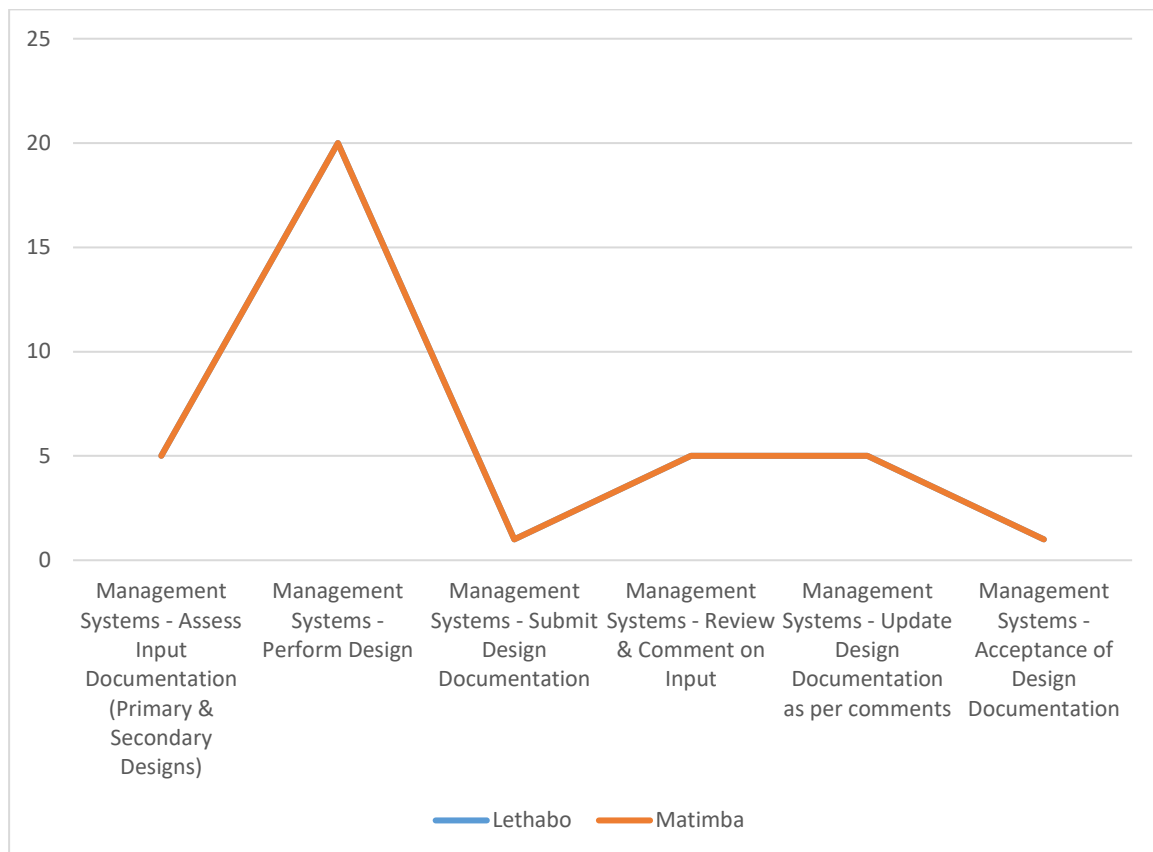


Figure 56: Management Systems activities and activity durations

The graphs in Figure 56 show perfect alignment of activities and activities durations on Management Systems deliverables.

Integrated End of Phase Design Package deliverables

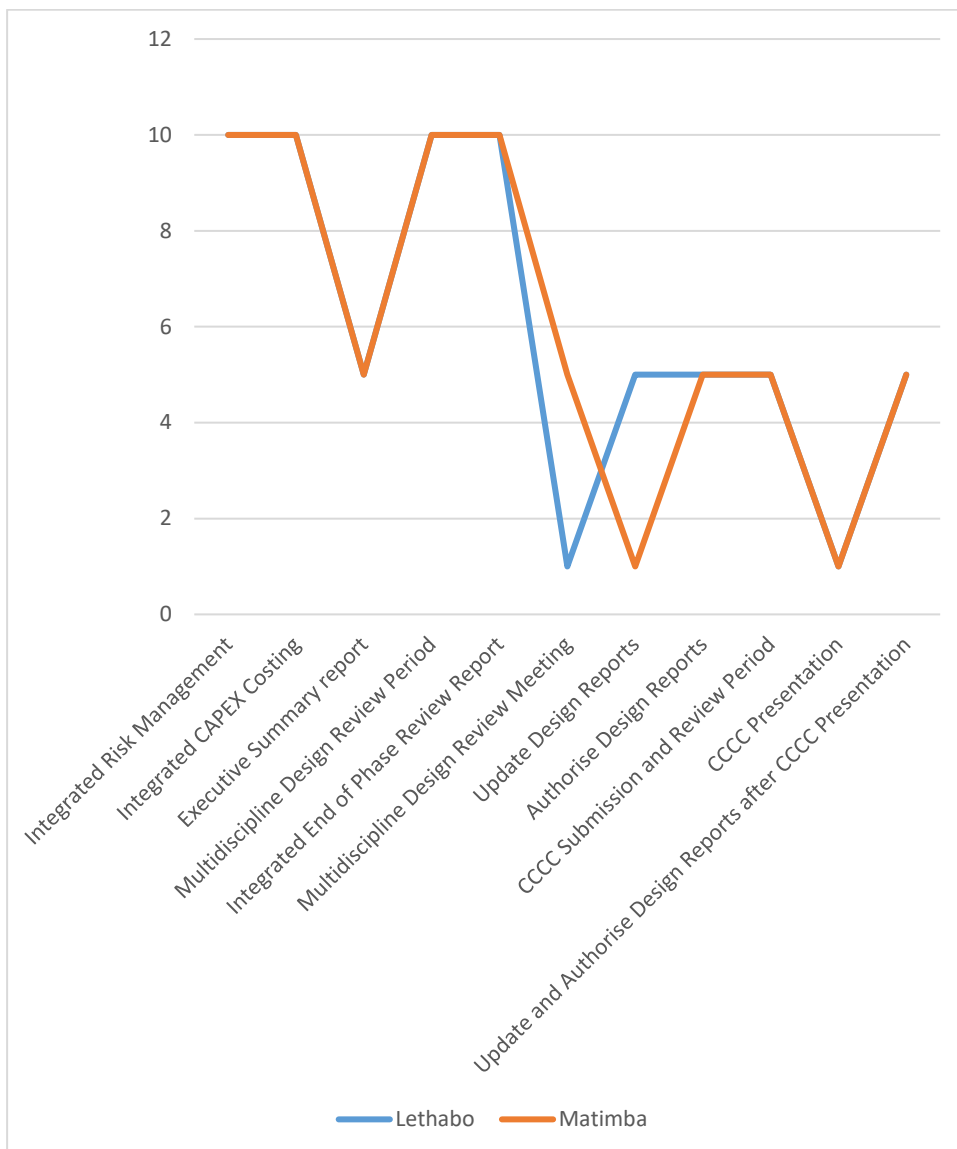


Figure 57: Integrated End of Phase Design Package activities and activity durations

The graphs in Figure 57 show a shift in activities durations on Integrated End of Phase Design Package deliverables.

4.3.3 Kendal and Lethabo Power Stations' High Frequency Transformer Projects

Figure 58 below indicate activities and activities durations for Lethabo and Kendal power stations' High frequency transformers (HFT) concept designs.

HFT Concept Designs deliverables

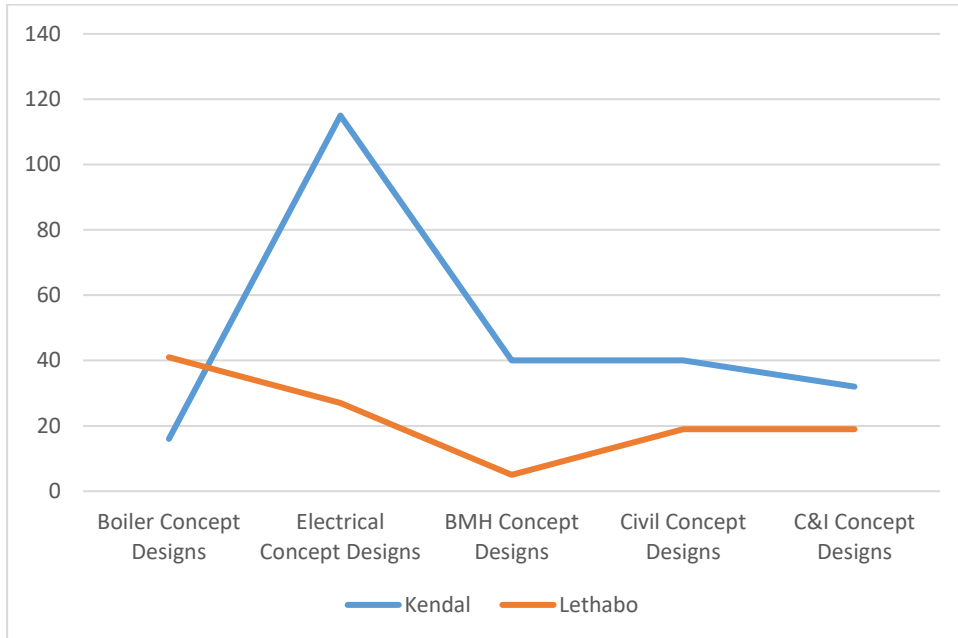


Figure 58: HFT Concept Designs activities and activity durations

The graphs in Figure 58 show major discrepancies on HFT Concept Designs deliverables activities and activities durations. (Project newness and complexity)

4.3.4 Analysis and Discussion on Secondary Data Results

The analysis of secondary data was achieved by utilisation of identified representative graphs for analysis and comparison of findings with the formulated investigative questions.

The identified representative graphs illustrate the following:

- **No variability** of similar deliverables. Figure 56 is the identified graph.
- **Variability** of **activities** and variability of **activity durations** of similar deliverables.
- Figures 41, 42 and 58 are the identified graphs representative graphs.

4.3.5 No variability of similar deliverables

Figure 56 below indicate typical graphs for **no variability** of similar deliverables.



Figure 56: Management Systems activities and activity durations

The graphs show perfect alignment of activities durations on similar deliverables for similar projects.

The research revealed that if two or more similar projects deliverables have **similar activities, same activity durations** and are **sequenced in the same manner**, their graphs are perfectly **superimposed** as one graph. This implies that similar activities and the same activities durations result in minimised variability of similar deliverables even to a point of eliminating variability. This can be demonstrated by means of Euclidean distance measure formula, which states that:

The distance **d** between two vectors **x** and **y** = $\sqrt{\sum_{k=1}^n (x_k - y_k)^2}$.

Where $d \geq 0 \in R$.

d = zero means that there is no variability and therefore the compared vectors are similar and as the value of **d** increases variability increases. Applying above formula to the graph in figure 56 (i.e.) letting **x** and **y** denote Lethabo and Matimba power stations' schedules

respectively, will yield a value of **d** equal to zero since x and y are measured on the same point k (**similar activity sequenced in the same manner within the deliverable**) and they are equal in magnitude (**activity duration**).

The graphs in figure 56 are similar and therefore the cycle times are **similar** or there is **no variability of cycle time** for their deliverables.

The results from primary data collected in questions 16 and 17 of the questionnaire survey, indicate that all participants (100%) of candidates agree that having differing time durations for similar activities will lead to variability of cycle times for similar engineering deliverables and differing activities for similar engineering deliverables leads to variability of cycle times for similar engineering deliverables.

It is reasonable to say the converse is true (i.e.) having similar activities durations and similar activities leads to similar cycle times.

4.3.6 Variability of Activities and Activity Durations of Similar Deliverables

The identified representative graphs in Figures 41, 42 and 58 above indicate **variability** of activities and activities durations. The graphs are **not** superimposed as one graph as in figure 56. The Circled areas A, B1, B2 and B3 in figure 42a below indicate the following:

- Variability of **activities** for similar deliverables. (B1, B2 and B3)
- Variability of **activity durations**. (A)

It should be noted that figure 42 and 42a is the same graph. The researcher added an **a** to indicate that the graph is used for analysis.

Eskom Matimba Power Station and Lethabo Power Station Control and Instrumentation Projects Schedules. (Turbine Primary)

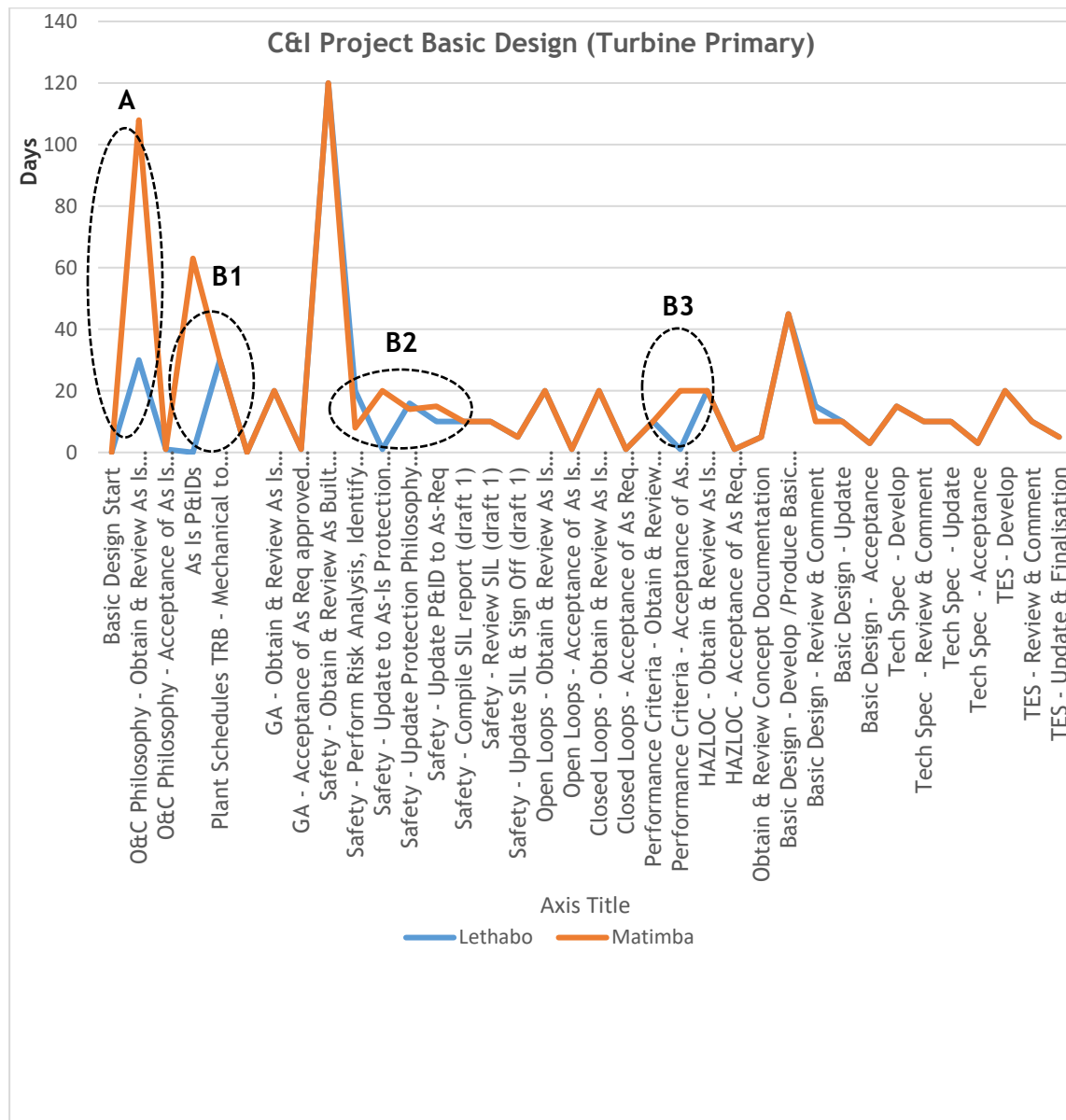


Figure 42a: Eskom Matimba Power Station and Lethabo Power Station Control and Instrumentation Projects Schedules. (Turbine Primary)

Figure 42a demonstrates variability of activities and activities durations for Eskom Matimba and Lethabo power stations' control and instrumentation project schedules for the Turbine Primary plants.

The research revealed that while differing activities for similar deliverables leads to variability of activities, **inconsistent consolidation** and **decomposition** of similar activities for similar deliverables seem to contribute towards variability of the engineering deliverables cycle times

as the combination or separation of these activities does not always match the summation of corresponding activities durations in practice. This is because the allocation of activities durations does not necessarily consider the consolidation or decomposition status of activities. These consolidation and decomposition of similar activities add to non-value adding activities. Koskela (1992) asserts that every time an activity is decomposed into sub-activities that can be executed by different specialists, an increase in non-value adding activities occurs.

Below figure 59 further reinforces above analysis based on the same projects used in figure 41 above.

Analysis of variability of activities and common activities

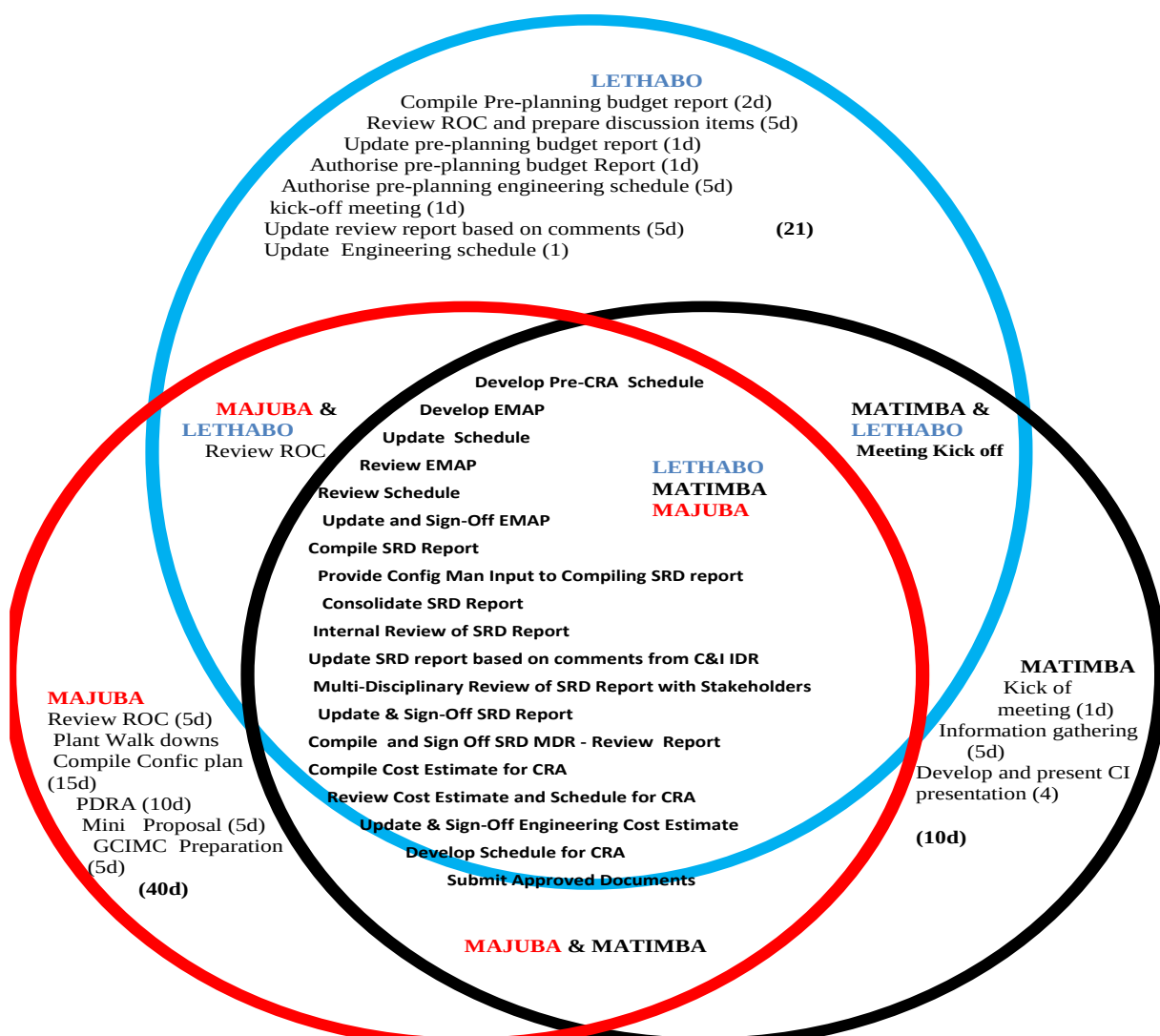


Figure : 59 Analysis of variability of activities and common activities

Source: Author

The analysis demonstrates **variability** of **activities** for similar deliverables and **common activities** for similar activities as follows:

- **Common activities**

- Matimba and Lethabo
 - 1 unique common activity
- Majuba and Lethabo
 - 1 unique common activity
- Matimba and Majuba
 - no unique common activity
- Matimba, Lethabo and Majuba
 - 19 common activities

- **Variability of activities**

- Lethabo has 8 additional activities with a total duration of 21 days using Matimba, Lethabo and Majuba common activities as a base.
- Matimba has 3 additional activities with a total duration of 10 days using Matimba, Lethabo and Majuba common activities as a base.
- Majuba has 5 additional activities with a total duration of 40 days using Matimba, Lethabo and Majuba common activities as a base.

It should be noted that figure 59 profile is based on the Matimba, Lethabo and Majuba common activities in order to demonstrate cycle time variability for similar activities.

Having appreciated variabilities above, it is interesting to observe figure 2a below for Matimba, Lethabo and Majuba (pre-concept designs) cycle time profiles for similar deliverable (Same project as in figure 41 and 59).

The cycle time profiles seem to mirror the profiles for variations of **additional activities total durations** with Matimba having the least **additional activities total durations** followed by Lethabo and then Majuba.

This is an observation emanating from the analysis. The consistency of this typical profile will need further research as the analysis does not take into consideration the logical relationships of activities.

Cycle time profiles for Matimba, Lethabo and Majuba pre-concept designs

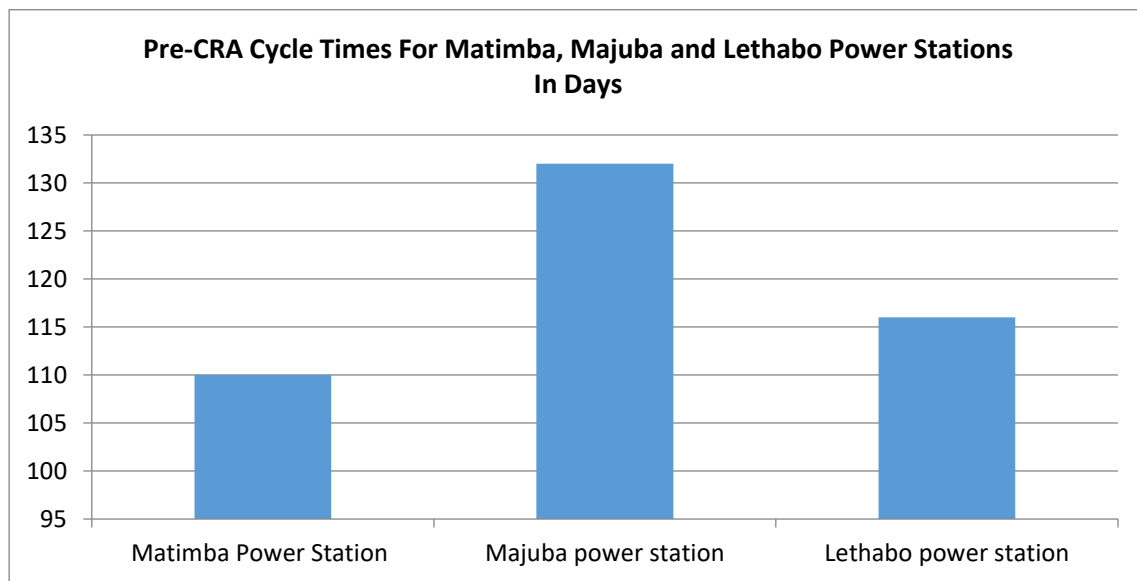


Figure 2a : Cycle time profiles for Matimba, Lethabo and Majuba pre-concept designs

Source: Eskom

The main take away from this observation is that a combination of variability of activities and variability of activities durations, indeed have accompanying variability of cycle times for similar deliverables.

The figure above is the same as figure 2 in Chapter 1. The researcher added an **a** to indicate that it is used for analysis.

These variabilities can be attributed to the following in relation to the factors of focus:

- Inconsistent application of **engineering processes**
- inadequate **intra-organisational knowledge transfer**

4.3.7 The impact of inconsistent Application of Engineering Processes

The application of engineering processes inherently influences activities and how they are carried out. As supported by 88.6 percent of the research candidates in the research surveys question 7, inconsistent application of engineering processes leads to cycle time variability. Based on above it can be deduced that if activities of similar deliverables are subjected to the same influence of engineering processes, they are likely to be similar. The other way of putting it is that if the same engineering processes are applied to similar deliverables during or before activities are scheduled, the **activities** variability will be minimised or eliminated and subsequently **activity durations** variability will be minimised.

4.3.8 The Impact of Inadequate Intra-organisational Knowledge Transfer

Considering figure 42a, Inadequate intra-organisational knowledge transfer manifested in all cycled areas (A, B1, B2 and B3) for the following argument: If there was adequate knowledge transfer on similar activities for similar deliverables, the activities and activities durations variability would have been minimised as there would have been lessons learned from cross-functional teams.

- Considering the Eskom Matimba Power Station and Lethabo Power Station control and instrumentation (C&I) Basic designs schedules, there are some areas within the plotted graphs that are superimposed. See figures 43 and 46.
 - The main contributor to these similarities is that the two projects were developed concurrently having key resources working across the two projects.
 - These setup increased proximity and ongoing relationships of project participants as they share tacit knowledge through both dialogue and activity as asserted by Nonaka and Takeuchi (1995).
- Considering the Matimba Power Station, Lethabo Power Station and Majuba Power Station medium voltage (MV) pre-concept designs, the variability of graphs is noticeable. See figure 41.
 - Above projects were developed separately and independently by the same engineering department.
 - The prevalent form of knowledge transfer was explicit knowledge transfer in the form of engineering processes, procedures, and other forms of documentations.
- Considering Lethabo and Kendal power stations' High frequency transformers (HFT) concept designs schedules in figure 58 above, the graphs do not show any similarity as if the projects are completely different from each other even though they have similar deliverables.

- This is a clear indication of inadequate to no intra-organisational knowledge transfer and inconsistent application of engineering processes.

4.3.9 Comparison with formulated Investigative questions

Table 12: Comparison with the Formulated Investigative Questions

INVESTIGATIVE QUESTION	REPRESENTATIVE FIGURES	CONSOLIDATED ANALYSIS	COMMENT ON LITERATURE SUPPORT
Direct relationship / No Direct relationship between variability of activities for similar engineering deliverables and cycle times of similar projects.	Figure 41 ,42 and 58 and 59	It was observed that variations in activities for similar engineering deliverables led to variations in cycle times. These variations include: 1. Additional activities. 2. Consolidation and decomposition of activities. 3. Differing activities names for the same function.	This is supported by literature in Chapter 2 under Project activities attributes
Direct relationship / No Direct relationship between variability of time durations for similar activities of similar engineering deliverables and cycle times of similar projects.	Figure 56	It was observed that in the absence of variability of similar activities durations, no additional activities and no inconsistent consolidation or decomposition of similar activities, there were no cycle times variability of similar deliverables cycle times.	This is supported by literature in Chapter 2 under Project activities attributes

4.4 Synthesis of secondary and primary data analysis with Literature

Since the influence of application of engineering processes on cycle time variability relies mainly on the engineering management framework and existence of engineering processes, variability of cycle time due to application of engineering processes is likely to be minimised with more established management framework and engineering processes.

In well-established management framework and engineering processes with clearly defined knowledge transfer context, the main driver of variability is intra-organisational knowledge transfer mainly due to **social capacity** and **absorptive capacity**. As indicated in Chapter 2 Tsang and Inkpen (2005) define **social capacity** as the embedded resources within the network of relationships of individuals or organisations and absorptive capacity relates to the willingness and ability to learn. Cummings and Teng (2003).

Whereas in the poorly established management framework and engineering processes, both the application of engineering processes and intra-organisational knowledge transfer drive cycle time variability. This is so because the management framework forms part of the project management context.

Shin-Tien Chen and Bao-Guang Chang (2012) confirm that an organisation with a higher degree of formalisation has its operations built on a set of standardised procedures, so that an organisational member can effectively acquire, assimilate, transfer and apply the required knowledge and capacity, to increase their absorptive capacity of organisational learning. This further confirm the criticality of formalisation of processes on knowledge transfer.

4.5 Latest conceptual framework

The following additional developments were observed during the analysis of primary and secondary data regarding the conceptual model:

- There is a causal relationship between activities attributes and Intra-organisational knowledge transfer. See H2a and H2b in figure 60 below.
- There is a causal relationship between activities attributes and application of engineering processes. See **H1a** and **H1b** in figure 60 below.
- Intra-organisational knowledge transfer and application of engineering processes influence cycle time variability **through** activities attributes. See **H3** and **H4** in figure 60 below.

The activities attributes play **mediatory** role between the application of engineering processes and intra-organisational knowledge transfer thus making them **mediating variables**. Baron

and Kenny (1986) define the mediator variable as the mechanism through which the focal independent variable is able to influence the dependent variable of interest.

- The introduction of non-value adding activities are introduced by:
 - Decomposition and consolidation of activities.
 - Additional activities for similar deliverables.
 - Differing names of activities for similar deliverables.

These non-value adding activities and their amount, influence **variability of activities** and **variability of activities durations** thus playing a moderating role. See **H3a** and **H3b** in figure 60.

Based on above observation it can be concluded that **well defined activities** lead to consistent activities and minimised non-value adding activities for similar deliverables and consistent activities for similar deliverables contributes to minimised cycle time variability of similar engineering deliverables.

- Variability of activities has some influence on variability of activities durations. See **H3c** dotted lines in figure 60. This is supported by above statement that refers to well defined activities.

The implication of above observed salient points is that the **implied** direct relationship between (1) Intra-organisational knowledge transfer and cycle time variability and (2) direct relationship between Application of engineering processes and cycle time variability in the initial conceptual framework in figure 3, **no longer hold strongly** since there is evidence of **mediation** by activities attributes.

The extent of mediation is not in the scope of this research, although the extent of mediation is not determined, it is reasonable to expect that there is a certain amount of direct influence of cycle time variability by both the application of engineering processes and the intra-organisational knowledge transfer. See **H1c** and **H2c** dotted lines. Antonio Pardo and Marta Román (2013) in their article “Reflections on the Baron and Kenny model of statistical mediation” indicate the existence of partial and complete mediation and assert that the extend of mediation should not only be based on statistical data but the theory should back it up. The article does not seem to indicate absolute complete mediation.

Latest Refinement of conceptual framework for Cycle time variability minimisation for similar engineering deliverables

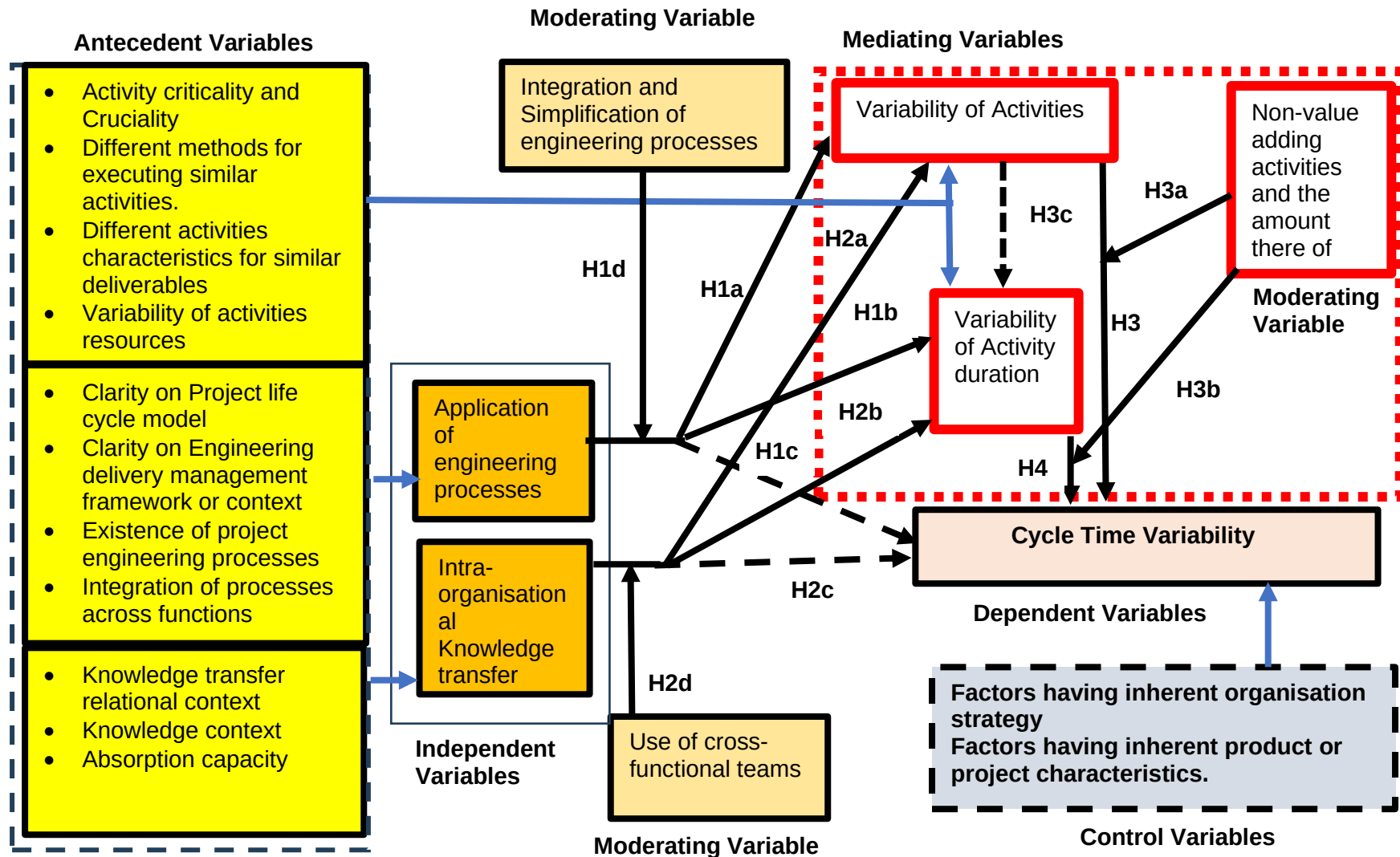


Figure 60: Latest Refinement of conceptual framework for Cycle time variability minimisation for similar engineering deliverables

Source: Author

4.6 Conclusion

In this chapter the presentation, analysis and discussion on both the primary and secondary data for the research were presented and the secondary data and the primary data were synthesised with the literature. The latest updated conceptual framework was presented. In the next chapter, the development of the framework model for minimising cycle time variability is presented.

CHAPTER 5

5 Development of Framework Model for Minimising Cycle Time Variability of Similar Engineering Deliverables

5.1 Introduction

As indicated in Chapter 3 under 3.10, the development of the framework model has been progressive from the beginning of the study. To recap, the following progression took place:

1. Development of the Initial Conceptual Framework

The development of the initial conceptual framework was done in the early stages of the research work at the research proposal stage informed by the researcher's observation and limited literature review. See figure 3 above.

2. 1st Refinement Conceptual

The first refinement of the conceptual framework was done as the literature review information unveils, thus necessitating refinements on the initial conceptual framework based on emerging information. See figure 20 above.

3. Latest Conceptual Framework

The latest conceptual framework was refined based on the cumulative salient information from:

- The literature review.
- Primary data analysis
- Secondary data analysis
- and emerging information related to the research. See figure 60 above.

5.2 The Framework Model for minimising cycle time variability of similar engineering deliverables.

The objective of the framework model is to initiate the building blocks for minimising cycle time variability for similar engineering deliverables.

- The latest conceptual framework is the main input to the framework model.
- The major difference between the latest **conceptual framework** and the **framework model** is that the relationships in the conceptual framework are linear in nature whereas the relationship in the framework model allows for non – linear relationships and can be iterative.
- The framework model is a more expanded process that attempts to model real life practical undertakings.

- The variables are simplified into the **leading**, the **lagging** and the **outcome variables**. Detailed explanation is provided under explanation of the framework model for minimising cycle time variability below.

Figure 61 below indicates the proposed cycle time variability minimisation **framework model** for similar engineering deliverables. The model is based on the above discussed progressive developments.

Cycle Time Variability Minimisation Framework Model for Similar Engineering Deliverables

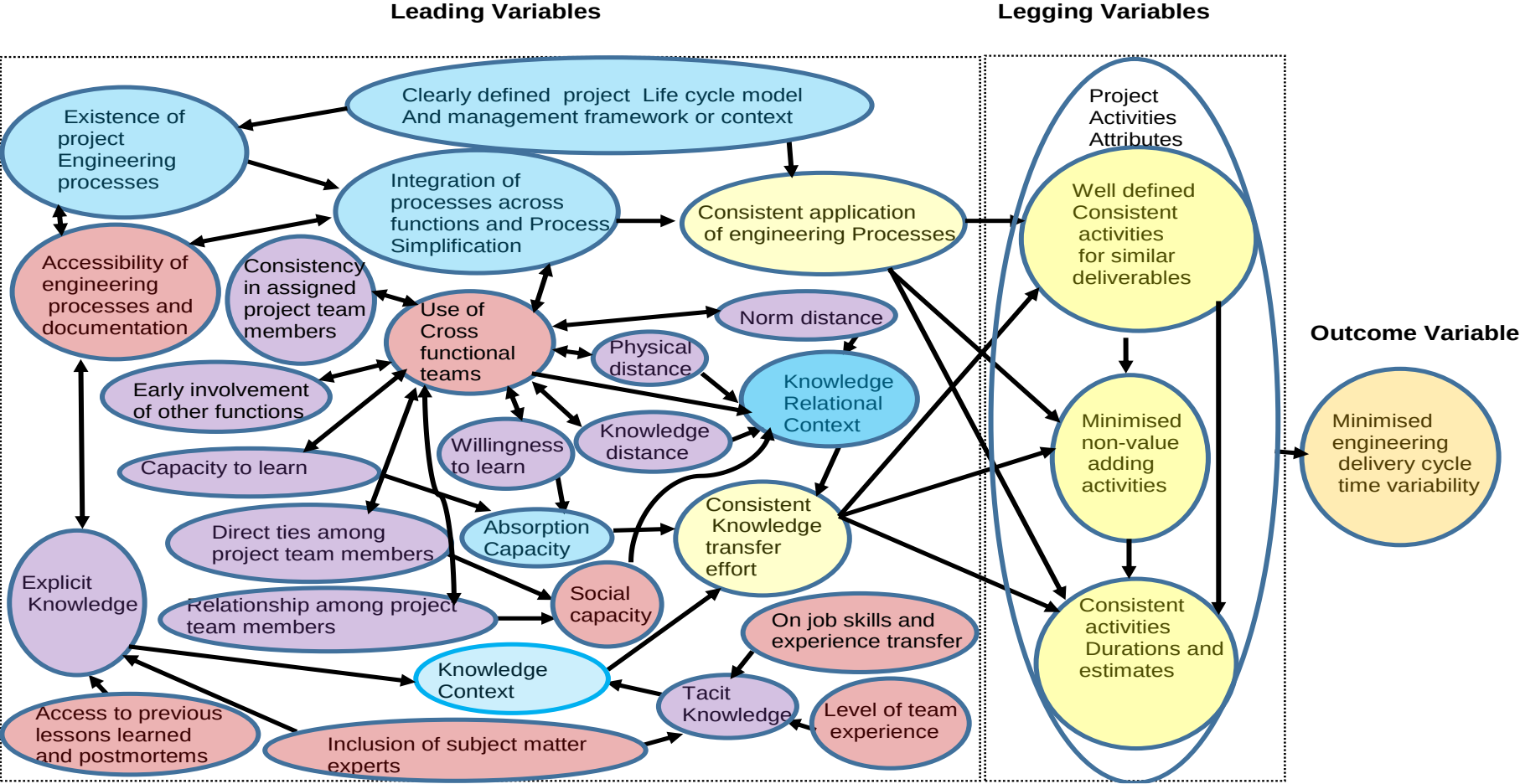


Figure 61: Cycle Time Variability Minimisation Framework Model for Similar Engineering Deliverables

Source: Author

5.3 Explanation of the framework model for minimising cycle time variability

The model is divided into three main components, which are:

- The leading variables consisting of the independent variables including their input variables.
- The lagging variables consisting of the mediating variables including their moderating variables.
- The Outcome variable is the ultimate deliverable of the model.

5.3.1 Leading variables

The main leading variables consist of the following:

- **Consistent Application of Engineering Processes** which is linked to the following input variable:
 - **Clearly defined project life cycle model and management framework.** This input variable is the cornerstone or foundation of the Consistent application of Engineering Processes variable. It is informed by the Engineering Management Framework through the Engineering Operating Model that forms part of the factors having inherent organisational strategy mentioned in Chapter 2. It provides the **context** of project engineering processes.
 - **Existence of project engineering processes.** This input variable is key to the application of engineering processes since application of engineering processes cannot take place if the engineering processes do not exist.
 - **Accessibility of engineering processes and documentation.** This input variable is key into gaining access to existing processes and documentation as it will assist in the application of engineering processes. Just having processes available, is not enough, they must be accessibly. This input variable is linked to **explicit knowledge variable**.
 - **Integration of processes across functions and processes simplification.** This input variable determines the effectiveness and efficiency of **applying engineering processes** in order to deliver comprehensive products since it considers factors inherent in other functions or disciplines and simplify for ease of application. This variable is identified as the **moderating variable** in the latest conceptual framework in figure 60; and it is linked to:
 - Existence of project engineering processes
 - Accessibility of engineering processes and documentation that is linked to Explicit knowledge variable.

- Use of cross-functional teams variable.
- **Consistent Knowledge Transfer Effort** which is linked to:
 - **Knowledge transfer relational context;** the input variables are:
 - Knowledge distance
 - Norm distance
 - Physical distance
 - Cross-functional teams
 - Social capacity: the input variables are:
 - Direct ties among project team members
 - Relationship among project team members

The knowledge transfer relational context is the key enabler of transferring knowledge especially tacit knowledge. It is characterised by social interactions.

- **Absorptive Capacity:** the input variables are:
 - Willingness to learn.
 - Capacity to learn.

The absorptive capacity includes the capacity to absorb knowledge by individuals and the entity or group of knowledge participants. The willingness to learn and the capacity to increase absorption of knowledge and will increase intra- organisational knowledge transfer.

- **Knowledge Context:** the input variables include:
 - Tacit knowledge with the following input variables:
 - On job skills and experience transfer
 - Level of team experience
 - Inclusion of subject matter experts
 - Explicit Knowledge with the following input variables:
 - Inclusion of subject matter experts
 - Access to previous lessons learned and project post-mortems.
 - Accessibility of engineering processes and documentation

The knowledge context variable encompasses the key forms of knowledge. Understanding of these forms of knowledge is key in the transfer of knowledge.

- **Use of Cross-functional teams**

This variable is the key link between intra-organisational knowledge transfer and the application of engineering processes. It determines the effectiveness and efficiency of intra-organisational knowledge transfer and is a critical component of project success. As can be seen in the model it links with both intra-organisational knowledge transfer variables and the application of engineering processes input variables.

Use of cross-functional teams is identified as the moderating variable for intra-organisational knowledge transfer in the latest conceptual model in figure 60 it Links with:

- Direct ties among project team members
- Relationship among project team members
- Integration of processes across functions
- Capacity to learn.
- Knowledge distance
- Norm distance
- Physical distance
- Consistency in assigned project team members.
- Early involvement of other functions

5.3.2 The lagging variables

The main lagging variables are the **Project Activities Attributes**. Project Activities Attributes is the collective name for activities components.

The main inputs to the Project activities Attributes are the **Consistent Application of Engineering Processes** and **Consistent Knowledge Transfer Effort**. Their input variables are already discussed above. The lagging variables include:

- Well defined activities for similar deliverables.
- Minimised non-value adding activities.
- Consistent activities.
- Consistent activity durations.
- Consistent activity duration estimation.

These variables form part of the link between both **consistent application of engineering processes** and **intra-organisational knowledge transfer** and the **outcome variable**.

5.3.3 The outcome variable

The outcome variable is the ultimate result of all inputs. (i.e.) Minimising engineering delivery cycle time variability for similar engineering deliverables.

It should be noted that the input variables in figure 61 above, are not exhaustive and that the relationships are not necessarily always linear or one-way as can be seen with **the use of cross- functional teams** links. The researcher attempted to use key variables that he deemed representative enough to be included in the framework model.

5.4 Application of the framework model for minimising cycle time variability for similar deliverables

Since the objective of the framework model was to initiate the building blocks for minimising cycle time variability for similar engineering deliverables, the framework model can be used as a basis for analysing cycle time variability for similar engineering deliverables. The analysis can be achieved by utilising different evaluation tools, such as and not limited to:

- **Systems dynamics**

- System dynamics is a modelling approach that has the ability to represent dynamic behaviour of complex systems. Rodrigues and Williams (1998). Application of this tool is not in the scope of this research, and it is too involved to provide limited demonstration on the Framework Model. Application of Systems dynamics is a field of research on its own.

- **The Analytic Hierarchy Process (AHP)**

- AHP is used to derive ratio scales from both discrete and continuous comparisons. The comparisons may be from actual measurements or from scales that indicate the relative strengths of preferences and feelings. Saaty (2005).
- It reduces complex decisions into pairwise comparisons. Saaty (2005).
- AHP is suitable where intuition, rationality and irrationality in connection with risk and uncertainty can be found. Palcic and Lalic. (2008).
- The tool is a top-down hierarchy that starts by structuring a **decision-making problem as a hierarchy** in the form of an upside-down tree where the **main goal** is placed on top. **Partial objectives that meet the main objective** are placed at the second level. Leal (2019).
- Each partial objective at the second level can be **decomposed into third level objectives**. Leal (2019).

- It should be noted that in earlier literature the term objective is referred to as the main goal, partial objective as the criteria, and the third level as alternatives. Saaty (2005), Pachemska et.al (2014). In earlier literature, levels start after the **main goal**.
- The author preferred the Leal (2019) approach as it attempted to simplify the AHP and could easily relate to the authors work without changing the original principle.
- In this research.
 - **Decision-making problem** is related to **framework model** (minimising cycle time variability for similar engineering deliverables),
 - **Main goal** is related to **minimising cycle time variability**,
 - **Partial objectives** is related to **lagging variables** (Activities Attributes),
 - Decomposed into third level objectives is related to the **Main leading variables** (Application of Engineering and Intra-organisational Knowledge Transfer).
- The first level components are given weights or priorities and the subsequent level components are ranked according to weights or priorities given in the first level.

Below is a typical generic hierarchy structure for AHP.

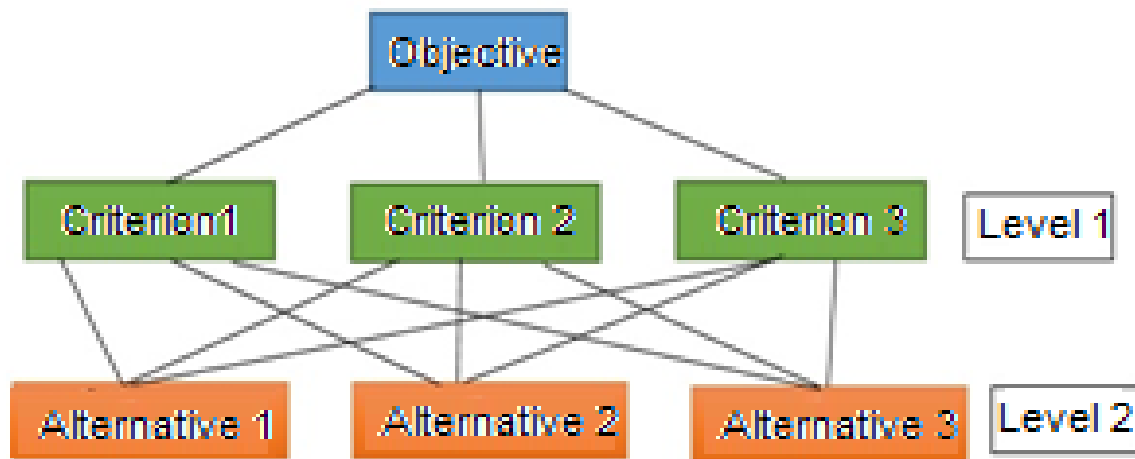


Figure 62: Generic hierarchy structure for AHP

Source: Obtained from Palcic and Lalic. (2008)

Illustration of AHP Hierarchy structure for minimising engineering delivery cycle time for similar engineering deliverables is presented in figure 63 below:

Illustration of AHP Hierarchy structure for minimising engineering delivery cycle time for similar engineering deliverables

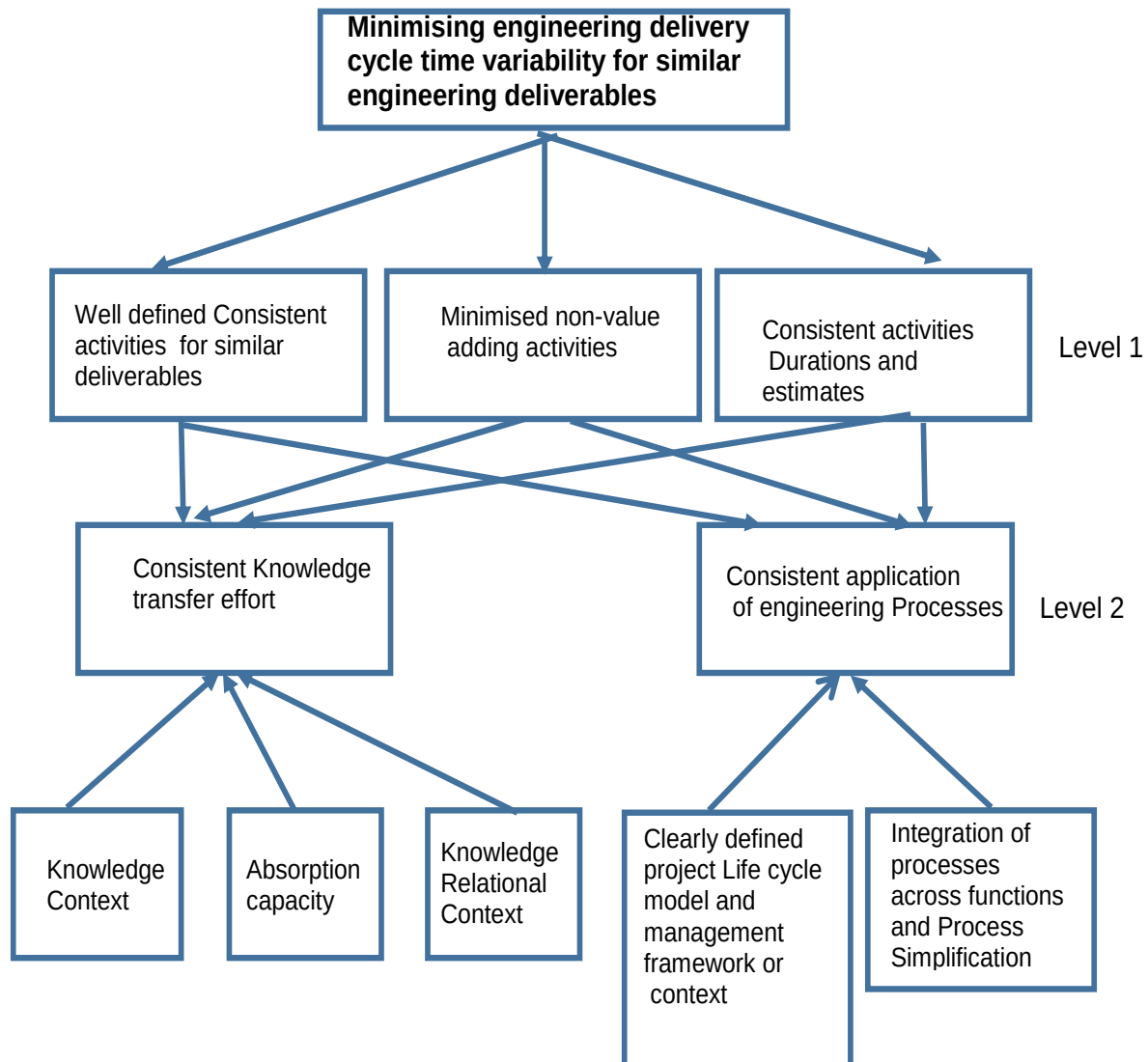


Figure 63: Illustration of AHP Hierarchy structure for minimising engineering delivery cycle time for similar engineering deliverables

Source: Author

- The first level components are given weights or priorities and the subsequent level components are ranked according to weights or priorities given in the first level.

- **The analytic network process (ANP)**

- Is inclusive of the AHP, the AHP is a generalised form of the ANP. The ANP supports modelling dependencies and feedback between elements in the network that include clusters and nodes.
- It is suitable for evaluating decisions in fields that are characterised by existing dependencies of higher-level elements on lower. Saaty (2005).
- ANP computes complex relationships between decision elements through replacement of a hierarchical structure with a network structure Kheybari. et al (2019)
- Below is an illustration of a possible ANP network for minimising cycle time variability for similar engineering deliverables. Indicating loops and nodes.

An illustration of a possible ANP network for minimising cycle time variability for similar engineering deliverables.

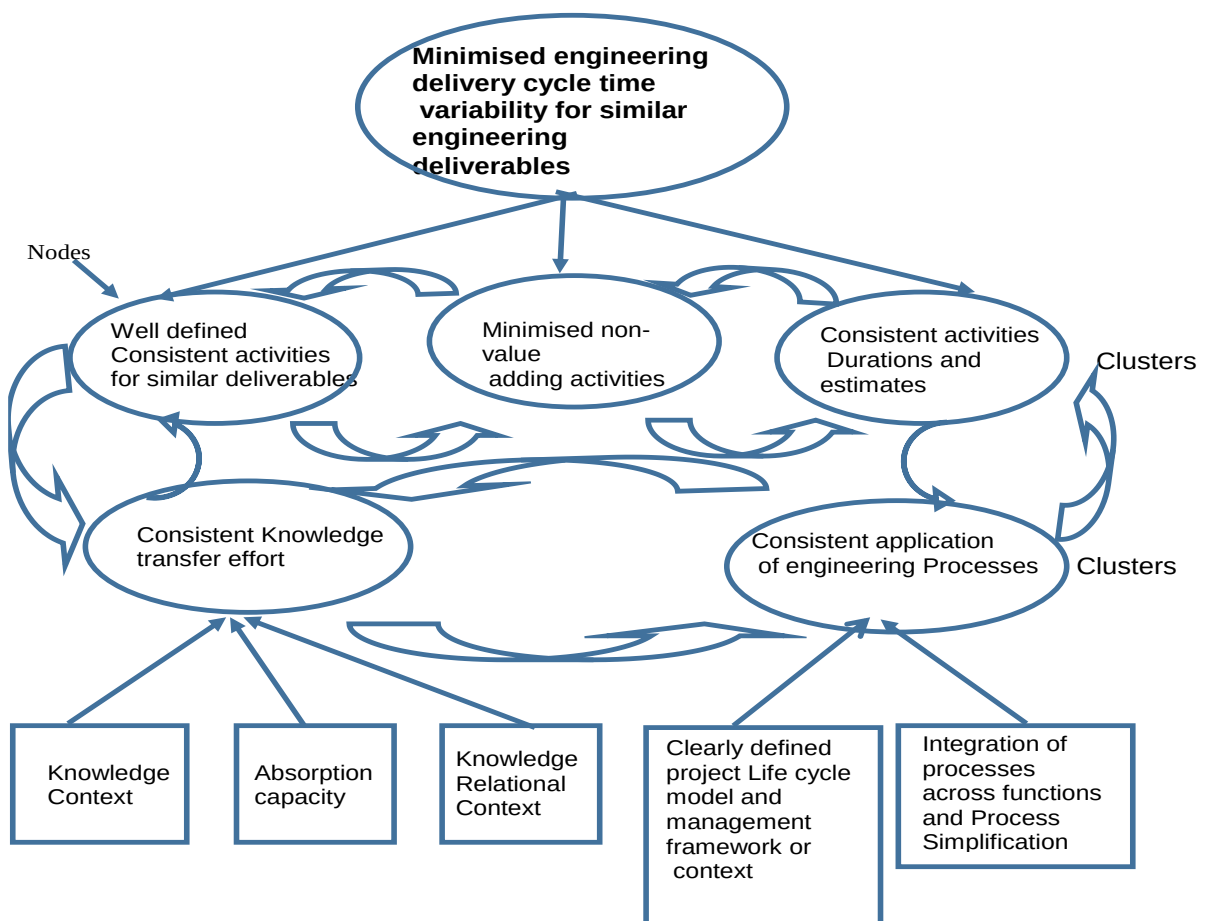


Figure 64: An illustration of a possible ANP Network for minimising cycle time variability for similar engineering deliverables.

Source: Author

- **Simple Weighted average tools generally used to evaluate key performance indicators.**

This tool is one of the simplest and most popular tools used in evaluating key performance indicators in business performance management. The key indicators are derived from the business objectives and focus areas.

Most advanced businesses, group the key performance indicators according to the balanced scorecard. Kaplan Norton (1996).

The researcher opted to use this tool for initial demonstration of operationalising the framework model because of its simplicity. In this research, this weighted average tool is used as a base for developing the scoring tool for engineering delivery cycle time variability. See Table 13 below. The scoring tool is the simplest and the least accurate compared to the systems dynamics, AHP and the ANP.

The developed scoring tool can provide an early indication of the risk of cycle time variability by conducting an upfront analysis on the factors contributing to cycle time variability during the planning stages of the project and early stages of project execution. It can also be applied during lessons learned and project post-mortems in order to evaluate factors that could have contributed to cycle time variability.

Below is an illustration of a **typical simple weighted average scoring tool**. It should be noted that the input factors are not exhaustive. An exhaustive list of input factors cannot be feasibly included in the scoring tool. The main focus is placed on the key leading variables. (i.e.)

Application of engineering processes and intra-organisational knowledge transfer.

The weightings for the key factors were obtained from expert opinion consensus during model validation.

Table 13: Cycle Time Variability Scoring Tool

				Scoring Criteria			Weighted Score
Project Execution factors	Weight	Input factors to key factors	Weight	Acceptable Full compliance	Tolerable 75% compliance)	Unacceptable 50% compliance	
Engineering Processes	56%	Adherence to project life cycle model. Project phases and Stage-gates Requirements					
		Formal appointment of relevant engineering team members					
		Early involvement of all relevant functions					
		Integration of engineering processes across functions					
		Accessibility and visibility of engineering processes documentation					
Intra-Organisational Knowledge Transfer	44%	Access to lessons Learned					
		Use of cross-functional teams					
		Level of team experience					
		Inclusion of subject matter experts					
		On job skills and knowledge transfer					
Average Score							

Source: Author

5.4.1 Application of scoring tool

The total weight of the scoring tool equals to the sum of the key leading variables weights, that are further divided into respective weights of their input variables. The inclusion of the respective input variables depends on the level of analysis required. A more detailed analysis will include lower levels of input variables. The scoring tool is divided into:

- Key independent variables captured as project execution factors.
- Weights for key independent variables totalling to 100%
- Input variables to key independent variables captured as input to key factors.
- Respective weights for input to key factors totalling to the respective weight of the key factors.
- A scoring criterion which depends on the tolerance level of variability, in this scoring tool the criteria is set as follows:
 - Full compliance is deemed acceptable.
 - 75% compliance is deemed tolerable.
 - 50% and below is deemed unacceptable.
- The weighted scores
 - The weighted score will be the result after evaluation of each input to respective key factor.
- The average score
 - The average score is the average of the weighted scores.
 - The average score is not the acceptance criteria, but an indication.

The acceptance criteria for this scoring tool is that all input variables should score at least 75% compliance.

5.4.1.1 The evaluation process

The evaluation process requires the following:

- Cross-functional team and an independent facilitator
 - The facilitator will facilitate the scoring process by the cross-functional team.
- Proof of relevant documentation
 - Proof of relevant documentation will serve as means to validate the scoring.

It should be noted that this is a very subjective process, which will require a lot of good faith to be successful.

5.4.2 Contribution of the framework model

The framework model will assist in serving as a basis for continuous improvement in minimising cycle time variability.

It is expected that the benefits of utilising the recommended framework model for cycle time minimisation on similar project engineering deliverables would go beyond the project engineering space into other areas that are technical and non-technical in nature.

Within the Eskom power generation space, the framework model can be directly adapted in the outage management space as there are repeated major maintenance activities with similar deliverables.

The model is not limited to Eskom as it can be used in other industries having similar projects requiring similar engineering deliverables.

The literature review conducted under the heading **activities attributes** in Chapter 2, indicated that activities attributes variability (Planned vs Actuals) within a particular project, could lead to an increase in the cycle time of that project subsequently leading to variability of similar activities attributes when compared among similar projects. We can draw a conclusion that the framework model can also contribute towards **minimising cycle time** of a particular or individual project.

The implication of the statement above is that the framework model is **not only limited** to minimising **cycle time variability** of **similar projects** but can also contribute in minimising **cycle time** of a **particular projects**.

5.5 Model validation

To recap from Chapter 3 the validation process took place in 2 Phases in which phase 1 had 3 steps that related to the meeting engagement with a team of experts in the engineering projects development area. The objective of phase 1 was to obtain feedback on the usefulness and relevance of the framework model.

The phase 1 steps were as follows:

- **Identification of relevant experts in the engineering projects development area.**

The identified experts consisted of:

- Manager Complex Projects from Eskom Project Development Department
- Chief Advisor Project Development from Project Development Department
- 2 Middle Managers Project from Project Development Department
- Senior Advisor Capital Efficiency from Capital Efficiency Strategy Department

Invitation of experts to attend the validation meeting and provide background information. Proof of meeting invitation is capture in Annexure D.

The background information included:

- a. The proposed framework model.
- b. The related proposed scoring tool

- **Facilitate the engagement meeting and receive feedback from different experts on the usefulness and relevance of the model in the engineering project development area.**

- Proof of meeting attendance is captured in Annexure E.
- The meeting was held on **Microsoft Teams** platform.

Phase 2 was involved in acquiring independent opinion on the **levels of influence of variables** contributing to cycle time variability and to provide the **weighting on the key independent variables**.

The researcher forwarded questionnaires with regards to the **labelled model links** requesting experts to provide their independent opinion on the levels of influence of variables contributing to cycle time variability and to provide the weighting on the key independent variables for the **scoring tool**. Proof of forwarding questionnaires with labelled model links is captured in Annexure F.

Below is the validation questionnaire forwarded to individual experts for independent opinion on the model links and the weighting for the scoring tool (table 13) discussed under practical application of the framework model.

Table 14: Template for List of Labelled Links for Validation Purpose

Factor		% Weight of contribution to cycle time variability minimisation
Consistent application of engineering processes (W1)		
Consistent Knowledge transfer effort (W2)		
Factor	Influence Rating on a scale of (1-9). 1 being little to no influence and 9 being very influential. Follow the arrow.	
Link A		
Link B		
Link C		
Link D		
Link E		
Link F		
Link G		
Link H		
Link I		
Link J		
Link K		
Link L		

Expert Opinion

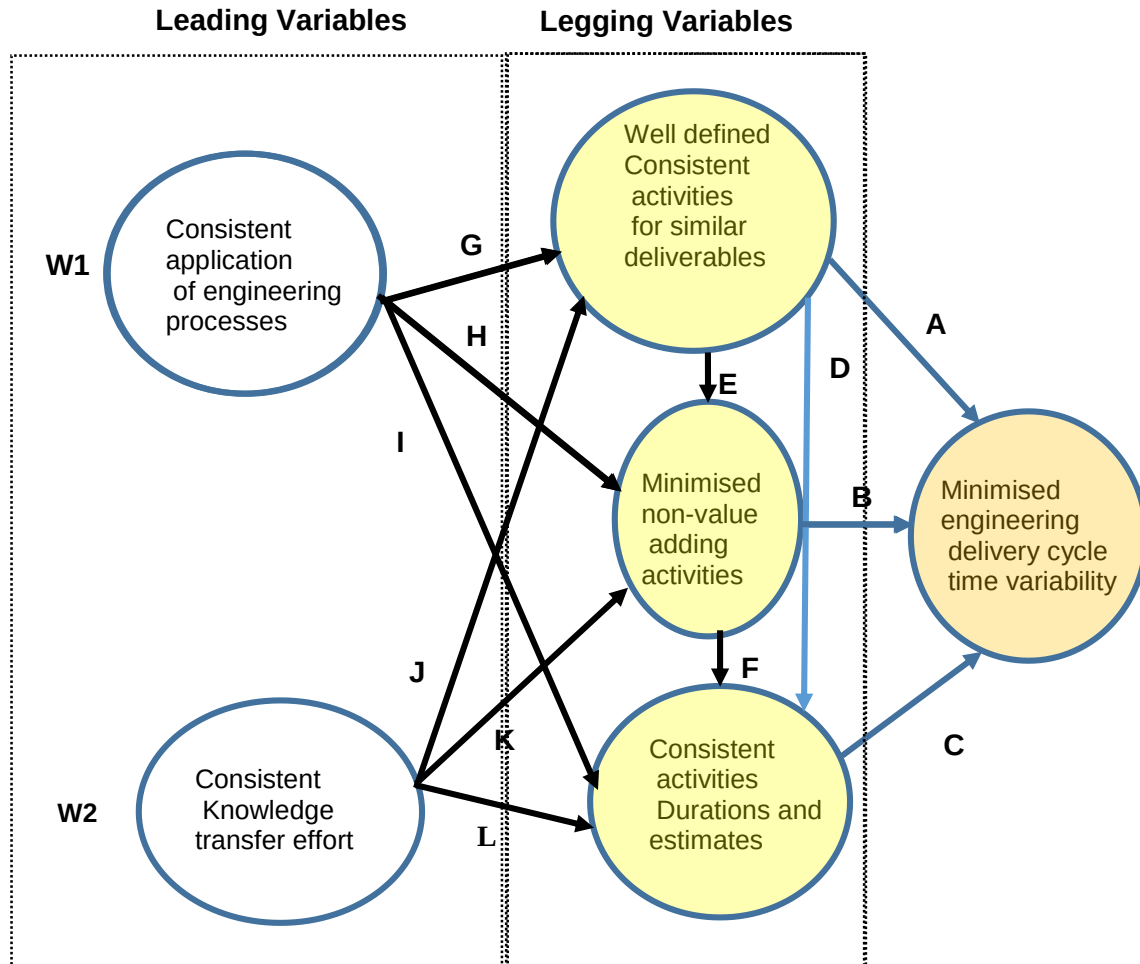


Figure 65: Labelled Key Framework Model Links for Validation Purpose

Source: Author

5.5.1 Phase 1 Model Validation Results

All experts confirmed that the model was relevant and could be more useful if it is operationalised with simplicity.

5.5.2 Phase 2 Model Validation Results

Results for Ratings on the level of influence by both the leading and lagging variables

Below table captured the independent opinions of experts on the allocation of ratings for level of influence by both the leading and lagging variables.

Table 15: Results for Ratings on the level of influence by both the leading and lagging variables

Factor	Influence Rating on a scale of (1-9). 1 being little to no influence and 9 being very influential. Follow the arrow.				
	Manager Complex Projects	Chief Advisor Project Development	Middle Manager Project Development (1)	Middle Manager Project Development (2)	Senior Advisor Capital Efficiency
Link A	7	8	8	8	8
Link B	7	7	6	6	7
Link C	6	6	7	7	8
Link D	8	7	7	8	8
Link E	8	2	8	6	8
Link F	7	7	6	6	8
Link G	8	7	7	7	8
Link H	7	7	7	6	8
Link I	9	7	8	7	7
Link J	8	7	9	8	8
Link K	7	7	9	7	7
Link L	7	7	8	8	8

Results for allocation of weights for the key independent variables

Below table captured the independent opinions of experts on the allocation of weights for the Key independent variables.

Table 16: Results for allocation of weights for the key independent variables

Factor	% Weight of contribution to cycle time variability minimisation				
	Manager Complex Projects	Chief Advisor Project Development	Middle Manager Project Development (1)	Middle Manager Project Development (2)	Senior Advisor Capital Efficiency
Consistent application of engineering processes (W1)	60%	65%	60%	35%	60%
Consistent Knowledge transfer effort (W2)	40%	35%	40%	65%	40%

5.5.3 Analysis of Phase 2 Validation Results

The single factor Analysis of variance (ANOVA) was conducted to determine if there were significant differences among the opinions of experts concerning the level of influence of factors as per the questionnaire and allocation of weights for the key independent factors. This was conducted to check for consensus.

An ANOVA test is a statistical test used to determine if there is a statistically significant difference between two or more data sets. The Null hypothesis is that the means for the analysed data sets are the same.

Level of influence by both the leading and lagging variables.

The single factor Analysis of variance (ANOVA) was conducted to determine if there were significant differences among the opinions of experts concerning the level of influence of factors as per the questionnaire. This is conducted to check for consensus. An ANOVA test is a statistical test used to determine if there is a statistically significant difference between two or more data sets. Below is the conducted Single factor ANOVA.

Table 17: The single factor Analysis of variance (ANOVA) For Independent Opinions of Experts on the Allocation of Ratings for Level of Influence as per Key Framework Model Links

Anova: Single Factor						Significant level : 0.05
SUMMARY						
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
Link A	5	39	7,8	0,2		
Link B	5	33	6,6	0,3		
Link C	5	34	6,8	0,7		
Link D	5	38	7,6	0,3		
Link E	5	32	6,4	6,8		
Link F	5	34	6,8	0,7		
Link G	5	37	7,4	0,3		
Link H	5	35	7	0,5		
Link I	5	38	7,6	0,8		
Link J	5	40	8	0,5		
Link K	5	37	7,4	0,8		
Link L	5	38	7,6	0,3		
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	14,45	11	1,31364	1,2921	0,25787	1,994580015
Within Groups	48,8	48	1,01667			
Total	63,25	59				

The null hypothesis is not rejected since the P value = 0.25787 and the results is not significant at $p < 0.05$. This implies that there is significant consensus among the experts.

The consensus by the experts serves as **validation** of the framework model since they agree with the critical flow of the model.

Allocation of weights for the key independent factors

Table 18: The Single Factor Analysis of Variance (ANOVA) For Independent Opinions of Experts on the Allocation of Weights on the Allocation of Weights for the Key Independent Factors

Anova: Single Factor						significant level: 0.05
SUMMARY						
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
Consistent application of engineering processes	5	280	56	142,5		
Consistent Knowledge transfer effort	5	220	44	142,5		
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	360	1	360	2,526316	0,150625	5,317655072
Within Groups	1140	8	142,5			
Total	1500	9				

The null hypothesis is not rejected since the P value = 0.15 and the results is not significant at $p < 0.05$. This implies that there is significant consensus among the experts.

Since the intent of the exercise was to obtain consensus opinion on the weighting of the key independent variables from the experts, the objective is met and the allocated weighting of **56%** for consistent application of engineering processes and **44%** for consistent knowledge transfer are used as the initial inputs for the scoring tool.

Based on literature review and both analysis from primary and secondary data the intra-organisational knowledge transfer is likely to be the most dominant source of cycle time variability as it has a lot of input variables. This observation does not seem to be consistent with the collective experts' opinion on the allocated weights of both the application of engineering processes (**W1 = 56%**) and intra-organisational knowledge transfer. (**W2=44%**). This could be because of the premise they held at the time of their evaluation. If the premise was that Eskom does not have adequate processes for minimising cycle time variability the weighting of **W1** will increase and if the premise is that there are adequate processes the weighting of **W2** will increase.

In this case, it can be deduced that their premise was that Eskom does not have adequate processes for minimising cycle time variability. This is consistent with the results from primary data in question 4 in which 60 percent of candidates believed that Eskom does not have comprehensive tools for minimising cycle time for similar engineering deliverables within

similar project phases across different projects that are executed on similar plant areas. There was one expert who deviated from this premise and gave a higher weight of (**W2 = 65%**)

5.6 Limitation of the Framework Model

Although the model can be expanded to include other parameters, it is based on the derived focus areas identified by the researcher based on the scope of the research. As the name suggests, it serves as a framework, and it is limited in terms of providing specific quantifiable values and providing dynamic simulations.

The proposed scoring tool of the model relies on inputs from cross-functional teams and the diligence of the facilitator. This makes it more subjective.

The model mainly focuses on factors influencing cycle time variability as prioritised by the researcher and it is by no means sufficient to eradicate nor to reduce cycle time variability significantly without the aid of best practice tools from a variety of other disciplines and practices.

It should be appreciated that the model is inherently complex. INCOSE Complex Systems Working Group White Paper (2015) assert that complexity is often created by the interaction of people, organizations, and the environment that are part of the complex system surrounding the technical system. PMBOK seventh edition (2021) assert that Complexity is the result of human behaviour, system interactions, uncertainty, and ambiguity.

The framework model for this research fits the description of complexity. Having appreciated the complex nature of the framework model, only relaying on typical linear tools like the **typical weighted average** tool provided in table 13 or the AHP explained in 5.4 above, will limit the benefits of the framework model. The most appropriate tools to maximise the framework model benefits, will be tools suitable to evaluate complexity like and not limited to **systems dynamics** or to some extent the **analytic network process (ANP)**. Application of these tools is not in the scope of this research but proposed for future research.

5.7 Key Success Factors of the Framework Model

As indicated in the limitations of the framework model above, the framework model should be complemented by incorporating best practices and tools from a variety of related disciplines or practices for minimising cycle time variability on existing and new similar engineering deliverables. This practice will ensure continuous improvement of the framework model and contribute to its relevance and sustained usefulness.

The Analogous Estimating tool mentioned in Chapter 2 is the simplest and most fundamental tool to use in the reduction of variability of activities and activities durations for similar engineering deliverables during project duration estimation, as it seeks to analyse similar tasks and it sources information from actual completed work. As indicated in chapter 2 the reliability of the Analogous Estimating tool is dependent on the **extend of similarities of previous activities attributes** and the **expertise of project team members** conducting the analysis. This statement speaks to the key factors contributing to cycle time variability as follows:

The extend of similarities of previous activities relates to activity durations, activity characteristics including activities names. As observed in the latest conceptual framework above in figure 60 and the framework model in figure 61, activities attributes are influenced by application of engineering processes and intra-organisational knowledge transfer. Inconsistent intra-organisation knowledge transfer worsens inconsistencies in the expertise of project team members and inconsistent activities attributes is worsened by both inconsistent intra-organisational knowledge transfer and inconsistent application of engineering processes.

As Pyzdek (2003) assert an investigation is required during the process of determining activities in order to determine if similar projects or subprojects were executed previously and historical information for activity definitions, activity durations and problems encountered to be obtained. Activity duration estimation could be achieved by adjusting parameters to suit the current project environment. (PMBOK sixth edition)

The adjustments of these parameters should consider factors contributing to variations of similar deliverables and integrate best practices and emerging information into the development of similar projects with similar engineering deliverables. In this research, factors contributing to cycle time variability and their relationships are encapsulated in the Framework Model.

Figure 66 below indicates the continuous incorporation of best practices in the framework model.

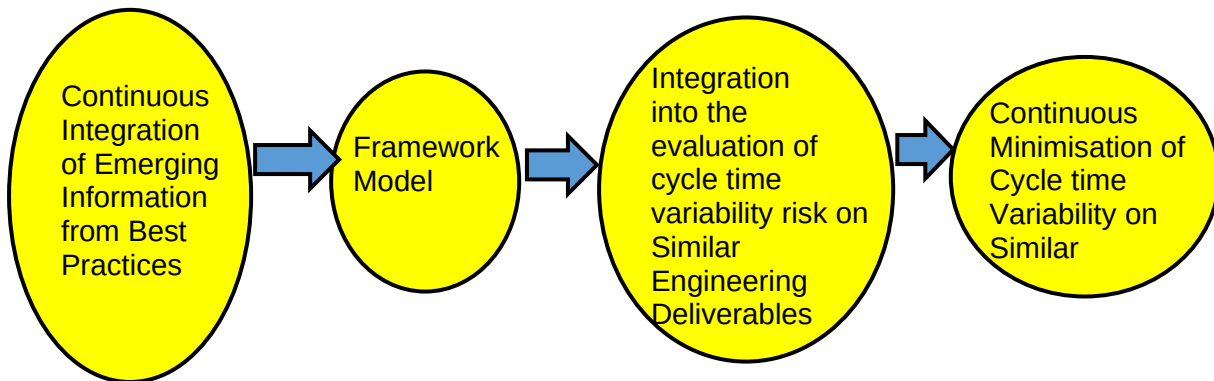


Figure: 66 Continuous Incorporation of Best Practice in the Framework Model

Source: Author

Figure 66 illustrates integration of continuous emerging information from best practices into the framework model that is integrated into the evaluation of cycle time variability risk on similar engineering deliverables leading to continuous minimisation of cycle time variability.

5.8 Conclusion

In this chapter, the developed framework model was presented. The validation of the framework model and the related illustrative scoring tools presented. The limitations and key success factors of the model were elaborated upon. In the next chapter the research is concluded, and recommendations provided.

CHAPTER 6

6 CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

In this chapter, the research is concluded; the key research objectives and the key findings are briefly discussed, and the following areas are revisited in terms of how the research findings addressed them:

- The purpose of the research
- The research problem and its significance
- The research question.
- Investigative questions and formulated hypothesis
- The main deliverables of the research
- The limitations.

In this same chapter, the research challenges and their resolutions are explained; the recommendations and recommended areas of further research are provided, and the chapter is concluded.

6.2 The key research objective

The key research objective was to **set a base for minimising cycle time variability of similar engineering deliverables** and to **contribute towards project engineering related bodies of knowledge**.

6.2.1 Setting a base for minimising cycle time variability of similar engineering deliverables.

The latest conceptual framework, the framework model and the scoring tool in Chapter 4 and 5 above serve as evidence that this objective is met. The relevant specific discussions were done in the respective chapters. The key takeaway from discussions on the conceptual framework, framework model and the scoring tool are as follows:

- **Latest Conceptual Framework (figure 60)**

The application of engineering processes and intra-organisational knowledge transfer influences cycle time variability through activities attributes thus indicating the presence of mediatory role of **activities attributes** between **application of engineering processes** and **cycle time variability** and between **intra-organisational knowledge transfer** and **cycle time variability**. The implication of this finding is that the initial conceptual

framework assumption of having both the application of engineering processes and intra-organisational knowledge transfer directly influencing cycle time variability **no longer hold strongly**. The extend of the mediatory role played by the activities attributes is not determined in this research.

- **Framework model (figure 61)** - The framework model attempts to provide a visual indication of key factors influencing cycle time variability and how they relate to each other. The following points should be noted:
 - The model consists of the **leading variables** and their **input variables**, the **lagging variables** and the **output variable**.
 - The Lagging variables are linking the leading and the output variables. The lagging variables are the same variables mentioned in the final conceptual framework above as the mediating variables. (i.e.) The activities attributes.
 - The presented model input variables to the leading variables are not exhaustive as they can be expanded to allow for more details as the space allows and more information become available.
 - The model is non-linear and iterative in nature; this can be suitably used as a base for tools such as systems dynamics.
- **The scoring tool (table 13)** - The scoring tool is a means of operationalising the framework model in a simplified manner. The following should be taken into consideration:
 - The scoring tool is subjective as it depends on the facilitator's judgement and the inputs of the team members.

6.2.2 Contribution towards project engineering related body of knowledge.

- The developed latest conceptual framework and the framework model could form a basis for analysis of cycle time variability of similar deliverables in related academic studies allowing the use of diverse evaluation tools in the market and emerging ones.
- The use of the scoring tool could be extended to other related industries for assessing cycle time variability risk and improving similar projects schedule estimations.
- The study increases awareness on factors influencing cycle time variability for similar engineering deliverables and their relationships.
- A paper on the synopsis of this research was submitted, accepted and presented at the 33rd Annual Southern African Institute of Industrial Engineering Conference. (SAIIE 33)
- The researcher proposes further research on related topics emanating from the research. This could further contribute to the body of knowledge as the prospective researchers further engage on the proposed further research.

6.3 Key research findings

6.3.1 Primary Data

Table 19: Key research findings – primary data

Main Topic	Research Finding	Implications
Existing systems and practices	- There is no framework nor adequate tools for minimising cycle time variability. - There is no concerted effort to share lessons learned and the intra-organisational knowledge transfer is unstructured with minimal awareness of its existence. - There is a strong agreement that Eskom engineering processes are aligned with the project management processes.	- The implementation of the framework model could assist in providing a basis for minimising cycle time variability. - A structured approach to implementation of intra-organisational knowledge transfer need to take place. - Since Eskom processes seems to be well established, more emphasis needs to be placed on consistent application of these processes.
benefits of minimising cycle time variability for similar engineering deliverables	The overall perception is that minimising cycle time variability will be beneficial for the reduction of schedule risks and improvement of schedule estimation of subsequent similar engineering deliverables.	There is a need to latch on the awareness of the benefits of minimising cycle time variability, as this will increase buy-in into the implementation of the framework model.
Research questions based on the 1 st refined conceptual	The overall perception on the application of engineering processes, intra-organisational knowledge transfer, activities	An increased awareness on factors contributing to cycle time variability and how they relate to each other is key to cycle time

framework (Key factors)	durations and activities, is that they have influence on the cycle time variability and inconsistent application of engineering processes and intra-organisational knowledge transfer leads to cycle time variability. Similarly inconsistent activities and inconsistent activities durations of similar engineering deliverables leads to cycle time variability.	variability minimisation; this can be achieved through appreciation of the framework model.
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6.3.2 Secondary Data

Table 20: Key research findings – Secondary data

Area of Analysis	Findings	Implications
No variability	The research revealed that if two or more similar projects deliverables have similar activities, same activity durations and are sequenced in the same manner , their graphs are perfectly superimposed as one graph. This implies that similar activities and the same activities durations result in minimised variability of similar deliverables even to a point of eliminating variability.	No implications since this is ideal.
Variability of activities	It was observed that variations in activities for similar engineering deliverables led to variations in cycle times. These variations include: 1. Additional activities. 2. Inconsistent Consolidation and decomposition of activities.	• Efforts to be made to standardise consolidation and decomposition of similar activities in order to minimise inconsistencies.

	3. Differing activities names for the same function.	• Efforts to be made to standardise activities names for similar deliverables.
Variability of activities durations	It was observed that in the absence of variability of similar activities durations, no additional activities and no inconsistent consolidation or decomposition of similar activities, there were no cycle times variability of similar deliverables cycle times.	• Efforts to be made to provide reasonably standardised activities durations for similar deliverables.

6.4 The purpose of the research

The following constituted the purpose of the research:

- Studying factors contributing to cycle time variability on engineering delivery cycle time.
- Studying the impact of factors contributing to cycle time variability on similar engineering deliverables.
- Identifying areas of focus for minimising engineering cycle time variability on similar projects.
- Developing the framework for minimising cycle time variability on similar projects.

All above deliverables were delivered as anticipated. The delivery of above deliverables was achieved by means of conducted literature review captured in Chapter 2, research surveys and analysis of research results and relevant project schedules captured in Chapter 4 and development of framework model captured in Chapter 5.

6.5 The research problem and its significance

The research problem statement

The problem statement for this research is defined as:

To minimise cycle time variability on similar engineering deliverables within similar project phases across different projects that are executed on similar plant areas.

The developed framework model and the associated scoring tool attempt to minimise cycle time variability on similar engineering deliverables as per the problem statement. This was one of the research objectives.

6.6 The significance of the research problem

The reason why the research problem was significant is that variabilities of cycle times make it difficult to utilise information from previous and current similar projects for the purpose of similar project schedule estimation and reduction of similar projects engineering deliverables delivery risk, leading to possible schedule overruns. This was due to the lack of a structured framework of identifying and evaluating factors contributing to cycle time variability of engineering deliverables. The developed framework model and the associated scoring tool is expected to assist in this regard.

6.7 The research question, investigative questions and hypothesis testing

In an attempt to answer the research question effectively, it was broken down into manageable focused investigative questions that formed the basis for hypothesis testing. Below was the formulated research question:

How can cycle time variability of similar engineering deliverables within similar project phases across different projects that are executed on similar plant areas be minimised.

This question was answered by the delivery of the framework model and the associated scoring tool. As mentioned in Chapter 5 under the key success factors and the limitation of the framework model, the model and the associated tool will be more effective if they continuously incorporate best practices from related fields.

The hypothesis supports the literature, questionnaire survey results analysis and secondary data analysis. This is captured in Chapter 4 in detail.

6.8 The main deliverables of the research

The following were the main deliverables of the research.

- Identification of focus areas for minimising cycle time variability on similar projects engineering deliverables.
- The development of the framework for minimising engineering delivery cycle time variability on similar projects.

These deliverables were progressively delivered as follows:

- Identification of factors contributing to cycle time during literature review. Captured in Chapter 2 under factors contributing to cycle time.
- Identification of focus areas of the research. Captured in Chapter 2 under focus areas of the research.
- Delivery of the final conceptual framework. Captured in Chapter 4.
- Delivery of the framework model and the scoring tool. Captured in Chapter 5.

The final conceptual framework is the main input of the framework model.

6.9 Limitations of the research and assumptions

Research Assumptions	Limitations	Comment
The research would receive good participation from the targeted sample	This assumption was based on normal business as usual and could not have anticipated limitations imposed by the covid-19 national lockdowns.	The impact of covid-19 did not significantly affect the participation of candidates, as the response rate based on the targeted sample was 71%. The mitigation effort seems to have been effective. See Research Challenges below.
The questionnaire survey design was adequate to pull relevant information from participants.	The questionnaire survey questions were based on the researcher's understanding of the research environment and the formulated investigative questions emanating from the literature.	The results from the research proved to be consistent with literature and the analysis of the secondary data. This provides confidence that the questionnaires were reasonably adequate to pull relevant information.
The available obtainable secondary data was sufficient to provide relevant information for the research.	The information on projects is not always well organised as different project names are likely to be given to projects with similar activities and main deliverables.	The results from analysis of the secondary data proved to be consistent with literature review and the analysis of primary data. This provides confidence that the obtainable secondary data provided reasonably sufficient relevant information.
The critical path method was the dominant means of determining the activities and major deliverables durations.	The critical path does not include all activities of the deliverables but only those found in the longest path. This makes it difficult to evaluate similar activities and activities durations from other similar projects as there might be	The research focused on the activities and activities durations and did not consider the logical relationships of activities in the secondary data. The approach of not focusing on the logical relationships of the activities made it feasible to present and analyse the secondary data.

	inconsistencies of activities on the critical path across similar projects.	
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6.10 Research challenges

The research preparations took place during the period in which Eskom was undergoing restructuring especially within the Group Technology Division where the researcher was working. Within the same period, the country was on lockdown due to the pandemic (covid - 19) and since then the normal working arrangements were drastically changed.

There was a stage during the research when the researcher was not sure if he would continue to work in the environment that would support the research work as engineers and engineering managers were being re-linked to different power plants across the country. Some of the research participants did not have tools for returning questionnaires as they were using Eskom tools before the lockdown and could not access them during the lockdown.

Since the research was an Eskom case study and the nature of the research required that permission should be obtained before one can conduct the research, the restructuring of Eskom Group Technology and the lockdown made it difficult to obtain permission to conduct the research and to obtain ethics clearance from the institution. The following were difficulties experienced:

- Transition to new reporting lines by the researcher affected the protocol of requesting permission to conduct research leading to at least 8 months delay of collecting data.
- The new role at the power station demanding working extended hours including weekends in order to minimise the impact of load shedding by Eskom. The new role was in the Outage Management space.
- Online availability of the signatories was very limited and the lack of mobility due to the lockdown could not allow face-to-face follow-ups on the documents that needed to be signed.

6.11 Resolutions to Research Challenges

Upon engagement during the process of relinking the researcher to power generation, it was agreed that the researcher continue to work in the power generation project environment.

- The Power generation General Manager agreed to support the research, and signed the necessary documents for the approval to conduct research within Eskom and allowed the use of Eskom data.
- The Power Station General Manager's support led to the Eskom Generation Group Executive manager's approval.

- The new manager agreed to support the research.
- Data collection and engagements were done electronically and where participants could not sign and scan consent forms, they gave consent by means of emails.
- In order to minimise the impact of poor questionnaire returnable, the researcher forwarded five more questionnaire surveys to participants. (i.e.) the target sample was 21 candidates, the researcher forwarded 26 questionnaire surveys to participants. This resulted in having 15 returned questionnaire surveys.

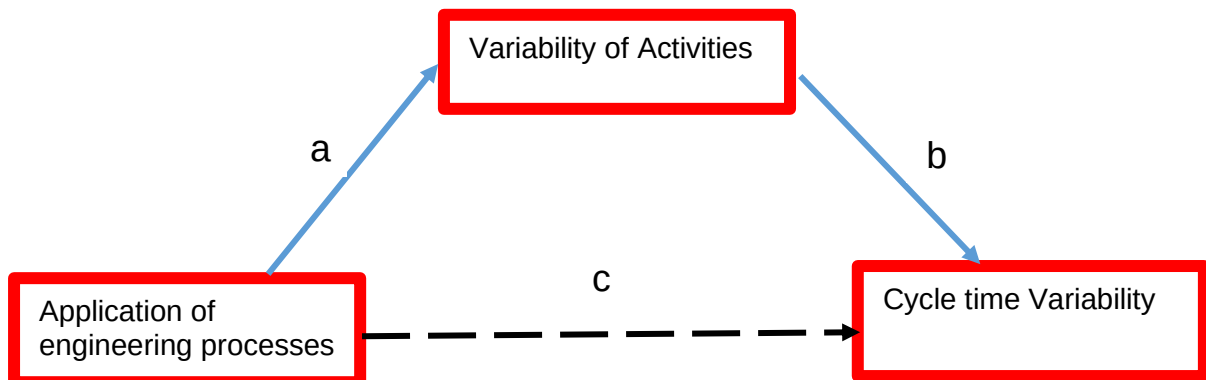
6.12 Recommendation

The successful use of the framework for minimising cycle time variability is already captured in the key success factors above. The most salient point to consider is that the framework model should be integrated with emerging information from best practices to ensure continuous improvement.

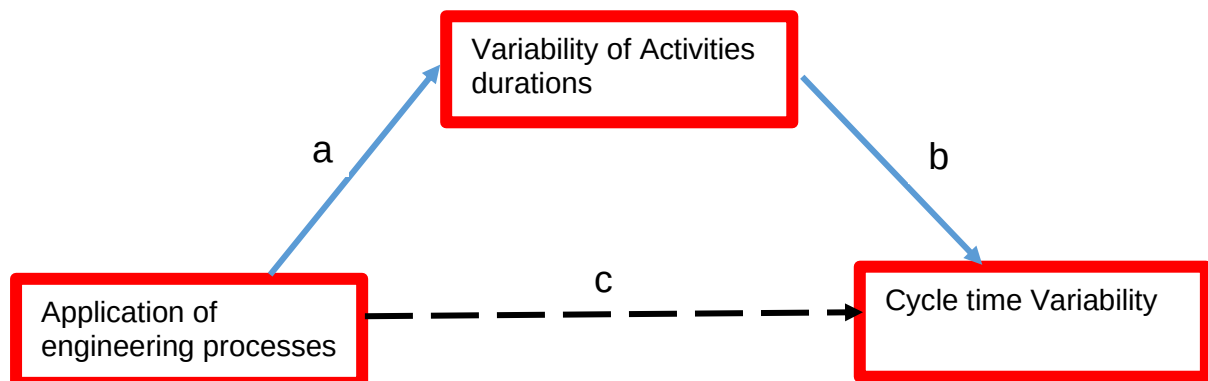
6.13 Recommended further research.

Considering the latest conceptual framework and framework model, the following further research is recommended:

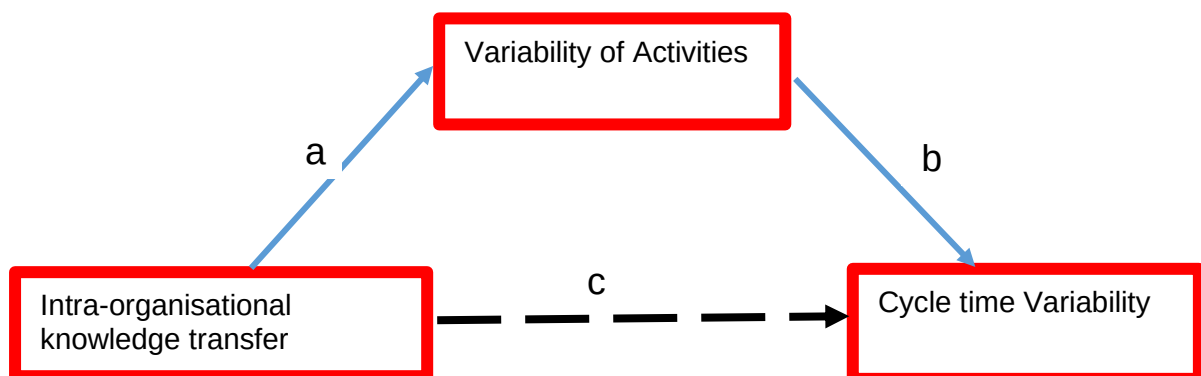
- Establishing the extend of mediation by **variability of activities** between **application of engineering processes** and **cycle time variability**. Schematically represented below:



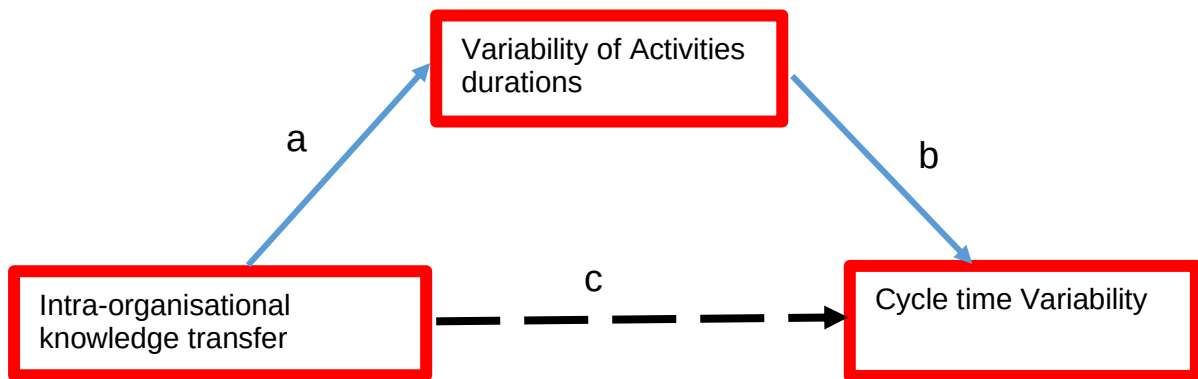
- ii. Establishing the extend of mediation by **variability of activities durations** between **application of engineering processes** and **cycle time variability**. Schematically represented below:



- iii. Establishment of the extend of mediation by **variability of activities** between **intra-organisational knowledge transfer** and **cycle time variability**. . Schematically represented below:



- iv. Establishment of the extend of mediation by **variability of activities durations** between intra-organisational knowledge transfer and **cycle time variability**. Schematically represented below:



- v. Application of **systems dynamics** using the **framework model** as a building block for modelling.
- vi. Application of the analytical network process (ANP) using the framework model as a building block for modelling.

6.14 Conclusion

It is the researcher's view that the research was successful and that the developed framework model for minimising cycle time variability on similar engineering deliverables could be used as a building block for **minimising cycle time variability of similar projects** and **reduction of cycle time on an individual project** in other industries other than Eskom Power Generation Plants.

The framework model and the latest conceptual framework can be useful additions into the literature review databases for contribution in the project engineering related bodies of knowledge.

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List of Eskom Process Control Manuals (PCM) and Procedures

474-12344 Generation Engineering Operational Plan 2022_23 to 2025_26 (Rev 1)
240-43898151 PCM for Perform Verification and Validation
240-44271204 PCM for Manage Engineering Delivery
240-44443156 PCM for Manage Engineering Accountability
240-44509520 PCM for Define Requirements
240-44509530 PCM for Develop Functional Architecture
240-44509543 PCM for Design System
240-44509564 PCM for Design Analysis
240-44460228 PCM for Finalise Engineering Work
240-44460271 PCM for Set Up Engineering Work
240-44460283 PCM for Assess Stakeholder Request
240-45541565 PCM for Manage Technology Philosophies and Standards
240-44682732 PCM for Provide Engineering during Commissioning
240-44682816 PCM for Provide Engineering during Construction
240-44682832 PCM for Provide Engineering during Manufacturing
240-44682850 PCM for Provide Engineering during Project Sourcing
240-46953552 PCM for Plan Technical Effort
240-46693733 PCM for Manage Technical Queries
240-46977030 PCM for Manage Requirements
240-46977377 PCM for Manage Interfaces
240-46977866 PCM for Manage Technical Decision Making
240-49910527 Procedure for Plan and Select Technologies
240-52380420 SCOT Standards Development and Change Implementation Procedure
240-53113685 Design Review Procedure
240-53114002 Engineering Change Management Procedure
240-53114026 Project Engineering Change Management Procedure
240-53114186 Project Plant-Specific Technical Document and Records Management Procedure
240-157724745 Generation Engineering Skills and Competency Framework Standard
240-46977482 Perform Technical Assessment
240-125189944 Engineering Assurance Assessment Standard
240-1519202940T Eskom Generation Learning & Development Strategy

240-124830536 Plant Life Cycle Management

240-136815819 Procedure for Project Definition Readiness Assessments

240-132148433 Generation Technical Process Governance Committee TOR (Rev 1)

ANNEXURES

ANNEXURE A: PERMISSION TO CONDUCT RESEARCH AT ESKOM

Annexure A below is desensitised due to the protection of personal information (POPI) Act. The original copy is with the researcher and can also be accessed through the promoter.



MEMORANDUM

To: [REDACTED], Group Executive Generation Reference:
From: Mr. Thoka Mocheke, Middle Manager, Lethabo Power Station, NWU PhD student Version: 0
Date: 17 June 2020
SUBJECT: REQUEST FOR PERMISSION TO CONDUCT DOCTORAL STUDIES RESEARCH AT
ESKOM

PURPOSE

1. The purpose of this submission is to request approval from the Group Executive to grant permission to conduct doctoral studies research at Eskom. The requested permission is for academic purpose only.

BACKGROUND

2. My Doctoral studies were approved through the Eskom further study process in 2018. The research topic is: *Minimising engineering delivery cycle time variability on similar projects: An Eskom case study* which is aimed at optimising cycle time for engineering delivery during project development and execution. Above research topic was successfully defended at the University's Title Registration Colloquium which took place on the 31st October 2019.
3. As part of my doctoral research, it is required that a research be conducted using Eskom data and to distribute research questionnaires to the relevant personnel in the disciplines of interest.

REQUEST FOR PERMISSION TO CONDUCT DOCTORAL STUDIES RESEARCH AT ESKOM

4. The request is in compliance with the Procedure 240-128258875, **Procedure for Development** under point 3.5 which states that "permission to undertake research using Eskom information will be approved by the relevant Divisional/Group Executive". Further to this, the institution requires confirmation that due internal processes are followed in obtaining permission to conduct research (Ethics Clearance).
5. The requested permission is for academic purpose only and in no way waives Eskom's Intellectual Property Rights. The intellectual property gained during this process of further study will belong to Eskom as well as any benefit arising there-from.

REQUESTED APPROVAL

6. That the Group Executive grant permission to Mr TG Mocheke to conduct doctoral studies research at Eskom which includes using Eskom data and distribution of research questionnaires to the relevant personnel in the disciplines of interest.

FINANCIAL IMPLICATIONS

7. No financial implications for this approval

BUDGET IMPLICATIONS

8. No budget implications for this approval

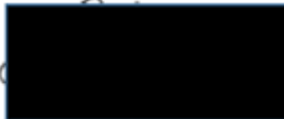
REQUEST FOR PERMISSION TO CONDUCT DOCTORAL STUDIES RESEARCH AT ESKOM

Compiled by:



Thoka Mocheke
MIDDLE MANAGER
LETHABO POWER STATION
17 June 2020

Recommended/~~Not recommended~~



GENERAL MANAGER – LETHABO POWER
STATION

Date: 2020/06/23

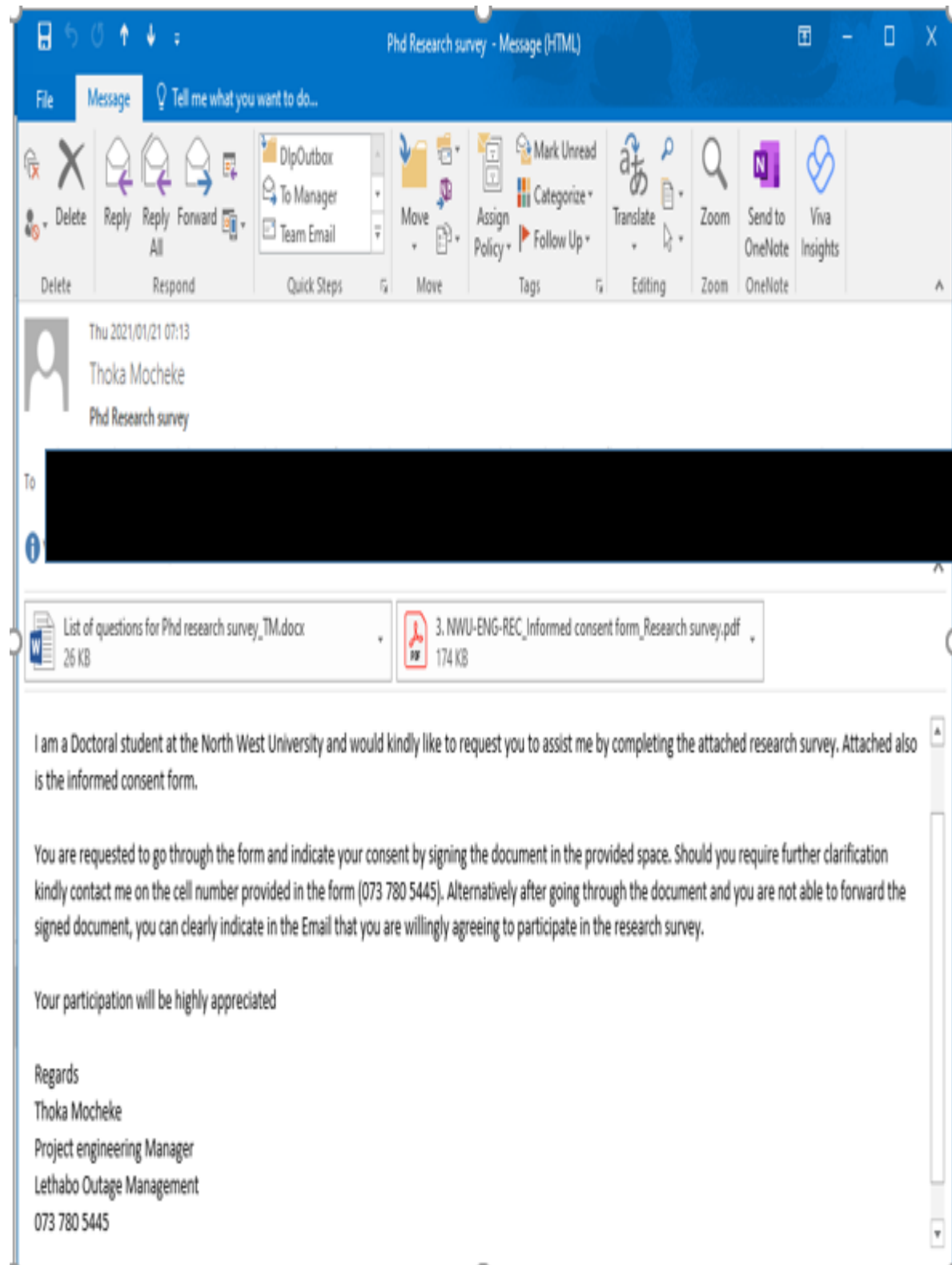
Approved/~~Not approved~~



DESIGNATION: GROUP EXECUTIVE,

APPENDIX B: PROOF OF INVITATION TO PARTICIPATE IN RESEARCH SURVEYS

Annexure B below is desensitised due to the protection of personal information (POPI) Act. The original copy is with the researcher and can also be accessed through the promoter.



ANNEXURE C: RESEARCH SURVEY QUESTIONS

List of questions for research survey

Kindly answer the following questions by indicating with a mark (x) in the applicable space.

1. My project role is:

Project Manager	Project Engineer	Construction Manager	Engineering Manager	Other (Specify)

2. How long have you worked in the Eskom power generation project environment

2 years	
Between 2 years and 5 years	
Between 5 years and 10 years	
More than 10 years	

3. Eskom has a well-established framework for capturing, analysing and retrieving lessons learned for similar engineering deliverables within similar project phases across different projects that are executed on similar plant areas.

Strongly Agree	Agree	Disagree	Strongly Disagree

4. Eskom has comprehensive tools for minimising cycle time for similar engineering deliverables within similar project phases across different projects that are executed on similar plant areas.

Strongly Agree	Agree	Disagree	Strongly Disagree

5. Eskom engineering processes are aligned with the project management processes.

Strongly Agree	Agree	Disagree	Strongly Disagree
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6. Following engineering processes accounts for most project delays within Eskom power generation project environment.

Strongly Agree	Agree	Disagree	Strongly Disagree

7. Inconsistent application of engineering processes within similar projects lead to cycle time **variability** of similar project engineering deliverables for similar projects executed on similar plant areas.

Strongly Agree	Agree	Disagree	Strongly Disagree

8. Simplified project engineering processes will minimise inconsistencies in applying them.

Strongly Agree	Agree	Disagree	Strongly Disagree

9. I am aware of an Eskom organisational knowledge transfer system which is applicable to the power generation project environment.

Strongly Agree	Agree	Disagree	Strongly Disagree

10. The organisational knowledge transfer system has an impact on lessons learned for similar engineering deliverables on similar plant areas across different project in the power generation project environment.

Strongly Agree	Agree	Disagree	Strongly Disagree

11. There is a concerted effort to share lessons learned for similar project engineering deliverables on similar plant areas across different projects in the power generation project environment.

Strongly Agree	Agree	Disagree	Strongly Disagree

12. Lessons learned are more effective when all relevant disciplines within the project are participating in the process.

Strongly Agree	Agree	Disagree	Strongly Disagree

13. Lessons learned for similar project engineering deliverables are well structured in the power generation project environment.

Strongly Agree	Agree	Disagree	Strongly Disagree

14. Cycle time **variability** of similar engineering deliverables is solely attributed to the lack of skills and competencies.

Strongly Agree	Agree	Disagree	Strongly Disagree

15. Inadequate knowledge transfer on similar project engineering deliverables within similar projects leads to cycle time variability of similar engineering deliverables.

Strongly Agree	Agree	Disagree	Strongly Disagree

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16. Having differing **activities** for similar engineering deliverables will lead to variability of cycle times for similar engineering deliverables.

Strongly Agree	Agree	Disagree	Strongly Disagree

17. Having differing **time durations** for similar activities will lead to variability of cycle time for similar engineering deliverables.

Strongly Agree	Agree	Disagree	Strongly Disagree

18. All project engineering activities are accessible to all relevant disciplines within the project and can be viewed on request.

Strongly Agree	Agree	Disagree	Strongly Disagree

19. Minimising cycle time variability for similar engineering deliverables will improve schedule estimates for subsequent similar engineering deliverables.

Strongly Agree	Agree	Disagree	Strongly Disagree

20. Minimising cycle time variability for similar engineering deliverables will reduce project delivery risk.

Strongly Agree	Agree	Disagree	Strongly Disagree

ANNEXURE D: PROOF OF PHASE 1 VALIDATION MEETING INVITATION

Annexure D below is desensitised due to the protection of personal information (POPI) Act. The original copy is with the researcher and can also be accessed through the promoter.

 **Thoka Mocheke Phd studies framework model val...** Chat Files Details Scheduling Assistant +5 +

[X Cancel meeting](#) | [Copy link](#) | Show as: Busy ▾ | Category: None ▾ | ...

 Monday, 29 May 2023 14:30 - 15:30

[Show meeting info ▾](#)

 **B** *I* U ~~S~~ |    Paragraph ▾ |     |   | 99   |  

Good day

As discussed Kindly avail yourself for the above meeting. Attached is the word document containing the framework & related proposed score card and the SAIE presentation article which I found to be suitable to provide you with some background on the research.

Your attendance will be highly appreciated

Kind regards
Thoka Mocheke
Project engineering manager
Eskom Lethabo Power Station
016 457 5753

Microsoft Teams meeting

Join on your computer, mobile app or room device

ANNEXURE E: PROOF OF VALIDATION MEETING ATTENDANCE

Annexure E below is desensitised due to the protection of personal information (POPI) Act. The original copy is with the researcher and can also be accessed through the promoter.

Thoka Mocheke Phd studies framework model validation - Attendance report 5-29-23 (3) - Excel							
File Home Insert Page Layout Formulas Data Review View Tell me what you want to do...							
Clipboard		Font		Alignment		Number	
Styles							
13							
A	B	C	D	E	F	G	H
1. Summary							
Meeting title	Thoka Mocheke Phd studies framework model validation						
Attended participants	6						
Start time	5/29/23, 2:23:36 PM						
End time	5/29/23, 3:34:43 PM						
Meeting duration	1h 11m 6s						
Average attendance time	54m 16s						
2. Participants							
Name	First Join	Last Leave	In-Meeting Duration	Email	Role		
Thoka Mocheke	5/29/23, 2:24:12 PM	5/29/23, 3:32:52 PM	1h 8m 39s	MochekTG@eskom.co.za	Organizer		
	5/29/23, 2:29:45 PM	5/29/23, 3:10:37 PM	40m 52s		Presenter		
	5/29/23, 2:30:15 PM	5/29/23, 3:34:43 PM	1h 4m 27s		Presenter		
	5/29/23, 2:30:33 PM	5/29/23, 3:34:42 PM	1h 4m 9s		Presenter		
	5/29/23, 2:37:52 PM	5/29/23, 3:11:22 PM	33m 29s		Presenter		
	5/29/23, 2:38:49 PM	5/29/23, 3:32:51 PM	54m 2s		Presenter		

ANNEXURE F: PROOF OF PHASE 2 ENGAGEMENT

Annexure F below is desensitised due to the POPI act. The original copy is with the researcher and can also be accessed through the promoter.

