Development of a Lean Six Sigma Framework for Identification and Minimisation of Inefficiencies in Construction Projects.

Department of Industrial and Systems Engineering.

BIR 890: Master's Dissertation

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Abstract

Introduction: This dissertation has focused on the systematic identification, analysis, and reduction of inefficiencies within the construction project domain through the utilisation of Lean Six Sigma. With the construction sector facing challenges such as budget overruns, delays, and resource misallocation, the need for effective strategies to enhance project efficiency becomes imperative. The Lean Six Sigma methodology, known for its success in various industries, offers a structured and data-driven approach to continuous improvement. This research adopts a comprehensive approach by incorporating literature reviews, case studies, and empirical data collection to explore the integration of Lean Six Sigma principles within the context of construction project management. The study begins by establishing the theoretical foundation, elucidating the fundamental concepts of Lean Six Sigma and its historical effectiveness in streamlining operational processes. Subsequently, it delves into a thorough evaluation of the unique constraints and complexities associated with construction projects, emphasising the importance of a tailored approach to enhance efficiency.

Purpose: The objective of the dissertation is to carry out an extensive examination of the elements that lead to delays in projects and assess their subsequent effects. By comprehending the consequences and origins of these inefficiencies, adjustments were made to the lean six sigma tool to enhance the processes involved in construction projects and strive to reduce these inefficiencies to the greatest extent possible. As a result, both time and cost overruns were minimised, leading to savings in operational expenses. Consequently, the research endeavours to uncover the underlying causes of process inefficiencies and implement lean six sigma tools as effective solutions to address these inefficiencies.

Approach: The practical aspect of the dissertation involves the utilisation of Lean Six-Sigma tools and methodologies in a real-life construction project, focusing on the identification of bottlenecks, waste, and unpredictability. To identify inefficiencies, a value stream map was constructed, while control charts were employed to measure variation. To gain a deeper understanding of the factors contributing to process inefficiencies, a fishbone diagram and factor analysis were utilised. Additionally, an EOQ model was employed to predict material lead time, which aids in effective planning. Furthermore, a scheduling and project monitoring tool, namely the CiteOps software, was developed, along with a visual dashboard created using PowerBi, enabling remote tracking and monitoring of project efficiency. The successful implementation of Lean Six Sigma in construction was illustrated through practical examples from previous studies, highlighting the adaptability and effectiveness of this framework.

Findings: During the research, it was discovered that project delays and inefficiencies were largely influenced by lead time, delayed order placement, and task corrections. The correlation coefficient of lead time and placement was found to be 0.66, indicating a strong relationship between these factors and their significant impact on the efficiency of the project process. To mitigate long lead times, an EOQ model was implemented to forecast lead time and plan accordingly. The utilisation of project management software, such as CiteOps software, enhanced accountability among team members and facilitated better planning, enabling the timely identification and resolution of delays. By addressing these issues early on, their impact on the project was minimised. It is recommended to continue utilising the software and EOQ model to minimise the influence of factors that contribute to process inefficiency.

Research limitations: The data used for the time study is only for the period when the project delays were at their climax and not from when they first occurred. This means the data used in this research may not be an accurate representation of the issue. The data sampled for this project may be insufficient due to limited availability.

Originality: In this dissertation, the DMAIC approach was customised by combining the Six Sigma techniques, statistics, and differential equations to better quantify and understand the impact that delays have on the effective time spent on project completion.

Keywords: Six Sigma, Lean, Lean Six Sigma, Inefficiencies, Inefficiency Minimisation, DMAIC

Certification

This is to certify that Modiehi Mophethe's work titled "Using the Lean Six Sigma Framework to Identify and Minimise Inefficiencies in Construction Projects" is a record of original work carried out by her under the supervision and guidance of Dr Michael K. Ayomoh. The dissertation was submitted in fulfilment of the requirements for the degree Master of Engineering (Industrial and Systems Engineering) at the Faculty of Engineering, Built Environment and Information Technology.

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Chapter 1

Introduction

1.0 Chapter Overview

In this chapter, a comprehensive overview of the research is presented, starting with an introduction to the background information on the implementation of lean construction and lean six sigma frameworks in construction projects. It explains how these frameworks are used to address inefficiencies in construction projects and improve overall project performance. The chapter also includes a problem statement, which highlights the specific concerns within the construction project that the research aims to address. It further discusses the implications of these concerns and why it is important to find a solution. To guide the research process, the chapter outlines the research questions that will be addressed. These questions were designed to analyse and solve the issue systematically. The overall aim and objectives of the study are clearly stated, providing a clear direction for the research. Furthermore, the chapter explores the project rationale, motivation, and scope. It explains why it is important to study this particular construction project and what it aims to achieve throughout the research. It further discusses the limitations and delimitations of the study, ensuring transparency and accountability in the research process. Finally, the chapter presents a detailed map of the research process. This map guides the reader throughout the various stages of the study, helping them understand the structure and flow of the research. It serves as a roadmap for the rest of the research, ensuring that the study is conducted in a logical and organised manner.

1.1 Background Information

The construction industry is known for its continuous development, as it incorporates cutting-edge technologies and efficient processes to achieve excellent results while reducing costs. Therefore, it is essential for construction companies to regularly assess their operational dynamics and adopt strategies that not only align with the latest advancements in the field but also improve the quality of their work, enhance operational efficiency, eliminate inefficiencies, reduce expenses, and optimise financial gains (Andony B., 2021).

Figure 1-Traditional project management phases currently deployed in most construction projects (Eby, 2003)

Figure 1 illustrates the conventional project management techniques employed in construction projects, which hold significant importance in ensuring the success of a project (Eby, 2003). However, it is crucial for management to continuously adapt and enhance these processes to effectively address the specific challenges encountered in their projects. The amalgamation of various factors, such as the project's pace, adherence to quality standards, and cost efficiency, provides the company with a solid foundation and competitive advantage amidst the ever-growing competition in the construction industry. These factors collectively determine the fate of the project, (Eby K., 2023)

Construction projects are susceptible to inefficiencies that often result in unplanned expenditures, unforeseen circumstances, cost overruns, project delays, and compromised work quality. Hence, it is paramount to establish an efficient construction process design that ensures optimal quality at minimal costs. This optimisation involves assigning tasks to the most qualified personnel and completing them within the designated timeframe

A previous study has outlined three conceptualisations of a production management paradigm, namely, transformation (also referred to as construction and architecture), flow, and value generation (Koskela, 1992).

The definitions were explained in a previous study in the following manner:

1. Construction *architecture* involves the hardware, material, information flows as well as the management style within the construction project.
2. *Production planning* includes the organisational design and work breakdown structure.

The construction industry is known for its unpredictable nature, which has led to the development of various project management tools and strategies to enhance performance. One such improvement is the introduction of lean project management and lean six sigma construction. These approaches aim to identify and eliminate inefficiencies in the material flow of a project, ultimately leading to a more streamlined workflow. By eliminating these inefficiencies, projects can benefit from reduced spending and improved adherence to deadlines. This is why the concept of lean construction was developed, as it encompasses the principles of lean thinking and production management to creatively manage construction projects and minimise inefficiencies (Al-Aomar , 2012).

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Figure 2-Typical factors affecting project efficiency (Hogan, 2023).

The primary goal of lean construction is to optimise value and minimise expenses throughout the project's duration. Nonetheless, the initial phase of attaining this objective necessitates identifying common elements that impact process effectiveness, as outlined in figure 2. Inefficiency contributors during the project's advancement can be classified as follows, according to (Hogan P., 2023):

1. Construction defects;
2. Construction delays;
3. Overproduction;
4. Excess inventory;
5. Unnecessary transport;
6. Transportation of materials and equipment
7. Unnecessary movement of people.
8. Processes with high control variation.

This concept is associated with a decrease in variability, which refers to the unpredictable nature of workflow that cannot be relied upon. This decrease is indirectly caused by unpredictable changes, also known as variability, which can come from various factors that need to be addressed individually. At times, it may be necessary to pause or delay the workflow in order to address these causes. In the construction industry, some common causes of variability include long lead times, delayed delivery, equipment breakdown, design errors, labour-related issues such as strikes and accidents, and changes in organisational structure. Previous research has shown that implementing lean techniques can result in cost savings of up to 25% compared to traditional project management approaches (Al-Aomar , 2012).

These techniques primarily focus on transforming the conceptual design of the project into a tangible lean product and process design that aligns with the project scope and design criteria. The first part of these techniques involves a detailed design of the product, sourcing of components and materials, as well as logistics and transportation management. The second part is the lean assembly, which includes delivering components and materials to the client, as well as the labour and construction involved in project delivery.

Lean construction is an approach that evaluates the value-added (VA) aspect of the construction process, which encompasses flow, delay, and errors. The objective is to continuously enhance the quality and minimise the variability present in construction projects. To achieve this, the concept of six-sigma is employed as a method that can be applied across various industries, including construction. The integration of six-sigma with lean construction allows for a harmonious collaboration. The focus of six-sigma on improving quality aligns with lean construction's emphasis on expediting delivery, reducing delays, and minimising rework (Andony B., 2021).

Similarly, lean construction contributes to the quality focus of six-sigma by reducing process variability, streamlining workflow, and fostering transparency on-site. The use of a six-sigma rating enables the quantification and benchmarking of job quality. In the highly competitive construction industry, continuous improvement in quality and performance is crucial. By implementing the lean six sigma methodology, construction companies aim to enhance process efficiency by simplifying the flow, enabling them to allocate resources and efforts towards activities that directly contribute to project success while minimising costs. This research combines the principles of six-sigma and lean construction, resulting in the concept of Lean Six Sigma Construction, which strives to improve the construction process through the reduction of inefficiencies, costs, variability, and the enhancement of work quality using the DMAIC process (Al-Aomar , 2012).

The primary objective of this study is to examine, discern, and classify the various inefficiencies within the construction industry, while simultaneously creating a comprehensive framework based on the principles of six-sigma methodology. This framework aims to measure and compare the quality, cost, and schedule efficiency of lean construction practices. Additionally, the research endeavours to enhance the company's profitability by minimising avoidable expenses.

1.2 Problem Statement

Company XYZ is currently engaged in a significant endeavour to construct a concrete wall alongside a railway track in the Western Cape, a province located in South Africa. To complete this project, the company has been allocated a budget of fifty million Rands, which will be utilised exclusively for this purpose. Moreover, the surplus funds will be reinvested in the company for future undertakings. To optimise their profitability, Company XYZ is keen on minimising any inefficiencies in their processes, thereby reducing construction costs and maximising profit margins. While the company's headquarters are primarily situated in Gauteng, the construction project itself is based in the Western Cape. This geographical distance poses additional expenses for the company, as it necessitates the transportation of their engineers and other professionals from the headquarters to the construction site and vice versa.

During their stay in the Western Cape, the company generously covers the expenses of their personnel, including food, accommodation, transport, and entertainment. However, these expenditures contribute to the company's operational costs. To closely monitor the progress of the project, the management has been frequently traveling from Gauteng to the Western Cape, resulting in increased travel frequency compared to their usual routine. Unfortunately, the construction project has encountered various delays due to inefficient processes. These delays encompass political interference, such as the approval of safety documents, as well as frequent strikes leading to high absenteeism. Additionally, obtaining occupation of live overhead lines, a process that may take up to twenty-one days, has further contributed to the project's setbacks. High lead time of sourced materials and long fabrication time of the pre-cast concrete panels necessary for the wall construction. These may take up to seven days to be fabricated. The fabrication of the concrete panel is a protracted process where after installing the columns, the concrete consultants measure day by day and only manufacture the panels after this measurement has taken place. The company also experiences delayed payments from the clients which delays the sourcing of construction material. Western Cape is known for its unpredictable weather conditions where the project comes to a standstill when it gets too windy or it is raining. The project will not commence until the weather clears.

During the process of installation of the columns, a five-meter-deep trench was dug up and it was found that there was underground water. It took up to twenty-one days for the consultants to give recommendations and solve this issue. As mentioned earlier, professionals such as the project manager, quantity surveyor and engineers are in Gauteng (more than one thousand kilometres away from the construction site), decision making takes long and the communication platform is only through email. Project progress and efficiency determination is not completed using real-time data. Therefore, the project must be paused until after the engineers have completed their over-inspection.

Due to this reason, there have been many design and task corrections which further delay the project. The engineering drawing of the contemporary designs must first be submitted for approval to the professionals who are more than one thousand kilometres away. The project is also paused until approval is received. The company is not planning to hire more workforce that is based in Western Cape, as the project is only for a limited amount of time. The construction project is facing several challenges that are causing delays in the progress. One of the main issues is the high lead time of the sourced materials and the long fabrication time of the pre-cast concrete panels required for the wall construction. It takes up to seven days for these materials to be fabricated. The process of fabricating the concrete panels is quite lengthy, as the concrete consultants measure the columns on a daily and only manufacture the panels after these measurements have been taken. This adds to the overall time required for the construction.

Another factor contributing to the delays is the delayed payments from the clients, which in turn delays the sourcing of construction materials. Additionally, the project is located in the Western Cape, which is known for its unpredictable weather conditions. When the weather becomes too windy or rainy, the project comes to a standstill until the weather clears. This further hampers the progress of the construction. Moreover, the project experiences design and task corrections, which further delay the construction. Despite these challenges, the company does not plan to hire more workforce based in the Western Cape, as the project is of limited duration.

1.3 Research Questions

1. What activities are identified to cause process inefficiencies?
2. How will the Lean Six Sigma approach minimise these inefficiencies?
3. How will Lean Six Sigma contribute to the success of this project and ultimately, the company?
4. What are the techniques used to enable remote project monitoring and efficiency determination?

1.4 Research Aim and Objectives

1.4.1 Aim

The aim of this research is to map out the current construction workflow and identify the factors causing process inefficiencies. Once these factors have been identified, the DMAIC framework will be utilised to minimise their impact on process inefficiencies in an organised manner and it will deploy a fully functional software and dashboard that will assist in remote project tracking and monitoring.

1.4.2 Research Objectives

This research aims to achieve the following objectives:

1. Identify, define and categorise factors that contribute towards construction process inefficiencies.
2. Determine each factor’s impact on construction process inefficiencies.
3. Make use of a Lean six-sigma framework to minimise inefficiencies in the construction project.
4. Digitalise the construction project to enable remote progress and efficiency tracking, monitoring and supervision.

1.5 Research Rationale

The existence of factors that contribute to inefficiencies in construction projects not only raises the risk of exceeding the allotted time but also jeopardises the delivery of subpar work and compromises the safety of all parties involved. The implementation and enforcement of regulations have resulted in a delay of more than thirty days. Additionally, the extended lead time for construction materials is unacceptably long, leading to further delays and inefficiencies in the project. The manufacturing and fabrication of precast panels occur before the installation of the columns, resulting in an even longer lead time and an increased risk of introducing process inefficiencies. Accurate time scheduling and precise estimation of building materials are crucial for most construction projects. When these tasks are executed optimally, it ensures a consistent availability of building materials and shorter lead times. However, there are instances where clients' payments are delayed, which can lead to project delays and increased costs. The management team is responsible for ensuring that the project meets acceptable standards by conducting regular over-inspections. However, due to their location being over a thousand kilometres away, they can only visit the construction site once a month. This limitation reduces the efficiency of over-inspections and leaves room for errors and the delivery of poor project quality. Minimising travel costs is just as important as the necessity of conducting thorough inspections and regularly monitoring the progress of the project. This research proves its importance by proposing a solution that addresses these factors collectively:

1. The identification and definition of factors that contribute to process inefficiencies are achieved through the implementation of Lean Six Sigma methods. These methods involve a comprehensive analysis of the current construction workflow, with a focus on identifying activities that do not add value to the overall process. By assessing the current performance and addressing any deviations, a clear understanding of the main concerns within the construction project process can be obtained. This understanding is crucial to effectively address and improve the identified inefficiencies.

2. An important step in the process improvement journey is the analysis and improvement of the construction process itself. This step involves determining the scope and magnitude of the identified problem factors, as well as categorising them accordingly. Additionally, the impact of these factors on process efficiency is evaluated, and they are ranked based on their level of impact. The factor with the highest impact is then prioritised for intervention, and a proposed solution is developed to minimise its negative effects. Through this systematic approach, it is expected that the overall process efficiency will be significantly enhanced.

3. In addition to process improvement, control and monitoring are essential aspects of managing a construction project. The digitalisation of the project enables the management team to closely track the process efficiency and effectively delegate tasks remotely. This not only reduces traveling costs but also facilitates better oversight and enables rapid decision-making. By embracing digital tools and technologies, construction projects can benefit from improved control and monitoring, leading to enhanced efficiency and productivity.

Ultimately, this research will minimise the impact of the factors that contribute towards process inefficiency by identifying, defining, measuring and improving these factors.

1.6 Research Motivation

The construction industry is a dynamic sector that constantly undergoes changes. New concepts, techniques, and technologies are regularly introduced, prompting the need for continuous adaptation. The motivation behind this dissertation on process optimisation through the application of lean six sigma stems from the rapid evolution observed in the construction industry. Additionally, the curiosity to explore the integration of business improvement techniques, specifically lean six sigma, with construction management played a significant role in sparking interest in this research.

The development of a framework aimed at minimising process inefficiencies can have far-reaching benefits beyond just improving factors like building quality and costs. Although certain factors, such as lead time, pose complex challenges as they are beyond the control of management, techniques borrowed from other study areas, such as inventory management, can be employed to optimise and exert some control over lead time. By utilising the lean six sigma framework, construction managers can create streamlined and optimised processes. This not only benefits the company and the client but also ensures the safety of individuals within and around the construction site. The adoption of lean six sigma techniques in process optimisation guarantees high-quality construction, ultimately contributing to the safety of occupants and the overall environment.

1.7 Scope of the Research

The aim of this study is to identify and define the various factors that contribute to inefficiencies in construction project processes. These activities will then be categorised and analysed to determine their impact on the current performance of the project. To gain a better understanding of process efficiency, a trend analysis and control variation will be conducted. Additionally, the existing business model will be mapped out, and optimisation techniques from other study areas will be applied to improve the identified factors and minimise their negative impact on process efficiency. Furthermore, the implementation of Lean Six Sigma provides a systematic approach to reducing inefficiencies within a company.

By minimising these inefficiencies, not only can the company's profit margins be improved, but also the overall quality of the project delivered to the client. Eliminating activities that do not add value to the construction and quality of the project can significantly enhance construction performance. To achieve this, a new workflow will be proposed to enhance task delegation, supervision, and accountability. Lean Six Sigma techniques will be utilised to reduce inefficiencies and enhance overall performance. The process efficiency will be continuously monitored and tracked in real-time, even remotely. Finally, a solution will be proposed to enable the management team to remotely access and monitor the progress of the project. By updating the on-premises report server dashboard in real-time, the management will have a clearer understanding of the process efficiency, facilitating rapid decision-making. Additionally, a monitoring system will be developed to assist the management team in overseeing the progress of the construction on-site.

This system will provide valuable insights and enable the management team to effectively monitor the project's progress. By implementing these measures, the management team will have improved visibility and control over the project, ensuring its successful completion.

1.8 Limitation of the Research

The scope of this research is specifically aimed at enhancing the business process of the project. It will solely utilise business improvement strategies and business process management techniques to streamline the existing construction processes. However, it should be noted that this research does not intend to propose any solutions or recommend civil engineering techniques for implementing new construction methods. The primary focus of this study is to optimise the already established and pre-existing process of the Precast Concrete Wall building project.

It is important to acknowledge that the data collected for this research was gathered within a limited timeframe. Therefore, it may not accurately represent the inefficiencies in the construction process throughout the entire duration of the project. The findings should be interpreted with caution, considering the potential variations that may occur over an extended period of time.

Furthermore, it is crucial to highlight that this research will solely concentrate on identifying, defining, analysing, improving, and controlling the various factors that influence process efficiency within the predetermined project scope set by the project manager. The aim is to enhance the overall effectiveness of the processes and activities within this specific scope, rather than addressing broader aspects beyond the project's boundaries.

1.9 Delimitation of the Research

Delays have a significant impact on the performance of construction projects and can ultimately affect the quality of the work delivered to the client. Each moment spent on non-value-added activities not only costs the company money but also diminishes its chances of gaining a competitive advantage. Therefore, it is crucial to concentrate fully on activities that contribute to the success of the project. One powerful tool that can assist in achieving this goal is Lean Six Sigma, this aims to streamline, improve, and optimise business processes. By utilising this tool, inefficiencies can be reduced, and the focus can be directed towards delivering high-quality products to clients. However, it is important to note that certain aspects will not be addressed in this dissertation:

- Firstly, the research will not explore or recommend specific technical construction techniques that ensure the production of a decent-quality concrete wall. It will not delve into the latest construction techniques or factors that influence the building of a precast concrete wall.

- Additionally, civil engineering techniques and approaches will not be within the scope of this research. The investigation will also not recommend the specific building materials required for quality construction or any construction equipment involved in the building process, as this area falls under the responsibility of a quantity surveyor.

- Furthermore, the focus of this research will solely be on the Western Cape concrete wall project and will not extend to other projects the company may be involved in. It will not aim to improve the company's overall business process or study any other aspects of the company's operations. The reason for this limitation is the time constraints of the research project, which do not allow for an in-depth analysis of all areas of the company. Moreover, it is important to clarify that this dissertation will not modify or derive the Economic Order Quantity model.

- Although this model could potentially optimise material lead time, the research will only adopt a generic model that assumes a constant demand for building materials.

- Lastly, this research will not review any literature on construction management, concrete design, or health and safety in the construction industry. These topics are beyond the scope of this dissertation and will not be explored or analysed.

1.10 Project Organisation

This research consists of six chapters as enumerated below.

Chapter 1: Introduction

The introductory part offers an overview of Lean Six Sigma's history and its use in the construction sector. It helps to acquaint the reader with the study topic by breaking it down into manageable chunks and outlining the format of the research work. Following that, the problem statement section delves into the topic, providing a full account of the difficulties experienced by the construction company. The problem description then generates research questions, which help to define the study aims and directly address the identified concerns. The aim section highlights the research's targeted deliverables and coverage, whilst the research objectives explain particular topics to be addressed and act as responses to research questions. The project rationale supports the project's importance, whereas the motive emphasizes the conditions that drive the study. The project scope elaborates on the research objectives, restricting what the study will only focus on, whereas the research limits define the research's bounds. Research constraints describe topics that are not addressed by the study and why they are excluded. The project structure gives a glimpse of the report's appearance and content. Finally, the definition and terminology section clarifies technical words and abbreviations that may be unknown to certain readers, ensuring that the text is clear and understandable throughout.

Chapter 2: Literature review

This chapter started off with a brief chapter overview that gave an insight into understanding the exact content to expect as the chapter is unveiled.

In this chapter, the following underlisted formed the sub-headings:

1. Historical trends of construction inefficiencies.
2. Common inefficiencies in construction.
3. Typical delays in construction projects.
4. Impact of human behaviour on construction project processes.
5. Impact of technological innovation on construction projects.
6. Reason construction efficiency is essential to the environment.
7. Legal implications of construction inefficiencies.

8. Effect of delay causes on process efficiency.
9. What is lean six sigma?
10. Applying lean six sigma in construction.
11. Six sigma methodology.
12. Expansion of DMAIC framework to the minimisation of construction efficiency.
13. Strategies for implementing construction projects.
14. Traditional project management strategies for inefficiency minimisation.
15. Cost-benefit of deploying Lean Six Sigma in construction.

In chapter 2, the application of the lean six sigma methodology in previous studies is presented and discussed. This is used to form a strong foundation for the development of the proposed solution that is aimed at improving process efficiency.

Chapter 3: Research methodology

In this chapter, the first sub-heading is a chapter overview that presents an introduction of the research methodology. The second sub-heading is the conceptual framework research design which shows the development of the proposed solution of the research. This is a schematic diagram showing the problem statement-objectives and research approach. The third sub-heading is the theoretical framework which explained the theories that governed each of the items of the conceptual framework. The final part of chapter 3 is the model solving sub-heading. This sub-section customised the DMAIC framework to address and propose a solution to the problem statement. A mathematical model was also presented in this chapter.

Chapter 4: Research Manuscript

This chapter presents a research manuscript which is currently under review by the journal International Journal for Lean Six Sigma and is titled “Using the Lean Six Sigma Framework to Identify and Minimise Inefficiencies in Construction Projects”.

Chapter 5: Conclusion and Recommendation

This chapter reaffirmed the completion of the research and validity of the proposed solution and techniques. In the conclusion, the objectives attainments are presented to reassure the reader that the objectives and research goals are achieved and a map is given as a means to direct the reader to the sections that addressed the objectives. The research findings are discussed in detail and a brief chapter summary is also presented. The reader is presented with advice on specific issues that address the problem statement. Lastly, the conclusion also has recommendations that offer advice on the way forward and maintenance of the novel changes in the project. It also specifies and recommends opportunity for the continuity and further development of this dissertation and future work.

1.11 Definition of Terms & Notations

This sub-chapter presents the notations that are used in this dissertation. It also defines the notations and acronyms to give the reader a clearer understanding of what each of them mean.

1.11.1 Definition of Terms

1. DMAIC- This is the Lean Six-Sigma framework that is used as a blueprint to optimise the construction processes. The acronym is defined as follows: Define, Measure, Analyse, Improve, Control.
2. LSS -Lean Six Sigma. Lean Six Sigma is a method of process improvement that employs a collaborative team effort to enhance performance by methodically eliminating operational waste and minimising process variation.
3. LCL- Lower Control Limit. It is the lowest number that a process may obtain without being deemed out of control.
4. UCL- Upper Control Limit. It is the highest number that a process may obtain without being deemed out of control.
5. Mean- Average. A mean is a numeric amount that represents the middle of a group of numbers and is intermediate to the extremes.
6. R-value – correlation coefficient. A correlation coefficient is a numerical measure of a statistical connection between two variables.

1.11.2 Notations

Q_0 -Initial quantity of inventory. This is the initial quantity of building material that is available prior to ordering. Measured in units.

Q^* -Optimal quantity of inventory. This is the optimal amount of building material that should be on site at any one moment to fulfill demand without having too much extra material or running out of material. Measured in units.

D -Demand of the inventory. The rate at which building material is used and needed during construction. Measured in units.

θ -Rate of deterioration of the available building material. Measured in units/day.

t – This is the building material storage time before use. Measured in days.

T -Cycle duration. This is the lead time and is measured in days.

k -Cost per order (OC). This is how much each order costs and is measured in Rands.

P -Purchase price for the item (PC). This is the cost per item purchased, measured in Rands.

Qt –Available quantity of building material after the effects of demand or deterioration or both. Measured in units.

h -Holding cost (HC) per unit. This is the cost of storing building material. Costs include the hiring of a storing container to store cement. This is measured in Rands per unit.

Cd -Deterioration Cost. This is how much the company loses when building material deteriorates or gets stolen. It is measured in Rands.

C- Cost per unit item

HC- Inventory Holding Cost

OC -Inventory Ordering Costs

PC- Inventory Purchasing Costs

TC- Inventory Total Costs. This is the combination of all the costs of purchasing, storing or losing building inventory.

σ- Standard deviation.

1.12 Chapter Summary

This chapter has provided the initial, fundamental, and comprehensive introductory details that can be advantageous to the reader and offer them a thorough understanding of the research. It encompasses various aspects such as the background information, problem statement, research questions, research aim, research objectives, research rationale, research motivation, research scope, research limitations, research delimitations, project organisation, and finally, the clarification of acronyms, abbreviations, and notations. By presenting this extensive introductory information, the reader is equipped with a solid foundation to comprehend the essence of this research.

Chapter 2

Literature Review

2.0 Chapter Overview

The purpose of this chapter is to provide a comprehensive and evaluative review of current research, academic papers, books, and other relevant materials related to the implementation of Lean Six Sigma in construction projects. Initially, it examines the factors that contribute to inefficiencies in construction projects and their consequences. Furthermore, it will define Lean Six Sigma and its significance in optimising construction projects. Additionally, previous success stories of Lean Six Sigma will be explored. The chapter is structured as follows:

Historical Trends of Construction Inefficiencies:

This sub-chapter delves into the historical trends of construction inefficiencies and underscores the importance of process improvements. Moreover, inefficiencies have been exacerbated by inadequate project management methods, labour scarcity, and sluggish technological advancements. The various approaches are presented and discussed in this sub-chapter.

Present Day Inefficiencies in Construction Projects:

This sub-chapter explores inefficiencies in construction projects, including inactive work, ineffective work, and delays. Understanding these factors can minimize inefficiencies and improve project outcomes.

Typical Delays in Construction:

This sub-chapter provides a concise overview of the common delays encountered in construction projects. It delves into the various factors that can contribute to delays.

Impact of Human Behaviour on Construction projects:

In this sub-chapter, the impact of human behaviour on large-scale public infrastructure projects is emphasised in a study conducted in Kenya. This study emphasises the significant connection between human behaviour and technological innovation in the construction sector.

Impact of Technological Innovation on Construction Projects:

This sub-chapter emphasises the significance of project management tools. The utilisation of project management software is essential in the construction industry as it plays a vital role in enhancing productivity by simplifying communication, teamwork, and organisation.

Reason Construction Efficiency is Important to the Environment:

Within this sub-chapter, the focus is on the positive contribution of construction efficiency towards the environment. Construction activities have a notable impact on the environment, resulting in deforestation, health concerns, and increased energy consumption. However, green construction endeavours to strike a balance between environmental preservation and efficiency by implementing environmentally responsible practices throughout the entire lifespan of a building.

Legal Implications of Construction Inefficiencies:

This sub-chapter emphasises the legal consequences that arise from inefficient construction processes. Inefficiencies in construction projects often result in legal complications, including contractual obligations, regulatory penalties, and non-compliance with health and safety standards. Failure to implement adequate construction precautions not only exposes parties to legal obligations but also poses risks to their credibility and financial stability. The sub-chapter provides a comprehensive explanation of these implications.

Effect of Delays:

This sub-chapter focuses on the inefficiencies that have a substantial impact on construction projects beyond just the project timeline. It highlights the consequences of delays, such as disruptions, decreased productivity, higher costs, compromised project quality, third-party claims, and premature contract termination.

Applying Lean Six Sigma in Construction:

This sub-chapter discusses the proposed solution to the optimisation of process inefficiencies. Lean Six Sigma methodologies can be beneficial in construction by reducing non-value-added activities. Value Stream Mapping (VSM) helps identify inefficiencies, but it's crucial for initial identification without further analysis or process improvement capabilities.

Six-Sigma Methodology:

This section of the chapter provides a detailed explanation of the step-by-step solution methodology. The main objective of this approach is to minimise defect rates and recognise the connection between project defects, inefficient processes, and overall client satisfaction levels. In the context of construction projects, Six Sigma principles are applied to identify and minimise inefficiencies.

Using DMAIC in Construction:

The subsequent sub-chapter provides a comprehensive analysis of the Lean Six Sigma methodology, DMAIC, shedding light on its practical implementation in numerous construction process optimisation endeavours.

Strategies for Implementing Construction Projects:

In this sub-chapter, various approaches are proposed for the implementation of construction projects. The utilisation of statistical methods plays a vital role in reducing inefficiencies within the construction industry.

Importance and Cost-Benefit of Implementing Six-Sigma:

This sub-chapter provides a detailed analysis of the advantages and disadvantages associated with the utilisation of Lean Six Sigma to optimise inefficient construction processes.

Using literature and research on Lean Six Sigma, this section conducts a thorough examination and evaluation of the primary factors that are responsible for ineffective project management within construction.

2.1 Review

The purpose of this analysis is to acquire a comprehensive understanding of the factors that contribute to inefficiencies to identify industry best practices and potential solutions for addressing the specific problem at hand. Additionally, by examining past experiences and successful resolutions to similar challenges, it aims to gain further guidance in reducing inefficiencies in the construction process. Furthermore, it will address the limitations associated with significant findings to enhance overall comprehension. This assessment not only provides contextual details for future inquiries but also serves as a foundation for informing recommendations that directly improve the performance of current projects and address previously identified issues. Effective management of construction projects can significantly impact their success. In the face of increasing competition in the construction sector, combining factors such as project progress rate, adherence to quality standards, and cost-effectiveness establishes a strong foundation and competitive advantage for firms (Ballard et al, 2001).

These factors interact to either make or break a project. Various obstacles may arise during a project, necessitating project managers to educate themselves on different types of challenges and their impact on project development. It is crucial to employ effective strategies for identifying and resolving these challenges. This highlights the significance of finding construction management methods that minimise inefficiencies in construction projects. Reducing inefficiencies in the construction sector is of utmost importance due to its significant and varied ramifications. Insufficient project management can lead to substantial financial burdens, including cost overruns caused by delays, rectifying mistakes, and rework. These challenges not only jeopardise companies' economic goals but also have an impact on sustainability and profitability. Moreover, inefficient practices can impede the timely completion of projects, resulting in disruptions that may affect subsequent stages and lead to missed deadlines. This can result in client dissatisfaction, potentially attracting contractual penalties, putting client relationships at risk, or even damaging the reputation of firms (Maripandi and Abisha, 2023).

Timely delivery plays a crucial role not only in raising industry standards but also in fostering positive partnerships between contractors and customers, ultimately leading to satisfactory project outcomes beyond mere temporal considerations. Therefore, in addition to its implications on timeframes and finances, it also affects fundamental aspects such as security measures and quality control, guarding against faults, errors, and hazardous situations, all of which hurt overall project efficiency. Henceforth, mitigating inefficiencies is a mandatory necessity to sustain elevated standards for safety measures for workers' protection as well as end-users'. Effective project management does not just minimise negative consequences but also fosters beneficial results. It boosts overall productivity by enabling employees to concentrate on tasks that add value rather than being bogged down with preventable setbacks, repeating work or unnecessary procedures (Maripandi and Abisha, 2023).

Consequently, this facilitates a more streamlined and efficient workflow which leads to enhanced resource utilisation such as materials, labour and equipment efficiency. Moreover, as sustainability takes precedence in today's world, tackling inefficiencies is congruent with the values of conscientious and environmentally friendly building. Ineffectual methods can lead to excessive use of resources and heightened production of inefficiencies. By diminishing inefficiencies, construction endeavours have the potential to enhance resource management techniques, decrease inefficiency levels as well as foster a more sustainable and ecologically mindful field altogether. Efficient project management is essential for construction projects to cope with various external situations, ensuring the ability of firms to respond effectively and maintain resilience when facing unforeseen obstacles such as economic instability or shifts in regulations. By prioritising efficiency, construction companies can reap benefits not only for specific projects but also for the industry as a whole (Oshingade and Kruger, 2022).

When they deliver timely and high-quality work while staying within budget, clients trust them more. Skilled professionals are attracted to join their team, and investors want to invest in them. This creates an environment of growth that is essential for successful construction businesses. To achieve financial stability, timely project completion with safety measures intact alongside sustainability efforts prove crucial, resulting in a better reputation and competitive edge across the entire industry ultimately leading it towards strength and success over time.

2.2 Historical Trends of Construction Inefficiencies

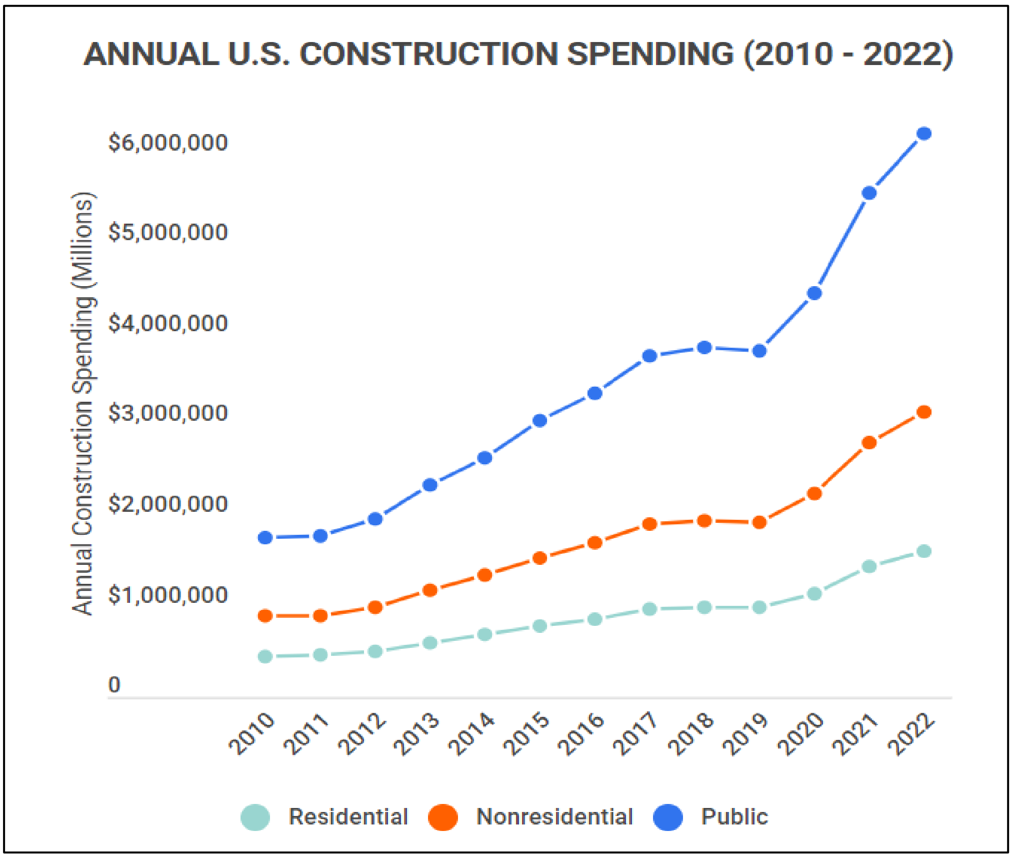

Figure 3-Rapid increase of the cost of construction inefficiencies. (Kolmar, 2023)

The construction industry has a long history of complex dynamics and practices that have contributed to inefficiencies in projects. Figure 3 presents one of the most common factors that are a result of project inefficiencies. Project inefficiencies cause increased spending and also increase the risk of cost overruns (Maripandi and Abisha, 2023). To effectively address these multifaceted challenges, it is essential to gain an understanding of their historical trends and underlying factors.

Developing comprehensive strategies for minimising inefficiency requires careful consideration of the following issues. The construction industry is known for its fragmentation, which presents a persistent challenge and entails the involvement of numerous stakeholders such as architects, contractors, subcontractors, suppliers and regulatory bodies. Such diversification leads to coordination complexities along with communication gaps that result in delayed output or misunderstandings among various parties working on a project. This lack of seamless collaboration often prompts rework requirements due to misaligned objectives or methodologies amongst different entities involved. The lack of standardisation in construction projects causes inefficiencies as unique project designs and specifications result in variations in materials, methods, and practices. This absence impedes the realisation of economies of scale while increasing the possibility for errors or conflicts to arise. However, implementing standardised approaches could streamline processes by enhancing predictability and reducing risks associated with inevitable inefficiencies. During the construction process, design changes continue to be a major concern. Modifications may arise due to shifting client needs, insufficient initial planning, or unforeseen site circumstances (Apollo et al., 2018).

These alterations require modifications in procurement methods as well as scheduling and resource distribution strategies over time which can result in additional challenges and possible declines in efficiency levels. Insufficient project management methods have consistently caused inefficiencies in the construction industry over time. Delays and cost escalation result from issues such as inadequate coordination, incorrect scheduling, inaccurate expense forecasting, and insufficient risk mitigation plans. It is crucial to implement improved project management methodologies that include enhanced collaboration, accurate planning, and dependable monitoring mechanisms for reducing such. The labour availability and productivity in the construction industry can be affected by cyclical demand changes as well as regional labour shortages. This, in turn, may cause a scarcity of skilled workers or lower their level of efficiency which could result in project delays and increased expenses for hiring additional employees. To address these concerns, workforce planning and training programs along with initiatives to attract and retain experienced personnel has been suggested (Apollo et al., 2018).

Projects in the construction industry have been known to lag in adopting technological advancements, which sets them behind other industries while increasing the likelihood of errors or redoing tasks. To resolve this issue, it is imperative to embrace new technologies like Building Information Modelling (BIM) and advanced project management software as a solution for enhancing efficiency by overcoming these bottlenecks caused by slow technology adoption. Construction procurement encompasses various activities such as material sourcing, contract negotiation and inventory management. These processes can be challenging if not performed efficiently, leading to delays caused by supplier disputes or inadequate contract terms that may result in shortages of materials. To mitigate these challenges, construction firms need to streamline their procurement practices by implementing effective strategies aiming at strengthening relationships with suppliers while also adopting modern approaches that will lead to improved efficiency gains. In the past, regulatory compliance requirements and permitting processes have posed significant challenges for construction projects due to their intricate nature. These hurdles not only extend project timelines but also exacerbate administrative duties (Agenbag and Amoah , 2021).

However, collaborating with regulatory authorities beforehand, engaging in pre-planning activities and utilising digital tools that facilitate easy permit applications can potentially mitigate some of these difficulties. Inclement weather is an inevitable hurdle that construction projects, especially those conducted outdoors, must face. Unfavourable meteorological conditions can impede progress by causing work stoppages or delays in the predetermined timeline, forcing added expenses for rescheduling and temporary protective measures. To combat these risks, comprehensive contingency planning along with adaptable scheduling plans incorporating sophisticated forecasting technology is crucial to minimise disruptions stemming from adverse climate interferences (Schuldt et al., 2021).

One of the most common issues in construction projects throughout history has been the lack of a collaborative approach among stakeholders. This results in substandard communication and coordination, as information silos prevent vital data from being shared effectively between different teams. Such inefficiencies often lead to errors, duplicated efforts or rework of tasks. However, establishing an environment that values collaboration through digital platforms for sharing information can help overcome these challenges and positively impact project outcomes. To tackle these historical patterns and influences, the construction industry has to undergo a comprehensive systemic overhaul. It is necessary to introduce initiatives such as better standardisation of procedures, improved project management practices, wider technology adoption across all areas in the ecosystem (from machinery and equipment usage through marketing), strategic workforce planning for personalised employee training programs pre-empting skills deficits that would arise from automation trends or lingering shortages; more streamlined procurement processes – including lean thinking methodologies with collaborative culture among stakeholders (Apollo et al., 2018).

2.3 Inefficiencies in Construction Projects.

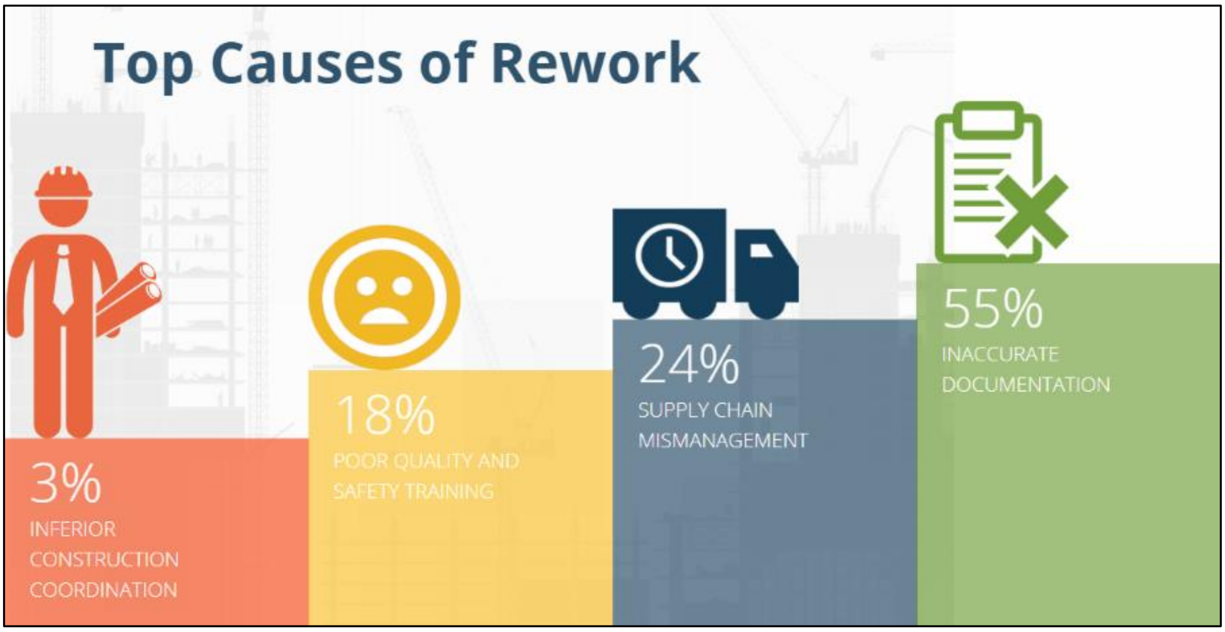

Figure 4-Typical Causes of Process Inefficiencies. (Andony, 2021)

Toyota defines inefficiencies as anything beyond the minimum equipment, materials, parts and labour required for production. In other words, inefficiencies include activities that drive up costs as mentioned in figure 3, but do not contribute directly or indirectly to project progress or "delay causes". Inefficiencies factor in various cost types like opportunity costs and efficiency measures such as staff productivity and equipment effectiveness. The inefficiencies may originate from issues with flow, activity conversion or management functions too. Figure 4 gives an illustration of the typical causes of project delays, however, measuring overall project inefficiency differs across stakeholders: owners experience lost revenue through delays impacting operational facilities' viability and space rental while contractors incur higher overhead, material and labour expenses due to prolonged delivery periods marked by inflationary pressures. Timely completion is an indicator of performance quality. It reflects positively on building processes rife with unpredictability that stems from factors such as contractual relationships, resources available, party participation, and environmental constraints. Finishing projects within stated timelines remains elusive generally (Shahhosseini et al., 2017).

Inadequacies within construction projects can lead to inefficiencies caused by the following:

1. Inactive work.
2. Ineffectiveness at work.

Reducing inefficiencies in projects involves getting rid of or decreasing activities that hinder the project's progress and do not directly contribute to its success. Eliminating such inefficiencies can significantly simplify achieving success and boost productivity along the way. Managing a project is no easy feat as unexpected events may arise causing complications and inefficiencies, which if left unchecked could threaten both company and project achievement; hence why minimising inefficiency is critical. Understanding the actions potentially responsible for delaying project work during a given project sequence becomes essential when attempting their elimination from proceedings - there are diverse types of shortcuts considered inefficiencies commonly seen throughout most procedures (PlanRadar., 2023).

Understanding these various forms first before any attempt at reduction would save time in due course. Factors that cause inefficiencies typically include the following according to (Shahhosseini et al., 2017):

1. Transport

Material deliveries may cause long lead times. Slow deliveries may force the project to come to a halt, waiting for the arrival of material before the project proceeds.

2. Inventory

In construction, it is important to order enough building material to run the project, but it is equally important to ensure that no excess building material that will be unused. The building material must be available on request.

3. Motion and Waiting

Resources must be allocated to the correct and respective departments. Allocating employees to departments that they are not experienced in may result not only in delays but may also compromise the quality of the project.

4. Overproduction

Delivering more than the requested amount may lead to delays. The time inefficiencies in production of what is not required may be invested in other activities that will contribute towards the results of the project that are required.

5. Defects

It is essential to allocate the right employees to the right jobs. Assigning jobs to the wrong people may lead to delays and increased defects in production. This may lead a loss of profit and an increase in inefficiencies. Employees’ talents and skills must be put to beneficial use as this will contribute towards achieving an optimal process.

6. System

Production systems may be outdated or make use of old technologies. There may be innovative technologies in the market that are designed to simplify and eliminate processes or activities that do not contribute towards the advancement of the project.

7. Bureaucracy

The administration step of the project is unpredictable. Awaiting approvals and acquiring licenses to use or occupy certain estates may result in project delays. A qualitative model that identifies activities that reduce productivity in construction was identified. The study conducted by Shahhosseini et al., 2017, further elaborated on the loss of productivity in complex construction projects that can be explained by the use of the following five categories of non-productive time:

1. Inefficiencies due to idling
2. Inefficiencies due to travelling.
3. Inefficiencies due to slow work.
4. Inefficiencies due to ineffective work.
5. Inefficiencies due to rework.

2.4 Typical Delays in Construction

Delays are defined as any occurrence that extends the time needed to fulfil a contractual obligation. These obstructions can impede project advancement and lead to dissatisfaction from all parties involved. Delays subsequently generate higher overhead expenses through prolonged timelines, additional material procurement needs, and increased labour expenditures.

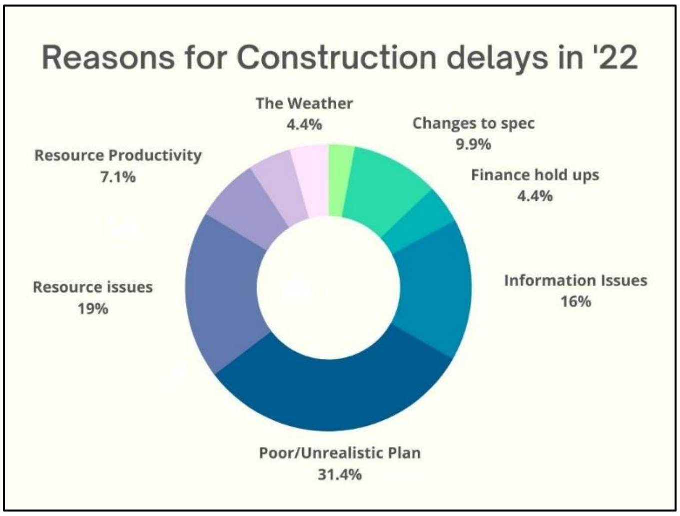

Figure 5-Typical causes of project delays in construction. (Burns, 2016)

Delays in construction projects can stem from various sources as can be seen in figure 5, these include factors related to the client, contractor, consultant, materials and labour. Additionally, external elements such as weather conditions or political interference may also lead to setbacks. Using factor analysis, it was determined that lack of commitment is the most critical cause of project delays This conclusion was drawn through a regression model which identified other factors like poor decision-

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making on behalf of project owners and mistakes made during construction as significant contributors towards overall delay. Other contributing causes include inadequate site management leading workers being resistant towards necessary change resulting in diminished productivity levels while cost performance features prominently alongside quality as crucial concepts linked with scheduling when mentioning cornerstones behind successful completion efforts. Research into disruptions caused by delayed constructions gathered data via questionnaires given mostly across three primary stakeholders participating within these programs namely clients, contractors along consultants revealing forty eight reasons why building jobs experienced unanticipated hold-ups categorised amongst eleven major groups (Mehta et al., 2022):

1. Project contract
2. Contractor
3. Client
4. Consultant
5. Material
6. Design-team
7. Labour
8. Equipment
9. Contractual-relationship
10. Contract
11. External disruption delays

The utilisation of the 'IBM SPSS' software, which is the name of a Structural Equation Modelling Software, and indices allowed for the identification of key factors responsible for delays and disruptions in projects. These include: employee strikes, project reworking as a result of employee errors or negligence, limited supply materials on the market, inadequate communication between clients and contractors, poor planning and scheduling tactics during project development stages coupled with inconsistencies found within designs - which all contribute to equipment shortages along with decision-making and problem-solving processes being delayed. Furthermore, unacceptable quality building materials are also cited motive contributors; additionally exceeding costs across timeframes further exacerbate this issue. It has been discovered through prior research that inefficiencies thoroughly stems from two core categories-inefficiencies present amongst work tasks completed-inactive vs ineffective completion practices namely analysed respectively elsewhere (Mehta et al., 2022).

Numerous instances in the construction industry have revealed that delays commonly occur due to insufficient subcontractors, inadequate resources from project management organisations, unclear or incomplete drawings, late payments from clients and disputes between contractors and their consultants. While effective communication amongst all parties involved can help minimise these setbacks, it is not always feasible. Delays are closely related with contractor failure and poor performance. The primary reasons behind project delays and unsatisfactory performance are attributed to contractor incompetence. This can be traced back to insufficient funding for projects, improper building techniques, ineffective planning methods resulting in subpar scheduling practices, deficient management strategies, inadequate on-site supervisory procedures, as well as unskilled labour force. Project inefficiencies in the construction industry are often caused by issues related to contractors and labour. These problems can result in disputes between the organisation and their contractors as well as additional time and cost overruns. These factors ultimately have a negative impact on project outcomes through increased costs, low productivity, and contractual disputes, among others. It is essential for project planners and managers to proactively identify factors that may increase the risk of the occurrence of the abovementioned implications of project inefficiencies (Shahhosseini et al., 2017).

The following factors were identified as common and impactful contributors to project delays beyond just contractor-related ones.

1. Weather and Climate Conditions:

Weather and climate conditions were identified in over 74 studies as key factors contributing to project delays. This is an uncontrollable cause of project delay. Most studies conducted to investigate the causes of delays identify weather or climate as a significant cause of project delays. The delays caused by weather changes and unpredictability may subtly influence the project schedule performance and become very difficult to plan around due to its unpredictable nature. The most significant impact of weather conditions is the loss of work routine and rhythm due to unforeseen occurrences. In such cases, it is often recommended that weather conditions be considered during the planning stage of the project. Furthermore, contractual agreements between the client and the contractor must make mention of possible delays that could be out of the control of the contractor (Schuldt et al., 2021).

Construction projects are naturally dependent and rely heavily on weather conditions. Undesirable weather conditions could result in increased absenteeism and a shortage of skilled labour as employees cannot work under bad weather conditions; the project would then have to be put on hold. In situations where on-site equipment is not stored correctly, adverse weather conditions may cause equipment damage, further delaying the project. This may affect the efficiency of the equipment's performance and its wear and tear. Extreme weather conditions may also cause delays in the sourcing and purchasing of construction materials. Additionally, cases such as drought or flooding may cause scarcity and increase the purchasing costs of materials (Schuldt et al., 2021).

2. Communication and Coherency

The biggest cause of conflict between project stakeholders is poor communication. A lack of effective communication may cause poor coordination during the project's lifecycle. During the scheduling and sequencing stage of the project, project coordination and communication must be at their optimum. Effective coordination and communication minimise the risks of project delays. Project success significantly depends on transparency and effective communication. Many modern methods can be used to improve communication between all parties during the project's lifecycle. These include newly improved communication strategies such as using multiple channels like emails, phone calls, virtual meetings, social media, and interactive dashboards that show the progress of the project (Mishra, 2020).

A project that relies on team coordination and coordinated activities progresses efficiently when there is adequate and effective communication as this lowers the chances of disputes and conflicts between the project stakeholders. A few studies recommend the use of cloud technologies to improve project coordination and communication. This provides a digital environment for each project stakeholder and keeps them up to date with the project's progress regardless of their location. It also allows for dynamic interaction at all stages of the project, improving coordination and reducing the possibility of errors and reworking in the project (Mishra, 2020).

3. Planning

The planning phase of the project is essential. This is where the project manager builds the project roadmap, including the project scope, schedule, constraints, resources, work breakdown structure, and risk analysis. Planning aims to communicate project deliverables, expectations, schedules, team roles, and responsibilities The planning phase forms the foundation on which the project is formed; it is imperative that it is efficiently done as it guides the project to completion. Poor planning may delay project milestones and hinder project schedule performance. The consequences of poor planning are unrealistic expectations from the workforce, lack of coordination, increased errors and reworking, poor site management, and delayed sourcing of construction materials. Overall, these may cause delays in construction activities. The quality of project planning can be enhanced by considering best practices during the planning phase (Durdyev and Hosseini , 2018).

4. Construction Materials

The construction process begins by designing a concept and using materials to transform the conceptual design into a finished product. The importance of construction materials is highlighted. It is impossible to transform a design into a physical facility without adequate construction materials; thus, it is imperative to have construction materials at the right time to prevent project delays and disruption of the labour momentum. Multiple factors may contribute towards material shortage, namely:

- Changes in design
- Delays in material delivery

- Price fluctuations
- Procurement of materials
- Resource allocation
- Unreliable suppliers
- Political factors
- Theft
- Inefficient use of construction material

The availability of funds is highly recommended to minimise material shortages. Projects experience delays due to limited material availability as a result of a sudden increase in demand. The risk of experiencing project delays increases when there are material shortages (Durdyev and Hosseini , 2018).

5. Project Finances

Financial issues and delayed payments were identified as the fifth most common reason for project delays. Poor cash flow management, insufficient resources, and unstable markets may cause financial issues. The lack of finances may delay the procurement and sourcing of construction materials and paying employees, which may increase the risk of strikes and boycotts, thereby hindering the progress of the project (Durdyev and Hosseini , 2018).

6. Construction Equipment and Processes

The plant or site equipment shortage may result in approximately 5% loss in working time. This is equipment that enables the workforce to handle heavy work on-site. Shortage of such equipment often means the project must be paused before advancing to the next phase. Another factor to consider is the presence of skilled and licensed operators. The absence of these employees could also cause the project to be paused. Construction process could involve using outdated processes for a certain construction project. There are new technologies introduced in the construction market which are designed to perform certain construction tasks faster and save time. Failure to keep up with latest trends in technology and improved or simplified processes and methods may hold the project back as certain tasks may take longer than they should (Durdyev and Hosseini , 2018).

7. Construction Labour

Appointing the right personnel is crucial for achieving project success. Skilled employees are indispensable to construction projects, whereas unskilled labour can have a negative impact on productivity. Additionally, labour shortages cause tight schedules and delays in meeting targets. The choice of management style also greatly impacts project outcomes such as time, cost, quality and safety; this may influence employee motivation, morale and productivity levels. Project leaders should evaluate their leadership styles thoughtfully--a democratic approach promotes greater workplace efficiency but primarily with skilled workers while different approaches suit other skill sets better and choose the most appropriate one accordingly to maximise results within specific project contexts. The presence of untrained workers on a project generally results in subpar performance, as their lack of expertise and propensity for mistakes can foster an "I'm incapable" mind-set that ultimately diminishes productivity (PlanRadar., 2023).

A deficit in skilled labourers also jeopardises both the quantity and quality of work completed, potentially causing delays to delivery deadlines which may then induce schedule overruns, increased expenses, plus inferior final products. The success of any project hinges on skills, which can fall under three categories: conceptual, technical or physical. As such, it's imperative for a manager to pinpoint and acknowledge the capabilities of each team member to assign appropriate tasks. Not only does this boost efficiency but also performance and productivity amongst employees. Improved output comes from having well-versed staff members who are healthy both mentally and physically within their respective fields. Employees who possess advanced skills are more likely to achieve higher levels of productivity and maintain good physical and psychological health, enabling them to effectively complete tasks necessary for project success. In the construction industry, predicting labour force is a crucial strategic management practice. It acknowledges the pivotal role of human resource management in enhancing performance and ensuring project success (Mpofu et al., 2017).

Assigning tasks according to employees' education or proficiency level is imperative as skilled workforce significantly contributes towards achieving project deadlines and overall efficacy. The second most important factor leading to construction inefficiencies is the absence of job-specific expertise among workers as revealed by their investigation. This not only results in project delays but also leads to wastage of building materials. Inexperienced employees have a negative impact on both completing projects within scheduled deadlines and escalating overall expenses incurred during construction work. The occurrence of faulty work is often linked to inexperienced employees and foremen. This can exacerbate project rework, leading to delays that impede progress. Despite this setback, the construction industry has made strides in improving productivity through breakthrough technology and innovation. Nonetheless, certain aspects remain undeniably labour-intensive with worker shortages being triggered by rapidly increasing numbers of concurrent projects among other factors like political tensions or conflicts e.g., Afghanistan's civil wars which depleted human resources causing significant delays on various sites. Essential components for labour include skilfulness, experience and qualifications; however these are lacking in cases where poor employee capabilities result in severe schedule lapses as well as inferior quality work -thereby posing numerous challenges including additional job do-overs plus overall delay periods within a project plan timeline (Enshassi A., 2010).

8. Site Management

The site manager enforces the project plan and ensures it is executed and followed. The manager must plan and organise site activities. If this is done poorly, it may result in project delays. Poor planning and scheduling were identified in a study conducted by Nagapan et al., (2012) as the key variables that cause inefficiencies in construction projects. In the study, inadequate planning and scheduling was ranked third by the Mean Rank Value Coefficient, 7.78. The project's management can either make or break the project as they play a dominant role in generating inefficiencies. This occurs when they do not monitor their employees during material handling. Poor site management puts the project at risk for delayed completion, poor flow of information between the project stakeholders, poor coordination of site activities, and poor resource allocation. This is a reflection of poor planning and poor plan implementation (Durdyev and Hosseini , 2018).

9. Condition of Construction Equipment

The issue pertains to the occurrence of frequent breakdowns caused by defective equipment. Delays in project completion and potential financial losses can result from repairing the malfunctioning machines, which highlights the significance of investing in preventive maintenance measures to avert future disruptions. The progress made in construction technology and equipment could streamline building procedures, minimise the time required for these tasks. Producing enhanced productivity levels while reducing delays within a project is achievable through this advancement. The impact of stoppages on an organisation can be catastrophic as legal actions may arise from unfulfilled obligations leading to loss of revenue, decreased output efficiency or sudden unanticipated costs that were not part of previous contracts subsequently resulting in early termination before their intended conclusion date. Advancements in technology and automation have had a profound impact on the construction industry. Traditionally, manual labour was used for most construction tasks which consumed time and required significant human effort. However, with modern technologies such as 3D printing, drones, and advanced robotics equipment designed to streamline processes while minimising project duration; efficiency has significantly increased by working faster than any manual process ever could (e-Architect, 2022).

The progress of construction technology has facilitated the growth of the industry, which in turn led to an expansion of services offered by construction companies. Previously, the construction field was predominantly male-dominated. However, with the advancement of labour-saving technology in construction, women now have increased opportunities to work in this industry. This not only benefits individual employees but also positively impacts organisations by broadening their workforce and creating more job opportunities while promoting workplace diversity and inclusivity (e-Architect, 2022).

2.5 Impact of Human Behaviour on Construction projects

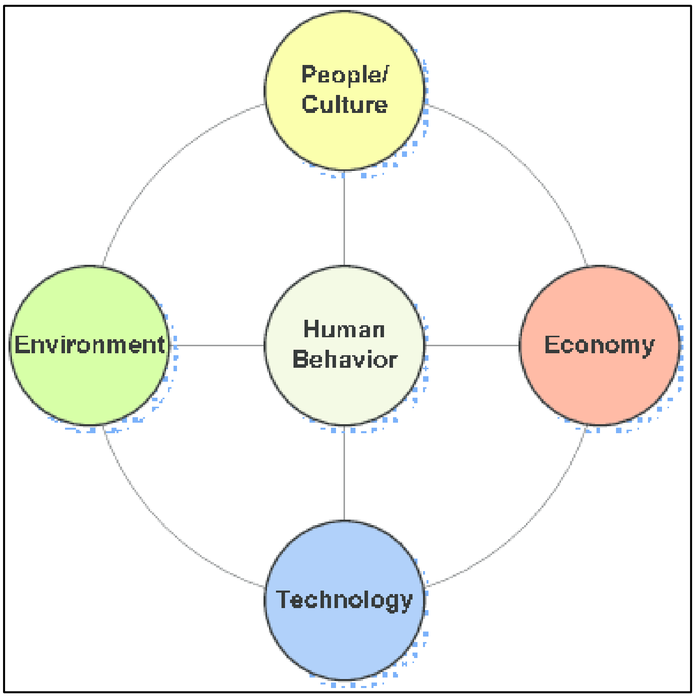

Figure 6- Factors affecting and affected by human behaviour (Bhattacharjee, 2009).

A thorough study conducted in Kenya highlights the significant impact of human behaviour on complex, large-scale public infrastructure projects. (Omonyo, 2017) stated that human behaviour plays a critical role in shaping project outcomes as evidenced by this research as presented in figure 6 (Bhattacharjee, 2009). Several behavioural aspects result in diverse impacts across these megaprojects. The research exposes optimism bias as a notable influence, which is the psychological tendency of decision-makers to undervalue risks and overestimate favourable outcomes. This inclination intensifies when projects are almost finished, motivating stakeholders to persist in ineffective efforts that result in exceeding budgets and postponing deadlines. Research indicates that risk aversion is a common bias impacting both forecasting and decision-making processes, leading executives to select conservative approaches which could hinder innovation and agility. Ultimately, this may negatively affect project success as well as compromise effective decision-making abilities (Omonyo, 2017).

The study highlights the crucial influence of organisational and project culture over prejudices and consistent inaccuracies in decision-making. It is imperative to develop a work environment that promotes openness, teamwork, and rationale-based judgment to curb partiality while enhancing the overall efficacy of projects. The communication and control dynamics of project teams are greatly influenced by human behaviour. Successful coordination, decision-making, and overall project performance depend on the understanding and management of the behavioural factors affecting team interactions. It is crucial for achieving project success to address communication hurdles while implementing effective controls mechanisms in place. Strategic behaviours, including absence of long-term commitment and rent-seeking habits by special interest groups, have been recognised as harmful aspects that can impact project outcomes adversely. Such practices may jeopardise the primary objectives of a project and redirect resources towards personal or group benefits (Hughes and Thorpe, 2014).

Comprehending and handling the various effects of human actions is crucial for project managers and organisations intending to effectively plan, implement, and administer projects. Identifying and lessening these behavioural impacts can facilitate informed decision-making, greater transparency, as well as superior outcomes for a project. By introducing techniques that consider human behaviour into their approach; stakeholders can tackle intricate situations while contributing towards overall progress in achieving successful projects. To address and reduce the adverse impacts of human behaviour on project results, there are several measures that project managers can implement. These include the establishing of a transparent and accountable culture where the project managers can foster transparency and accountability within their team by keeping all stakeholders informed about project goals, objectives, and progress. This approach minimises the negative impact of biases or strategic misrepresentations that may arise during the project's execution. One way to minimise the negative effects of communication and control problems is by promoting stakeholder engagement and teamwork. Project managers can achieve this through involving stakeholders in decision-making processes and fostering collaboration among team members (Omonyo, 2017).

Ensuring sufficient resources and support to mitigate the impact of individual behaviour and cognitive biases, project managers can guarantee that team members possess the essential resources, expertise, and proficiency they need to assist in carrying out the project successfully. Project managers can implement risk management strategies that effectively identify and mitigate risks associated with human behaviour, reducing the impact of optimism bias and risk aversion. Adopting a flexible and adaptive approach to project management enables project managers to address uncertainty, emergence, and rapid change in complex projects while minimising biases and strategic misrepresentation. Through promoting a culture of learning and continuous improvement through encouraging innovation, creativity, attaining process maturity; this mitigates negative impacts on biases improving outcomes for future successful project delivery by addressing potential issues relating from human behaviour. The significance of projects' triumph greatly hinges on communication and collaboration as well. These two factors can enhance coordination, decision-making abilities, as well as overall project accomplishments considerably. The following are some examples showcasing how these elements impact the outcomes of a project according to (Omonyo, 2017):

1. Improved coordination can be achieved through effective communication and collaboration among project team members, stakeholders, and partners. This ultimately ensures that everyone is aligned towards the same goals and objectives while minimising misunderstandings and conflicts.
2. Effective communication and collaboration can facilitate better decision-making by ensuring all relevant information is shared and considered, reducing the impact of biases while improving the quality of decisions.
3. Collaboration enables the promotion of innovation and creativity as it gathers varying perspectives and ideas, resulting in novel solutions to project obstacles.
4. Effective communication and collaboration can enhance problem-solving processes by enabling team members to share their knowledge and expertise. Consequently, issues are identified and addressed quickly for efficient resolution.

5. Stronger Trust and Relationships: By communicating effectively and collaborating, project team members, stakeholders, and partners can build deeper trust with each other. Such relationships foster a positive project environment that ultimately leads to improved performance in every aspect of the initiative. To wrap up, effective communication and collaboration hold enormous weight in shaping project results. Accordingly, it's crucial for project managers to give priority to developing efficient strategies that promote engagement among all stakeholders towards the attainment of overall success

The connection between human behaviour and technological innovation is crucial in the realm of construction projects. Attitudes towards change as well as the ability to embrace and optimise technology greatly influence how successful innovations are within this sector. By introducing advancements in technology, efficiency, precision, and data-driven insights can revolutionise construction processes. However, for these benefits to be realised it's important that integrate our understanding of human behaviour with new technologies seamlessly. As the industry gravitates more towards innovative practices accommodating intricacies related to individual tendencies becomes increasingly important for success. The synergistic relationship forged between cutting-edge tools with those leading a project proves vital for ensuring optimal utilisation and achievement when using such advanced methods during construction endeavours (Soundararajan and Reddy, 2020).

2.6 Impact of Technological Innovation on Construction Projects

Figure 7- Impact of technology and improvement of efficiency in construction. (PlanRadar., 2023)

Project management software is essential in enhancing the efficiency of construction projects as it facilitates the implementation of a cohesive platform that streamlines communication, collaboration, and overall organisation. The following are some ways in which this software bolsters efficiency within the realm of construction according to (Agenbag and Amoah, 2021):

1. Collaboration and Communication.

The software for managing projects allows team members to communicate in real-time, irrespective of their geographic locations. This minimises the time lag when exchanging information and expedites the decision-making process.

2. Collaboration Spaces.

Typically, these platforms contain collaborative spaces that allow project stakeholders to exchange files such as documents and drawings along with other pertinent information. By serving as a centralised repository of data, it helps prevent the occurrence of information silos and guarantees everyone is working from current material.

3. Management of Documents.

A centralised document repository is available through project management software, where all necessary documents are stored. This helps team members to quickly access and use the latest version of any file or record, thus minimising errors that may arise due to obsolete material. The software frequently comprises of attributes for version control which aid teams in monitoring document modifications over a period. This attribute is critical, particularly within construction projects where frequent design revisions and updates occur.

4. Scheduling and Managing Tasks.

Project management software enables the allocation of responsibilities to designated team members, complete with distinct targets and levels of urgency. This strengthens responsibility for progress tracking at both individual and group level. Gantt Charts and Scheduling Tools aid in the development and display of project timetables, allowing teams to detect vital paths, dependencies, and potential constraints. This enables proactive management of project timelines.

5. Management of Resources.

When it comes to construction projects, there are multiple resources that come into play like labour, equipment and materials. To allocate these resources effectively while avoiding overallocation or underutilisation, project management software proves beneficial for efficient tracking.

6. Tracking the Budget.

Numerous project management tools come equipped with budget tracking capabilities, making it possible for teams to keep a close eye on spending and avoid exceeding their costs.

7. Management of Risk.

The identification and mitigation of risks are vital in project management, which is why many software tools provide functionalities to detect and evaluate potential problems. By being proactive through these features teams can address issues before they worsen, ultimately enabling a smoother execution of the project.

8. Tracking Issues.

The software facilitates tracking of challenges and problems that occur while constructing. As seen in figure 7, inspections can be done using drones. This does not only promote efficiency by ensures employees safety as well. When these issues are promptly resolved, teams can avoid them from turning into significant hindrances to project advancement.

9. Analysis and Reporting.

Project management software offers options for creating reports and analytics pertaining to project performance metrics. By utilising this data-dependent approach, teams can pinpoint patterns, assess important indicators of success and make knowledgeable judgments with the aim of ongoing enhancement. Dashboards that are customisable allow users to manipulate the display of pertinent metrics, furnishing a current evaluation on project status and effectiveness.

10. Incorporation with External Tools.

The integration of project management tools with other commonly used software in construction, such as Building Information Modelling (BIM) applications, design tools and accounting systems, enhances interoperability. This results in streamlined workflows and reduced duplication of data. Using project management software leads to enhanced communication, streamlined workflows, better resource allocation and improved decision-making for construction projects. These efficiency gains ultimately translate into successful completion of the project within prescribed timelines, cost reductions and an overall accomplishment of goals. One of the most powerful project management tool is Building Information Modelling.

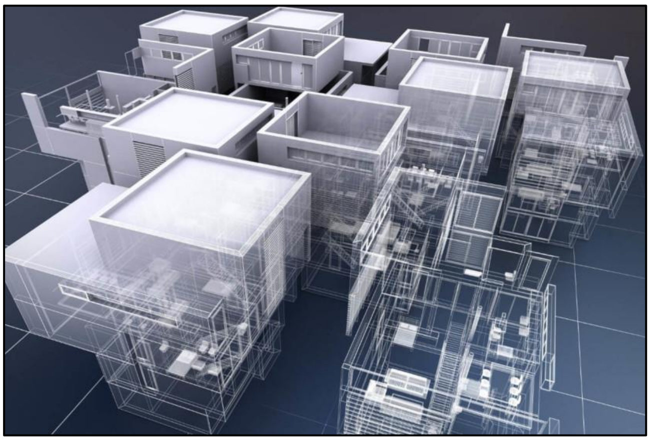

Figure 8- Visualisation of buildings using BIM. (PlanRadar., 2023)

The arrival of Building Information Modelling (BIM) is a pivotal moment for construction projects, as it presents an advanced and unified approach to design, documentation, and teamwork. BIM represents the physical and functional features of structures through digital means which has garnered attention due to its potential in upgrading the construction industry as can be seen in figure 8. More than typical 2D drawings, BIM produces data-enriched 3D models that aid visualisation, coordination and communication throughout project development. Therefore this article aims at investigating how innovative applications brought about by BIM results in tangible advantages that improve efficiency levels alongside proliferating quality across collaboration efforts affecting overall progress of ongoing building projects (Bryde et al., 2013).

A study scrutinised how BIM affects six crucial performance indicators (KPIs) in the field, including quality control by reducing rework, timely completion of tasks, cost efficiency optimisation, safety enhancement that lowers lost man-hours incurred due to accidents or injuries at work sites while keeping track of dollars per unit performed for each square foot along with units completed within one hour. The respondents of the survey were in agreement that using a BIM-based approach had a positive impact on construction metrics when compared to traditional methods without integration. The top three Key Performance Indicators (KPIs) with favourable responses were quality, completion within schedule and accomplishment per man-hour. This highlights how BIM has great potential for enriching both the standard of construction as well as project timelines and workforce productivity efficiency. The research highlights the need for further investigation and validation regarding BIM's perceived impact on construction KPIs. Additional studies are required to confirm observed trends, with a focus on real-world case studies that support the adoption of BIM by AEC firms (e-Architect, 2022)

This call for more comprehensive research underscores how multifaceted and evolving this domain is; therefore, deeper empirical evidence must inform industry-wide decisions effectively. Overall, while most perceive BIM as having a positive influence in various areas like quality assurance, timely completion & productivity, it is challenging to evaluate its overall impact due to differing perspectives amid diverse construction scenarios. Project management software is essential for construction projects, as it improves efficiency, collaboration and overall project outcomes. In the complicated setting of a building site with many tasks, stakeholders and deadlines to consider; this type of software provides one central platform which enhances planning schedules while monitoring progress in real-time. Such programs enable effective communication among team members even when working remotely promotes swift decisions making hence quick identification and resolution challenges along the way (Hughes and Thorpe, 2014).

Functions including Gantt charts aid projecting timelines by highlighting crucial paths thus allocating resources efficiently promoting better job quality throughout every phase. Document sharing with version control also ensures that all involved parties are well-informed at all times via access to up-to-date information while streamlining risk through tracking potential setbacks or milestones achieved within pre-set timeframe easing transformational processes on large construction sites such steps minimises delays plus reduce costs leading prompt completion together delivering quality infrastructure solutions promptly meeting set needs across multiple industries today quickly proliferating globally resulting successful growth advances everywhere. Other factors that are improved by the keep up with technological advances in construction projects are listed and explained below according to (Agenbag and Amoah , 2021):

1. Improved accuracy and precision

In previous years, construction workers heavily relied on their expertise, abilities, and instinct during the construction process. This approach to work was deemed unsafe as it depended on human intuition and allowed for numerous human errors. In numerous instances, workers had to make mistakes and learn from them before they could master their craft. This presented a safety risk not only to the construction workers themselves but also to the clients and the surrounding community. However, the advent of technology in the construction industry in recent years, including 3D printers and other robotic equipment, has revolutionised the way employees construct buildings. This advancement in accuracy and precision has also led to enhanced safety for both construction workers and clients, as the structures are now dependable and secure to inhabit.

2. Increased construction speed

Construction projects usually require a significant amount of time to be completed, as they are influenced by various factors such as human behaviour, productivity, capital availability, work precision, and the occurrence of reworks. Nevertheless, the advent of modern technology has introduced shortcuts that not only enhance the precision of the work but also expedite the pace of construction projects.

Figure 9- Drones used in construction (e-Architect, 2022).

Figure 10-3D printing in construction (e-Architect, 2022).

Figure 9 and 10 depict technologies that have been specifically developed to reduce the need for human involvement and mitigate human errors. These advancements enable projects to be executed at a significantly accelerated pace, proving particularly advantageous in urgent situations like natural disasters, where swift and dependable construction is of utmost importance.

3. The Building of Complicated and Intricate Structures

Figure 11- 3D printed Intricate parts of building (e-Architect, 2022).

In the past, the construction of complex and intricate structures such as the one shown in figure 11, was nearly unattainable due to technological constraints. Nevertheless, in recent times, advancements in technology, particularly the utilisation of 3D printers, have made it feasible to accomplish such feats. These technological innovations have not only made the once-impossible achievable but have also demonstrated efficiency in terms of time management.

4. Increased safety for construction workers

The construction sector comprises hazardous working conditions that pose risks to its workers, clients, and the surrounding community. These working environments expose individuals to potential dangers, which can result in severe injuries and even fatalities. However, the adoption of cutting-edge technology has the potential to alleviate these risks. By enabling construction workers to operate from safe distances and employing drones for surveys and building inspections, the use of advanced technology has been proven to substantially decrease the likelihood of injuries and fatalities.

5. Ability to work and inspect at heights and confined spaces

Figure 12- Working above water of unknown depth (e-Architect, 2022).

Construction workers frequently face hazardous situations when working in challenging locations, as depicted in figure 12. These locations encompass tasks performed at elevated heights, within confined spaces, and over bodies of water with uncertain depths. However, with the utilisation of advanced robotic machinery, such risks can be mitigated, allowing construction workers to carry out their duties securely from ground level (Hughes and Thorpe, 2014).

6. Recycling and Reusing Construction Material

Inefficient construction materials that were once deemed as waste can now be repurposed and recycled thanks to the utilisation of 3D printers and other robotic equipment. Previously, these materials would have been discarded when they were no longer needed. However, with the advent of modern technology, such materials can now be reintroduced into the system by employing them in the process of 3D printing, thereby resulting in cost savings for the company (e-Architect, 2022).

7. Building of custom-made structures

Figure 11 demonstrates the capability of modern technology to construct intricate and elaborate structures. By employing robotic equipment and 3D printers, the construction industry gains the versatility to fabricate tailor-made structures that cater to the unique requirements of clients.

8. The Ability to Monitor Construction Projects Remotely

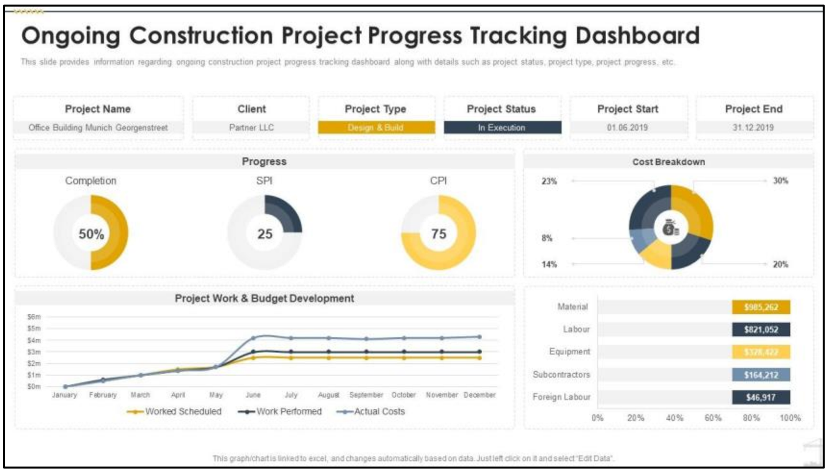

Figure 13- Online dashboard used to track project progress (e-Architect, 2022).

The presence of construction employees, particularly foremen and supervisors, on the construction site was mandatory to oversee the advancement of the construction project. However, this requirement might have resulted in potential delays, considering that these employees often have multiple projects to oversee. Inadequate monitoring of projects can lead to an increase in human errors, the need for additional work, and ultimately, a slowdown in project progress. In recent times, the implementation of business improvement techniques, such as the creation of dashboards and the installation of onsite cameras for real-time monitoring, has provided supervisors and foremen with the ability to remotely monitor their projects. This newfound flexibility enables workers to effectively track and oversee multiple projects simultaneously.

9. Use of Virtual Models of Construction Projects

Figure 14- Use of virtual model for construction projects (e-Architect, 2022).

Experienced construction workers and architects previously had to depend on their instinct to strategize construction projects, a process that consumed a significant amount of time and exposed the project to potential reworking and design alterations. However, with the advent of advanced technology like 3D printers and virtual models, exemplified in figure 14, construction workers now have the ability to fabricate a prototype of the final product even before commencing the project. This empowers the workers to meticulously plan and design projects, leading to enhanced outcomes and reduced instances of reworking.

10. Ability to expand the team by working with other professionals.

The utilisation of modern technology in construction has paved the way for the involvement of various professionals, including architects and engineers, to form a cohesive construction team. By utilising online meeting platforms and Modelling programs like CAD, team members are able to enhance communication and collaboration, ultimately leading to improved project outcomes. It is crucial for companies to stay abreast of the latest technological trends and advancements to streamline traditional project development processes and eliminate redundant ones. In the past, the construction industry heavily relied on manual labour to carry out most of its tasks, which proved to be time-consuming and physically demanding. However, thanks to advancements in modern technology, this sector has witnessed a significant boost in efficiency, resulting in reduced delays and the production of higher-quality results (Suermann and Raja, 2009).

2.7 Reason Construction Efficiency is Important to the Environment

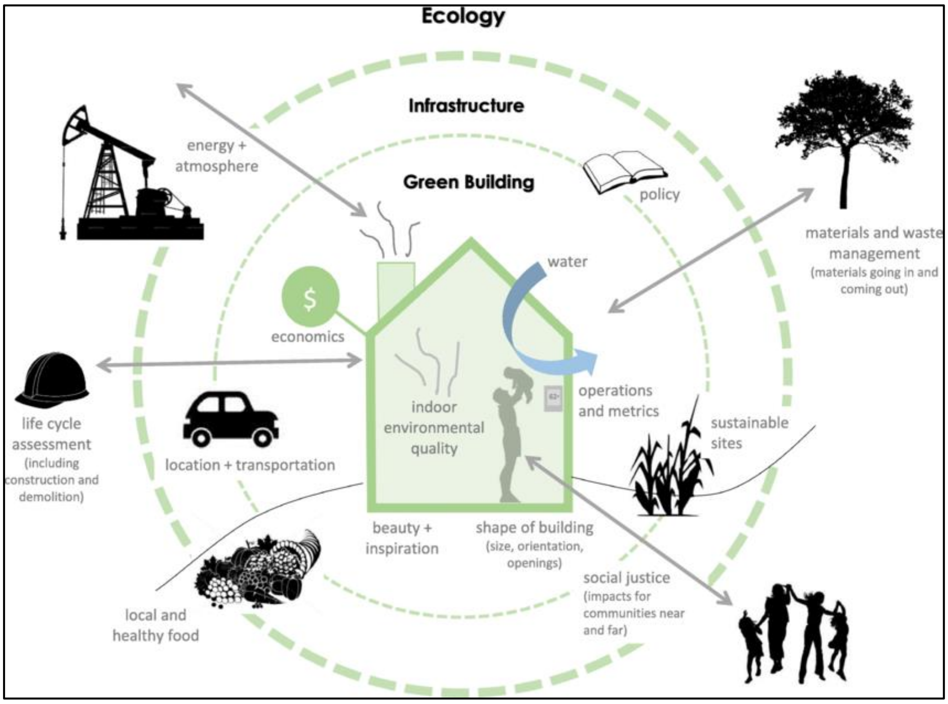

Figure 15- Impact and benefits of green construction (Cole, 2019).

The impact of construction on the environment is notable as seen in figure 15. Clearing sites for building purposes leads to deforestation, resulting in an imbalance of the eco-system. Furthermore, dust and noise generated from these activities affect human health by causing respiratory issues or chronic symptoms such as migraines and heart diseases. It also consumes a large amount of energy while using materials responsible for CO2 emissions like steel, aluminium, and concrete. Additionally, construction can cause water pollution since pollutants seep into nearby watersheds infecting aquatic life thereby leading bad effects on them too. Green construction is a perfect way to develop a balance between environment preservation and construction efficiency. Green construction involves the utilisation of environmentally responsible and resource-efficient practices throughout a building's entire life-cycle, from siting to demolition (Cole , 2019).

It is focused on minimising the overall impact that constructed environments have on human health and natural resources by optimising energy, water usage as well reducing inefficiencies pollution, protecting occupants' welfare while improving employee productivity through sustainable materials use renewable energies sources in design consideration for indoor environmental quality. Performing this process often requires certification under green-building rating systems such as USGBC-LEED (US Green Building Council's Leadership in Energy and Environmental Design) which reward whole-building approaches to promoting sustainability performance with regards to both human & environment health areas; it should be noted however that "green" mainly focuses only those aspects impacting these factors wholly regarding sustainability- an all-encompassing concept considering social-economic continuity among its principles too. Green construction brings about several benefits for the environment, including reduced energy consumption through energy-efficient design and technology implementation that lowers green-house gas emissions (Banawi A and Bilec , 2014).

It also involves water conservation techniques such as rainwater harvesting, greywater recycling, and utilisation of water-saving fixtures to reduce overall usage. By utilising sustainable materials in constructing buildings, green construction reduces resource depletion while minimising environmental damage during extraction processing and transportation stages. Additionally, inefficiencies reduction plays a crucial role in this process by diverting demolition inefficiencies from landfills, reducing their environmental impact further. Improving indoor quality with better ventilation systems which uses non-toxic material improves occupant health significantly underlines one more benefit among others is preserving biodiversity via ecologically balanced practices towards site development strategies, followed therein contributing to fulfilling sustainability goals across sectors was intended originally (Cole , 2019).

2.8 Legal Implications of Construction Inefficiencies

The nature of construction projects demands meticulous planning, coordination and execution. However, inefficiencies in these endeavours can lead to severe legal implications for all parties involved. This piece delves into the various legal ramifications caused by project inadequacies while also shedding light on probable measures to minimise such risks (Moffat and Irvin, 2020).

1. Obligations and Liability under Contract.

Figure 16- Legal agreements in construction. (Moffat, 2020)

The contractual agreements, as shown in figure 16, are a significant legal aspect of construction inefficiencies. These contracts typically establish particular timelines, quality criteria, and cost parameters in the construction process. Delays, exceeding costs or substandard product quality can constitute as breaches to these obligations outlined by such agreements leading parties including project owners, contractors and subcontractors towards disputes that seek protection for their respective interests.

If project timelines are adversely affected by inefficiencies, contractors may be subject to pre-determined monetary penalties as outlined in the contract. These penalties serve to compensate the owner for any delays that occur. However, if inefficiencies arise due to unforeseen circumstances such as changes in project scope or external factors beyond their control, contractors have the option of seeking extensions of time and additional compensation (Moffat and Irvin, 2020).

2. Legal Consequences and Compliance Regulations.

The presence of construction inefficiencies may have legal repercussions regarding adherence to regulatory requirements. Regulatory entities enforce rigorous protocols aimed at safeguarding public safety, preserving the environment, and conforming to building codes. Inadequate timeframes, alterations in design plans or other types of insufficiency could result in failure to meet such standards which can subsequently generate regulatory penalties, halting project progressions or even attracting litigation consequences. Non-compliance with health and safety standards may lead to harsh legal consequences, such as monetary penalties and even criminal charges. Inadequate implementation of construction precautions not only puts labourers at risk but also exposes the involved parties to persisting legal obligations that could harm their credibility and financial standing (Gingerich and Mike , 2023).

3. Conflict Resolution and Legal Proceedings.

Disagreements between project stakeholders frequently arise due to construction inefficiencies, such as delays in the timeline, exceeding budget estimates, poor workmanship or failure to meet contractual obligations. To avoid lengthy and costly legal proceedings for conflict resolution, alternative dispute resolution methods like mediation or arbitration are becoming a popular option within the construction industry. In cases where alternative dispute resolution fails, resorting to litigation becomes an option. However, legal proceedings can prove to be lengthy and costly while also causing strain on relationships among those involved in the project. Court hearings may delve into construction inefficiencies which requires careful documentation, support from experts and navigating complex construction law with adequate representation (Moffat and Irvin, 2020).

4. Mitigating Risk through Insurance.

Robust insurance coverage is crucial due to the legal consequences of construction inefficiencies. Construction experts often have different types of insurance, such as liability and professional indemnity insurances, along with performance bonds. Insurance acts as a critical measure for risk reduction by offering financial protection and legal assistance in case any conflicts or litigations arise from issues related to ineffectiveness during construction projects. The legal consequences of construction inefficiencies are complex and wide-ranging. They cover duties outlined in contracts, compliance with regulations, resolution of conflicts, and reducing risk exposure. Key players involved in construction projects need to work within this multifaceted legal framework by prioritising clear communication channels among all parties concerned while ensuring strict adherence to contractual terms.

Adopting effective practices that minimise risks along with leveraging insurance coverage when required can aid stakeholders mitigate potential litigation hazards. By acting proactively, such as promptly addressing areas where insufficiency exists, key players could lower their vulnerability from a liability perspective while preserving sound business relationships centered around an ethical foundation-leading ultimately towards successful project outcomes (Szewc., 2022). To prevent legal issues on the construction project, there are numerous actions one may undertake.

5. Familiarise with the Law.

Being well-versed in the law is a top-notch approach to steer clear of legal hassles. It entails keeping abreast with recent advancements in construction laws and seeking counsel from an attorney before initiating the project. This step could help thwart several potential litigations even before they occur (Szewc., 2022).

6. Obtain a contract.

To steer clear of legal issues, it is advisable to establish a contract that clearly delineates the duties and obligations of all parties engaged in the project. Additionally, such an agreement ought to detail how any disagreements will be resolved. Crafting a comprehensive contract can pre-emptively obviate numerous potential legal difficulties (Moffat and Irvin, 2020).

7 Purchase insurance.

To prevent legal issues, it is crucial to ensure adequate insurance coverage is available. This entails possessing both liability and workers' compensation insurance. In case of an error at the workplace, these policies can serve as a safeguard against any potential lawsuits filed against the project owner (Moffat and Irvin, 2020).

8. Adhere to Construction Regulations.

Local building codes are mandatory for all construction projects since they guarantee the safety of labourers and civilians alike. Failure to adhere strictly to these guidelines may result in substantial financial repercussions or a jail term. Furthermore, if an accident takes place at the worksite leading to injuries, the employer could be held responsible, especially when non-compliance with local building regulations is proven (Moffat and Irvin, 2020).

9. Rapidly Resolve Disagreements.

Speedy resolution of any arising disputes on a construction project is crucial to prevent them from escalating into legal proceedings. Lingering conflicts increase the likelihood of litigation; however, prompt dispute resolutions eliminate future potential lawsuits and mitigate lingering issues. Undertaking construction projects can prove to be intricate and hazardous. There exist various potential legal predicaments that may surface during the project's duration; nevertheless, several precautionary measures can curb such issues. Familiarising oneself with relevant laws, procuring a contract beforehand, and adhering to safety regulations are just three of many effective strategies in guaranteeing triumph for your construction venture (Moffat and Irvin, 2020).

2.9 Effect of Delays

Inefficiencies within construction projects can have far-reaching consequences and broader impacts that extend beyond the immediate timeline of the project. These consequences can affect various aspects of the project and the stakeholders involved. Here are some significant outcomes and broader impacts of inefficiencies in construction projects. Delays can be viewed as a symptom that can only be minimised or even avoided once the underlying causes have been identified and rectified. The success of any project relies on its ability to be completed on time, within budget, and with exceptional quality. Any disruption to the project's objectives puts it at risk of either finishing on time but exceeding the budget, or completing on time but with compromised quality. It is crucial to address project delays promptly and minimise their impact as they have adverse effects on the project's objectives (Aswin, 2022).

These delays can lead to work disruptions, decreased productivity, increased costs, compromised project quality, third-party claims, and even early termination of contracts due to client dissatisfaction. There are instances where delays result in disputes and claims. It has been proven that issues related to contractors and labour are often linked to delays and can lead to time and cost overruns, as well as disputes between the organisation and their contractors. It has been found that delays have six distinct effects on project objectives and delivery: time and cost overruns, arbitration, abandonment, litigation, and arbitration.

It has been determined that the occurrence of time and cost overruns can be attributed to inadequate material selection, limited material availability in the market, and the absence of a supervising engineer on site. To accurately estimate the duration of project activities, it is crucial to consider factors such as the actual skill levels, unforeseen events, efficiency, and productivity during work hours, as well as errors and misunderstandings. Delays have a detrimental impact on the productivity and quality of work carried out by contractors, leading to issues such as contractual disputes, decreased productivity, and an escalation in construction expenses (Santso and Soeng , 2016).

The following thirteen effects of delays have been identified in construction projects:

1. Time Overrun

Time overrun is a common consequence of delays in a project. There are various factors that can contribute to this, such as a lack of skilled and experienced employees and contractors. In such situations, the organisation must allocate additional time for training their employees. Instead of focusing solely on project advancement, time must now be dedicated to teaching and training employees for specific tasks. Another factor that leads to project time overruns is the need for reworking. This arises when there is a shortage of skilled workers within the organisation. Insufficient skills often result in errors or poor quality work, which then requires reworking. This additional task also diverts time away from project progression. Murali et al., (2007) argue that client interference is another contributing factor to time overruns. Having a client who frequently changes or adds to the agreed-upon designs is not ideal. This often necessitates redoing certain tasks to meet the new client specifications and may require retraining or training employees for tasks that were not originally planned (Santso and Soeng , 2016).

Moreover, it increases the risk of contractual disputes, further impeding project progression. Time overruns can also be attributed to issues related to materials, such as poor performance in the procurement department. It is crucial to have an efficient supply chain and ensure that the sourcing process is efficient when ordering authentic materials from reliable suppliers. The material should be ordered in the right quantity and quality. Additionally, long lead times can contribute to time overruns. The project manager must consider the lead time when ordering construction materials to avoid delays and interruptions in the project. Time overruns have been identified as one of the major consequences of delays, impacting project costs and quality directly (Apollo et al., 2018).

2. Cost Overrun

There are various elements that impact and influence cost overruns. According to Koushki et al., (2005), three primary causes of cost overruns have been identified. These causes include issues related to contractors, materials, and financial constraints faced by owners. To mitigate the risk of human error and reworking, it is crucial for organisations to select competent contractors. If contractors lack the necessary skills in their respective fields, the likelihood of reworking increases. This may result in demolishing substandard structures and rebuilding them to meet the required standards. Consequently, more materials need to be purchased, and better contractors must be hired. All of these factors contribute to cost overruns. Disputes with contractors are another contractor-related issue that can lead to cost overruns. Engaging in legal battles or settling lawsuits often incurs expenses that are not initially accounted for in the project budget. Accurate estimation of required materials by quantity surveyors or engineers is crucial for avoiding cost overruns. Poor estimates may result in excessive ordering of building materials that ultimately go unused (Santso and Soeng , 2016).

Additionally, in the construction industry, it is vital to select the appropriate grade or quality of building materials for specific tasks. A study conducted by Olanrewaju et al., (2022) revealed that the utilisation of poor quality building materials increased project costs by 50%. Poor quality materials can contribute to defects, reworking, and deviations, all of which require additional expenditures for correction. Overall, addressing these factors is essential to minimise cost overruns in construction projects. In some cases, clients may not pay the organisation on time, resulting in delays in the procurement stage. This situation may require the organisation to reallocate funds from other project activities to meet immediate needs. Additionally, the owner's financial constraints can also contribute to cost overruns. Assaf and Al-Hejji, (2006) identified several other factors that can lead to high cost overruns in a project, including high inflation, design changes, defective design, weather conditions, and delayed payments on contracts .

3. Disputes

Disagreements with contractors significantly impact project delays. These disputes not only require financial resources for resolution but also result in a decrease in employee morale, subsequently affecting their productivity. Consequently, this can lead to subpar performance and a decline in the quality of work delivered, ultimately increasing the likelihood of reworks. Delays can also arise from disputes related to clients. It is crucial to maintain a positive and constructive relationship with the client to ensure their satisfaction with the quality of work provided. The client possesses the authority to halt or even terminate the project until their expectations are met, resulting in further delays. The primary culprit behind these disputes is often a lack of communication and misunderstandings between the involved parties. It is imperative for the project manager to possess strong interpersonal skills and actively work towards minimising misunderstandings, conflicts, and disputes. Effective communication skills also play a vital role in the smooth progression of the project. The most common causes of disputes in construction include unforeseen site conditions, issues with neighbouring properties, delayed payments for completed work, improper construction methods leading to substandard structures, and discrepancies in contracts (Oshingade and Kruger, 2022).

4. Arbitration

It is crucial for the organisation to possess documented evidence of agreements made with clients, contractors, and suppliers. This serves to minimise conflicts and ensures that all parties concerned are fully informed and satisfied with the terms of the agreement before commencing any work. Various factors that contribute to the need for arbitration include changes in orders, discrepancies in the contract, and a lack of effective communication between the involved parties. Failure to resolve these disputes may result in the initiation of the arbitration process. To reach a fair resolution, the involvement of a neutral third party is necessary (Oshingade and Kruger, 2022).

This process can often span several months, during which the project is typically put on hold until a mutually agreeable solution is reached. Consequently, these delays can significantly impact the progress of the project.

5. Litigation

Litigation refers to the process of bringing a legal matter before a court when two parties are unable to reach a resolution through amicable means. In cases where disputes cannot be resolved through mutual agreement, the parties involved present their arguments and evidence to the court for a final judgment. Various factors can contribute to the initiation of litigation, such as changes in orders, discrepancies in contracts, and a lack of communication between the parties. This legal process serves as a last resort to settle disputes (Moffat and Irvin, 2020).

6. Total Abandonment

Abandonment, whether temporary or permanent, stands as the most crucial setback in construction. This occurrence typically arises from financial constraints or unresolved conflicts between involved parties. The primary factors contributing to abandonment can be attributed to the client, consultant, contractor, or external influences. Such inefficiencies in utilising valuable resources not only jeopardise the project's completion but also pose risks to the neighbouring community, as unfinished structures may lack quality (Oshingade and Kruger, 2022).

7. Quality Compromises

When inefficiencies result in hurried work, redoing tasks, or insufficient attention to detail, the immediate outcome is the compromise of construction quality. These shortcuts can lead to below-average craftsmanship, deviations from design specifications, and an overall decrease in standards. The broader consequences of compromised quality are significant. Substandard work may require extensive corrections, resulting in additional expenses and project delays (Oshingade and Kruger, 2022). Furthermore, it can give rise to warranty claims, negatively impacting the financial stability of the construction company. Most importantly, consistent lapses in quality can tarnish the company's reputation, erode client trust, and have long-term implications for its credibility in the industry.

8. Safety Concerns

Inadequacies that contribute to hazardous working conditions present an imminent danger to the welfare of construction workers. The probability of accidents and injuries escalates, thereby endangering human lives. The broader consequences extend beyond the immediate safety risks. Safety incidents can lead to legal obligations, subjecting the construction company to lawsuits and regulatory penalties. The burden of increased insurance premiums becomes a financial strain, and the firm's reputation for safety is compromised, potentially dissuading both clients and skilled workers from affiliating with the organisation (Oshingade and Kruger, 2022).

9. Reduced Productivity

Inadequacies that hinder the productivity of the workforce have an instant impact on the efficiency of projects. When labour and resources are not optimally utilised, it results in delays, which in turn affect timelines and escalate project expenses. Decreased productivity has a wider influence on the overall efficiency and competitiveness of construction companies in the market. Reduced productivity can undermine the firm's profitability, restricting its ability to compete for projects and limiting opportunities for growth (Agenbag and Amoah, 2021).

10. Environmental Impact

Inefficient construction practices contribute to increased resource consumption and inefficiencies generation, placing immediate stress on the environment. The broader environmental impact involves regulatory scrutiny and potential fines due to non-compliance with sustainability standards. Additionally, reputational damage may occur as clients and the public become increasingly conscious of environmental practices in construction (Rajendran et al., 2009).

11. Stakeholder Dissatisfaction

Inefficiencies leading to dissatisfaction among project stakeholders, including clients, investors, and regulatory bodies, create immediate tensions and strain relationships. Dissatisfied stakeholders can have lasting effects. They may withhold future contracts, negatively influence the construction firm's reputation, and damage relationships with the broader community. This dissatisfaction becomes a significant hurdle in securing repeat business and expanding the firm's client base (Oshingade and Kruger, 2022).

12. Negative Industry Perception

High-profile instances of construction inefficiencies contribute to a negative perception of the entire construction industry, affecting public opinion. A poor industry reputation has broader consequences. It can impact investment in construction projects, attract increased regulatory scrutiny, and deter skilled professionals from joining the construction sector. The industry as a whole may struggle to attract top talent and secure public trust (Oshingade and Kruger, 2022).

13. Innovation and Technology Adoption

Resistance to adopting efficient technologies and practices immediately impedes innovation in the construction industry. This resistance may stem from a reluctance to invest in new technologies or a lack of awareness about their benefits. The industry's broader impact involves lagging in competitiveness and missing out on opportunities for sustainable practices, digital advancements, and improved efficiency. This resistance hinders the sector from evolving with technological advancements, potentially relegating it to a less competitive position within the broader market. There are techniques that researchers have introduced to combat project delays and to try minimise delays as far as possible. In an ideal construction world, there are no delays and the entire project runs with no disruptions (Agenbag and Amoah , 2021).

In reality, however, there will be delays and unforeseen events that cannot be planned for ahead of time. It is important to have a contingency plan before the delays occur, this will minimise delays and ensure that they are resolved in a short amount of time. Controlling variability can avoid frequent occurrence of delays and may minimise time and cost overruns. The major reasons for the delays were determined to be due to designer modifications, user changes, weather, site problems, late delivery, economic constraints, and an increase in quantity. Delays have a substantial correlation with contractor failure and inefficient performance. Project delays are inevitable in construction projects, but identifying and investigating these types is crucial for minimising them and improving schedule performance (Agenbag and Amoah, 2021). Lean Six Sigma can be implemented to optimise the project lifecycle, including the DMAIC framework, one of the various frameworks comprising the Lean Six Sigma approach.

2.10 Lean Six Sigma

2.10.1 What is Lean Six Sigma.

Figure 17- The lean six sigma framework. (Cousins and Michael, 2017)

The DMAIC framework of Six Sigma, as seen in figure 17, serves as a guide for enhancing processes and problem-solving with the intention of achieving excellence in products and services. Through measurement, it gauges how far a process is from perfection while tracking defects present within that particular system. Employing methodologies such as DMAIC helps organisations eliminate flaws systematically to approach greater levels of perfection across their procedures, reducing variance while upholding quality standards essential to improve client contentment. Designed particularly for data-driven businesses committed to creating superior strategies through systematic analysis, DMAIC enables consistent enhancements throughout all organisational functions. Independent or interdependent scenario-specific SOP (Standard Operation Procedure) optimised operations make use of this model exclusively when optimal performance is publicised alone holds significant value beyond mainly incorporated initiatives found within Six Sigma approaches asserted altogether. Ration-like strengths and quality level gains remain fairly steadfast without compromising overall requirements. (Bravo et al., 2020).

For construction companies to bolster their competitive advantage, improving process efficiencies is a crucial undertaking. This can be accomplished by implementing a methodical and effectively managed strategy that optimises productivity while minimising deficiencies. Alwi et al. (2002) research highlights the issues of variability, non-value-adding activities, and inefficiencies in the construction industry stemming from an excessive focus on converting building materials into physical structures rather than optimising workflow. Lean Six Sigma offers statistical techniques solely geared towards increasing efficiency within processes. The initial step in the technique is Lean, which seeks to enhance process efficiency by reducing instability, inefficiencies and variation. While it does not place emphasis on improving client products directly, it optimises every aspect involved in delivering completed goods from a customer's standpoint whilst closely monitoring all activities relating to design through maintenance stages. These pursuits are collectively called value stream - an integral factor that improves cross-departmental flow resulting ultimately in enhanced productivity throughout operations (Aswin, 2022).

Achieving this optimisation objective necessitates three key elements: enhancing capacity reliability & responsiveness at each phase by integrating them into one continuous operation customised within particular parameters fostering client endorsement culminating even potentially with brand loyalty". The goal of Six Sigma is to enhance processes by decreasing variations. It's a structured framework that embodies quality as the ability to deliver products in line with customer expectations, and its emphasis lies on constructing an efficient process which factors in all aspects important for satisfying clients. When variability goes down, predictability improves resulting in fewer errors during production thereby improving efficiency overall. The ultimate objective being the implementation of an effective methodology capable of elevating construction qualities such that project output conforms precisely to client specifications without defects or inefficiencies present within it. Each technique can function independently. Lean methodology, for instance, is used to manage interactions between activities and reduce the effects of variation. To effectively employ this approach, it's crucial to closely monitor work progress levels while minimising any inconsistency caused by process disruptions. Better control over interruptions through effective planning strategies leads to a significant improvement in project advancement (Bravo et al., 2020).

Lean Six Sigma is a comprehensive approach that combines the benefits of lean and six-sigma methodologies to form a structured framework centred on diminishing process inefficiencies (lean), alongside defects and variations (six-sigma).

2.10.2 Lean in Construction.

Lean production principles have been adapted to create construction lean, a systematic approach for eliminating inefficiencies and addressing issues within the construction process. Construction lean is based on the T-F-V theory (Transformation-Flow-Value) which encompasses a set of complementary approaches used in managing project-based production systems. The transformation stage involves converting inputs into outputs, while flow refers to the smooth movement of work or value between teams, ultimately benefiting customers. The end result, known as value, is presented and delivered to clients. Transforming construction projects involves breaking them down into unit, sub divisional, and divisional works, following the commonly used transformation model in the industry. Construction encompasses a series of integrated activities aimed at transforming building materials, ideas, and plans into a tangible structure. Construction lean, a systematic technique derived from lean production principles, has been developed to eliminate inefficiencies and address challenges within the construction process (Al-Aomar, 2012).

It is built upon the T-F-V theory (Transformation-Flow-Value) which encompasses a complementary set of approaches for managing project-based production systems. The transformation stage involves converting inputs into outputs, while flow ensures the seamless movement of work or value between teams, ultimately benefiting customers. The end product, referred to as value, is presented and delivered to clients. Transforming construction projects involves breaking them down into unit, sub-divisional, and divisional works, following the commonly used transformation model in the industry. Construction involves a sequence of integrated activities aimed at transforming building materials, ideas, and plans into a realised structure. Lean construction thinking manages the construction process from three views:

1. Task
2. Value
3. Process

Dynamic project control prioritises the smooth flow of work and minimises inefficiencies to ensure optimal results in construction projects (Andony B., 2021).

Unlike traditional methods that only identify variances after they occur, this approach actively manages the project from start to finish. By involving all stakeholders in the planning and downstream processes through cross-functional teams, lean construction emphasises collaboration and coordination within its dynamic process-oriented organisational structure. This not only boosts employee enthusiasm but also enhances productivity. In contrast, traditional construction relies on hierarchical management structures and static departmental silos for organisation. Lean construction aims to fulfil both internal and external goals through value management, whereas traditional construction struggles to identify and meet customer expectations. Lean construction emphasises the importance of clients understanding the overall purpose and value of a project (Al-Aomar, 2012).

The philosophy of Lean construction promotes continuous learning and development, as well as a relentless pursuit of perfection. This is in contrast to traditional approaches that often lack training and development opportunities, resulting in a passive and reactive workforce. The primary goal of Lean construction is to generate value by eliminating waste and optimising cost targets, leading to increased efficiency and productivity throughout the entire construction system.

1. The Lean Construction Management Philosophy.

Lean construction is specifically designed for the benefit of owners, architects, designers, project managers, engineers, suppliers, and constructors. It combines operational research with practical development during the design and construction phase, while also incorporating principles from lean manufacturing methods. Ultimately, its main objective is to ensure that the final products meet customer expectations by implementing efficient processes that aim for timely delivery without unnecessary complications associated with building activities. The workflow of lean construction aims to establish a smooth and uninterrupted flow in every value-adding activity. This is made possible through two crucial components: resource flow and information flow. The process can be categorised as either controllable or uncontrollable (Andony B., 2021).

A flow is considered controllable when it involves overseeing both the materials and equipment used. This level of control is achievable through proper planning and allocation of resources, as well as supervision of their utilisation. On the other hand, resource supply information from suppliers and design details constitute an unregulated flow. A workflow that adheres to the principles of lean construction can be seen as a continuous, spatial-temporal movement of labour and equipment across various stages in the construction process (Al-Aomar, 2012).

2. Workflow Continuity.

The main goal of workflow continuity is to minimise the downtime that occurs between two processes in a given workflow. This not only reduces construction costs but also maximises the value for the client while mitigating any potential delays. When there is a consistent flow throughout each step of the project, the direction improves towards maximum profitability as inefficiencies decrease and activities with significant returns increase. This ultimately creates added value for the client's investment, meeting their expectations. By maintaining workflow continuity, workplace issues can be identified and addressed early on, preventing them from escalating into larger problems that could potentially delay the project. It allows for the swift identification of underlying causes, leading to the prompt resolution of any complications that may arise. This promotes ongoing improvement in employee productivity and job training practices, fostering an environment that encourages continuous improvement within the organisation. It also raises work standards among management personnel, ultimately enhancing team spirit and the quality of performance throughout the execution phases. However, traditional construction projects tend to prioritise the development of construction technologies that only enhance productivity for value-added activities. This approach limits opportunities for progress, as it fails to address the entire value flow. By enhancing continuous workflow, there is potential for improvement in non-value-added activities as well (CMIC, 2023).

3. Loss during the Project Progression.

The construction process is riddled with uncertainties and unforeseen events that frequently disrupt the flow. The unreliability of tasks during project preparation prompts delays once work begins, slowing down post-construction activities as well. This can result in losses for all involved parties. The preparation phase of a project involves several steps that could potentially lead to delays. Prior to construction, factors such as material and equipment delivery, weather conditions on site, labour productivity level and the availability of funds are all considered significant in delaying or expediting progress . Any delay encountered not only leads to increased time wastage but may also negatively impact employee morale by causing conflicts between team members. This situation often results into hazardous working environments whilst compromising work efficiency levels overall (Al-Aomar, 2012).

4. Value Stream Map (VSM).

The methodology of lean comprises numerous tools aimed at detecting seven categories of inefficiencies present in a process. One such tool is the value stream map, or VSM, which employs a methodical approach to delineate the flow of both material and information throughout all activities required for project fulfilment. This technique presents an encompassing view of each step involved while pinpointing any inadequacies within the value stream.

During the mapping out of the value stream, the following key elements are important:

1. Process Steps:

The VSM depicts every step that is involved in the process. It includes the value-added and non-value-added activities. It also shows the process statistics such as the cycle time, the amount of inventory and pieces, as well as the number of operators (Al-Aomar, 2012).

2. Inventory

The Value Stream Map is also a depiction of inventory management as it highlights the storage, quantity, usage, and movement of inventory within the process (Chua, 2019).

3. Information Flow

The value stream map also illustrates information that is necessary to keep the process efficient. This includes time schedules, project specifications and material orders (Al-Aomar, 2012).

4. Cycle Time

This is defined as the time it takes to complete one cycle of the operation or one step within the construction process. The VSM also indicates this to give an idea of how long each step in the value stream takes.

5. Work in Process (WIP)

This is a type of inventory which is still in progress. This type of inventory is not the finished product nor is it the unprocessed product. In terms of construction, this would be a project that has commenced but still needs a few steps for it to be completed. This is also shown on the value stream map (Al-Aomar, 2012).

All these steps are put together and applied in construction.

2.10.3 Applying Lean Six Sigma for Inefficiency Identification

Construction can benefit from the implementation of Lean Six Sigma methodologies. To decrease non-value-added activities, businesses utilise lean tools and strategies. Value Stream Mapping (VSM) was employed to examine all sources of inefficiency including excess inventories and delays; however, the root causes behind suggested solutions were not identified. Another research project implemented Lean construction methods where poorly managed production processes led to major construction inefficiencies; a VSM was developed as a means of scrutinising and restructuring these systems to recognise and control such ineffectiveness (Swami, 2020).

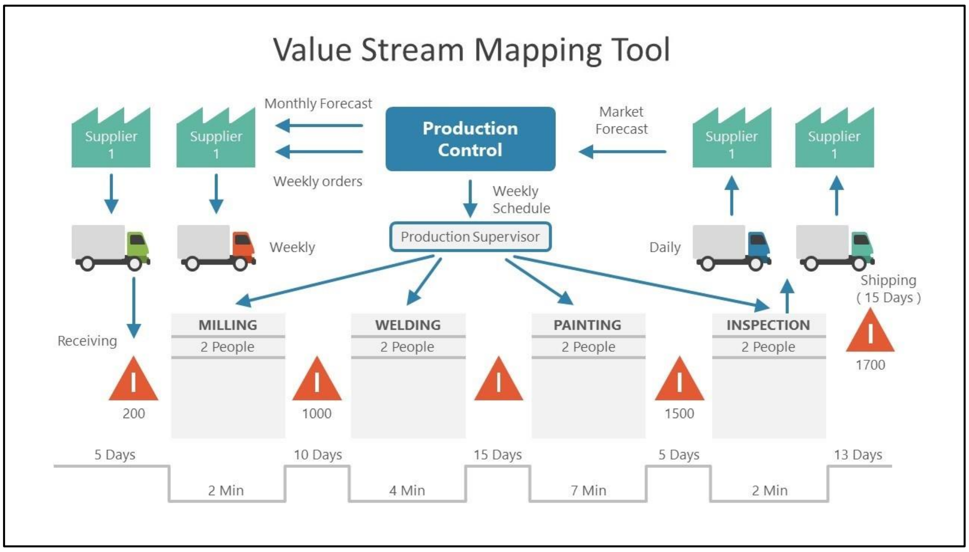

Figure 18- Example of a Value Stream Map (Garcia and Marco, 2014).

The value stream map, presented in figure 18, is an essential tool in minimising inefficiencies during the diagnosis stage. It enables pinpointing non-value adding activities and establishes decision-making processes accordingly. Outlining all information necessary to meet customer specifications, facilitates developing a comprehensive Lean system while highlighting macro-level issues like supply chain or project delivery deficiencies. Despite its efficiency-identifying ability, this mapping technique only diagnoses construction parameters without further analysis nor process improvement capabilities, making it crucial solely for initial identification purposes of said problems (Garcia and Marco , 2014).

2.10.4 Six-Sigma Methodology

Utilising statistical methods and a scientific approach, Six Sigma is a systematic and structured methodology that facilitates strategic process enhancement as well as new product or service development to significantly reduce inefficiencies and defect rates. In 1985, Smith created the Six-Sigma methodology to attain high levels of product manufacturing quality. This approach relies on a range of statistical and process-focused techniques such as structured approaches, value stream mapping and process mapping that work together to resolve variability in business processes like production challenges. The distinctiveness of the six-sigma approach lies in its emphasis on minimising defect rates. Due to inherent process variability and randomness, high defect frequencies often occur. Techniques within Six-Sigma work towards identifying and limiting that variability so that defects can be minimised. Additionally, this methodology recognises a noteworthy link between project defects, inefficient processes identified therein, and overall client satisfaction levels (Tehrani , 2010).

To tackle inefficiencies in construction projects using Six Sigma principles, the emphasis lies on enhancing process efficiency and minimising defects. To uncover any inefficiencies within a construction project, it is essential to first establish the objectives and measurable performance indicators related to time management, cost control, quality assurance, and safety compliance. Next, it is essential to closely examine areas that pose concerns such as scheduling delays or budget restrictions while also assessing instances of unsatisfactory workmanship impacting final product levels (Cousins and Michael , 2017).

2.11 In-depth Study of DMAIC to Minimise Inefficiencies

1. Define

This involves defining and understanding the issue at hand. This is done by understanding the client's requirements and the key factors that affect the process output. This is the problem or opportunity for improvement, the project goals, and client requirements. In this phase, the significant activities that are involved are the following, according to (Nowotarski et al., 2019):

1. Team Charter Development.

   This entails the business case, problem and goal statement, project scope, milestones, and roles.

2. Client Focus.
3. The client conveys their concerns, which are then translated into specific requirements and criteria.
4. Value Stream Mapping (VSM).

First, the process is defined and connected to the customers' requirements. Business process mapping is conducted for the existing process to identify the benefits and application of process mapping.

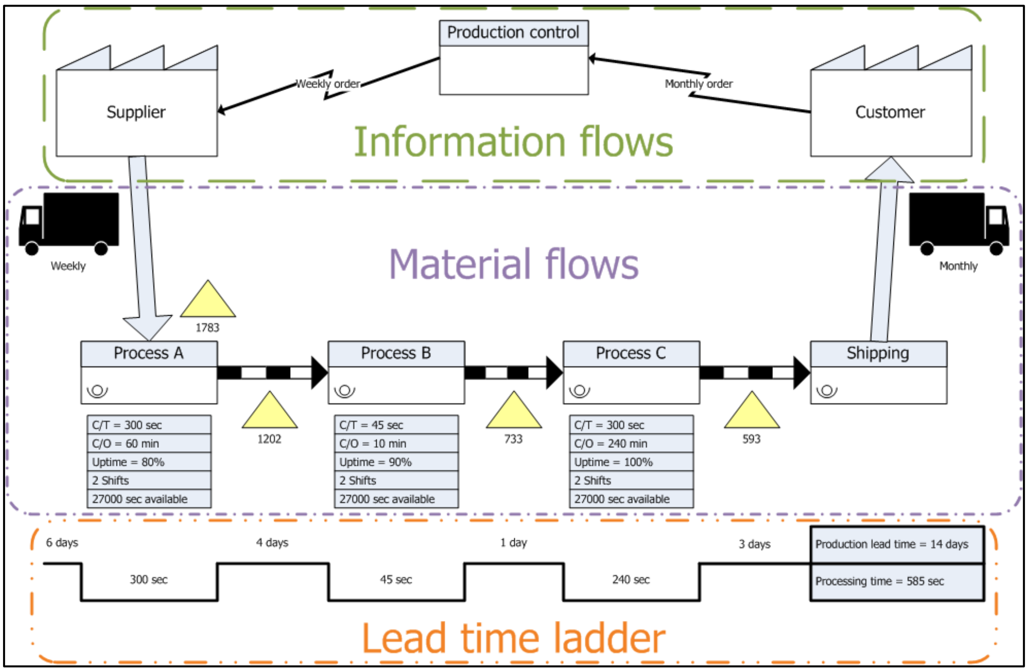

Figure 19-Value Stream Map for Process Mapping. (Dogan, 2019)

The VSM representation in Figure 19 provides a comprehensive overview of both value and non-value-added activities, along with essential process statistics such as cycle time, inventory quantity and movement, and number of operators involved. Additionally, the depiction also highlights crucial aspects like inventory management by showcasing storage utilisation rates and usage patterns. By encapsulating this vital information through its visualisation technique effectively; it enables better tracking to ensure maximum efficiency outcomes are achieved across every step within the production flowchart. One common tool used in developing lean systems is Value Stream Mapping (VSM). As noted by Javkhekar (2006), VSM aims an entire system while focusing on macro-level processes like supply chain management or delivering projects. It can identify potential inefficiencies during this mapping exercise but does not provide solutions (Swami, 2020).

Emphasises that using VSM helps diagnose issues with any given stage of implementation for building work but cannot improve processes without additional analytical tools or strategies beyond its scope.

2. Measure

This step makes use of the Six Sigma metrics to measure and attain the relevant data to the problem. The tasks involved in this phase include a clear definition of performance standards and specification limits; development of a data collection system and verification as well as validation of the measuring system. This phase of the DMAIC framework aims to quantify the extent of the problem. Statistical Process Control Charts are tools that are often used to determine if a process is in a state of statistical control and measure how far from perfect the process is. It measures the variation in a process and how the process changes over time (Van den Bos et al., 2014).

Control charts are used in the following instances:

1. During problem identification and correcting the problems as they occur.
2. To determine if a process is stable or not.
3. During the analysis of patterns of process variation from non-routine events or common causes.
4. When determining to either prevent problems or make fundamental changes to the process during quality improvement.

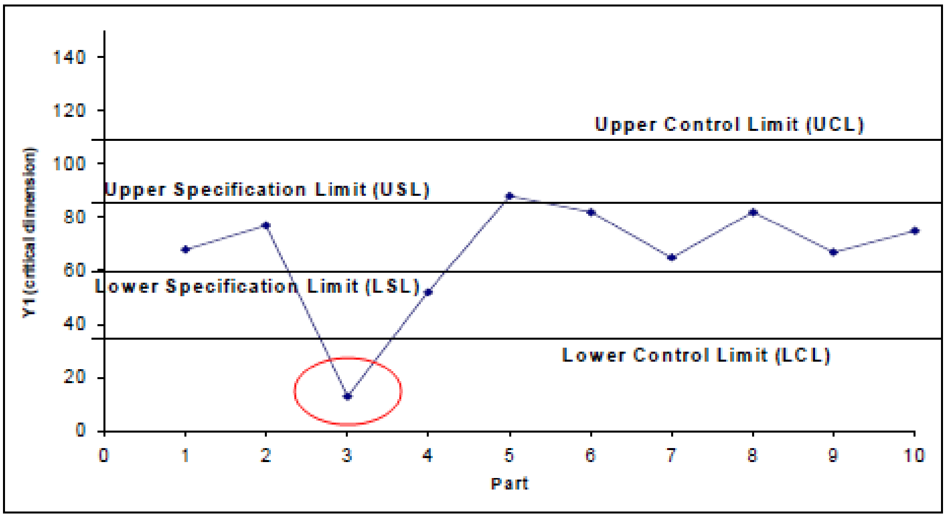

Figure 20- Control chart for a process that is out of control (Abdelhamid, 2021).

The control chart depicted in Figure 20 serves as a statistical tool to distinguish between common cause variation and special cause variation. The Upper and Lower

Control Limits (UCL and LCL), displayed in Figure 20, are determined based on the process mean, the process range (identified as 3 σ), and the standard deviation of the measured data. By analysing the position of the data points in relation to the control limits, we can determine whether the process is in statistical control or not. If the measured data falls within the control limits (UCL and LCL), it indicates that the process is under statistical control (Maryam and Tehrani, 2010).

On the other hand, if the measured data points fall outside of these limits, it suggests the presence of special cause variation. Conversely, data points that fall within the control limits indicate common cause variation, which is an inherent part of the process. In the case of the illustrated process figure 20, it is evident that the data points are outside the control limits, leading to the conclusion that the process is out of statistical control. Specifically, the data point represented by the red circle falls below the lower control limit, indicating the presence of special cause variation. It is crucial to investigate the cause of this variation and implement appropriate measures to eliminate it. The Upper and Lower control limits play a vital role in monitoring and tracking special cause variation (Maryam and Tehrani, 2010).

3. Analyse

This step uses statistical quality control techniques to analyse the production and process from which the issue stems. This assists in identifying the root causes of the problem. The collected data is then reviewed, and the root causes of the defects are then identified. The following are involved in this phase, (Kanbanize, 2023):

1. The value of each process step is examined.
2. The collected data must be inspected and transformed into graphs for visualisation.
3. Issues that cause the problem must be brainstormed using the fishbone technique.

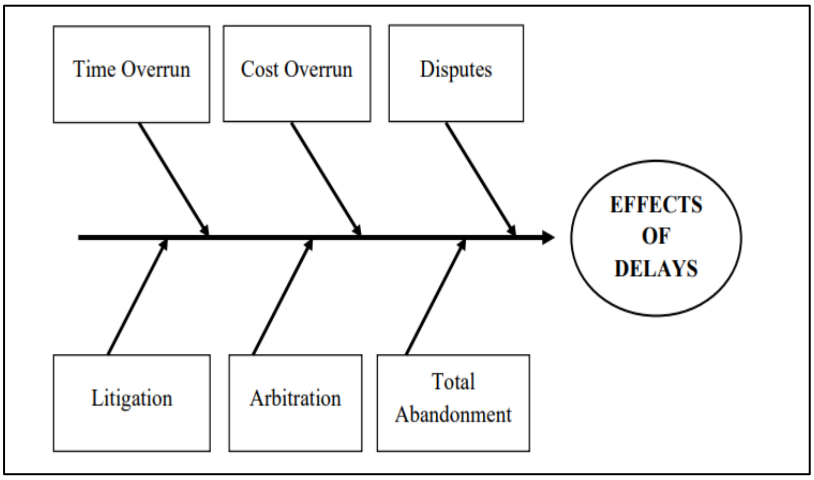

Figure 21- Effects of delays on a project (Assaf, 2006)

Figure 21 depicts a diagram that is employed to classify delays and ascertain their impacts. Previous research has demonstrated that implementing lean techniques to reduce costs can result in savings of up to 25% compared to the conventional project management approach. A cause-and-effect diagram, also known as a fishbone diagram, primarily focuses on brainstorming potential causes of problems and categorising them into relevant groups such as methods, machines, people, materials, measurements, and environments. It is utilised to identify the reasons behind defects and determine why a process is imperfect or variable. This diagram aids in breaking down the root causes that may influence an effect. The "fish" head represents the underlying problem, while the branches list the possible causes. All potential causes must be brainstormed and listed to determine the root cause of the problem (Kanbanize, 2023).

Factor analysis is another statistical technique that can be employed to analyse the relationships between numerous variables and identify the underlying factors that may better define patterns in the data. Its primary objective is to simplify and comprehend complex data by reducing the number of variables without altering the information's meaning. According to (Taffazolli and Shrestha, 2017), the analysis operates in the following manner:

1. Data Collection:

   In this phase, data from the multiple variables is collected, which could include measurements, survey responses, or observations.

2. Correlation Matrix:

   This matrix is created to examine the relation between all pairs of variables. It also shows the degree of correlation with every other variable in the dataset. In this case, the Kaiser Meyer Olkin test is conducted, and its value represents the ratio of the squared correlation between variables to the squared partial correlation between variables. These values vary between 0 and 1. The closer the value is to 1, the stronger the correlation. It can then be concluded that the factor analysis should give distinct and reliable results. However, a value of 0.5 is accepted as the minimum.

3. Factor Extraction:

   This phase aims to identify the underlying factors or dimensions that explain the observed correlations among variables. The identification of these variables is inferred from the pattern of the data collected. The most popular methods of factor extraction include the Principle Component Analysis (PCA) and the Principal Axis Factoring (PAF).

4. Factor Rotation:

   This technique is applied to simplify and interpret the factors further. This helps to make the factors more interpretable and aligns them with the underlying theoretical constructs. The common method for this is the Varimax and Oblique rotations.
5. Interpretation:

   In this step, the factors, i.e. the combination of highly correlated variables, are then interpreted in the study context. The factors highly correlated to each other are believed to measure a common underlying theme/problem.

6. Reporting and Utilisation:

   The factor analysis results are then reported, and decisions can be made.

The basis of this analysis is to simplify complex datasets, uncover hidden patterns, and provide insights into the underlying structure of the data. It is best suited for dimension reduction, identifying key factors that cause and worsen variation in the data. All these factors simplify the interpretation of relationships among variables. In the above explanation, one can see that the factor analysis indicates factors that correlate. However, the reliability test can also be conducted to ensure that the factors determined from the model stay consistent over time. This can be done by conducting the Cronbach's Alpha test. The value of the Cronbach's Alpha test can also range from 0 and 1, where one denotes the most consistency. According to (Taffazolli and Shrestha, 2017), the C_{α} values indicate the following:

Table 1-The interpretation of the Cronbach's Alpha values (Taffazolli and Shrestha, 2017),

C_{α} **Range Values**	**Relatedness**
C_{α} > 0.9	Excellent
0.9 > $C_{\alpha} > 0.8$	Good
0.8> $C_{\alpha} > 0.7$	Acceptable
0.7> $C_{\alpha} > 0.6$	Questionable
0.6 > $C_{\alpha} > 0.5$	Poor
0.5> C_{α}	Unacceptable

The Toyota Production System relies on the "5 Whys" technique as a vital problem-solving approach to uncover the underlying causes of delays. This method involves repeatedly asking "Why" five times when confronted with a problem, enabling a deeper understanding and resolution. To effectively implement this technique, it is essential to assemble a cross-functional team comprising individuals from various departments who possess a deep understanding of the issue at hand. The problem must be thoroughly examined from multiple perspectives, and the team leaders should base their "Why" questions on factual data rather than subjective opinions. These questions should encompass the problem itself, its root cause, its frequency of occurrence, the rationale behind the answers, and the motivations behind each question. Subsequently, the team should pinpoint and address the root cause, implementing corrective measures during the improvement phase to safeguard the process against recurring issues (Kanbanize, 2023).

Following a designated period, the impact of the solution should be monitored, and if no positive outcomes are observed, the technique should be reapplied, and the process meticulously documented.

4. **Improve**

This step entails exploring alternative methods to those identified during the analysis stage. Potential solutions are devised, and the simplest solution is selected after identifying the root cause of the problem in the analysis stage. The solution is then presented to the project stakeholders. Process maps are created for the new solution, and a high-level plan is developed for the pilot solution. The final solution is implemented, and its benefits are evaluated. Once the most significant factor is determined in the analysis stage, a solution is formulated and put into action. Table 1 provides an interpretation of Cronbach's Alpha values (Taffazolli and Shrestha, 2017).

Once the degree of correlation is determined, factors with a strong relationship can be addressed and minimised using models like the Economic Order Quantity (EOQ) model. This model has the ability to predict the optimal quantity and timing for inventory orders. Ordering inventory at the right time reduces the risk of project delays caused by long lead times and delayed order placement. The EOQ model aims to order sufficient inventory at the lowest possible cost. This equation can be further manipulated to determine the best time to place such an order. The general equation is:

$$EOQ = \sqrt{\frac{2DS}{H}} \quad (1)$$

Equation (1) takes into account the demand (D), which can be interpreted as the rate at which certain material are used in construction; the ordering costs (S), which include shipping; and lastly, the holding costs (H) (Çalışkan., 2022).

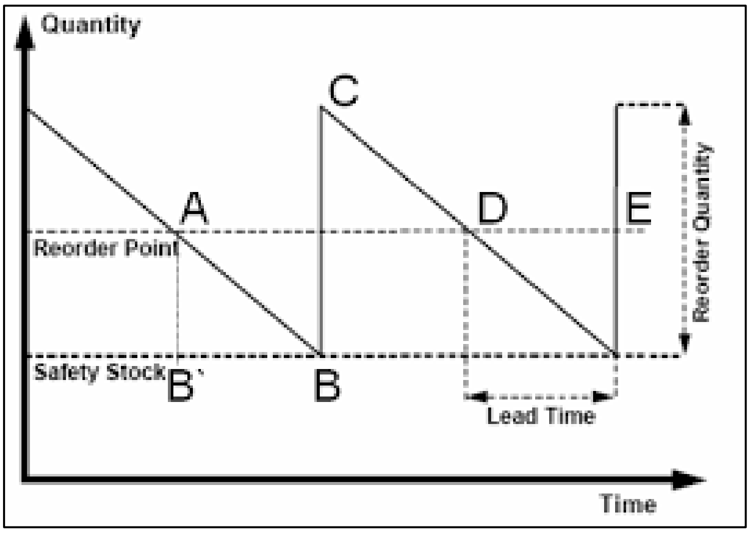

Figure 22- EOQ graph showing the reorder point (Chua, 2019).

The reorder point is shown in Figure 22. Its equation is presented below:

Reorder point = Daily usage* Lead time (in days)   (2)

From equation (2), the lead time is isolated and optimised using differential equations (Chua, 2019). If this solution is found to be sustainable, it is controlled and monitored .

5. Control

The final phase involves supervising and controlling modifications implemented to resolve the issue. Statistical process control techniques are employed to maintain progress, as leaders strive to establish measurable metrics that facilitate continuous monitoring of success. During this stage, adjustments can be made while seeking improvement. In the realm of construction projects, the DMAIC framework has been utilised to enhance the construction culture in Egypt; it has also been reported that productivity has increased as a result of implementing the DMAIC Framework. Ultimately, a regulated system is established to ensure consistent performance over time by utilising interactive forecasting dashboards or job planning software, among other tools designed to remotely track project advancements with real-time accuracy (Dubey and Yadav , 2016).

2.12 Strategies for Implementing Construction Projects

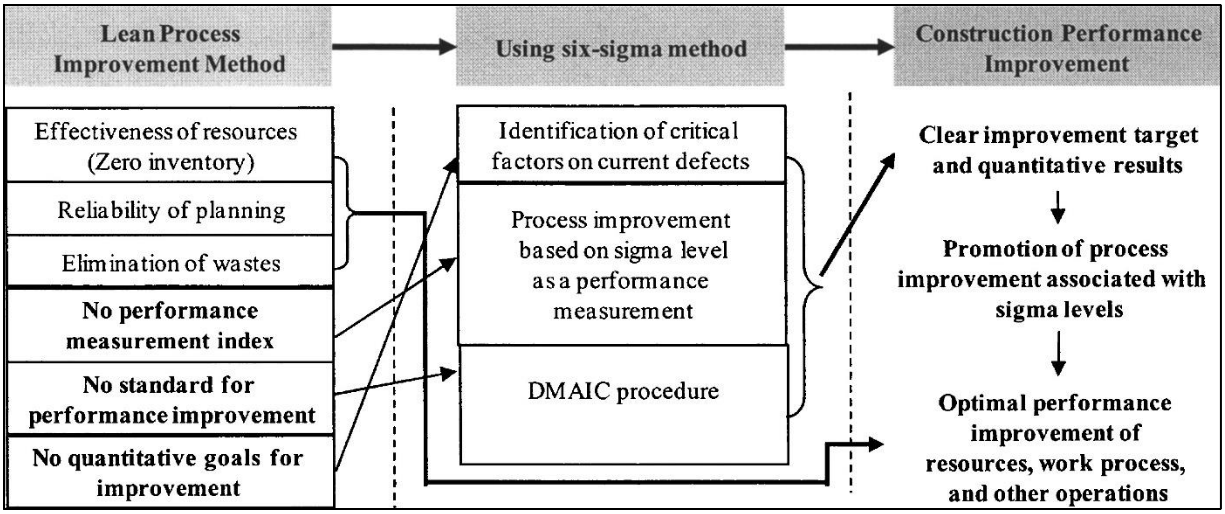

Figure 23- Guideline to using DMAIC in construction (Han et al., 2008).

Figure 23 gives a guide on how to apply DMAIC in construction. Teams with members from different departments or areas of expertise work together towards a common goal. Assemble cross-disciplinary groups consisting of experts in construction, project management, engineering and related fields. This collaborative tactic guarantees a holistic perception of complications while encouraging efficient resolution achievement. The following strategies are applied according to (Abdelhamid, 2017):

1. Integration of Technology:

Employ construction management software, Building Information Modelling (BIM), and other technological tools to simplify project communication, cooperation, and data supervision. The fusion of technology heightens precision and productivity in the compilation and evaluation of information (Suermann and Raja , 2009). Management of Risks: Incorporate risk management procedures into the DMAIC framework to pre-emptively mitigate potential risks that could arise from suggested enhancements. Establish methods of action plans to counteract the identified risks.

2. Culture of Continuous Improvement:

Create an environment where the construction organisation emphasises ongoing development. Motivate team members to engage in identifying and resolving inadequacies, and acknowledge accomplishments made possible by implementing DMAIC methods (Abdelhamid, 2017).

3. Education and Proficiency Enhancement:

Consider investing in training initiatives that aim to augment the expertise of construction professionals. Such programs should incorporate teachings on modern technologies, statistical analytical tools, and cultivating a disposition for ongoing betterment. Construction teams can systematically address inefficiencies, enhance project performance and contribute to the success of construction endeavours by customising DMAIC methodology according to specific challenges. The adaptability of this approach enables professionals in the construction industry to navigate complexities and achieve continuous improvement (Abdelhamid, 2017).

2.13 Project Management Strategies for Inefficiency Reduction

The sigma symbol (σ) is widely used in statistics to represent the standard deviation, which provides insight into how far the data set deviates from the mean. In the realm of Six-Sigma, the term "Sigma" refers to a metric that assesses a process's ability to produce outputs within the specified limits set by the client. Variability within a process necessitates the use of statistical methods to control and monitor quality and efficiency, as well as reduce defect rates. According to Deming (1986), "Statistical Control does not imply absence of defective items. It is a state of random variation, in which the limits of variation are predictable". There are two types of variation: common cause variation and special cause variation. Common cause variation arises from random sources such as natural problems or noise, and it is inherent in the system. Addressing this type of variation requires significant changes to the process and operating procedures. On the other hand, special cause variation stems from controllable sources like unexpected glitches that disrupt the process (Maryam, 2010).

It typically demands attention and correction to restore process efficiency. Understanding the distinction between these variations is crucial when addressing quality issues. Deming (1986) recommends addressing special cause variation and restoring normal operation before tackling common cause variation.

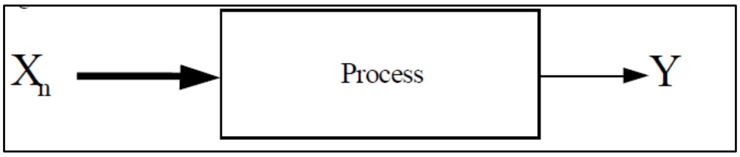

Figure 24- Illustration of a variable process (Maryam, 2010).

Figure 24 shows a process with X_n inputs and the outputs as Y. This is a variable process which will yield a variable Y output. Assuming the output, Y, follows a normal distribution with the mean value as the ideal value (Maryam, 2010).

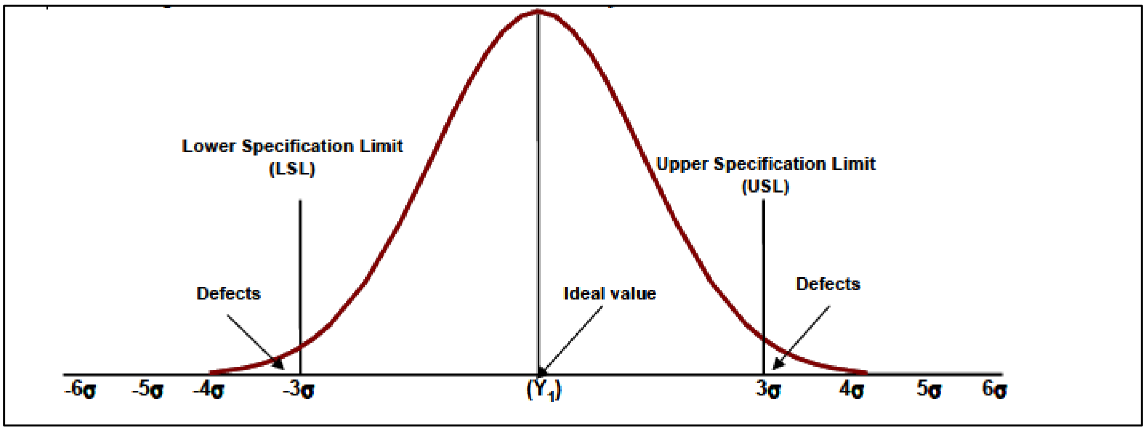

Figure 25- Distribution Curve (Maryam, 2010).

Figure 25 shows a normal distribution using 3 σ as the lower specification limit and upper specification limit. These would be the specification limits that are chosen by the client. Figure 25 forms the foundation of control charts. These are charts that indicate when a process is outside of the control limits (Maryam, 2010).

1. Work Planning and Scheduling

In 1996, Ballard introduced the Last Planner approach, which utilises lean principles to optimise value for clients and minimise inefficiencies during a project. This method emphasises planning at the task level or short-term schedule, connecting high-level project schedules with daily execution requirements. The implementation of the Last Planner method is a proactive strategy that provides advanced information for efficient control. By identifying potential problems during the planning stage, this approach enhances project coordination and promotes seamless workflow development. A reliable workflow system is crucial as it simultaneously improves timeliness, cost-effectiveness, quality, and safety within the overall context of a project. Insufficient unity and coordination within a team lead to decreased efficiency, increased disagreements among members, as well as delays and higher expenses. Consequently, these factors exacerbate project obstacles. To avoid wasting time due to working in isolation, it is essential to ensure that all project team members are well-informed about shared objectives. Lack of coordination and consensus on goals can result in misunderstandings or neglect of overall targets (PlanRadar., 2023).

In 2003, Barcala et al. proposed an information model to integrate various construction phases and enhance collaboration among stakeholders. With the continuous advancements in Information Technology (IT) and Communication tools, improving the conveyance of data among workers can effectively elevate integration levels for different aspects of a construction project process. The pull system is responsible for pulling the upstream material and the current project progress on-site to align with the planned or budgeted work progress on-site. It serves as a crucial tool that enables and ensures a seamless flow of work (PlanRadar., 2023).

2.14 Importance and Cost-Benefit of Implementing Six-Sigma

There are several reasons why it is important and valuable to implement the six sigma methodology in construction projects. The reasons are as follows, through its detailed methodology of error detection and correction, Six Sigma serves as a formidable framework for raising the quality standards within construction projects. Given that such endeavours are inherently multifaceted with an array of stakeholders and intricate processes involved, by providing structural guidance on how to minimise discrepancies - meticulously identifying them along with remedying any issues found – it succeeds in significantly reducing incidents of errors or workplace injuries while also lowering costs associated thereof (Aswin, 2022).

Ultimately then, with this transformative impact evident through better alignment between pre-existing expectations, its rigorous approach ultimately results in marked improvements reflected throughout all aspects pertaining towards delivery concerning superior workmanship as well as ensuring satisfaction from clients alike. The construction industry depends on efficient time management, which is where Six Sigma comes in. By taking a methodical approach to project assembly and fixing any hindrances that may arise, it aims to optimise processes and remove obstacles. Through streamlining procedures and eliminating bottlenecks, the goal of Six Sigma is crystal clear: improving delivery times for construction ventures significantly. This methodology's emphasis on data-based decision-making ensures adherence to deadlines at all stages while optimising the entire process - leading stakeholders towards better outcomes overall as an added benefit too (Apollo et al., 2018).

The implementation of Six Sigma in construction projects may lead to *cost reduction*, albeit not explicitly stated. This is because the emphasis on precision and efficiency inherent in this methodology contributes significantly to enhanced cost-effectiveness through minimising delays, curbing rework, mitigating errors and optimising processes. By streamlining operations for improved quality control and time management, Six Sigma paves the way for tangible financial savings without making it a primary focus within the construction realm. The fundamental principle behind Six Sigma is to enhance *process optimisation* in construction projects systematically, employing data-driven techniques. It strives for precision through detailed analysis of information and identification of primary improvement areas, ultimately decreasing errors and variations. This methodology serves as a reference framework for the teams involved in construction processes desiring streamlining their functions while improving efficiency across various stages of project execution by minimising unwanted deviations with an overall growth in workflow management; thus contributing to constructing leaner pathways that efficiently lead towards achieving success goals (Aswin, 2022).

The top priority of Six Sigma is *satisfying customers* by pinpointing and enhancing essential quality characteristics in construction projects. By aligning project outcomes with clients' particular demands and expectations, Six Sigma actively elevates customer satisfaction levels. The methodology's obligation to lowering flaws and ensuring excellence corresponds directly with client concerns. Through applying the principles of Six Sigma, not only do construction projects meet but surpass customer anticipations, fostering more durable client connections while boosting the overall image of the building company (Aswin, 2022).

To summarise, the aims mentioned encapsulate Six Sigma's general objectives and seamlessly incorporate with the complexities of construction projects. The methodology targets better process improvements, defect reductions, and overall efficiency enhancements in perfect alignment with diverse challenges unique to the industry. It presents a structured approach towards achieving project delivery excellence.

2.14.1 Cost-Benefit

The construction sector encounters distinct obstacles, such as intricate projects, stringent schedules and financial constraints. Lean Six Sigma represents a methodology that emphasises process enhancement and inefficiencies reduction to address these challenges satisfactorily. Through this essay's analysis of the economic implications involved in implementing Lean Six Sigma within construction, it evaluates the initial expenses against future cost-savings prospects. Investment at the start. To incorporate Lean Six Sigma into the construction industry, a significant initial investment is required. This encompasses costs associated with training personnel at different levels, procuring and implementing technological solutions, as well as restructuring current processes. The introduction of programs to inculcate Lean Six Sigma principles throughout the workforce necessitates both financial commitment and time. Additionally, it's essential to invest in data analytics tools and software for efficient project monitoring and decision-making purposes. While some construction firms may face difficulty regarding these upfront expenses; nevertheless they are imperative prerequisites for benefiting from this methodology over an extended period of time (Aswin, 2022).

The adoption of Lean Six Sigma in construction brings about various long-term economic benefits, which are manifold. A key among them is the elimination of operational inefficiencies and inefficiencies. By employing a systematic approach, Lean

Six Sigma detects and removes unnecessary steps and redundancies to achieve streamlined processes that boost productivity levels significantly. This enhanced efficiency leads to substantial cost savings over time arising from minimised labour expenses as well as optimised utilisation of resources. In addition, the methodology prioritises quality management which leads to a decrease in defects and mistakes during construction projects. This decline in repetitive work and related expenditures plays a key role in achieving cost savings over time. By delivering timely and defect-free project completion, customers are more inclined towards contentment ultimately resulting in recurring business opportunities and favorable recommendations through word-of-mouth marketing strategy (Andony B., 2021).

Construction risk management receives proactive attention through Lean Six Sigma, which identifies and resolves potential issues before they escalate. By adopting a preventive stance, this approach reduces the chances of expensive disputes or delays while safeguarding valuable resources and time. Additionally, the continuous progress culture fostered by Lean Six Sigma promotes innovation and flexibility within construction firms to help withstand changing market conditions with greater resilience. A cost-benefit analysis was conducted in a study to correct defects that were detected and find their causes (Aswin, 2022).

Table 2- Defects and causes of construction inefficiencies discovered in a study conducted by (Aswin, 2022).

S.No.	Defects	Causes
1	Scaling and Honeycomb	No rigid and water tight formwork
		Improper compaction and vibration on concrete
2	Dampness	Inaccurate moisture level check and water proofing
3	Corrosion of Reinforced steel	Inadequate concrete clear cover
4	Damage of exterior surface	Insufficient curing of concrete
5	Peeling Paints	Improper cleaning and priming
		Inaccurate water proofing
6	Spalling and Chipping	Inadequate concrete clear cover

The cost-benefit analysis was conducted, shown in table 2. It determines whether the application of DMAIC as an option to rectify the issues was feasible or not. This study proved that applying DMAIC for such a project was the most cost-effective and high-value method. To sum up, the economic impact of implementing Lean Six Sigma in construction necessitates weighing both initial expenses and long-term benefits. Despite seemingly high upfront costs, embracing this methodology can increase efficiency, minimise errors and elevate project standards, making it a wise investment for lasting triumphs (Aswin, 2022).

Construction companies that choose to incorporate Lean Six Sigma not only enjoy significant cost reductions via optimised practices but also reap advantages such as satisfied clients and a resilient corporate culture. Ultimately, benefiting from sustained financial gains reinforces the value of using this approach when facing construction industry challenges. Finally, the use of Lean Six Sigma in construction projects has the possibility of transformative advantages, providing a strategic route for reducing inefficiencies and improving overall project performance. Lean Six Sigma's structured methodology, which includes both Lean concepts and Six Sigma technologies, provides a complete approach to identifying, analysing, and methodically addressing inefficiencies across the building project lifecycle (Dubey and Yadav , 2016).

2.15 Preferred Solutions

Lean six sigma is preferred as a solution that addresses the issues presented in this dissertation. The lean six sigma framework possesses the ability to identify inefficiencies within the construction project using techniques such as the value stream mapping. Furthermore, it also quantifies the extent of these inefficiencies by means of variation calculations. The identified issues are then analysed and ranked using techniques such as the fishbone analysis, which is able to categorise and organise each issue. Factor analysis is chosen to determine the factor impacting project inefficiencies the most. The EOQ model is chosen as one of the solutions.

Although this model belongs to inventory management, it can also be useful in determining the optimum order quantity and order time. This attempts to reduce the impact of the factor determined through factor analysis. All these chosen techniques work together to form a sustainable model that address the issues presented in the problem statement.

2.16 Chapter Summary

This chapter examines the benefits and obstacles of applying Lean Six Sigma in the construction sector. It investigates the elements that influence building process efficiency, as well as frequent issues faced throughout construction projects. By stressing project management tactics as the foundation for a tailored framework, Lean Six Sigma makes it easier to identify flaws and optimise processes, resulting in fewer errors, workplace accidents, and expenditures. The construction industry is implementing innovative technologies like Building Information Modeling (BIM) and improved project management software to reduce inefficiencies. Strategies include improving procurement techniques, collaborating with regulatory authorities, and utilizing digital solutions. A systematic overhaul is needed to promote efficiency in the industry.

Chapter 3

Research Methodology

3.0 Chapter Overview

This chapter provides a comprehensive overview of the methodology employed in conducting the dissertation. It encompasses both the conceptual and theoretical framework, which serves as a guiding map for readers to navigate through the application of the DMAIC methodology in the project. Additionally, it presents a proposed solution that aims to minimise inefficiencies in the construction project process. The initial section of this chapter features a schematic representation of the research methodology and design. The purpose of this schematic is to visually demonstrate the application of the DMAIC framework in the construction project and establish a connection with the EOQ model for process optimisation. Subsequently, the chapter delves into theoretical explanations to elucidate the suggested solution and its functioning. The theoretical framework encompasses a narrative explanation of how the DMAIC framework, adapted from existing literature, is tailored to address the research problem outlined in chapter 1. It utilises the DMAIC framework to define, analyse, and interpret the gathered data to effectively solve the problem. Additionally, it incorporates the EOQ model, which aims to tackle the primary factor contributing to inefficiencies in the construction process. In essence, this chapter combines data collection and analysis methods to extract the necessary information required to diagnose the causes of project delays, assess their impact, and subsequently propose suitable solutions. Furthermore, it recommends a permanent solution along with the implementation of remote monitoring techniques.

3.1 Conceptual Framework

This research uses a lean Six Sigma technique called the DMAIC to optimise the performance of a construction project. It combines data collection and the data analysis methods to extract the necessary information to diagnose the cause of the project inefficiencies, determine their impact, and find solutions accordingly. The research design is separated into the data collection phase and data analysis phase.

Time studies are conducted to determine the variance between actual and planned activities. This variance is the difference between the actual duration of certain activities and the planned duration which was forecasted in the project plan. The project plan and the planned duration for certain activities is captured on excel (the data is captured and presented in the appendix). The project gantt chart was designed on Microsoft Visio. Its purpose is to visualise the project schedule.

The attained data is first validated using descriptive statistics. This is to ensure that further analysis of the data and its results are reliable. This is done by determining the measures of central tendency where the mean, mode and median are determined. The measures of dispersion are also determined by calculating standard deviation and variance. This is done to determine variability and randomness of the data-points relative to the central tendency. Distribution curves are developed together with the skewness. This determines the distribution of the data.

The DMAIC framework is used to analyse the collected and validates data. The value stream map is designed on the “drawio-app”. It is used to identify non-value adding activities and issues within the construction process. Using the number of delay days captured in table 9 to table 18 in the appendix, a control chart is developed to quantify process inefficiencies by calculating the control variation. A Fishbone diagram (which is also designed in the drawio-app) is then created to categorise the types of delays described in the problem statement. The data presented in the appendix in table 9 to table 18 is used to conduct factor analysis. Factor analysis is used to determine the factors with the highest impact on process inefficiencies. Once that has been determined, the factor with the highest impact is then addressed using inventory management techniques, namely, the Economic Order Quantity model, to develop a model that predicts the optimum material order quantity and the optimum ordering time to minimise inefficiencies caused by delayed material delivery (high lead time). The data relating to delayed activities is then captured and stored on a database on “Microsoft Sequel Management Studio”. These models are then ran on “Microsoft PowerBI” to create a dashboard that presents control charts and real time process efficiency calculations such as the control variation as well as the real time order quantity. A planning and scheduling software is used to schedule jobs for employees to boost productivity and employee accountability. A detailed explanation of the research is given below, it also explains which section of the research addresses certain objectives and research questions.

The problem statement, objectives, and research approach outlined in chapter 1 are interconnected through the conceptual framework. This framework serves as a visual representation of the research design, effectively demonstrating how the proposed solution aligns with the problem statement and research questions. Although each approach has its specific relationship to certain aims and research questions, they all collaborate to achieve the overall research goals. This cohesive approach supports the integrated and comprehensive nature of the proposed solution. The utilisation and adaptation of the DMAIC framework are depicted in figure 26, showcasing how an inventory management solution is creatively employed to address the primary factor responsible for delays and process inefficiencies. This customised framework serves as a means to connect and identify a holistic solution to the problem statement, research objectives/aims, and research questions. The use of the DMAIC framework and its customisation is as follows:

1. The first phase of the DMAIC framework, known as the define phase, focuses on addressing research question 1. This phase involves thoroughly examining the construction project's process and identifying all the activities involved. Additionally, it aims to pinpoint the factors that contribute to process inefficiencies, shedding light on areas that require improvement.

2. Moving on to the measure phase, it also tackles research question 1 by quantitatively assessing the current process efficiency. This is achieved through the utilisation of control charts, which provide a visual representation of the process performance. By measuring key metrics and analysing the data, this phase helps to identify areas where the process may be falling short and in need of optimisation.

3. The analyse phase, like the previous phases, addresses research question 1. It employs factor analysis to delve deeper into the identified process inefficiencies. By examining the major contributors to these inefficiencies, this phase ranks them based on their impact, from the most significant to the least significant. This analysis aids in prioritising improvement efforts and focusing on the areas that will yield the greatest benefits.

4. Shifting to the improve phase, this stage of the DMAIC framework concentrates on finding solutions to the issues identified in the define, measure, and analyse phases. To tackle these challenges creatively, the Economic Order Quantity model is utilised. By proposing a solution that minimises the identified issues, this phase not only addresses research question 1 but also delves into research question 2.

5. Lastly, the control phase of the DMAIC framework aims to sustain the improvements made to the construction process. It achieves this by implementing project management software that enables remote monitoring of project progress. Additionally, it enhances planning and task delegation among employees. To provide real-time insights into process efficiency, a dashboard is created and uploaded to the company's on-premises report server. This phase directly addresses research question 3, as it enables management to remotely assess and monitor process efficiency.

The conceptual framework, depicted in figure 26, illustrates the entire process, starting from the identification of major process inefficiency contributors to the development, maintenance, and monitoring of the proposed solution. The DMAIC framework, a Lean Six-Sigma approach, is employed to guide this process. The define phase dissects the current construction project processes, utilising the value stream map (VSM) to visualise the process and identify the factors that impede project completion. The measure phase employs bar and control charts to quantitatively assess process efficiency

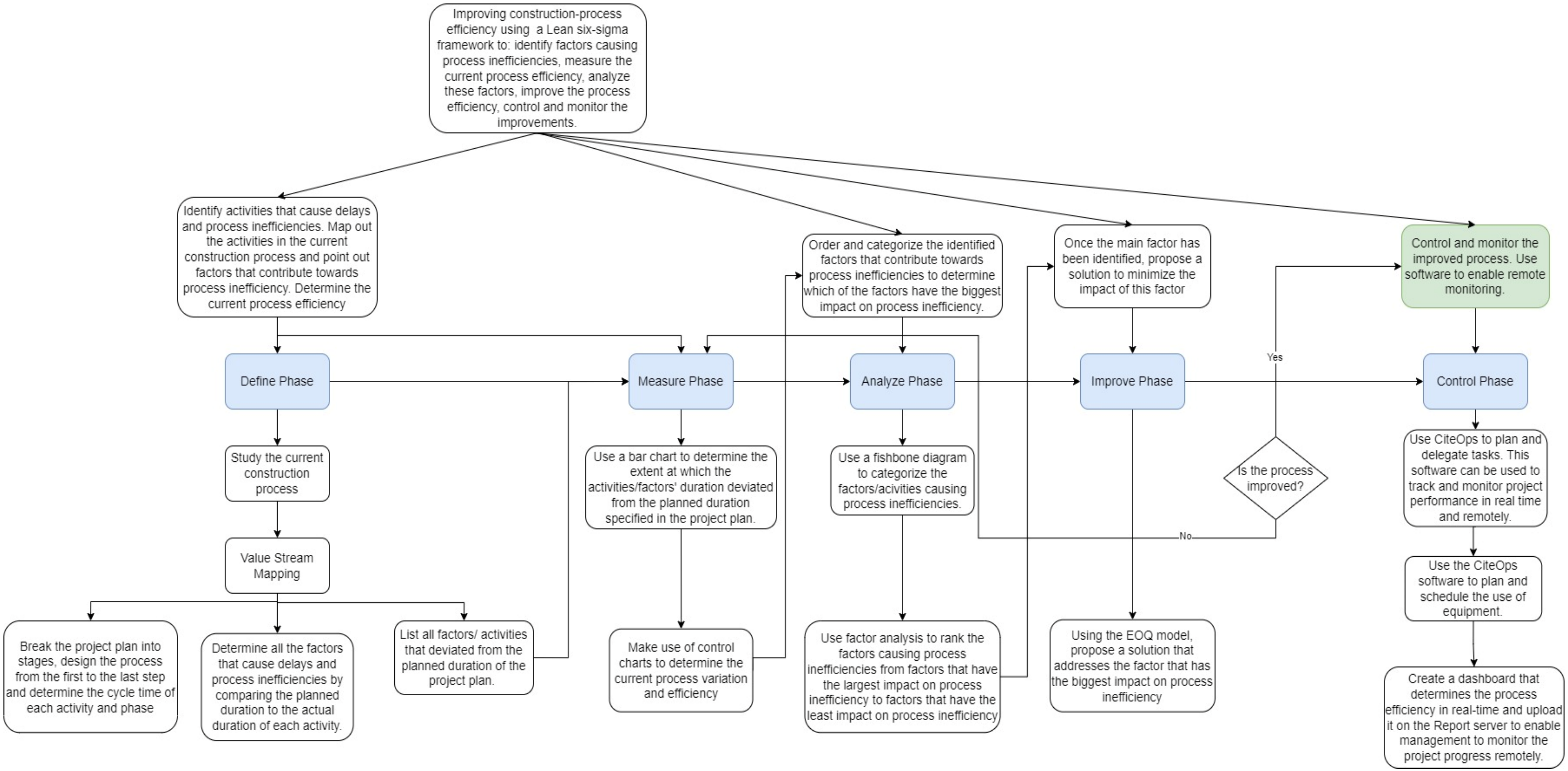

Figure 26- Conceptual Research Design

3.2 Theoretical Framework

The DMAIC framework, which stands for Define, Measure, Analyse, Improve, and Control, has been widely utilised in various industries to improve processes and achieve better outcomes. In the construction sector, numerous projects have successfully implemented the DMAIC methodology to optimise construction processes and enhance the overall quality of projects (Dubey and Yadav , 2016). This dissertation makes use of the previously derived EOQ model and includes the complete model in the “improve” phase. The EOQ model was previously derived as follows:

3.2.1 Mathematical Model

This model looks into optimizing the item quantity while keeping the budget at a limit. The following notations will be used:

- **Q**- order quantity for an item

  Unit- item measurement unit per batch

- **D**- demand rate for an item

  Unit-item measurement unit per time

- **p**- purchase price for an item

  Unit-money per item measurement unit

- **K**-ordering or setup costs

  Unit- money per batch of item

- **h**- holding or carrying cost rate

  Unit-money per item measurement unit per time

- **s**- shortage cost rate

  Unit- money per time measurement unit per time

- **n**- number of orders made

  Unit- batch per time

- **i**-inventory purchased

Unit- money per measured item unit

- **I**-inventory level

  Unit-item measurement unit

- **t**- time of interest

  Unit- time

- **T**- cycle time

  Unit- time

- **V**- total value of items
- λ – Lagrange's multiplier that aims to find maxima and minima
- ROP – Reorder Point

In this model, it is assumed that shortages are not allowed and demand is constant.

3.2.1.2 EOQ Model

For item j the total costs formulation is as follows (Çalışkan., 2022):

$$\frac{k\,D_j}{Q_j} + \frac{h_j\,Q_j}{2} \qquad (3)$$

The holding costs can also be represented with equation (4) (Çalışkan., 2022):

$$h = i.p \qquad (4)$$

Therefore, equation (5) for total costs holds for a single item (Çalışkan., 2022):

$$\frac{k\,D_j}{Q_j} + \frac{i_j.\,p_j.\,Q_j}{2} \qquad (5)$$

The following is also true for multiple items' **total costs**:

$$\sum_{j=1}^{n}\left(\frac{k\,D_j}{Q_j}\right) + \sum_{j=1}^{n}\left(\frac{i_j.\,p_j.\,Q_j}{2}\right) \qquad (6)$$

Part of inventory management and inventory ordering is the constraint of budget. The company needs to draw up a budget for the inventory they would like to order.

Determining the optimum inventory quantity may also enable them to save on costs. Therefore the following budget constraint hold is calculated based on how much the company spends on an item (Çalışkan., 2022):

How much is spent = $p_i \,.\, Q_j$ *(7)*

Equation (7) shows how much is spent on an average item (Çalışkan., 2022):

$$\frac{p_{j.}\, Q_j}{2} \tag{8}$$

Constraints (Çalışkan., 2022):

$$\sum \frac{p_j\,.\, Q_j}{2} \leq V$$

(9)

$$\sum \frac{p_j\,.\, Q_j}{2} - V = 0$$

(10)

Following equation (10) is the introduction of the Lagrange multiplier that aims to determine the minima and maxima in the total cost equation (Çalışkan., 2022). The constraint now forms part of the total cost equation:

$$\boldsymbol{\lambda}\,.\,(\sum \frac{p_j\,.\, Q_j}{2} - V)$$

(11)

$$\sum_{j=1}^{n} \left(\frac{k\, D_j}{Q_j}\right) + \sum_{j=1}^{n} \left(\frac{i_{j.}\, p_{j.}\, Q_j}{2}\right) + \boldsymbol{\lambda}\,.\,(\sum \frac{p_j\,.\, Q_j}{2} - V)$$

(12)

Equation (12) is then partially differentiated to determine the optimum equation that will represent the optimum order quantity (Q*) (Çalışkan., 2022).

$$\frac{\partial TC}{\partial Q_j} = \frac{-kD_j}{Q_j^2} + \frac{i \,.\, p_j}{2} + \frac{\lambda \,.\, p_j}{2} = 0$$

(13)

$$= \frac{-k \,.\, D_j}{Q_j^2} + \frac{p_j}{2}\,(i + \lambda) = 0$$

(14)

Now isolating Q_j^2 :

$$Q_j^2 = \frac{2 \,.\, k \,.\, D_j}{p_j\,(i + \lambda)}$$

(15)

$$Q_j = \sqrt{\frac{2 \,.\, k \,.\, D_j}{p_j\,(i + \lambda)}}$$

(16)

To find the optimum order quantity that accommodates the budget, λ must be determined and substituted into equation (16). Therefore, equation (17) is differentiated as follows (Çalışkan., 2022):

$$\frac{\partial L}{\partial \lambda} = \left(\sum \frac{Q_j . p_j}{2} - V\right) = 0$$

(17)

$$\sum_{j=1}^{n} \left(\sqrt{\frac{2 \,.\, k \,.\, D_j}{p_j\,(i + \lambda)}}\; x\; \frac{p_j}{2} \right) = V$$

(18)

$$\sum_{j=1}^{n}(\sqrt{\frac{2\,.\,k\,.\,D_j}{p_j\,(i+\lambda)}}\; x\; \sqrt{\frac{p_j^2}{2^2}}) = V$$

(19)

$$\sum_{j=1}^{n}(\sqrt{\frac{p_j\,.\,k\,.\,D_j}{2(i+\lambda)}} = V$$

(20)

$$V = \sqrt{\frac{k}{2(i+\lambda)}}\,.\sum_{j=1}^{n}(\sqrt{D_j p_j}$$

(21)

$$V^2 = (\sum_{j=1}^{n}(D_j p_j)\,)^2 x\; \frac{k}{2(i+\lambda)}$$

(22)

$$V^2\; x\; 2(i+\lambda) = (\sum_{j=1}^{n}(D_j p_j)\,)^2 x\; k$$

(23)

$$i+\lambda = (\sum_{j=1}^{n}(D_j p_j))^2\; x\; \frac{k}{2V^2}$$

(24)

$$\lambda = (\sum_{j=1}^{n} (D_j p_j)^2 \ x \ \frac{k}{2V^2}) - i$$

(25)

Equation (16) is then substituted into equation (26) to determine the optimum order quantity (Çalışkan., 2022):

$$Q_j{}^* = \sqrt{\frac{2\ .\ k\ .\ D_j}{p_j\ (i + \ (\sum_{j=1}^{n} (D_j p_j)^2 \ x \ \frac{k}{2V^2}) - \ i\ )}}$$

(26)

$$Q_j{}^* = \sqrt{\frac{2\ .\ k\ .\ D_j}{p_j\ \ (\sum_{j=1}^{n} (D_j p_j)^2 \ x \ \frac{k}{2V^2})}}$$

(27)

$$Q_j{}^* = \sqrt{\frac{4\ .\ V^2\ .\ D_j}{p_j\ \left(\sum_{j=1}^{n} D_j p_j\right)^2}}$$

(28)

$$\sum_{j=1}^{n} (\frac{k\ D_j}{Q_j}) \ + \sum_{j=1}^{n} (\frac{i_j.\ p_j.\ Q_j}{2})$$

The point of intersection is the optimum in terms of the total costs that will be incurred. A further decrease of the fixed costs passed this point will increase the variable costs. Therefore, using the optimum order quantity that has been derived in equation (29) shows that the optimum **total costs** are as follows (Çalışkan., 2022):

$$\sum_{j=1}^{n} \left(\frac{k\, D_j}{\sqrt{\frac{4\,.\,V^2\,.\,D_j}{p_j\,\left(\sum_{j=1}^{n} D_j p_j\right)^2}}} \right) + \sum_{j=1}^{n} \left(\frac{i_{j.}\, p_{j.}}{2} \sqrt{\frac{4\,.\,V^2\,.\,D_j}{p_j\,\left(\sum_{j=1}^{n} D_j p_j\right)^2}} \right) \quad (29)$$

3.3 Chapter Summary

This section introduces a research approach that employs the Lean Six-Sigma framework, DMAIC, to tackle the problem outlined in chapter 1. Figure 26 visually depicts the relationship between the problem statement, research inquiries, and methodology. The theoretical framework establishes fundamental concepts such as the EOQ derivation that was employed in this research, while past studies utilise the DMAIC framework in the field of construction. To address the issues highlighted in the problem statement, a tailored model is constructed based on the theoretical framework.

Chapter 4

Data Presentation, Analysis, Results and Discussion.

4.0 Chapter Overview

This chapter focuses on the presentation of the research data, its analysis as well as the analysis of the research results and discussion. It customises the DMAIC framework within the results by incorporating factor analysis to establish a hierarchy of factors that contribute to process inefficiencies and delays. It starts by first presenting and validating the data used for this dissertation. By identifying the factor with the greatest impact, which in this case is long lead times, the Economic Order Quantity model is utilised to predict the optimal material lead time and quantity. This approach aims to reduce the time spent on lead time delays. Additionally, the study employs various process improvement techniques and project management strategies to control and enhance the proposed solution. The utilisation of CiteOps software facilitates improved work planning and scheduling, while the development of dashboards enables remote monitoring and inspection of project progress.

4.1 Data Presentation and Validation

This section presents a discussion of the research data. The data was received as a secondary data however, it was originally collected using the time study techniques. Data validation is a crucial step in the data analysis process to ensure that the data is accurate, complete, and reliable. Descriptive statistics was used to validate the data. The mean, mode, standard deviation, variance and range determined in this section provides a summary of the data distribution and assists in identifying outliers or unusual patterns.

The data presented in table 3 below show the measures of central tendency which includes the mean, median and the mode. The mean signifies the average value of each of the factors presented in the tables. This is the balance point of the dataset, the typical value and behaviour of the dataset. The median is the middle value of the dataset for each of the factors presented in tables 3 and 4. This is the point where the dataset is divided into two parts, half of the values lie below this value and the other half lie above this value. This is important for skewed distributions. The mode shows the most common value in the dataset, this is also presented in table 3 and table 4.

It was used to describe the most typical observation. These values are important as they describe the central value around which the data is distributed. The mean, mode and median give an indication of a skewed distribution as they are not similar nor are they close to one another.

Table 3- Determination of the mean, standard deviation, mode, variance, range, confidence interval and skewness of the data presented in the appendix.

	Actual Lead Time	Delay in Ordering Time	Number of days to completes jobs
Mean	112.2	6.333333333	97.33333333
Median	70.5	3	79.5
Standard Deviation	104.9513516	7.062935471	69.81594851
Mode	327	0	0
Variance	11014.78621	49.88505747	4874.266667
Range	318	16	193
Confidence Interval	149.7563588	8.860772332	153.1977269
	74.64364115	3.805894335	41.46893974
Skewness	1.099	0.66	0.622

Table 4- Determination of the mean, standard deviation, mode, variance, range, confidence interval and skewness of the data presented in the appendix.

	Inspections Delays	Delayed Days Spent on training	Delay days due to weather	Delay days due to equipment availability
Mean	25.25	8.4	2.375	1.6
Median	27	2	1.5	1
Standard Deviation	4.687749993	14.89295135	2.133909892	1.264911064
Mode	27	1	1	1
Variance	21.975	221.8	4.553571429	1.6
Range	12.5	34	6	3
Confidence Interval	29.0009812	21.45424743	3.853724112	2.384
	21.4990188	-4.654247431	0.896275888	0.816
Skewness	-1.443	1.331	1.363	1.423

Tables 3 and 4 also indicate the measures of dispersion. These are signified by the variance, standard deviation and range. These are crucial measures when it comes to understanding variability of the data for the central tendency. As can be seen in table 3, lead time has the greatest range, variance and standard deviation. This indicates that it is the factor with the highest variation. This statement is also supported by factor analysis which can be found in the results below. The data has some variabilities with data points spread out over a wider range. Data relating to delays caused by equipment availability (found in table 4), has the smallest range, standard deviation and variance out of all factors presented in the tables.

This indicates that its measures of dispersion are small relative to the measures of central tendency. This factor may be the easiest to control out of all the other factors presented in tables 3 and 4 above.

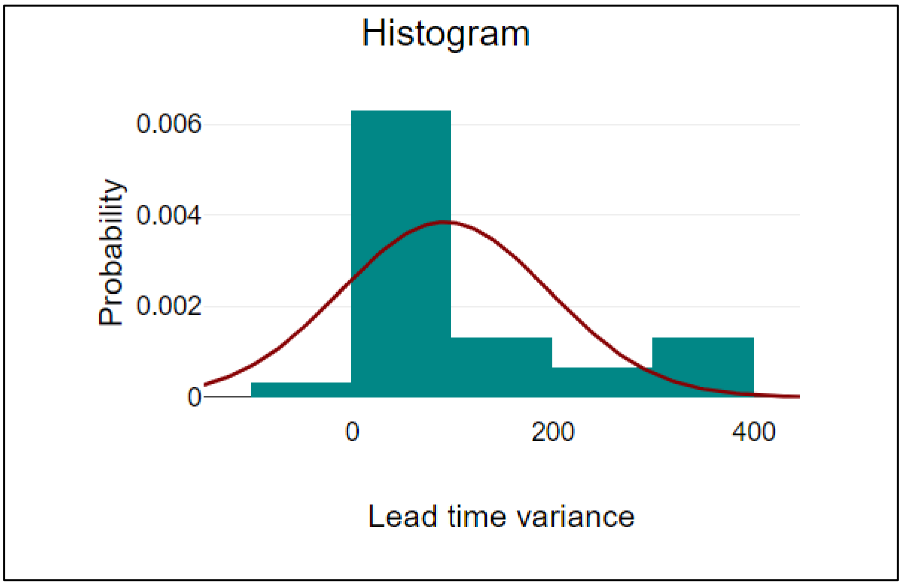

Figure 27- Histogram showing the distribution of the lead time data.

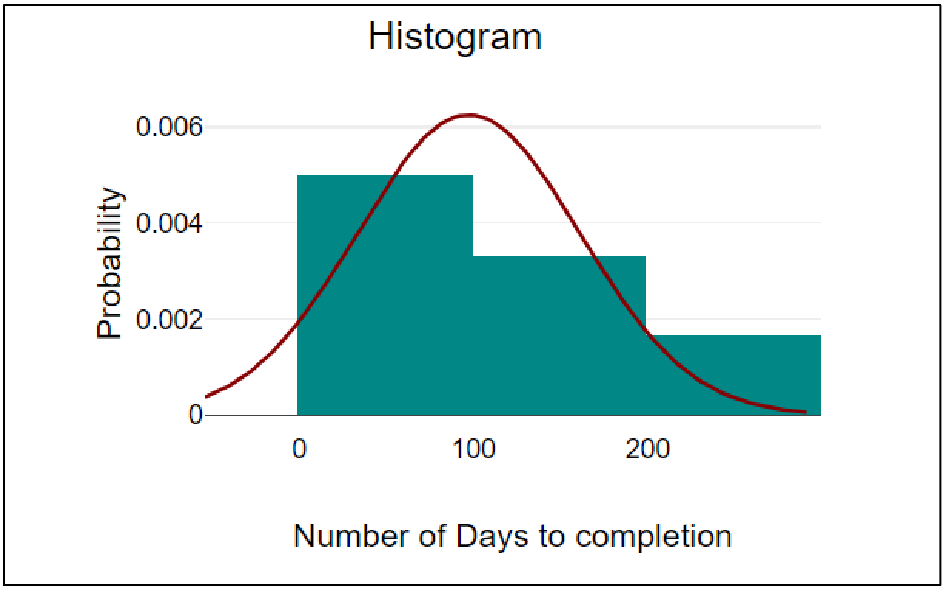

Figure 28- Histogram showing the distribution of the job completion days

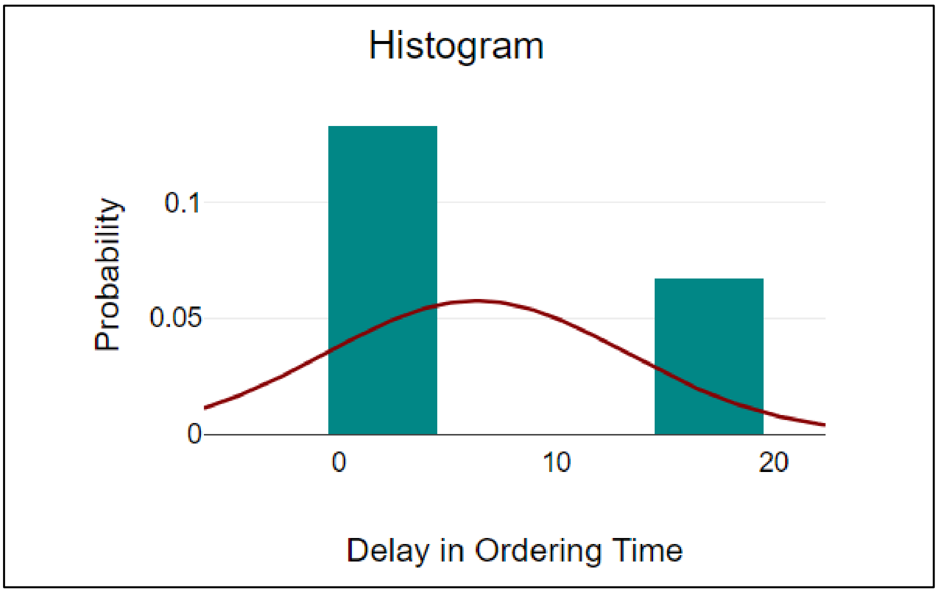

Figure 29-Histogram showing the distribution of the delay days of placing orders data.

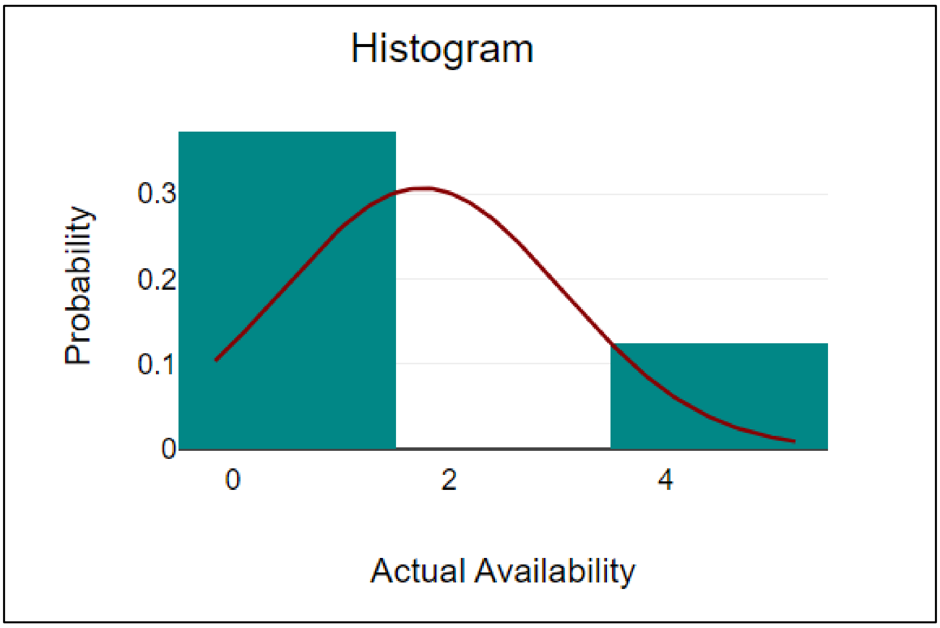

Figure 30-Histogram showing the distribution of the equipment availability data.

Lead time, delay in job completion, delays in order placement and equipment availability all consist of a positive skewness. In this case, it is expected that the mean would be greater than the median and the mode. The skewness of 1.099, 066, 0622, 1.331, 1.363, 1.423 respectively, supports the distribution depicted in figures 27-30 which present the "longer tail" on the right of the distribution curve or a positive skewness. This suggests that there are a few very high values or outliers in the dataset that are pulling the mean towards the right. This skewness indicates that the distribution is not symmetrical, and the bulk of the data is concentrated towards the lower end, with a few exceptionally high values on the right side.

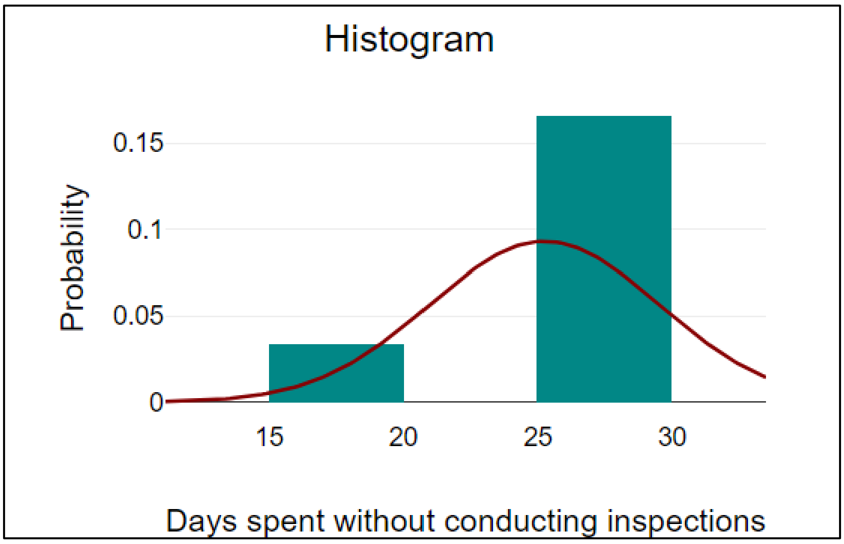

Figure 31-Histogram showing the distribution of the inspections delay days data.

Figure 31 presents the distribution curve for delays relating to inspections. This figure consists of a negative skewness of -1.443. The bulk of the data is concentrated towards the right side. The distribution is stretched out towards the lower values, and there are relatively few low values that pull the mean towards the left. In this case, the mean is lower than the median. The median tends to be closer to the right tail of the distribution where the bulk of the data is concentrated. It is usual for the mode to coincide with the highest peak of the curve. This is true for figure 31, the mode is 27 and the peak of the curve lies at 25.

It is normally expected for data to follow a normal distribution, however, it is also not unusual to have imperfections in data collection. It is preferred for skewness to be close to zero as this indicates that the data is close to a normal distribution and consists of less outliers and variation. However, for cases such as lead time, inspection frequency and weather conditions, these factors may usually introduce randomness in the data-set as the control does not normally lie in the hands of the data collector, based on other factors at play (Sematech, 2022). In this data-set, the skewness does not lie too far from zero and there are not many outliers present, this gives the assurance that the data is valid.

4.2 Results and Discussion

This section focuses on the customisation of the DMAIC framework to address the specific concerns outlined in the problem statement. To gain a comprehensive understanding of the current process, value stream mapping was employed, which is further enhanced by measuring the factors that contribute to inefficiencies. These factors are then analysed and ranked based on their impact, utilising factor analysis. To mitigate the impact of the most influential factor on project inefficiencies, a solution is proposed using the EOQ model. The implementation of the CiteOps software facilitates improved scheduling, monitoring, and task delegation in the construction project through digitalisation. Furthermore, project progress and efficiency are monitored remotely and in real time. In summary, the DMAIC framework was tailored to suit the requirements of the specific project, incorporating techniques from inventory management, project management, and statistics to effectively minimise inefficiencies within the construction project.

1. Define

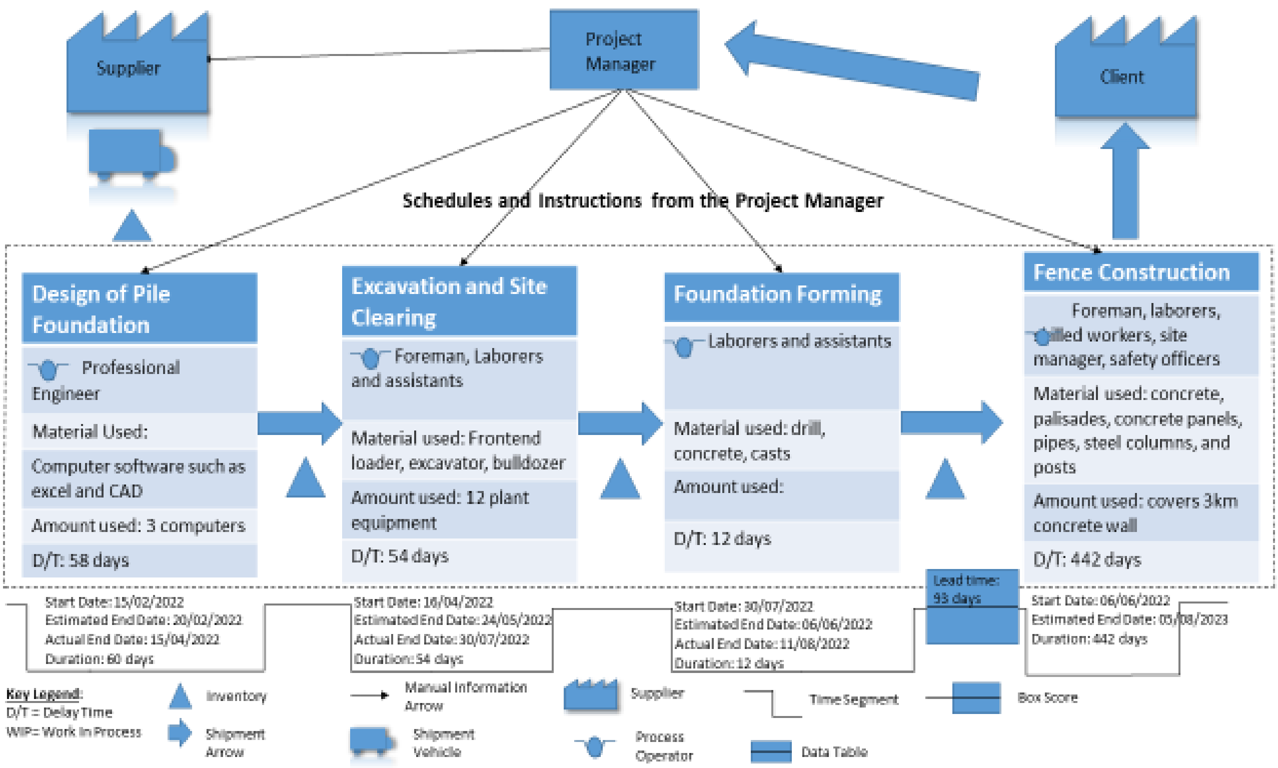

Figure 32-Value stream map for the construction project

The DMAIC process encompasses several steps, including problem definition and diagnosis, as well as the use of a value stream map (VSM) to identify potential inefficiencies. In this particular study, the causes of process inefficiencies within four stages of a construction project were identified: the design phase, excavation and clearing, foundation forming, and fence construction. Using the data collected during the research time studies (shown in tables 9-17 as well as figures 42-46 in the appendix), figure 32 shows that significant delays occurred during the design and excavation stages, lasting a minimum of fifty-four days. These delays were primarily attributed to the need for project redesign, which arose from inaccurate workspace measurements resulting from inadequate inspections and supervision. The approval of the improved design was also delayed by more than a month, as the project engineer took longer than expected to give their approval. The excavation stage experienced prolonged delays due to frequent equipment breakdowns and unplanned maintenance. Similarly, the foundation-forming phase encountered delays and breakdowns caused by incorrect pouring and curing procedures, which were a consequence of poor supervision and insufficient oversight. This stage had to be corrected four times, leading to further project delays. Additionally, delays were observed in the form of long lead times for building materials from suppliers, averaging ninety-three days. The fence construction stage is currently ongoing, but it may face additional delays due to adverse weather conditions. Extreme weather prevents the installation of concrete panels, necessitating a hold on this task until more favourable weather conditions prevail. The VSM provides a comprehensive overview of the project, highlighting the various stages involved and the factors contributing to process inefficiencies. The study identified several types of delay causes, including waiting periods for permits and occupation, employee induction and onboarding, material lead times, task reworking, concrete panel manufacturing, weather conditions, delayed material ordering, inspection of project progress by engineers, and availability of skilled employees.

2. Measure

To gauge the current performance of the project, this particular phase aims to establish a baseline by quantifying the factors that were identified during the diagnosis phase of the DMAIC.

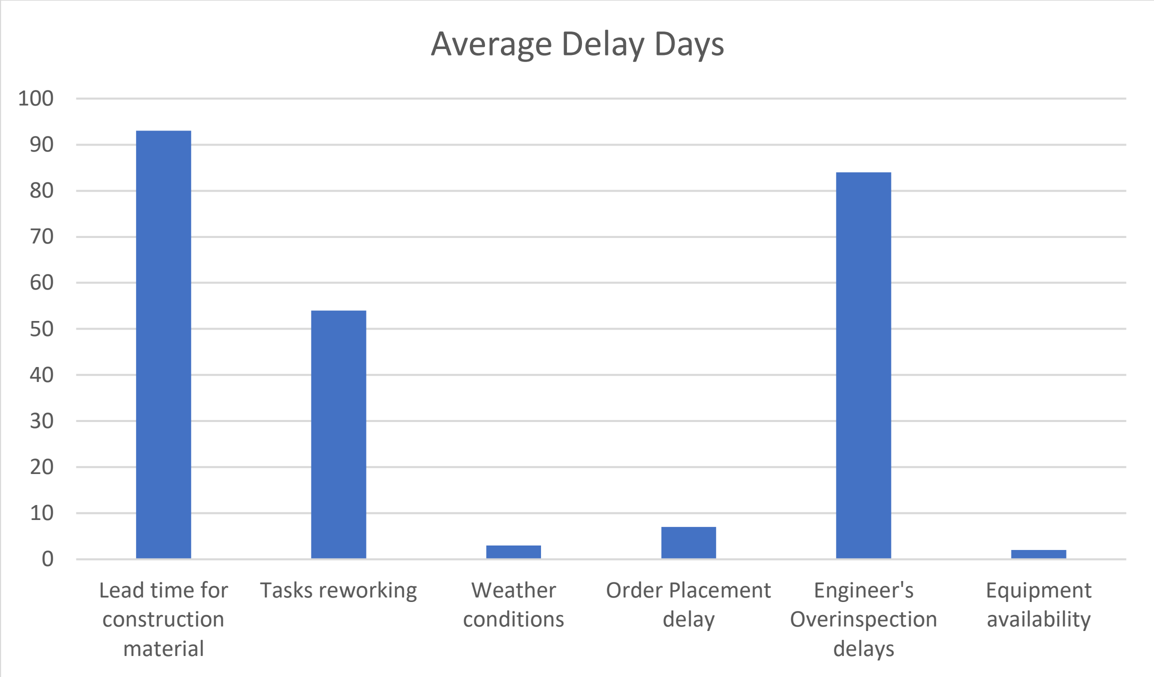

Figure 33- Visual representation of the frequency of the causes of delays.

The bar chart depicted in figure 33 serves as a visual representation and quantification of the delays encountered in the project. It offers insights into the primary causes of process inefficiencies, highlighting those that occur most frequently and have the potential to significantly impact the project's schedule performance. Figure 33 also highlights the top three potential causes of project delays, namely material lead time, job reworking, and over-inspections, which may require further investigation.

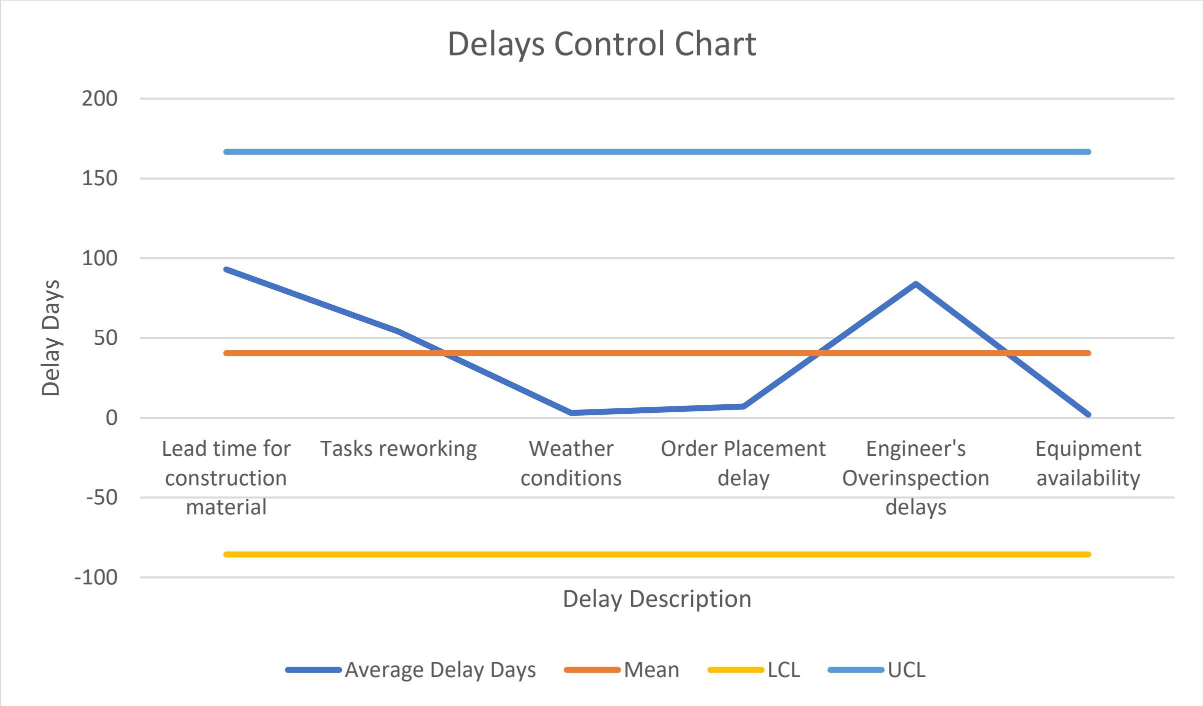

Figure 34- Control charts monitoring the variation in occurrence frequencies of causes of delays

Figure 34 displays control charts that assess the extent of process inefficiency factors. The process depicted in the aforementioned figure fluctuates between durations of three and one-hundred days. The process exhibits a significant level of variation, and this inference can be deduced from the control variation equation, which is determined by employing the subsequent formula:

CV = $\frac{\sigma}{\bar{x}}$ x 100

The formula is presented as the standard deviation (σ) divided by the average ($\bar{x}$) multiplied by 100. This percentage indicates the control variation which is a representation of how variable and efficient the process is. The project leaders agreed to a control variation of 40%, at most.

In relation to this particular procedure, where the average total delay days amount to 40.5 with a standard deviation of 42.05 days, the control variation reached 103.83%. This percentage indicates that the factors contributing to the delays are beyond control, thereby posing challenges in managing and forecasting the future instances and patterns of delay causes. Statistical techniques are utilised to assess the influence exerted by each delay cause on the project's schedule performance.

3. Analyse

Factor Categorisation

The fishbone diagram presented in figure 35 below categorises the identified causes of process inefficiency. This diagram is essential in brainstorming and determining the root causes of a problem.

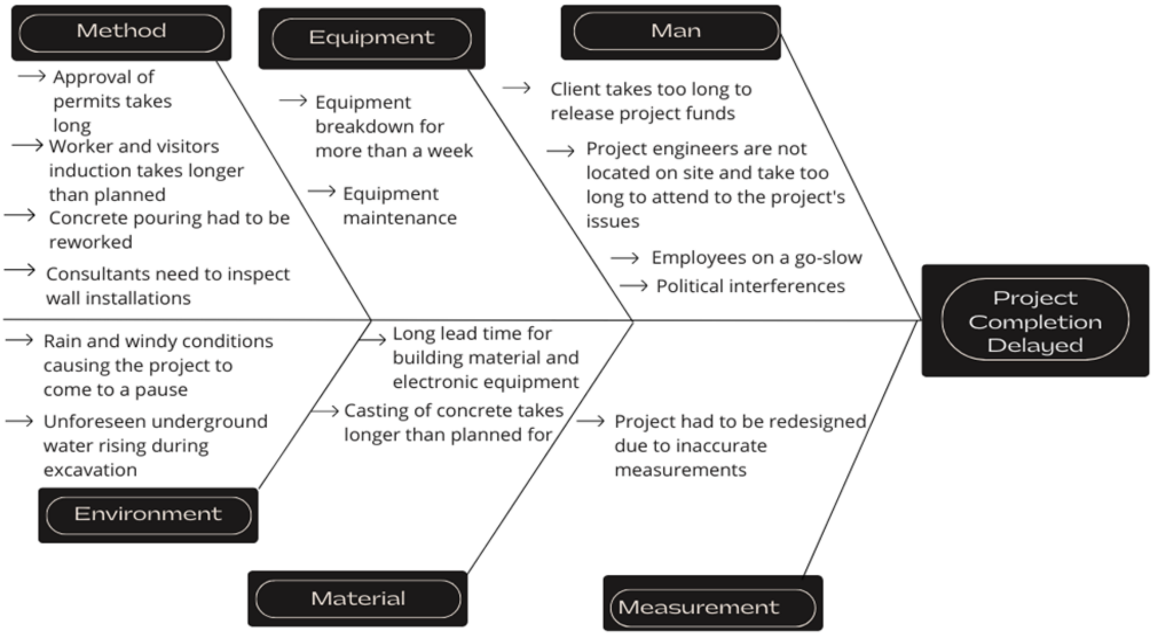

Figure 35- Fishbone diagram for the causes of delays.

The delays recorded in Figure 35 under the method category were a result of the specific procedures employed. The approval of permits was delayed due to the chosen procedure, while poor planning and grouping of trained and inducted employees caused delays in the induction process. Additionally, incorrect procedures and inadequate supervision led to the need for corrective measures during the pouring of concrete. Equipment-related delays were primarily caused by breakdowns and unplanned maintenance. Although maintenance is typically accounted for in the project plan, it may take longer than anticipated, resulting in unexpected project delays. This highlights the significance of regular preventative maintenance, which ensures that equipment remains in optimal condition and minimises the risk of frequent breakdowns. Failure to conduct regular preventative maintenance increases the likelihood of delays occurring due to equipment issues. Delays attributed to human factors are caused by clients not making timely payments, a lack of thorough inspection and supervision by the management team, political interference, and employee go-slows. Managing these human-related factors can be challenging; however, it is possible to address them by implementing cultural shifts, fostering mindset changes, and enhancing employee productivity. Measurement delays can be easily avoided through frequent equipment inspections. Supervisors and foremen should consistently inspect the work completed by employees and ensure that the equipment remains in good working condition. Delays related to materials are often beyond control, especially when they are the fault of the supplier. In such cases, organisations may enter into contracts with suppliers and establish acceptable lead times, which must be incorporated into the project plan. Environmental delays are typically uncontrollable, as construction activities are halted during extreme weather conditions. The impact and severity of these factors on process efficiency can be assessed through factor analysis.

Factor Analysis

The examination of these factors holds significant importance in assessing the influence they have on the efficiency of the process. A thorough investigation is conducted solely on the factor that exhibits the greatest impact on process efficiency. Factor analysis is used and presented below to determine the factor that exhibits the greatest impact. The data used to determine this is captured and presented in the appendix (tables 9–17). Consequently, a proposed solution is put forth to address this particular factor. Table 5 presents a variance table that enumerates the eigenvalues of the remaining identified factors. These eigenvalues serve as a basis for determining the percentage variance attributed to the factor under scrutiny. Further scrutiny of the eigenvalues allows for the calculation of the accumulated percentage.

Table 5-Variance table

Component	**Factor name**	**Eigenvalues**	**% of variance**	**Accumulated %**
1	Material lead time	2.93	48.86	48.86

Component	Factor name	Eigenvalues	% of variance	Accumulated %
2	Delay in ordering time	1.66	27.64	76.5
3	Reworking jobs description	1.27	21.25	97.75
4	Equipment availability	0.1	1.63	99.39
5	Days spent without conducting inspections	0.04	0.61	100
6	Number of days of rain	0	0	100

The eigenvalues presented in table 5 play a crucial role in determining the number of factors that should be further examined. Factors with eigenvalues below one are considered insignificant and are therefore excluded from further analysis as they do not make a substantial contribution to the overall percentage variance. The primary objective is to identify and analyse factors that have the greatest impact on the variance. To calculate the percentage of variance, the following formula was utilised:

$$\frac{Eigenvalue\ of\ factor}{\sum Eigenvalues} * 100$$

The purpose of this is to identify and pinpoint the reasons behind the delays encountered in this particular project. According to the data presented in Table 5, it is evident that factors 1, 2, and 3 contribute the most to the overall variation. Consequently, by reducing the variability associated with these factors, the control over the entire process will be greatly enhanced. As a result, the project's planning process will experience a significant improvement. Utilising the values derived from the calculations presented in Table 5, a graph was constructed to visually represent the data.

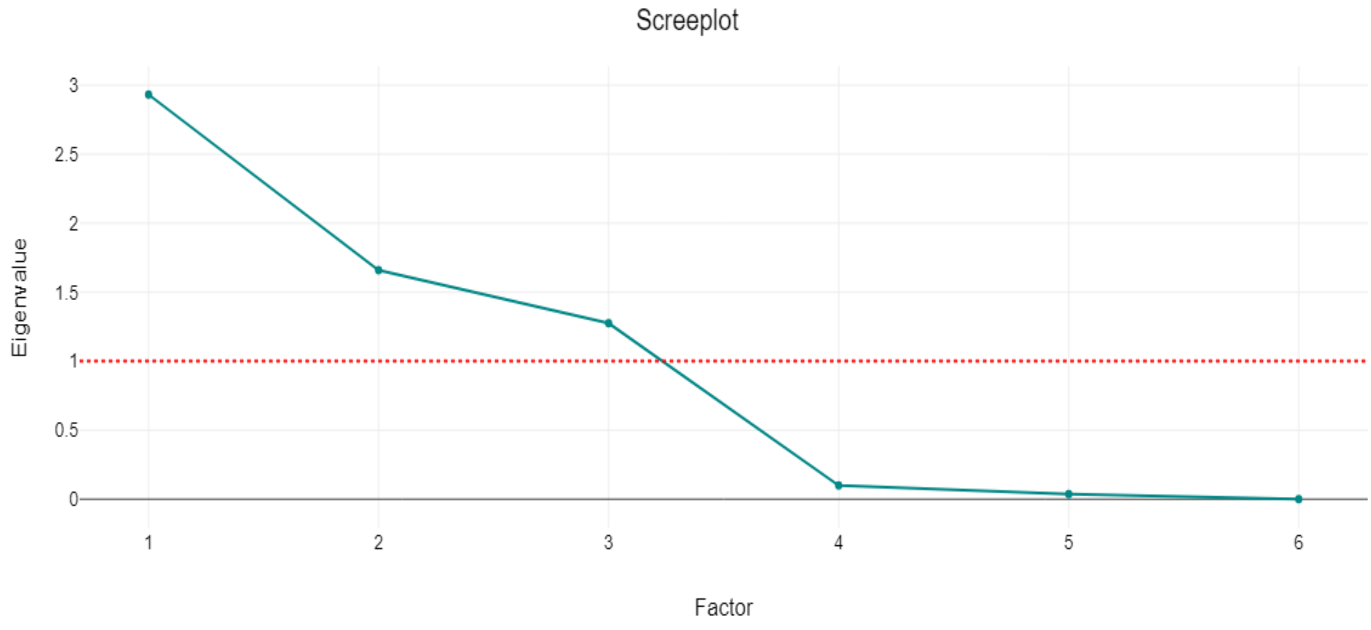

Figure 36- Screeplot for eigenvalues

Figure 36 highlights the significance of factors with eigenvalues greater than 1. This principle of factor analysis enables a reduction in the number of factors considered, focusing solely on those that contribute the most to the overall variance. Based on the findings in Figure 36, it can be inferred that three factors possess eigenvalues exceeding one, indicating their importance and necessitating an examination of their relationships with all the causes of delays. The screeplot guideline suggests retaining factors that precede the eigenvalue plateau. Consequently, factors 1, 2, and 3 should be retained in this scenario. Subsequently, the factor with the highest eigenvalue is selected, and a correlation coefficient is employed to determine which of the remaining factors has the most substantial influence on factor 1. To identify variables closely associated with these factors, a correlation coefficient table is developed below.

Table 6-Correlation matrix with loading factors for research data

	Lead time variance	Delay in ordering time	Reworking jobs description	Equipment availability	Days spent without conducting inspections	Number of days of rain
Lead time variance	1	0.53	0.66	0.41	-0.19	0.66
Delay in ordering time	0.53	1	-0.24	0.62	-0.5	0.53
Reworking jobs description	0.66	-0.24	1	0.03	0.22	0.39
Equipment availability	0.41	0.62	0.03	1	0.34	0.88
Days spent without conducting inspections	-0.19	-0.5	0.22	0.34	1	0.27
Number of days of rain	0.66	0.53	0.39	0.88	0.27	1

Table 6 presents the strength of the association between different variables. The correlation coefficient between lead time and reworking of jobs is 0.66, indicating a strong relationship between these two variables. Similarly, the delay in order placement significantly affects lead time, as evidenced by the strong correlation coefficient of 0.53. On the other hand, the correlation coefficient between equipment availability and lead time is 0.41, suggesting a relatively weak relationship. Interestingly, inspection frequency shows no relationship with lead time, as indicated by a coefficient of -0.19. Notably, weather conditions have a substantial impact on lead time, with a strong relationship and a coefficient of 0.66.

Based on these findings, it can be inferred that lead time plays a crucial role in explaining the total variance. By minimising the delay in order placement and addressing task corrections, it is possible to reduce lead time and potentially mitigate project delays. Therefore, it is imperative to optimise the timing of orders and develop a solution that provides recommendations on when and how much to order.

4. Improve

During this phase, the main objective is to enhance the underlying factors that were examined and identified in the analysis phase. The analysis phase has revealed that the lead time for materials has the most substantial influence on project delays and is greatly affected by the duration required to place an order. To address this issue, the EOQ model is utilised as a method to calculate the optimal time and quantity for placing orders using differential equations. This model specifically assumes that items do not deteriorate over time. Notations used for the model are as follows:

- Q_0 Initial quantity of inventory
- Q^* Optimal quantity of inventory
- D Demand of the inventory (How much is being used during construction)
- θ Rate of deterioration
- t Material storage time before use
- T Cycle duration
- k Cost per order
- p Purchase price for the item

- Qt Quantity after the effects of demand or deterioration or both
- h Holding cost per unit
- Cd Deterioration Cost
- C Cost per unit item
- HC Inventory Holding Cost
- OC Inventory Ordering Costs
- PC Inventory Purchasing Costs
- TC Inventory Total Costs

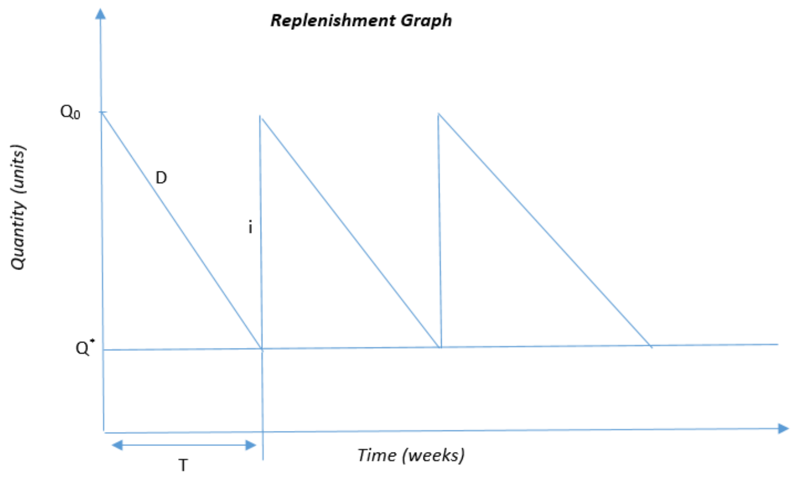

Figure 37- Replenishment graph showing optimum ordering time and quantity

The given assumptions are considered in the analysis: (1) Shortages or back ordering is not permitted, (2) Deterioration of the building material is not taken into account, and (3) The impact of demand is not considered, assuming a constant demand. In Figure 37, a Replenishment graph is presented, illustrating the initial quantity of building material in storage denoted as Q_0. The material is assumed to be consumed at a consistent rate, resulting in a decrease in the quantity of building material in storage. When the quantity approaches the optimum order quantity, indicated as Q*, in Figure 37, the building material needs to be reordered and replenished. This point on the replenishment graph is referred to as the reorder point. The optimal quantity of building material to be replenished is also represented as Q*. The ideal time to place an order for the building material is denoted as T in Figure 37. The quantity of building material to be purchased is represented as i. Once the building material in storage reaches the level of Q_0, the cycle begins again. The mathematical model is shown below.

Mathematical EOQ Model:

The company had specified a budget for material of R30 000 000 out of the total project cost of R52 000 000. Using the following information, the EOQ model is applied using equation 30 and 31 below:

$$Q_j^* = \sqrt{\frac{4\,.\,V^2\,.\,D_j}{p_j\left(\sum_{j=1}^{n} D_j p_j\right)^2}} \quad (30)$$

$$T = \frac{\sqrt{\frac{4\,.\,V^2\,.\,D_j}{p_j\left(\sum_{j=1}^{n} D_j p_j\right)^2}} + Dt}{D} \quad (31)$$

Table 7- Recommended optimum order quantity and order time.

Material	Average Quantity Used (units)	Estimated Days of reordering (days)	Purchase price per item (R)	Optimum order quantity (units)	Optimum order time (days)
Panels	86	33	850	261	36
Cement	230	30	80	5529	54
Palicades	158	141	950	163	142
Columns	58	32	1500	136	34
Rods	100	93	500	537	98

The data used to calculate the optimum order quantity and time is captured and presented in the appendix (table 18). By utilising T and Q*, individuals are able to ascertain the optimal timing for ordering additional materials. This strategic approach facilitates improved project planning and effectively reduces the delay period for the delivery of construction materials, thereby preventing any interruptions in the project's progress.

5. Control

This sub-heading introduces a framework that oversees the enhancements implemented in the construction project procedure. The integration of digital technology in construction projects plays a crucial role in monitoring and tracking the progress of the process. It ensures that the implemented improvements and new systems are followed by the employees, while also maintaining the efficiency of the project. By digitising construction systems and processes, each activity and decision is broken down and automated, minimising any potential obstacles that could hinder the efficiency of the process. This approach reduces process friction, optimises workflows, and facilitates early detection of any deviations from the established process. The utilisation of digitalisation has simplified and enhanced planning, scheduling, and process tracking, as outlined in the following sections.

Use of software for planning and scheduling:

The subsequent stage encompasses the regulation of the enhanced procedure and forthcoming outcomes. This particular section concentrates on the digitalisation of task assignment and the monitoring of activities. Advanced software tools like CiteOps are utilised to facilitate superior management, strategic planning, and effective monitoring.

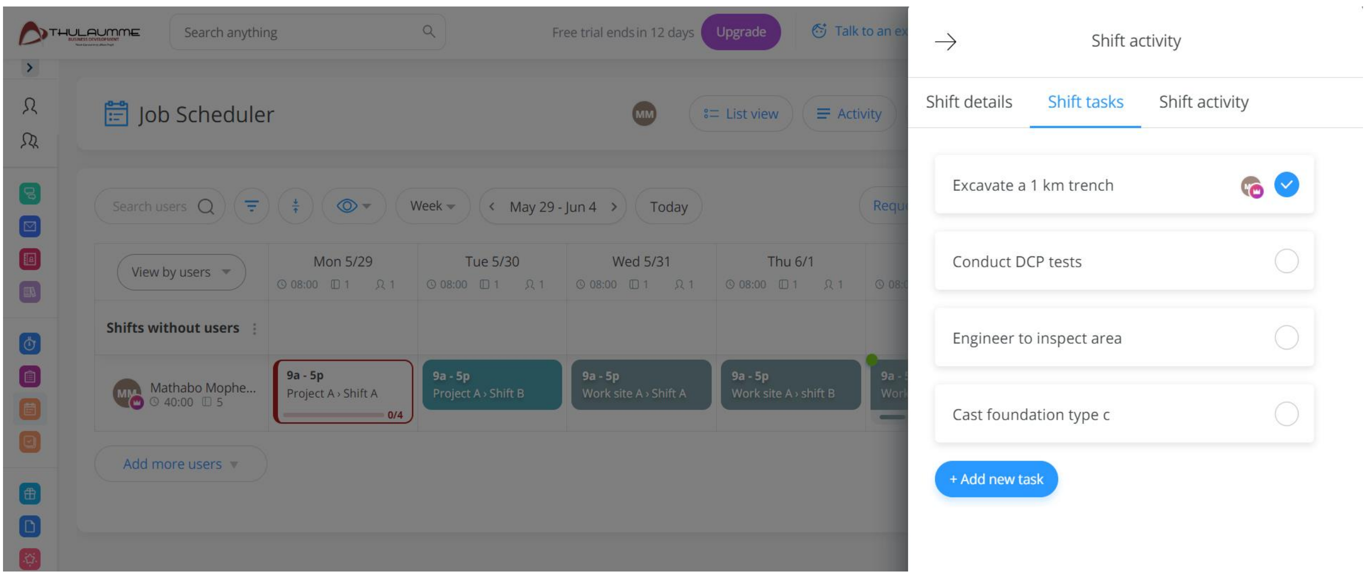

Figure 38- Job scheduler on CiteOps

The CiteOps software plays a crucial role in facilitating effective task management within the organisation. By encouraging all employees to download the application on their devices, the company ensures that everyone is connected and informed about their assigned tasks. Through the application, employees receive timely notifications regarding the tasks they need to complete, eliminating any confusion or miscommunication. To further streamline the workflow, a workplan is formulated for each shift. This workplan outlines the tasks that need to be accomplished during that particular shift. As employees complete their tasks, they have the ability to mark them as completed within the application. This feature allows for real-time monitoring of their work progress, providing supervisors and managers with up-to-date information on the status of each task. The shift schedule depicted in the job schedule provides a visual representation of the progress made by employees. It shows the number of completed tasks out of the total assigned for that specific shift. This visual indicator helps supervisors and managers quickly assess the progress made during each shift. In the example shown in Figure 38, the employee in Shift A has not completed any of the four assigned tasks. This discrepancy is highlighted in red on the calendar, drawing attention to the incomplete tasks. The employee is then required to provide reasons for not completing the tasks as instructed. These reasons can be found in the "shift details" tab, allowing supervisors and managers to understand the challenges faced by the employee and take appropriate action.

One of the key advantages of this system is that both the employee's supervisor and manager have access to the job schedule. This means that they can remotely assess the progress of the assigned tasks in real time, even if they are not physically present at the worksite. This feature enhances the frequency of inspections and enables the early detection and correction of mistakes. It also allows for prompt intervention if any issues or delays arise, ensuring that tasks are completed efficiently and on time. Overall, the use of the CiteOps software and the job schedule it generates greatly improves task management within the organisation. By providing employees with a clear overview of their assigned tasks and enabling real-time monitoring, this system enhances productivity, accountability, and the overall efficiency of the workforce.

EQUIPMENT MAINTENANCE SCHEDULE

MACHINE NAME	CONDITION	LOCATION	ASSIGNED TO	LAST MAINTENANCE DATE	Planned MAINTENANCE FREQUENCY in Days	NEXT MAINTENANCE DATE	NOTES
Pump 101	Acceptable but needs attention	On site	Kasango Tau	19/05/2022	30	19/06/2022	Impeller in beginning phase of wear. We will keep monitoring the equipment but it is working well at the moment.
Generator	Good	On site	Isaac Masete	23/05/2022	7	23/06/2022	Replaced bearing. Working well.
Breaker	Good	On site	Thabo Tswai	23/05/2022	30	23/06/2022	Working well.
Frontend Loader	Good	Workshop	Thabo Mononyane	14/05/2022	7	14/06/2022	Working well.
Poker and Drive Unit	Unacceptable and must be inspected frequently	On site	Lethabo Klaai	14/05/2022	7	14/06/2022	End shank needs replacing.
Light Driven Vehicles (LDV)	Acceptable but needs attention	Workshop	Thapelo Mashile	14/07/2022	7	14/08/2022	V-belt worn out.
Trench Compactor	Good	On site	Thabo Mononyane	17/05/2022	30	17/06/2022	Working well
Piling Rigs	Good	On site	Thabo Tswai	19/05/2022	7	19/06/2022	Working well

Figure 39- Equipment scheduler on CiteOps

Figure 39, as a monitoring tool, plays a crucial role in overseeing the utilisation and upkeep of equipment at the designated location. It serves as a comprehensive schedule that is generated on CiteOps, a platform that enables automatic tracking of equipment that requires maintenance or repairs.

The primary objective of Figure 39 is to minimise the occurrence of breakdowns by ensuring timely maintenance and keeping a record of the essential spare parts that need replacement. By regularly monitoring the equipment, potential issues can be identified and addressed before they escalate into major problems.

This proactive approach helps in reducing downtime and maximising the efficiency of the equipment. One of the key advantages of Figure 39 is its accessibility in real-time and from a remote location. This feature allows authorised personnel to monitor the status of the equipment and track its maintenance progress regardless of their physical location. This remote access capability enhances efficiency and enables prompt action to be taken in case of any emergencies or urgent maintenance requirements. In addition to tracking maintenance and repairs, Figure 39 also emphasises the importance of regular inspections of the equipment. Inspections are crucial for identifying wear and tear issues and documenting them as part of maintenance. Figure 39, a monitoring tool, helps organisations manage equipment, minimise breakdowns, and ensure smooth operations. Its automatic tracking, real-time accessibility, and documentation features contribute to a proactive maintenance process, improving equipment performance and longevity.

Live Dashboard

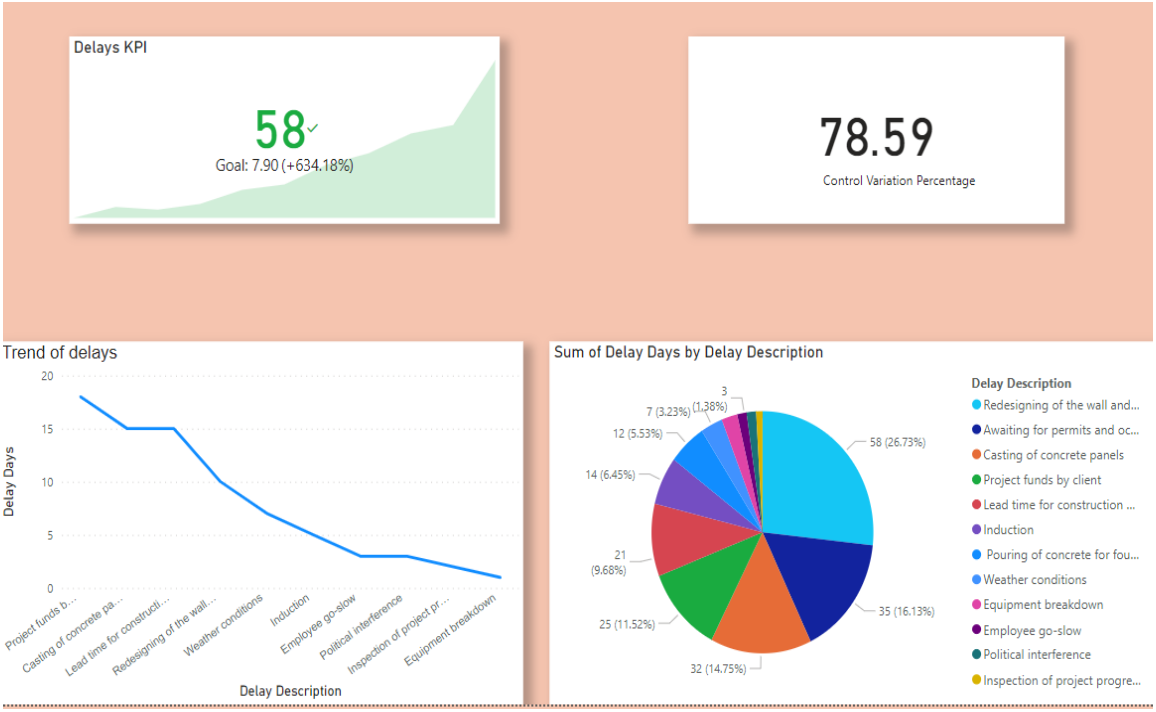

Figure 40-Visual dashboard of the project's overall progress

The improved employee management strategy depicted in Figure 40 involves the implementation of the CiteOps software, which is a digital tool that enhances communication and coordination among team members. This software allows the on-site supervisor to assign tasks to individual employees and track their progress in real-time. It also provides a platform for employees to report any issues or concerns they may have, allowing for quick resolution and preventing any potential delays or inefficiencies.

The CiteOps software also includes a feature that enables the on-site supervisor to monitor the productivity of each employee. This feature tracks the time taken to complete tasks and compares it to the expected time, providing insights into individual performance. This data can be used to identify any bottlenecks or areas where additional training or support may be needed. Furthermore, the software facilitates effective communication and collaboration among team members. It includes a messaging system that allows employees to communicate with each other and share important information or updates. This ensures that everyone is on the same page and can work together efficiently.

In addition to the CiteOps software, the improved employee management strategy also emphasises the importance of regular meetings. These meetings are conducted to review progress, address any issues or concerns, and ensure that tasks are being completed accurately and on time. By regularly bringing the team together, the on-site supervisor can foster a sense of accountability and teamwork, leading to improved overall performance.

Overall, the implementation of the CiteOps software and the improved employee management strategy depicted in Figure 41 have resulted in enhanced planning, increased employee productivity, and improved process efficiency. The combination of digital tools and effective communication and coordination strategies has allowed for better monitoring and management of construction project tasks, leading to more successful and efficient project outcomes.

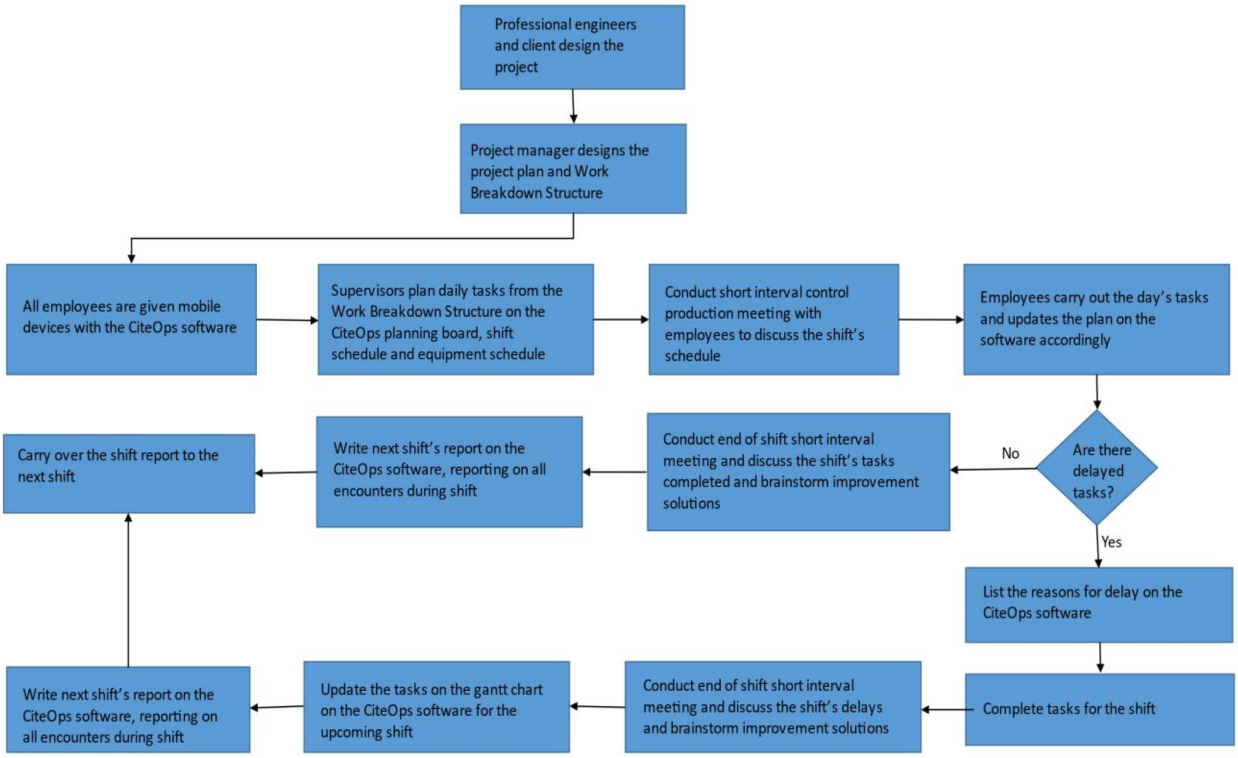

Figure 41- Improved team management.

4.3 Chapter Summary

This sub-chapter presented the data that was captured and utilised in this research. Data validation was conducted to ensure that the data used to validate the model, generates results that are valid and reliable. The results were presented and discussed by incorporating factor analysis in the DMAIC framework to create a hierarchy of variables that contribute to process inefficiencies and delays. It started with presenting and confirming the data utilised in this dissertation. The Economic Order Quantity model predicted the ideal material lead time and quantity by finding the most influential element, which in this case was large lead times. This strategy aimed to shorten the time spent on lead time delays by recommending optimum order quantity and time. The CiteOps software improved work planning and scheduling, with dashboards allowed for remote monitoring and examination of project progress.

Chapter 5

Conclusion and Recommendation

5.0 Chapter Overview

The final section of the dissertation provides a comprehensive summary of the research that has been conducted. It not only highlights the success of the methodologies employed but also outlines the findings of the research. Additionally, it offers practical suggestions for construction companies to adopt sustainable practices to reduce inefficiencies in construction processes.

5.1 Conclusion

The efficient execution of construction projects relies heavily on the coordination and supervision of tasks. This coordination ensures that project objectives are achieved within the specified timeframe, budget, and scope. It is crucial to optimize construction processes to meet quality standards while minimizing costs. To identify and address inefficiencies in construction projects, a modified version of the Lean Six Sigma approach called DMAIC (Define, Measure, Analyse, Improve, and Control) has been developed. This framework utilises inventory management principles to tackle the factors that have the greatest impact on process inefficiency. The DMAIC framework consists of five phases: define, measure, analyse, improve, and control. In the define phase, a value stream map is used to identify the factors contributing to process and project inefficiencies.

It has been found that the availability and ordering of materials and equipment are major contributors to project delays. The inconsistent availability and ordering of materials and equipment have resulted in a material lead time of seventy-one days. Furthermore, engineers' reluctance to conduct thorough inspections has also led to process inefficiencies. The lack of guidance from the management team during the construction phase has resulted in numerous tasks needing corrections among employees. This can be attributed to the physical distance between specialists and the construction site, which hinders timely decision-making. Project delays were found to be influenced by the availability of equipment, as evidenced by the excavation stage taking fifty-four days to complete. Several factors were identified as major contributors to process inefficiency, including waiting periods for permits and occupation, induction and onboarding of employees, material lead time, reworking of tasks, concrete panel manufacturing, weather conditions, delayed material ordering, inspection of project progress, availability of skilled employees, and equipment availability.

During the measurement phase, it was determined that the average total delay days were 40.5, with a standard deviation of 42.05 days. The control variation was calculated to be 103.83%, indicating that the process variation was 63.83% higher than the acceptable control variation for construction. This highlights the need for attention to be given to improving process efficiency. The diverse and unexpected reasons for delays made control exceedingly difficult. To determine the root causes of construction project process inefficiencies, the fishbone technique was employed in the analytical phase. This technique categorised the factors contributing to process inefficiency and factor analysis was conducted to rank these factors based on their impact. The lead time was found to have the highest impact on project delays, with delayed order placing being a significant influencing factor. The correlation coefficient between lead time and delayed order placing was calculated to be 0.66. The lack of over-inspection, which was hindered by equipment availability, emerged as the second most significant reason for delay.

The availability of remote inspection and monitoring technology was found to have a positive effect on reducing the frequency of over-inspections. The primary focus of the improvement phase was to develop a solution for addressing the variable with the greatest impact, which in this case was the materials lead time. To achieve this, an EOQ model was created to determine the optimal order quantity and order time. By utilising the equation derived in chapter 4, the precise ordering time for the specific construction materials can be calculated. This ensures that there is a sufficient supply of building material for the job and minimises delays caused by long lead time. CiteOps is an interactive system that connects management planning with the labour of frontline staff through digital assignment arrangement and updates for each shift. It allows supervisors and engineers to remotely track the progress of assignments in real-time. Additionally, offsite experts can utilise the system to monitor projects and hold personnel accountable, identifying potential concerns early on and preventing delays. Supervisors have the ability to monitor employee progress as they work, and the program facilitates the generation of shift reports and participation in daily review sessions. A visual report is then generated and uploaded to the company's on-premises report server, where real-time data is recorded. This approach enables offsite experts to monitor project progress while maintaining responsibility and eliminating delays.

5.2 Economic Order Quantity

This model has been used to derive an equation that determines the optimum order quantity. Using the derived equation, management can predict the best order quantity that will minimise project progression delays due to long lead times. It also derived a model that determines the optimum order time. The model is successful in ensuring the reduction of long lead times as it was one of the major factors that contributed towards process inefficiencies. The model determined that every thirty-six days, two-hundred and fifty-six panels must be ordered as they have a twenty-one day fabrication time, five-thousand-five-hundred and twenty-nine bags of cement must be ordered every fifty-four days, one-hundred and sixty-three palicades must be ordered every one-hundred and forty-two days, one-hundred and thirty-six columns must be ordered every thirty-four days as they also have a fabrication time of up to twenty-one days, and lastly, five-hundred and thirty-seven rods must be ordered every ninety-eight days.

5.3 Proof of Objectives Attainment

The research had well-defined objectives that aimed to reduce costs by optimising processes. These objectives involved identifying, defining, and categorising tasks that caused inefficiencies in the process. Additionally, the objectives included utilising a Lean six-sigma framework to address inefficiencies in construction projects. This involved understanding the impact of each factor on the process efficiency and implementing digitalisation to enable remote progress tracking and monitoring. The objectives were successfully achieved through the use of the DMAIC framework. This was evident in the development of a value stream map, which highlighted the factors contributing to process inefficiency. Furthermore, the framework quantified the impact of each factor, leading to the utilisation of the EOQ model to minimise the impact of material lead time, which was identified as the most significant factor.

Table 8- Objectives Attainment.

Objective Number	Objective Description	Sub-Section	Section	Chapter	Page Number
1	Identify, define and categorise tasks that contribute towards construction process inefficiencies and determine each factor's impact on construction process inefficiencies.	 4.1.4 4.1.4	2.3 2.4 4.1 4.1	2 2 4 4	p30-33 p33-41 p128-129 p132-137
2	Make use of a Lean six-sigma framework to measure the current process efficiency as well as minimise inefficiencies in construction projects.	2.10.3 2.10.4 4.1.4 4.1.4	2.10 2.10 2.11 4.1 4.1	2 2 2 4 4	p74-75 p75-76 p76-86 p129-131 p132-137
3	Digitalise the construction project to enable remote progress tracking, monitoring and supervision.	4.1.4	4.1	4	p137-144

5.4 Research Findings

The research findings are valid facts stumbled into during the course of this research even though some these facts were initially not set out as the primary research objectives hence, these are eye openers. In a bid to connect the findings to the main purpose of this research, it should be recalled that the purpose of this research is to examine and evaluate the various factors that lead to inefficiencies in construction projects. Through a comprehensive analysis, this study aims to identify and measure the impact of these factors. The research concludes by listing some findings that can effectively aid with the control and monitoring of the processes, thereby addressing the identified inefficiencies. The findings include:

1. A significant number of tasks were identified as the root causes of delays and inefficiencies in the process. The identification of these factors was accomplished through the utilisation of value stream mapping, which facilitated the identification of activities that did not add value to the completion of the project. The mapping of the construction processes played a crucial role in the diagnosis and definition stage of process optimisation. Six factors were recognised as the primary contributors to process inefficiency. These factors included lengthy material lead time, task corrections, unpredictable weather conditions, delays in order placements, inadequate over-inspection, and limited equipment availability.
2. The primary factors that significantly contributed to the inefficiencies in the process were the extended lead time for materials, the need for rework on tasks, and the delayed placement of material orders. These factors collectively resulted in a process control variation of 103.83%, surpassing the acceptable control variation by 63.83%. Consequently, the process became highly unpredictable, uncontrollable, and ultimately inefficient.
3. The fishbone technique was employed to categorise these factors, revealing that the primary causes of process inefficiencies were attributed to inadequate methods. Nevertheless, through factor analysis, these factors were prioritised based on their level of impact, ranging from significant to minor. The order of importance was determined to be as follows: extended material lead time, delayed material ordering, and unfavourable weather conditions. Notably, among these three factors, extended material lead time held the highest ranking, with a loading factor of 0.66, which was the closest to 1.
4. Based on the analysis conducted, the Economic Order Quantity (EOQ) model was employed to formulate equations that ascertain the most favourable order quantity and timing. By ensuring the timely and optimal ordering of building

materials, the detrimental effects of prolonged lead times and inefficiencies caused by delayed material procurement are minimised.

5. It is crucial to continuously monitor this enhanced procedure to maintain its optimal state. The implementation of CiteOps and dashboards in the construction project's digitalisation guarantees the real-time measurement of data, thereby enabling remote tracking of tasks and process efficiency by management.

5.5 Recommendations

The project's progress was influenced by dynamic factors that are subject to changes over time. To determine the most significant factors causing project inefficiencies, it is recommended to conduct factor analysis and establish a current hierarchy. The Economic Order Quantity (EOQ) model is specifically designed to determine the optimal order quantity and order time, which can effectively reduce long lead times. To promote transparency and accountability, it is advisable to upload control charts and dashboards on an on-premises report server accessible to all employees. However, it is crucial to ensure that the data displayed on the dashboard is regularly updated in a database and connected to the company's on-premises report server. This will enable the dashboard and control charts to provide the most up-to-date information regarding project progress. The utilisation of CiteOps software is highly recommended as it has been proven to enhance employee productivity by clarifying their responsibilities and expectations.

Additionally, it aids in efficient task delegation and minimises delays and variations within the process. The software also enables supervisors to monitor project progress in real-time and remotely, allowing for prompt error detection and resolution before they escalate into significant issues. The DMAIC framework has been tailored in this dissertation to incorporate inventory management and provide a generalised solution. Nevertheless, there are prospects for additional research and development of the proposed solution. This solution can serve as a basis for enhancing the EOQ model to accommodate construction projects with fluctuating demand for building materials, which is not always consistent. In terms of future possibilities, this solution can be modified to remain effective for projects that do not consistently order or utilise building materials at a steady pace, contrary to the assumptions made in this dissertation.

5.6 Chapter Summary

The final section of the dissertation encompasses the conclusion, research findings, objective achievements, and recommendations. It reaffirms the effectiveness of the tailored DMAIC framework in enhancing the efficiency of construction processes. Additionally, it offers valuable insights for future endeavours and potential enhancements. In conclusion, this chapter serves as a comprehensive summary of the dissertation, encapsulating the key elements such as the conclusion, research findings, objective accomplishments, and recommendations. It emphasises the effectiveness of the customised DMAIC framework in addressing inefficiencies in construction processes. Moreover, it serves as a valuable resource for guiding future work and potential improvements in this field.

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Appendices

Table 9- Material Sourcing delay times

Material Sourcing					
Project Activity	**Length of Panel**	**Planned Lead Time**	**Actual Lead Time**	**Lead time variance**	**Delay in Ordering Time**
230 X 90mm PFC Section 1	155m	22	22	0	0
120mm Pre – cast concrete panels	155m	21	33	12	3
900mm Palisade fence	155m	14	33	19	16
230 X 90mm PFC Section 2	195m	23	45	22	0
120mm Pre – cast concrete panels	195m	21	36	15	3
900mm Palisade fence	195m	14	36	22	16
230 X 90mm PFC Section 3	500m	23	93	70	0
120mm Pre – cast concrete panels	500m	28	100	72	3
900mm Palisade fence	500m	14	100	86	16
230 X 90mm PFC Section 4	465m	23	132	109	0
120mm Pre – cast concrete panels	465m	21	141	120	3
900mm Palisade fence	465m	14	327	313	16
230 X 90mm PFC Section 4	520m	22	326	304	3
120mm Pre – cast concrete panels	520m	21	327	306	16
900mm Palisade fence	520m	14	327	313	0
203 X 203 I Section 1	155m	22	22	0	3
120mm Pre – cast concrete panels	155m	21	26	5	16
900mm Palisade fence	155m	14	26	12	0
203 X 203 I Section 2	195m	23	43	20	3
120mm Pre – cast concrete panels	195m	21	41	20	16
900mm Palisade fence	195m	14	41	27	0
203 X 203 I Section 3	500m	23	41	18	3
120mm Pre – cast concrete panels	500m	28	9	-19	16
900mm Palisade fence	500m	14	104	90	0
203 X 203 I Section 4	465m	23	104	81	3
120mm Pre – cast concrete panels	465m	21	253	232	16
900mm Palisade fence	465m	14	142	128	0
203 X 203 I Section 4	520m	22	146	124	3
120mm Pre – cast concrete panels	520m	21	242	221	16
4,2m Palisade fence	539m	14	48	34	0

Table 10- Data table for jobs that required reworking

Reworking Jobs Description	Planned State Date	Actual Project Start Date	Date Completed	Number of Days to Completion
In-between trains occupation	27/05/2022	27/05/2022	17 /06/2022	21
Redesign of concrete wall	15/02/2022	15/02/2022	15/04/2022	58
Excavation and site clearing	16/04/2022	16/04/2022	30/07/2022	54
Layout 1 to layout 12 of concrete wall (Black River Parkway, Salt River Station)	06/06/2022	11/08/2022	28/02/2023	214
Layout 16 to layout 26 (Depo entrance to Black River Parkway)	11/10/2022	11/10/2022	05/08/2023	136
Layout 26 to layout 32	11/12/2022	11/12/2022	11/03/2023	101

Table 11-Data showing the number of days of lack of inspections

Reworking Jobs Description	Engineers Inspection Frequency Delays (%)	Days Spent without Conducting Inspections
In-between trains occupation	90	27
Redesign of concrete wall	93,33333333	28
Excavation and site clearing	53,33333333	16

Layout 1 to layout 12 of concrete wall (Black River Parkway, Salt River Station)	90	27
Layout 16 to layout 26 (Depo entrance to Black River Parkway)	83,33333333	25
Layout 26 to layout 32	95	28,5

Table 12-Data showing the waiting period for permits

Description	Planned Date Applied	Actual Application Date	Delayed Application Days	Date Issued by PRASA
RSR permit	15/04/2022	25/04/2022	10	30/04/2022
Occupation permit	27/05/2022	05/06/2022	8	3/06/2022
Notification of construction works with the Department of Labour	03/10/2022	11/10/2022	8	18/10/2022
Full occupation	16/02/2023	18/02/2023	2	22/02/2023

Table 13-Data showing delays in employee training day

Induction and Training Description	Delayed Days Spent on Training
Fire fighting	3
SHE Rep training	1
Incident training	1
First Aid training	2
Layout 26 to layout 32 training	35

Table 14-Delays due to weather conditions

Delay Days due to Rainfall	Rainfall Amount (mm)	Number of Days of Rain
13/06/2022	90	1
14/06/2022	20	1
12/08/2022	17	2
13/08/2022	12	4
17/08/2022	11	1
18/08/2022	9	7
25/08/2022	10	2
29/08/2022	3	1

Table 15- Data showing the number of skilled employees

Profession	Number of Skilled Employees
Construction Manager	1
Civil Tech	1
Electrical Tech	1
Environmental Tech	1
Safety Officer	1
Stores Lady	1
Surveyor	1
Site Administrator	1
Skilled	5

Table 16- Number of unskilled employees

Unskilled Employees	Number of Unskilled Employees
Semi-Skilled	2
Labour	14

Table 17- Equipment and machinery availability

Equipment Description	Planned Availability	Actual Availability
Total Station	1	1
Dumpy Level	1	1
Generator	2	1
Poker and Drive Unit	1	1
TLB's	1	1
Light Driven Vehicles (LDV)	6	4
Trench Compactor/Whacker	1	1
Piling rigs	4	4

Table 18- Purchasing of construction material.

Material	Average Quantity Used (units)	Estimated Days of reordering (days)	Purchase price per item (R)
Panels	86	33	850
Cement	230	30	80
Palicades	158	141	950
Columns	58	32	1500
Rods	100	93	500

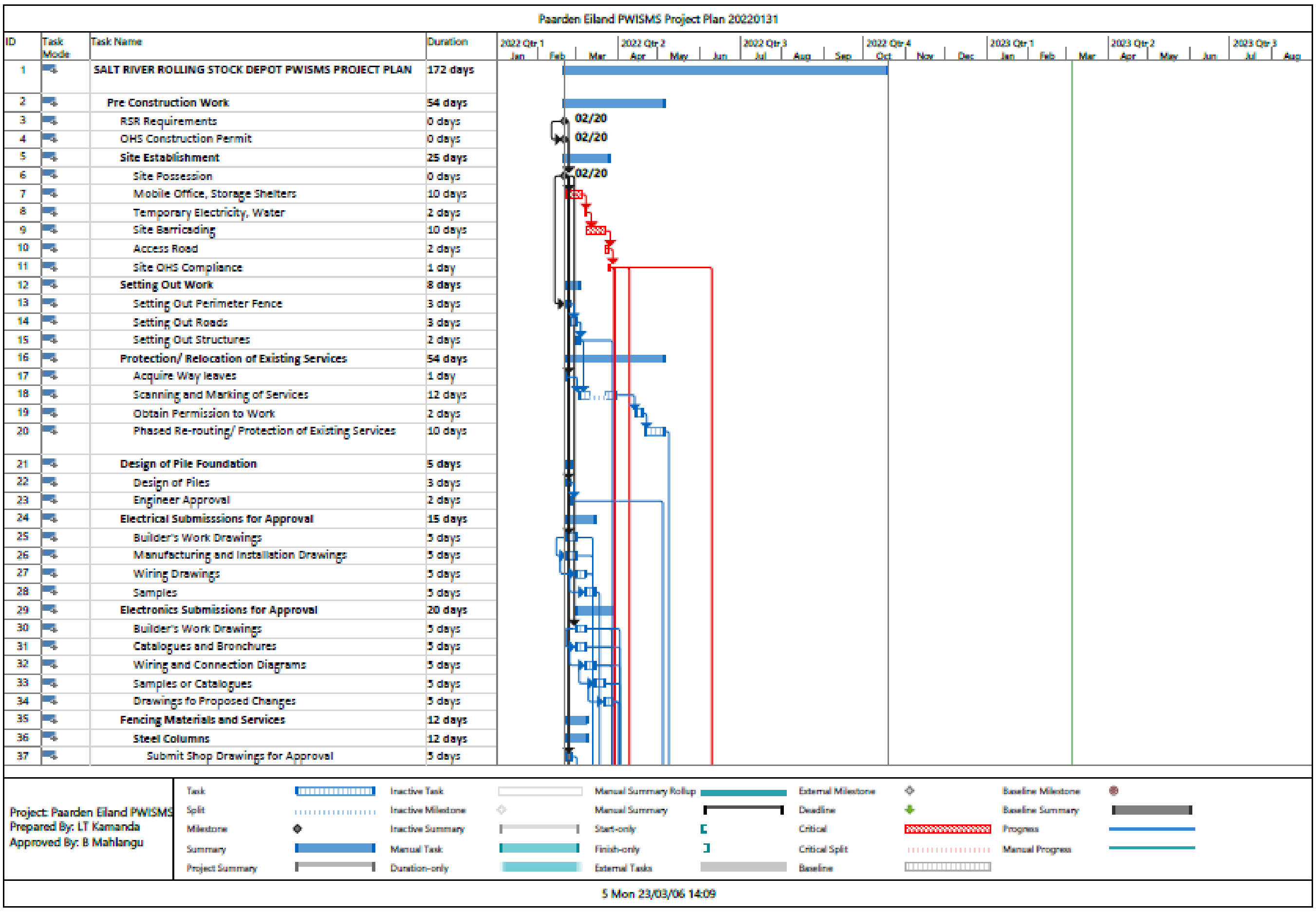

Figure 42- Wall Construction Project Plan

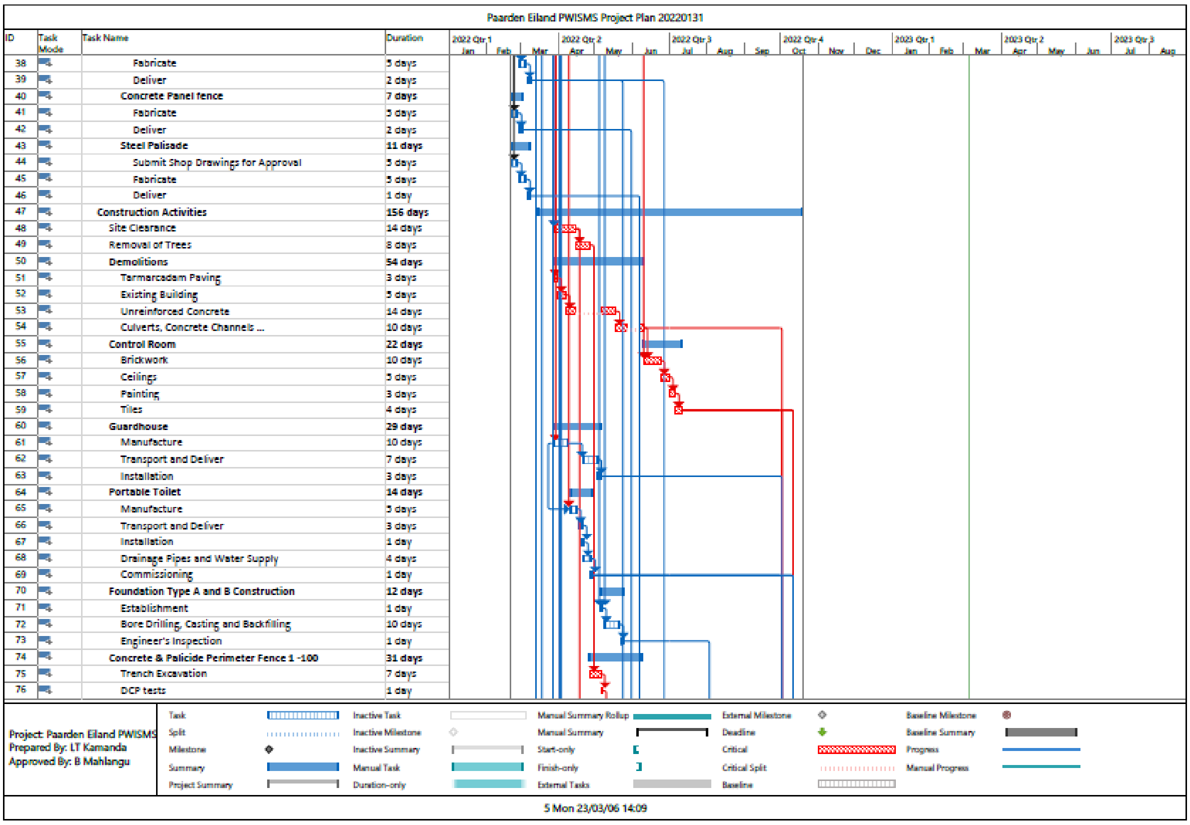

Figure 43- Wall Construction Project Plan

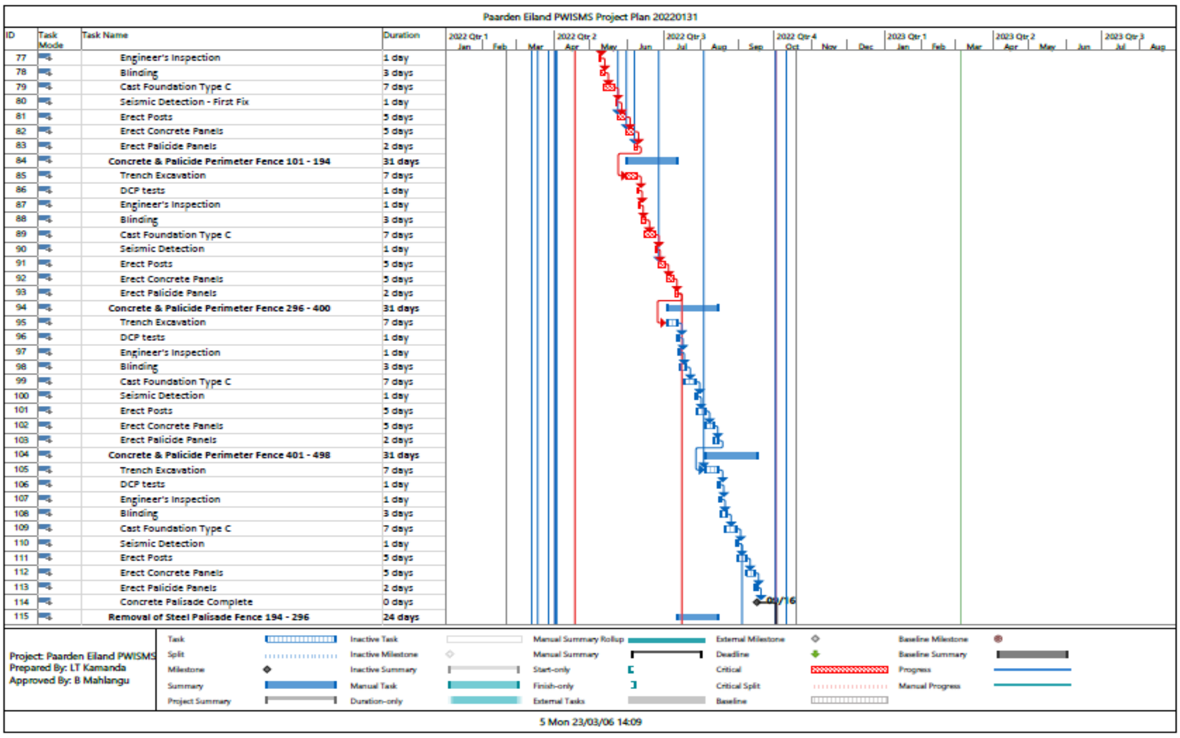

Figure 44- Wall Construction Project Plan

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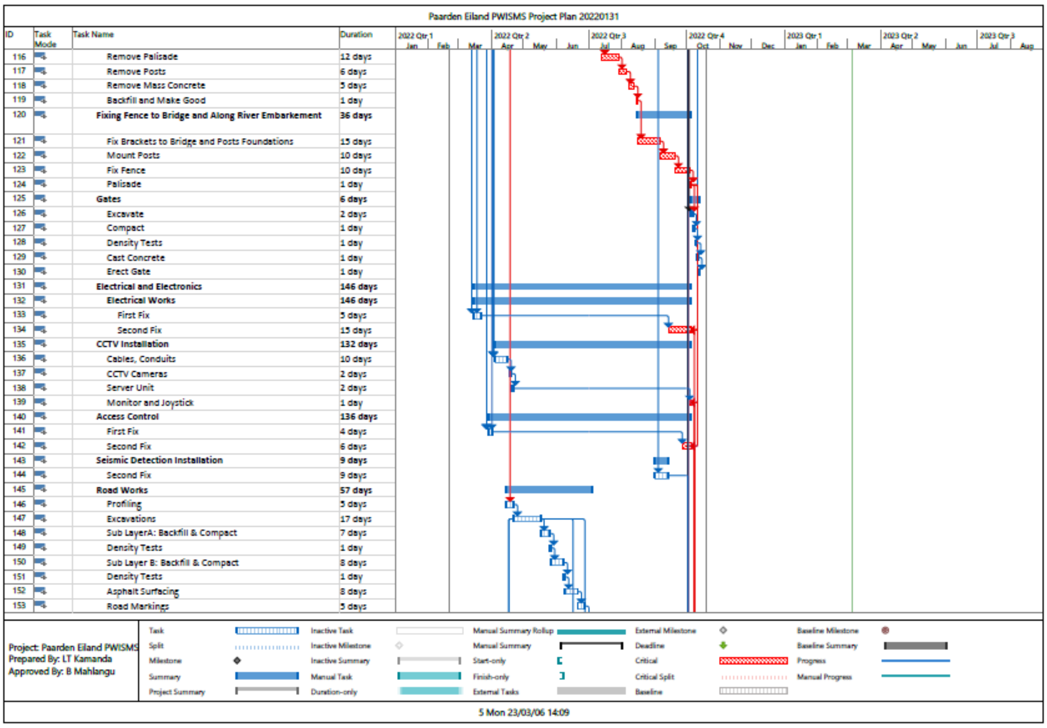

Figure 45- Wall Construction Project Plan

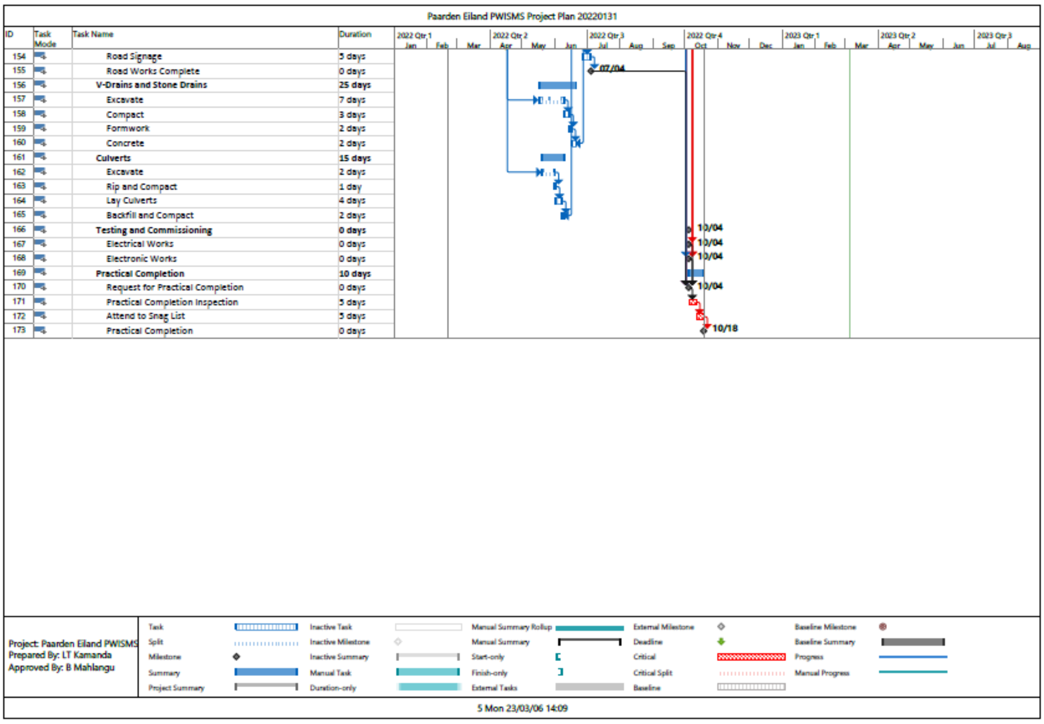

Figure 46- Wall Construction Project Plan