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A project management methodology for a mining stope

A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of

MASTER OF PHILOSOPHY

IN

ENGINEERING MANAGEMENT

AT THE

FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT

UNIVERSITY OF JOHANNESBURG

By

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08 August 2017

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ACKNOWLEDGEMENT

My supervisor Professor Jan-Harm Pretorius, I am grateful for your tireless supervision and guidance to the fulfilment of this research, your patience and understanding makes you the coolest supervisor.

My mentor Mr Peter Knottenbelt, your support and encouragement has made me realize that there are no limits to what I can achieve.

My partner in research Mbali Mpanza, I am grateful for the time you dedicated to read my research, your motivation is pushing me to do more.

The Officials of the mining company where the research was conducted, you did not even know me, yet you did not hesitate to give me this opportunity, I am grateful.

The contribution of everyone at the University of Johannesburg, Mining and Mine Surveying Department towards this research is appreciated.

“It was only through God that this work could be successfully completed”

This research is dedicated to my husband Matodzy Nelwamondo, my daughters Thando and Pfano Nelwamondo.
ABSTRACT

Although South Africa possesses more than 80% of the world’s platinum reserves, its reliability in supplying platinum to global markets is under threat. This is due to the decrease in output per worker of 49% (1999-2014), while the domestic cost have risen too quickly by more than 10% annually for the past 5 years. In addition, the continued decline in the commodity price by 38.3% (2012-2016) which has led a significant portion of the sector to mine at a loss in 2015. The chamber of mines has suggested that solutions to improve productivity and reduce cost pressures are required. This research aims to increase productivity by providing operational excellence through the improvement of efficiency by applying a project management methodology to a mining stope. The selected methodology for application was the Event Chain Project Management methodology, which should manage the inherent risks, which affect the mining stope schedule, improve the efficiency of operations by reducing the time spent in each activity, improve productivity by reducing the duration of the project, and reduce operational costs in the process. A case study used to carry out the research in platinum mines; data collected using a motion time study to measure the current efficiency of operations in each mining stope through actual activity durations. The results indicate that through the application of the Event Chain Project Management methodology, risks affecting the mining stope schedule were properly managed, the efficiency of operations was improved through the reduction of time spent in each activity, productivity was increased by reducing the project duration, and operational costs were reduced in the process.
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1. BACKGROUND

1.1. Introduction
The total mining industry production was 4.9% lower in 2016 compared with 2015; it decreased by 1.9% year on year in December 2016, with the main contributor to this negative trend being the Platinum Group Metals (PGM) with -15.1% and contributing -3.8% percentage points (Statistics South Africa, 2016). Although South Africa possesses more than 80% of the world’s Platinum reserves, the continuous depreciation in production output of the PGM by 8% since 2008 has put the industry under the threat of being seen as an unreliable supplier to global markets. This decline in production caused by the decrease in output per worker of 49% (1999-2014). In addition, the continued decline in the commodity price by 38.3% (2012-2016) and an increase in operational costs during the same period has resulted in a significant portion of the sector to mine at a loss in 2015. A turnaround strategy is required to overcome these challenges, the Chamber of Mines has suggested among others, the need for solutions to improve productivity and reduce cost pressures. The uncovering of these solutions will ensure that this industry thrives and reaches its potential of growing production to more than 322 tonnes by 2020 (Baxter, 2016).

1.2. The mining stope
The study area is an underground mining stope where the extraction of PGM takes place using conventional drilling and blasting mining method. The PGMs are mined in the Bush veld complex, which comprises of three distinct reefs, Merensky, UG2 and Plat reef. These reefs are shallow dipping at 9º and 25º, averaging about 10º respectively, and are regarded as narrow tabular ore bodies due to their thickness, which is usually less than a meter (Musingwini, et al., 2009). Activities in an underground conventional mining stope are sequential, daily and linked to achieve a blast. Furthermore, characterised by deadlines, start and finish times, and resources are required in order to achieve the daily blast. In most cases, daily activities are usually unrecognized due to their small size, repetitiveness and continuity (Mokoena, et al., 2013). Although the conventional mining method may be the most prevalent in narrow tabular ore-bodies, it does have its own set of challenges among others low productivity. In the past, different methods were tried to improve productivity in conventional mining; these methods included changing from conventional method to mechanized method. The conventional mining method is the extraction of a mineral using hand-held pneumatic drill machine, while mechanized methods involves the extraction through mobile trackless machinery. The assumption has always been that mechanisation decreases labour costs and increases
productivity, while the conventional method increases labour costs and decreases productivity. This assumption was tested when Lonmin embarked on a project in 2004 to convert the Saffy shaft mining method from conventional to mechanization, but in 2012 Lonmin made a decision to revert back to conventional mining method; because mechanisation failed to improve productivity and reduce cost (Anon, 2012). Furthermore, the conventional method overall ranked the most efficient compared to hybrid and mechanized mining methods, when considering parameters such as grade control, extraction ratio, dilution reduction, operating costs and production rate. The results were based on an Analytic hierarchy process (AHP) which belongs to a technique of multiple criteria decision analysis (MCDA), it is a tool that can be used to select the best alternative from a finite set of alternatives (Muswingini & Minnitt, 2008).

1.3. Risks in a mining stope
The mining industry has a high-risk profile, with risks involved in exploration, operations, commodity price, regulatory, financial, exchange rate fluctuations and political risks. However, given all the advanced risk assessment tools available for use, the mining industry still maintains its highly ranked profile; this due to its fragile nature of risks and uncertainties; which have potential to cause failure (Holmes, 2003). Mndzebele (2011) states that risks are unpleasant facts in all mining type projects. Phillis (2009) suggests that a stope could equate to a micro-project due to its concurrent activities that require precise execution with limited resources within a finite shift duration. Due to the afore-mentioned nature of mining, traditional operational management techniques cannot effectively improve productivity. Because operational management deals with the planning, organising, and controlling of activities affecting human behaviour, this done through models. These models represent schematic representation of the situation, used as a tool for decision-making (Kumar & Seresh, 2009). Therefore, operations management cannot deal with the risky nature of mining, because a mining stope qualifies to fall within the field of project management due its “project like” environment. Moreover, changes in a project environment are inevitable, in order to manage them effectively, organizations sometimes change their operations, by creating strategic business initiatives that are developed and implemented through projects (InstituteProjectManagement, 2004). According to Patrick (2013), project environments are characterized by high degrees of risks and uncertainties, which result in the project failing to meet the requirements of the triple constraint, because they are often late, over budget, and under scope. These risks are discrete occurrences that may affect the project in a bad way, and
uncertainties are uncommon states of nature, characterized by the absence of any information related to a desired outcome (William, 2004).

Due to their nature, mining stope operations are highly affected by internal risks, which are occurrences that a project team can control or influence. They come in a form of time, cost, scope changes, inexperienced people, staffing, materials and equipment. Time as a risk in a mining stope originates from the finite shift duration, allocated for the completion of all activities required to achieve a blast. Any unexpected change in project scope is a risk because of the limited time available for project completion. Team member’s availability increases the chances of project success; however, absenteeism, annual leaves, and lack of the required skill or experience to execute the activity are common risks associated with members in the mining stope teams. The availability of resources and equipment required to carry out project activities is a common risk in a mining stope. These risks have potential to affect the planned project duration leading to delays in activities and ultimately project failure. According to Razaque (2012), there is an existing liaison between risks residing in the project and related activity time. Therefore, the significant way to manage risks in a project is to understand their effects on project schedule, in order to estimate a reliable project schedule. Patrick (2013), further states that every organization can achieve competitive advantage by completing projects sooner. This competitive advantage comes through the realization of project benefits, and the fast delivery of projects with the same resources, reduces the overall costs per project. In the mining industry, costs are a biggest challenge, according to the Chamber of mines (2016), domestic costs have risen too quickly; electricity prices have trebled in 7 years, wages up more than 10% annually for the past 5 years, and stores and materials up more than 10% annually for the past 5 years. Therefore, the reduction of a mining stope project duration can influence positively on the reduction of costs.

1.4. Productivity

This research aims to increase productivity and reduce costs by providing operational excellence through the application of a project management methodology to improve efficiency in a mining stope. Productivity is the effectiveness of the input effort as measured in terms of the rate of the output produced; and can assess the extent to which a certain output extracted from a given input. However, in operations productivity is highly affected by operational deficiencies, regarded as internal factors. One of the powerful tools used to increase operational productivity is work-study, which is a systematic examination of methods used to carry out activities in order to improve the effective use of resources and to set up standards of
performance for the activities carried out. Work-study aims to examine the way in which an activity is carried out; it simplifies and modifies the operational method, so that a standard time for performing that activity is set. It embraces techniques such as method study and work measurement. Method study is the systematic recording and critically examining ways of doing things in order to make improvements; and work measurement is the application of techniques designed to establish the time for a qualified worker to carry out a task at a defined rate of working. When these techniques are applied to study the work in an operation, the productivity will increase as indicated in Figure 1.1: Work Study. Work-study helps to achieve the smooth production flow with minimum interruptions, and reduce the cost of operation by eliminating wastage in time and resources (Kanawaty, 1992). However, work-study as an operational management tool cannot deal with risks and uncertainties within operations.

![Figure 1.1: Work Study (Kanawaty, 1992)](image)

1.5. Project managing risky stope operations

According to Koleczko (2012), the management of risks and uncertainties is the fundamental principle of project management’s role. Furthermore, Virine (2017) states that project management is the art of analysing and managing risks, without risks, there is little need for project management. Because project management is extremely flexible and can be adapted to
any project, its strength focused on adaptation to different project needs, including risky projects (Malczyk, 2011). The suggestion by Moorosi (2010) that the use of Project Management Best Practices can contain costs and increase production in a Gold mine, although this was an endeavour to render high-tech projects a success in the industry. It gives effect to the use of project management as a tool to improve productivity in all mines due to the similar. A best practice is “an idea that asserts that there is a technique, method or process through research and application that is more effective at delivering a particular outcome than any other technique, method or process” (Gina, 2009). According to Munns (1996), project management is a tool used to improve efficiency and performance in operations; furthermore, it is more efficient than traditional functional management methods, especially in complex environments.

A project is “a temporary endeavour undertaken in order to create a unique product, service, or results. It is temporary because it has a definite beginning and definite end, once the project reaches its objective the project ends. However, temporary does not necessarily mean short, as most projects are designed to create a lasting outcome. The uniqueness of the project refers to the unique deliverable, which come in a form of product, services or results (Project management Institute, 2004). However, projects can advance the organization’s performance to higher levels, and operationalise business plans (Van Wyngaard, et al., 2011). Projects are used to drive the desired positive change within an organization; all operational processes like business re-engineering, product development and operations improvement are projects (Prakash, 2017). As contemplated by Strauss (2016) the application of project management principles within the production-mining environment, referring to it as “operational project management” could significantly contribute to the sustainability and competitiveness of platinum mines.

This research aims to provide operational excellence by improving efficiency in a mining stope, through the application of a project management methodology, which will manage inherent risks affecting the mining stope schedule, by improving the efficiency of operations through the reduction of time spent in each activity, improve productivity by reducing the project duration and reduce costs in the process. Although considered a challenge to create a workable methodology for a project, however, a good methodology can improve productivity in a project (Kononenko & Kharazii, 2014).
1.6. Problem Statement

The Platinum Mine where the study was conducted has reduced its estimated production outlook for 2017 to 710 000 platinum ounces from the initial plan of 750 000 platinum ounces, this will affect the production guidance of 830 000 building up to 2020. The reduction was due to a deterioration in production from an average face advance of 17m per month in 2009; to a 35% decrease, of an average face advance of 11m per month in 2016. Which is 15% less than the current planned average face advanced per month of 13m. There are many external factors, which contribute to this deterioration in production among others, frequent issuing of Section 54 stoppages, underground fires, and falls of ground incidents. However, the company seeks to improve efficiency through operational excellence strategies that will improve productivity regardless of external factors.

1.6.1. Research Objectives

This research aims to provide operational excellence by improving efficiency in a mining stope, through the application of a project management methodology, which will ensure the following:

- Manage internal risks in a mining stope affecting the mining stope schedule.
- Improve the efficiency of operations by reducing the time spent in each activity.
- Improve productivity by reducing the duration of the project.
- Reduce operational costs.
- Be a pilot for all other Platinum mines with similar conditions.

1.6.2. Research Questions

This research aims to provide operational excellence by improving efficiency in a mining stope, through the application of a project management methodology, which will answer the following questions

- Will the selected methodology be able to manage internal risks affecting the stope schedule?
- Will it improve the efficiency of operations by reducing the time spent in each activity?
- Will it improve productivity by reducing project duration?
- Will it reduce operational costs?
1.7. Research Outline

The first chapter introduces the problems faced by the mining industry, which have necessitated the need for improvement solutions in the production of PGM’s; furthermore, it states the objectives of the study. The second chapter reviews literature, which link a project management methodology and the project’s success, literature in project risks and risk management apply. Moreover, literature on the previous work done on the application of project management in the mining industry, and reviews the literature on available project management methodologies to understand each one’s characteristics and compare them with the requirements of the project. A methodology for a stope selected in this chapter. The third chapter elaborates on the methodology used to conduct this research; methods of data collection, analysis and interpretation are used. The methods used to test the data’s reliability and validity, and ethical considerations. Forth chapter deals with the application of the principle of selected methodology on the data collected, in order to test if this method can manage internal stope risks affecting the project schedule, improve the efficiency of operations by reducing the time spent in each activity, improve by reducing the project duration and reduce costs by reducing project duration. The firth chapter draws a conclusion from the analysis performed in Chapter 4. Then the sixth chapter recommends ways to dealing with the event identified.

1.8. Summary

This chapter introduces the problems faced by the mining industry, and the problems of deteriorating performance on the Platinum mine; all this has necessitated the need for solutions to improve productivity in platinum mining. A conventional mining stope classified, as a project requires a project management methodology that will enhance efficiency of operations by sufficiently dealing with the internal risks and improve productivity. This is in response to the requirement stated by the Chamber of Mines to deal with the challenges faced by the South African Platinum mining industry. The following chapter will discuss the literature review on this topic.
2. A PROJECT MANAGEMENT METHODOLOGY FOR A MINING STOPE

2.1. Introduction
In a study conducted by Joslin (2016) in project management methodologies, it is proven that there is a relationship between the project management methodology (PMM) used in a project and the project’s success. The PMM is a tool meant to increase project’s success by enhancing project effectiveness, the comprehensiveness of the methodology towards the project will determine the success or failure of the project. When the PMM is incomplete or limited it compromises on the project’s efficiency, quality and its probability to succeed. The study further indicated that 50% of people who have used the PPM have experienced limitations in methods, processes, tools and techniques, because the methodologies differ in entirety and suitability for different projects. A method applied in a particular situation and a methodology is the sum of all methods and their understanding; other methodologies deemed incapable of serving other projects, while others sometimes overlap. Therefore, the selection of the right method for a project is the first step to project success (Joslin & Muller, 2016).

2.2. Project management use in industries
Over the years, project management has moved away from using “user-friendly” processes, now based on structured methodologies that aim to improve performance by enhancing productivity. More companies have recognized the need for application of project management in their processes; its use has spread to all industries. Their processes involve continuous action, operations, changes, which occur in a definite manner. Operations are concerned with ensuring that the day-to-day business is controlled, and the transition of projects into production goes smoothly; while continuously improve the quality of service. Although there is a general perception that operations and projects are different and total opposites; in contrast, there is a link, the continuous improvement required in operations is “project” driven. Companies are now welcoming project management, and its application in their workplace for improving performance and efficiency. The Information Technology (IT) industry, which deals with the use of computers and software to manage information; is one of the leaders in this intervention. It has employed a more projective view to its work, moreover, it uses a set of project management techniques and tools to accommodate the complex IT work (Burke, 2007). Furthermore, the mining industry has also recognised project management as a useful tool used to put together a team of specialists for a successful completion of mining capital projects (Engineering news, 2014). Capital projects are lengthy investment used to build, add or
improve on a project; they require the use of significant capital, both financial and labour, to start and finish. Zentano (2008) concluded that uncertainty is inherent in capital projects; they require rigorous risk assessment and management, which project management, can offer through its management of change and unpredictable conditions (Zentano & Ferguson, 2008). Mining companies are known to outsource the skill for managing their capital projects from consultants, due to the high risks involved (Baloyi, 2013). Project management in mining capital projects reduces the period between commencement of major expenditure and revenue collection, and improving project returns. This achieved through the mining phase-gate approach, which requires feedback on all activities in a phase prior to the opening of the next gate. This approach has sound support for project management; furthermore, it ensures commitment to up-front planning, requirement use, scenarios and work break down structures (Ireland, 2008). Due to the outsourcing of the project, managing skills in mining capital projects, when operations commence the skill is lost with the consultants; it does not feed into the mining operations.

2.3. Project Management

According to Project Management Body of Knowledge, a project is a temporary endeavour undertaken in order to create a unique product or service. Temporary means that there is a definite beginning and definite end, however, most projects are undertaken to create lasting results. Projects are unique because they involve the creation of something new; therefore, every product or service undertaken is different from any other. Project Management (PM) is the application of knowledge, skills, tools, and techniques to project activities in order to meet the stakeholder needs and expectation from a project (Project management Institute, 2004). The knowledge applied comes from the ten-project management knowledge areas, which provide ways to organize and categorize knowledge and skills needed in a particular specialty. These knowledge areas link up major professional fields, and the skills required are for leadership to ensure that the diversity within a team embraced for the benefit of the project. The skills in PM are the soft skills that complement technical skills, these skills enables the project manager to lead the project team in coming together; they include communication skills and leadership skills. PM uses powerful tools to track down absent deliverables, analyse data, and communicate information to stakeholders, these tools include software’s and apps. The techniques in PM describe the proper way to gather information, communicate information, and the most efficient and effective way of doing things, this done through the project
management methodology. Project Management Methodology (PMM) is “set of guidelines or principles that can be tailored for a specific situation”. These guidelines provide a project’s framework and guide the project throughout its life cycle (Chartvat, 2003). A project’s life cycle is the inter-related phases of a project, a programme or portfolio and provides a structure for governing the progression of work. It plays a major role in narrowing the project's focus, and keeping the objectives in order (Picariello, 2015). However, according to Saad (2011), a project will encounter the triple constraint in its life cycle (Saad, 2011). The triple constraint represented in Figure 2.2: The Triple Constraint is a fundamental concept to the theory of project management, which combines three project restrictions. These restrictions are traditional factors, which are inter-dependent; they are scope, time and cost. These three factors relate in a defined and predictable way, because the cost is a function of scope and time; if one changes, then another must change in a defined and predictable way. None can change without affecting another. For example, if the scope decrease, it is likely to take lesser time and cost less. The opposite is true; the reduction of project duration will result in cost reduction and the scope reduction (Baratta, 2006).

**Figure 2.2: The Triple Constraint (Van Wyngaard, et al., 2011)**

According to Van Wyngaard (2011), the relations between the triple constraint involves trade-offs, and these trade-offs need consideration and prioritisation in order to realize strategic decisions. Furthermore, He states that a polarity management approach can provide a practical mechanism to facilitate optimum trade-offs between the key triple constraints. However, Mokoena (2013) suggests that some projects that un-accomplished within set constraints, with
the key reasons for this failure being failure to identify, monitor, control and manage project risks.

2.4. Project Risk Management

According to the PMBOK (2013), project risk management is the process of conducting risk management planning, which includes identification, analysis, response planning, and controlling risk on a project. Its main objectives of is to increase the likelihood and impact of positive events, and decrease the likelihood and the impact of negative events in the project. Risk identification is the process of determining which risks may affect the project and documenting their characteristics. Risk analysis is the process of prioritizing risks for further analysis or action by assessing and combining their probability of occurrence and impact, and numerical analysis, which measure the effects of identified risks on overall project objectives. The response involves the development of options and actions to enhance opportunities and to reduce threats to project objectives. Risks control is the process of implementing risk response plans, tracking identified risks, monitoring residual risks, identifying new risks, and evaluating risk process effectiveness throughout the project. The afore-mentioned processes involved in risk management illustrated in Figure 2.3: Risk Management Process.

![Risk Management Process](Debono_2016)

The successful execution of risk management is feasible through a Risk Management Plan (RPM), which is a document used to record all foreseen risks, estimate impacts, and define responses. The RPM requires that the project objectives be clearly stated, and understood by all stakeholders. The contents of the RPM include the process used to identify, analyse, evaluate and respond to risks throughout the life of the project, clearly defined roles, and the process of risks reporting (Kasap & Kaymak, 2007).

2.4.1. Risk Identification

The main purpose of the risk identification process is to generate a comprehensive list of risks based on those events that might delay the achievement of the project objectives. The risk
require identification, which is the process of determining which event might affect the project and documenting their characteristics, this is done by the project team with assistance from experts during the planning phase. According to PMBOK (1996), risk identification is not a onetime process; it must be conducted on a regular basis through the project, furthermore, it should address all risks. Risks are currently classified under, Internal, External, Technical and Unforeseeable risks. Internal risks are inherent in a project and associated with time, cost, unforeseen conditions, scope changes, inexperience, poor planning, people, staffing, materials, and equipment. External risks associated with regulatory issues, environmental matters, government, and market shifts. Technical risks involve the changes in technology, and unforeseeable contribute 10% of project risks (ProjectManagementInstitute, 1996).

There are tools available for use in a risk identification process among others, document reviews and information gathering. Document review involves the reviewing of project documents associated with current and previous projects. Information-gathering techniques include brainstorming, Delphi technique, interviews, Assumption Analysis, Risk register. Team members perform brainstorming; it focuses on the identification of risk for the project. The Delphi technique is when a team of experts consulted anonymously with a list of required information, all responses from experts compiled together and results sent back to them for further review until a consensus is reached. Interviews conducted with project participants, stakeholders, and experts, to identify risks. Assumption Analysis is the identification of different scenarios of the project and determining their validity, this helps in identifying risks for the project. A Risk Register is a document updated regularly throughout the life cycle of the project used to record experienced risks; it becomes useful to future projects. The process of risks identification will expose the sources or risks and provide alerts; these alerts will ensure that the right actions taken at the right time (ProjectManagementInstitute, 1996).

### 2.4.2. Qualitative and Qualitative Risk Analysis

The qualitative risk analysis is a subjective method, while the quantitative risk analysis is an objective method. Both methods play a major role to determine which risks warrant a response by determining the probability of occurrence, the severity of impact, and determine which risks requires full analyses based on its ranking (William, 2004). The probability of occurrence is the measure of the relative frequency or likelihood of occurrence of the risk, and it addresses the uncertainty dimension of the occurrence; while the impact addresses the effects dimension of the occurrence (Hillson & Hulett, 2004). The probability of risk occurrence calculated using the ratio of the number of favourable outcomes of the risk to the total numbers of the possible
outcomes. The scale used for the outcome is a percentage from 1%-100%, 1 being least probable and 100 being the more probable (ProbabilityFormula, 2017).

Equation 2.1: Probability Formula (ProbabilityFormula, 2017)

Probability = Number of favourable outcomes

Number of possible outcomes

In order to determine the consequences of each risk impact, a scale of 1-10 scale is used, (1) assigned to no impact and (10) to catastrophic impact, as indicated in Figure 2.4: Severity Scale. The risk occupying a scale of (1) is not a risk as there is no impact, and a risk occupying a scale of (10) will cause project failure. The severity of impact assessment criteria may include financial, schedule, health and safety, security, environmental, employee, customer, and operational impacts (Curtis & Carey, 2012). However, for this project will focus on operational impacts on the project schedule.

<table>
<thead>
<tr>
<th>Severity</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catastrophic</td>
<td>10</td>
</tr>
<tr>
<td>Extremely</td>
<td>9</td>
</tr>
<tr>
<td>Very High</td>
<td>8</td>
</tr>
<tr>
<td>High</td>
<td>7</td>
</tr>
<tr>
<td>Moderate</td>
<td>6</td>
</tr>
<tr>
<td>Low</td>
<td>5</td>
</tr>
<tr>
<td>Very Low</td>
<td>4</td>
</tr>
<tr>
<td>Minor</td>
<td>3</td>
</tr>
<tr>
<td>Very Minor</td>
<td>2</td>
</tr>
<tr>
<td>None</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 2.4: Severity Scale (FMEA, 1998)

The probability of the risk occurrence and severity of impact is determined through the risk impact assessment. Risk impact assessment is the process of assessing the probabilities and consequences of risks if they occur. The results from this assessment used to rank the risks in order to prioritize them, this process provide insights on where resources maybe needed to manage or mitigate the realization of high probability and high consequence of risk occurrence (SystemEngineeringGuide, 2017).

Risks ranking is a qualitative evaluation used to acquire information about the threat and its performance; more often, risks matrix is used (Munier, 2014). However, in this case a formula is used Equation 2.2: Risk Ranking. The process of risks ranking can provide realistic measure
of the potential impact and its relative importance as compared to other events. It avoids allocation of resources to low impact events, and can be a powerful indicator of the order in which the responses are prioritized (Virine & Trumper, 2017). One of the ways used to rank risks is to analyse its probability of occurrence and its consequences on a project. According to Severian (2014), the risk of loss, designating potential risks is the result of the severity of the impact and the probability (Severian, 2014); risk ranking estimated using the probability of risk occurrence and the potential risk impact on the project.

Equation 2.2: Risk Ranking (OWASP, 2016)

\[
\text{Risk Ranking} = \text{Probability} \times \text{Severity}
\]

The qualitative analysis provides the ranking of risks prioritizes risks and lists the risk, which require quantification for response planning. Through the qualitative analysis the risks in a project are compared to other project risks, that can enable the decision makers to selected, continued or terminated the project. While the quantitative risk analysis provides a prioritized list of quantified risks and gives forecasts of potential project costs or schedule (William, 2004).

2.4.3. Risk Quantification

Risk Quantification involves risk evaluation in order to estimate the possible outcome, primarily concerned with determining which risk warrants a response plan. It involves further investigation into the highest risks on the project using different tools and techniques, which determine which risks, have the most impact on the project. The tools and techniques used in this process are among others the expected monetary value, statistical sums, simulations, and decision trees. The expected monetary value as a tool uses the risk probability and risk value to determine the possible outcome when the risk occurs. The statistical sums used as a technique to calculate a range of total project costs, from the costs estimates of individual works to an estimate of the entire project’s work. The simulations uses a model of a system to analyse behaviour or performance to predict the possible outcome. The decision tree is a diagram that portrays key interactions among decisions and associated chance risks as they are understood by the decision makers (ProjectManagementInstitute, 1996).

2.4.4. Risk Response Plan

Risk response involves defining appropriate and achievable step to a strategy in dealing with identified risks; it ensures that each risk requiring a response has an owner monitoring the response. These strategies include among others avoiding, transfer, mitigating and accepting
the risk. The risk is avoided by removing the source or executing the project in a different way, not all risks can be avoided, as this can be expensive and time consuming. The risk transferred by moving it to another party who is willing to take the responsibility, and who will bear the liability of the outcome. Risk mitigation reduces the probability and impact of a risk to an acceptable threshold, this strategy is more proactive as it is cheaper to prevent than to repair. Risk acceptance adopted when it is not feasible to respond to the risk, but cheaper to allow the risk occurrence. The tools and techniques used in the response plan include among others contingency planning, procurement and insurance. The contingency planning involves defining actions taken when the risk occurs. Procurement is the process of acquiring goods or services outside of the project; it is often an appropriate response to risks. Insurance arrangement is often available to deal with high category risks (ProjectManagementInstitute, 1996).

2.4.5. Risk Monitoring and Control
The Project risk control and risk monitoring is the step where there is tracking of how the risk responses are performing against the plan; furthermore, there is management of new risks. A comprehensive risk management programme is required to monitoring and control the risks on an on-going basis throughout the project life cycle. The identified risks require continuous reassessment for probability of occurrence and severity of impact, in order to accommodate any changes. The motoring and control process will ensure that corrective actions are taken on existing risk responses, if any deficiency is noticed, and enable the updating of the current response strategies (ProjectManagementInstitute, 1996).

2.5. The application of a Project Management Methodology to a Mining Stope
A case study was conducted previously in the application of a project management methodology in a Platinum mine, the Critical Chain Project Management (CCPM) methodology. The CCPM is a methodology aimed at planning; executing and managing projects that emphasizes on availability of resources (people, equipment, physical space) required to execute project tasks. Goldratt (1999) developed this methodology in response to many projects dogged by poor performance manifesting in longer than expected durations, frequently missed deadlines, increased costs in excess of budget, and substantially less deliverables than originally promised (Goldratt, 1999). The steps that led to the selection of this methodology for application in a mining stope not defined in the case study; however, there was visible improvement in productivity following the application (Phillis & Gumede, 2009). The successful application of CCPM at the Platinum mine was short lived, in an interview with the Platinum mine official, the official revealed, “The application was stopped as the
methodology had challenges”. Although the official did not elaborate on those challenges, in
the literature review done on the CCPM, the discovery was that the application of the
methodology leads to organizational change, including the way workers fulfil their work. A
study done by M. Verhoef for general projects on “what causes project workers to resist
working according to the principle of critical chain project management” can confirm that
there is clear resistance from workers to fully transit and adapt to the methodology.
Furthermore, workers find it hard to disassociate from traditional principles and, to some
extent, they appear easily falling back to old patterns. Resistance to change is a natural and
normal human response. The study further states that, the implementation of the methodology
often goes reasonably well; however, there are worries concerning long-term sustainment, and
currently there is no literature that shows evidence of long term sustained success of the
methodology (Verhoef, 2014). In a traditional industry like mining, there is limited flexibility
in a mining stoping project to accommodate such drastic change in operational activities
brought by the methodology. Moreover, the mining industry requires a sustainable
methodology that will buffer against the uncertainties inherent in the business due to volatile
commodity prices that are decreasing and increasing without any control from stakeholders.

2.6. Selection of a Methodology for a Mining Stope
Prior to commencement of any project, an adequate management methodology requires
selection to guide the project through its life cycle. The selection process is a challenging
exercise, as more often the companies do not always have a clear understanding of all existing
methodologies. There are variety of proposed methods used in selecting a methodology among
others; a selection based on existing recommendations when the selection team or individual
has limited knowledge of other methodologies, and there might be limited resources and time
to study other alternative methodologies for selection. Alternatively, when the team has
sufficient knowledge and resources to test all available methodologies, then all necessary steps
to be taken to test all methodologies against performance, cost management and related risks;
thereafter, the best one should be selected (Kononenko & Kharazii, 2014).
The methodologies available for selection include Projects in a Controlled Environment, this
method usually represented by its popular acronym, PRINCE2. It is a process-based tool, which
is flexible enough for use in all types of projects. In the United Kingdom, it is prevalent in
public sector projects and used worldwide. This is due to its unique characteristic of allowing
the Project Manager to share his/her financial and functional authority with senior
management. Secondly, the Agile Family, which include the Scrum, Extreme Programming,
Cristal and Lean Development methodologies, these methodologies use a duplicative method to determine the requirements for engineering and software development projects. This is done in a very pliable and mutual way, mostly used in small-scale projects; where the outcomes are complex for the customer to easily interpret. Developed for projects requiring significant flexibility and speed; it may be suitable for projects requiring less control and real-time communication within self-motivated teams (Newton, 2015). Thirdly, the Waterfall methodology, which is sequential in nature, mostly prevalent in software development, its model is difficult to use because it is in its original framework and structure. Fourthly, the Critical Chain Project Management (CCPM) methodology, which is a modified version of Critical Path methodology, the methodology’s ability to serve the needs of a mining stope are now questioned, following the decision by the mining company to stop its application due to challenges. Fifthly, Six Sigma methodology which is data driven, and was developed by Motorola to eliminate waste and improve profits. Lastly, the Event Chain Project Management (ECPM) methodology, it is regarded as the next level of advancement following the critical path and critical chain methodologies. The ECPM comes from a notion that “regardless of how well a project schedule is developed, some internal or external events may occur that will alter it”, therefore, a plan of action is required to deal with these events, and prevent them from altering with the project schedule (Chartvat, 2003).

Considerations were made on available methodologies; the selected methodology was the Event Chain Project Management methodology. This was based on the methodology’s capability to deal with risks and uncertainties affecting the project schedule, and its flexibility to serve complex projects; however, this research will further test if the methodology is for a mining stope. Because the selected project management methodology should be able to manage internal risks inherent in a stope affecting the stope schedule, improve the efficiency of operations by reducing the time spent in each activity, improve productivity by reducing the project duration, and reduce costs in the process.

2.7. The Event Chain Methodology

The Event Chain Project Management (ECPM) methodology is an uncertainty modelling technique, which does schedule network analysis for project management. It focuses on the identification and management of events that may affect projects, as it comes from a notion that all projects suffer from multiple risks. These risks are termed as events in the application of this methodology. The events often difficult to identify and analyse, which leads to inaccurate scheduling. The ECPM, said to be the next advanced methodology beyond the
critical path method and critical chain project management methodologies (Dr Dev Raj Jat, 2016). This was confirmed when it was compared with the critical path method in the construction industry, in a study by Pranam (2014), it was found to have a schedule performance index of 10.95% better than the critical path. Furthermore, it was found to be more effective as it provides a structured approach to identifying risks and to estimate a schedule that consider these risks (Pranam, et al., 2014). Although mining and construction are regarded as different industries, but they possess common challenges when executed; they both have inherent risks and uncertainties that have potential to cause project failure, therefore, the findings by Pranam (2014) are relevant to the mining industry.

The ECPM methodology mitigates against negative impacts of motivational and cognitive biases that lead to “best scenario” planning, which is often not achievable and results in inaccurate planning. This occurs due to the pressure experienced by project planners to complete the project quicker, it may be intentional and in most cases unintentional. According to one answer given, it is due to the tendency for expectations to affect perception, the project planners tend to seek more evidence that supports their hypothesis, while ignoring underlying issues. The accuracy of any project schedule can improve using actual performance to refine the schedule; this is possible through the incorporation of newly acquired knowledge in to the schedule (Virine & Trumper, 2011).

The ECPM methodology uses a well-tailored process to improve the accuracy of project schedule. This process include the use of methods to identify events, and quantitatively analysing them, drafting a plan of response, and then monitoring the events with the intention to control them. In order to ensure that the ECPM works effective, it is required that the method of events identification should be accurate, if not; they will lead to inaccurate results; irrespective of the analysis method used. Any risk template can be used based on historical data, the important characteristics to be considered for all risks is the frequency and rating in terms of its potential to impact the project. Most popular quantitative technique used are Program Evaluation Review Techniques (PERT), Monte Carlo analysis, and decision tree and sensitivity analysis. The PERT developed to address uncertainty in project schedule its own set of problems; the first being that it only gives accurate results if there is a single dominant path through a precedence network. Secondly, due to its probabilistic nature, it contains concepts that are unfamiliar to many stakeholders; hence people are reluctant to make use of it (Munier, 2014). The Monte Carlo is used to approximate the distribution results based on probabilistic inputs, the main advantage with this tool is that it incorporates risks and uncertainties into the
planned project schedule. There are certain limitations and disadvantages to the use of Monte Carlo Simulations; the limitations result from the tool giving overly pessimistic results, and any recovery action taken when the project slip are not considered. Moreover, defining distributions is not a trivial process, and when project managers come to a certain base, they tend to stick to it regardless of any change. The disadvantages being the complexity of the tool, and its unpopularity in project management environments due to its probabilistic nature (Munier, 2014). The decision tree helps to calculate the expected value of the project as well as to identify project alternatives and select better course of action. The sensitivity analysis used in this research combined with traditional visualization using bar charts, used to determine which risks have most potential impact on the project, and this is crucial for accurate project planning that accounts for risks and uncertainties and to define the relationship between different events, and uncertain variables and results analysis (Virine & Trumper, 2011).

The ECPM methodology focuses on events rather than continuous process problems, as they are fixable before they significantly affect the project. Furthermore, it insists that understanding of the relationship between the project and the events will influence actions to protect the project against events. These actions involve the application of ECPM principles, the first principle termed the moment of event and excitation. The second principle is the event chain, and the third principle is the event diagram, the fourth principle is the risk analysis, the firth principle is the risk quantification, and lastly the sixth principle is performance measurement (Virine & Trumper, 2011).

2.7.1. Principle 1: Moment of event and excitation states

This first principle of ECPM derived from the field of quantum mechanics; it explains the behaviour of matter in response to a force applied. Quantum mechanics describes the behaviour of very small objects, the size of atoms or smaller, in much the same way as relativity describes the laws of larger everyday objects. The ground state of a quantum mechanical system is its lowest-energy state; the energy of the ground state is the zero-point energy of the system. An excited state is any state with energy greater than the ground state. The ground state also called the vacuum state, which is the quantum state with the lowest possible energy. In the world of quantum mechanics, the laws of physics that are familiar from the everyday world do no work; instead, all events governed by probabilities, it is impossible to predict with certainty the outcome of a single experiment on a quantum system (Mayes, 2004).
In a project when a force in a form of an event acts on an activity, the activity responds by changing its form from ground state to excited state. The ground state is the original or planned state of the activity, while the excited state is the new affected state. The actual moment of the event occurrence can be absolute with an exact date and time or measured relatively to the activity’s start and finish time. The occurrence is probabilistic, defined using a statistical distribution; given a probability of occurrence calculated using Equation 2.1: Probability Formula. The probability also occurs differently in different states, as it is the property of the state. The severity of impact on the activity depends on when the event occurs within the activity; the impacts can materialize themselves in a form of delays, activity re-start, activity stop, activity cancel and even project failure. Figure 2.5: Event Causing Activity Transformation illustrates an activity in a normal state and in an excited state, the impact of the event is the property of the state rather than the event itself, the impact can be different if an activity is in a different state. Excitation indicates that something has changed the manner in which the activity will be carried out, the activity may require more or different resources, or require to be perform in different conditions. An event can influence the actual outcome of an activity to deviate from the estimate duration, because an activity is not a continuous and uniform procedure (Virine & Trumper, 2017).

![Statistical distribution for the moment of event](image)

Figure 2.5: Event Causing Activity Transformation (Virine & Trumper, 2011)

### 2.7.2. Principle 2: Event Chain

The second principle of ECPM is concerned with the occurrence of any event within a project, which has potential to trigger more events, forming an event chain, see Figure 2.6: Event Chain.
Any event can affect the activities in a project, more often events have multiple effects on activities; some events affect one or more activities in a project, while the others affect all the activities in a project. Events can have negative or positive effects on a project; however, in a mining stope all events have negative effects on the project. An event that causes another event is the sender; it has potential to cause multiple events affecting different activities causing multicasting of receivers. Multicasting is when there is communication between a single sender and multiple receivers, when an excited activity influences an activity on ground state to change to excited state. The effect of the event chain has rippling effects on the project, and can lead to project failure (Virine & Trumper, 2017).

![Event Chain Diagram](image)

*Figure 2.6: Event Chain (Virine & Trumper, 2011)*

### 2.7.3. Principle 3: Event chain diagram

The third principle illustrates the complex relationship between the events and the project, in a diagram form for all stakeholders involved to see. Due to the complexity of the relationship between the events, the event chain diagram uses a familiar structure of a Ghant chart to visualize the relationship between project events, see Figure 2.7: Event Chain Diagram. Single events shown in arrows, arrows pointing down are threats and arrows pointing up are opportunities. The use of plans, diagram and charts is prevalent in project management, as it uses concepts rather than objects, a picture rather than words. Psychologists have also discovered that images are more distinct from each other than words, and that increases the chances of retrieval. The purpose of an event chain diagram is not to show individual events
but to show the whole picture of the project. Event chain diagrams require continuous update, this include amongst other the change in probability of event occurrence and removal of an event (Virine & Trumper, 2017).

2.7.4. Principle 4: Event Analysis
The fourth principle is concerned with the event analysis, which enables the identification of the events, especially the critical events. The critical events are those events with the potential to cause project failure; their identification will ensure that an appropriate response plan is implemented. The analysis will further enable the assigning of probability and severity of event impact on the activity; furthermore, events ranking done by multiplying the event probability with event severity of impact as indicated in Equation 2.2: Risk Ranking discussed in 2.4.2. The probability of occurrence assigned a percentage from 1-100%, and the severity of impact assigned a scale of 1-10. The probability of 100% indicates that the event has occurred, and the severity of 10 indicates a total failure of the project due the event. The event ranking assigned a ranking between 1-100%, indicates which event has the highest potential to affect the project; these are the critical events, their proper management will ensure project success (Virine & Trumper, 2017). These analyses seeks to forecast and evaluate the impact of events, so that procedures adopted to avoid or minimize the impact (Raftery, 1999). Analysis techniques available for use to examine the impact depending on the type and size of information available.
the preferred technique by the ECPM methodology is the Monte Carlo Simulations. However, due to the nature and scope of the project combined with the limitations inherent within Monte Carlo Simulations, its use will not be necessary. Sensitivity Analysis will be in use to analyse the events identified in this project, it is a quantitative method, it aims is to examine the response or reaction of an output variable, in this case durations. Furthermore, it helps to discover correlation between the project parameter and each project activity. Correlations are influenced by common causes and constraints; common cause apply when the results of one activity will lead to changes in another activity due to the sequential nature of the project, while common constraints apply when activities are competing for the same resources (Virine & Trumper, 2011). The analysis of these correlations between the main project parameter and activities will enable the identification of critical events (Virine & Trumper, 2017).

The main purpose of risk analysis is to plan appropriate actions to deal with the events, through the implementation of a proper response strategy. According to Virine (2017), risk mitigation is a proactive plan that reduce the impact of the event to an acceptable level prior to occurrence, while the response plan allows occurrence and deals with the impacts after occurrence. The ECPM has an inherent mitigation plan, made up of four response strategies, the event avoidance, event acceptance, and event transfer and event limitation. Event avoidance occurs when the event avoided by removing the source or executing the project in a different way, while still aiming to achieve project objectives. Event acceptance adopted when the cost of managing a certain type of an event accepted, because the event is inadequate to warrant the added cost it will take to avoid it. Transferring an event involves finding another activity that can bear the liability of the event should it occur as the severity will be less. Event limitation is the prevalent response for the ECPM, it is a strategy the employs both avoidance and acceptance; it reduces the probability and/or impact of an adverse event to an acceptable threshold (Herrera, 2013).

2.7.5. **Principle 5: Critical event chains and event costs**

The fifth principle deals with the quantification of the events, which measures the extent of the critical event’s impact on the project as more often they affect more than one activity. Critical events are those events that have the most potential to affect the project, although their impact may differ for different activities; the goal is to measure their cumulative impact on the entire project. This will assist in revealing the economic loss or duration lost due to the occurrence of these critical events; however, this research only considers the impact on the project duration, hence termed Duration Cumulative (D<sub>cum</sub>), see Equation 2.3: Cumulative Duration.
In order to determine the cumulated duration resulting from events impact, a sum of all affected activities in a project considered, as the cumulated duration results from impacts of all affected activities. The effects on activities in a form of delays is visible when compared to the planned activity durations, however, correlation between each activity’s duration and the project duration must be performed; so that the event’s effect on activities and the whole project is estimated. The correlations performed using a Spearman's Rank-Order Correlation represented by \( k \) in the formula, which is the nonparametric version of the Pearson product-moment correlation; it measures the strength and direction of association between two ranked variables (Statistics, 2013), in this case, each activity duration is correlated with the project duration. The planned duration for each an activity represented by \( D_i \), and the actual duration which is affected by an event is represented by \( D'_i \).

\[
\text{Equation 2.3: Cumulative Duration (Virine & Trumper, 2011)}
\]

\[
D_{\text{cum}} = \sum_{i=1}^{n} (D'_i - D_i)^k_i
\]

2.7.6. Principle 6: Project Performance measurement with event and event chains

The sixth principle is a critical principle of the ECPM, which deals with monitoring of project activities using updated information to perform new analysis. These analysis performed during the project, can be used to recalculate the probability of event occurrence, and the actual impact; a new project schedule can be generated. However, the application of this principle is continuous through the project; therefore, if an activity is partially completed and events occurs.

There are three distinct approaches to this:

- Probabilities of a random event in a partially completed activity stay the same regardless of the outcome of previous events.
- Probabilities of events in a partially completed activity depend on the moment of the event. When the moment of the event is earlier than the moment when the actual measurement performed, the event will not affect the activity.
- Probabilities of events requires continuous definition by the subjective judgement of experts at any stage of an activity.
The chance that the project will meet a specific deadline monitored as indicated in Figure 2.8: Monitoring chance of Project Completion on Schedule, as can be seen, the chances change constantly resulting from various events and event chain. However, the risk response efforts, such as the event mitigation plan, can increase the chance of the project successfully meeting the deadline. This chance of project meeting the deadline continuously updated using actual updated results of the quantitative analysis (Virine & Trumper, 2017).

![Figure 2.8: Monitoring chance of Project Completion on Schedule (Virine & Trumper, 2017)](image)

2.8. Summary

The proven relations between a project’s success and the project methodology used required that time is taken to ensure that a suitable methodology is selected for a mining stope. The events chain selected as a more suitable methodology for the stoping project based on the methodology’s capability to deal with risks and uncertainties, and its flexibility to serve complex projects. Project management using event chain methodology is a great model to identify an event or the event chains that are affecting projects. The process of testing the methodology’s suitability for a mining stope is conducted in chapter 4. The following chapter will discuss the methodology used to carry out this research.
3. RESEARCH METHODOLOGY

3.1. Introduction
This research seeks to select a project management methodology for a mining stope project, which will manage internal risks affecting the project schedule, improve the efficiency of operations by reducing the time spent in each activity, improve productivity by reducing the project duration and reduce costs by reducing project duration. This research fulfils the requirements of research as a process in which scientific methods are used to expand knowledge in a particular field of study; it involves the application of methods in order to create scientific knowledge” (Welman & Kruger, 2003). It brings about a new perspective on existing research findings; the findings by Phillis & Gumede (2009) on the application of Critical Chain Project Management (CCPM) methodology to a mining stope. A case study research methodology was used to apply the CCPM methodology in a mining stope to improve performance, and there was a visible improvement in the overall performance, based on the results presented. Therefore, the same research methodology should be used to bring about a new perspective on this existing research.

Although different research methodologies can be used to carry out this research, a case study is considered appropriate; because this research demonstrates how a project management methodology can be used to improve productivity in a mining stope. Furthermore, it is based on contemporary activities occurring daily in a mining stope, the Author has no control over the behaviour and occurrence of these activities. As states by Yin (2009), in order to avoid misfits, there are three conditions, which influences the selection of the relevant methodology for research. These conditions include the type of research questions submitted, the extent of control over behavioural events, and the degree of focus on contemporary as opposed to historical events.

3.2. A case study
A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real life context; its inquiry copes with the technical distinctive situation in which there will be many more variables of interest than data point, and one set of results (Yin, 2009). This case study will describe the current efficiency of operations in the mining stope, and identify the key issues causing poor performance. Case study research is well suited to investigating complexity and generating context-dependent knowledge on which to base innovative strategies (Farquhar & Michelles, 2016). It is a problem-solving case study, which
intends to investigate the problem leading to poor productivity in mining stopes; furthermore, a solution to the problem is tested and proven (westernsydneyedu, 2016).

A single case study is used to carry out this research, because this research intends to reveal a suitable project management methodology for a mining stope. This is a typical case, which seeks to capture the circumstances and conditions of the daily operations in a mining stope; it represents the project environment of a stope. In addition, a well-formulated theory, the ECPM is tested, that will contribute to building knowledge and theory (Yin, 2009). A single case study allows the researcher to question old theoretical relations and explore new ones; and that permits a more careful study, based on deeper understanding of the subject (Gustafsson, 2017). Gustafsson (2017) concluded that although the selection between a single case study and multiple case studies depends on the context the information known and how much new information the case brings, the only difference between the two is the number of pages. There is generally more pages in multiple case studies than single case studies, which is not a big issue; the important issue is the researcher’s ability to understand and describe the context of the scene in question in such a way that the reader can understand.

The case study method allows the researcher to explore sharply the data within a specific context, because a small geographic area is selected to investigate real life occurrences. The identified pitfalls with the method is its questioned diligence, and its inability to produce a generalizing conclusion (Zainal, 2007). Contrary to this, Yin (2014), is of the view that when a process is given careful attention, the potential results will be of high quality research, which focuses on addressing rigour, validity and reliability. This research has taken into account all these challenges with the method, in order to counter against the challenges a methodological triangulation is used. Triangulation is the use of mixed methods, in this case qualitative and quantitative methods used to complement each other. Complementary triangulation is the use of quantitative and qualitative methods to generate an adequate image of reality; complementary findings provide a measure of overlapping but different facets of facets so that enriched understanding gained (Farquhar & Michelles, 2016). Quantitative research is empirical, using numeric and quantifiable data; conclusions based on experimentation and on objective and systematic observations (Belli, 2008). While the qualitative method is a scientific, it answers questions, collects evidence and produces findings that are applicable beyond the immediate boundaries of the study. These methods although different, can complement each other when used together; the qualitative method gives meaning to the numerical data collected through the quantitative method (Family Health International, 2016).
However, the success of triangulating two methods requires independence of methods during both data collection and analysis (McClinton & Greener, 1985).

3.2. Data Collection
The data was collected in a Platinum mine consisting of a complex with 13 shafts; five mining stopes were selected from four shafts 1, 10, 12 and 14. The collection was through qualitative and quantitative methods; qualitative data collected through the interaction with team members and quantitative was collected recordings. The collection instruments used were observations in a form of work-study through a motion time study, and questions directed at team members to give explanation to the observations. The motion time study aimed to measure the current efficiency of operations through the actual duration taken to complete each mining activity. The observations carried out using a stopwatch to measure the amount of time spent in completing each activity, start and finish durations recorded for each process involved in a mining cycle. Time study data collection is the act of tracking your processes and operations with the measured start and stop times; this will measure the current level of efficiency of processes in the mining stope. The intention is to determine the correct time it takes to complete an activity and the best way to carry out that activity. Furthermore, the results from the time study will be a baseline from which improvement be driven from, and they will assist in setting standard that will support and control performance. Moreover, all ineffective and lost times be eliminated (Al-Saleh, 2011). Observers were Mining Engineering graduates; they proceeded underground in the beginning of each shift and came out at the end with the miner of the panel daily. This done continuously for 12 shifts and all start and finish times recorded on a checklist, recording any source of delays and disruptions.

3.3. Method of Analysis
Qualitative and quantitative methods of analysis were used, this was done to ensure that one method compensate the weakness of the other; qualitative analysis was used to explain the quantitative results. Quantitative analysis done with Microsoft Excel (2016) using statistical procedures to conduct univariate analysis. A statistical analysis approach used to summarize and describe quantitative data in a meaningful way by explaining the qualitative component of the data. These analyses aimed to indicate the difference in time for the actual duration of activities, compared with the planned one; this process will indicate any discrepancies
attributed to event’s occurrence. Furthermore, the frequency of occurrence for each event recorded during data collection, was used to determine the probability of each event’s occurrence; then the severity of each event was scaled from 1-10, lastly each event ranked according to its potential to cause severe impact.

3.4. Reliability of the Data

The reliability and validity of the information collected is crucial for sound and accurate predictions, if data is valid, it must be reliable. Reliability refers to the replicability and consistency of findings, if done by different people or different methods will the rates be similar. In this case, measures were taken to ensure reliability in the data collected through the motion time study observations (Roberts & Priest, 2006). Firstly, the observers were qualified Mining Engineers who are familiar with the use of a stop watches to record durations, and the checklist used were clear on all the activities involved. Secondly, the experience in the field enabled informed rationale in data judgement; all original copies of raw data kept for verification purposes. Lastly, the Author processed the raw data from the checklists to the computer, all cautions taken to ensure elimination of errors.

3.5. Validity of the Data

Validity refers to the credibility or believability of the research information; moreover, the data should be valid for the study purpose (Roberts & Priest, 2006). According to Farquhar (2016), case study research has attracted criticism due to its lack of rigour, and often the depth of information provided is sometimes questionable. Triangulation is a useful tool, which can assist in restoring the credibility and believability of the information by minimizing biases. In this research, this is achieved with multiple methods used in data collection and data analysis. The correct use of multiple methods assist in data substantiation, data believability and reduced errors; furthermore, strengthens the findings (Farquhar & Michelles, 2016).

3.6. Ethical Consideration

Any research conducted requires diligence and honesty; this ensures that rights of human beings are protected from any violation. The study does not involve people as research subjects; it involves the collection of data from an organization, data that is not publicly available. However, permission granted by the organization in support of the study, and ethical clearance requirements were fulfilled.
3.7. Summary
This chapter outlines the methods followed in conducting this research, this include the methods of data collection, methods of data analysis and interpretation. Furthermore, the methods used to test the data’s reliability and validity, and ethical considerations pertaining this research. The following chapter will deal with discussions and analysis of the results.
4. RESULTS AND ANALYSIS

4.1. Introduction
The study focuses on activities taking place during the morning shift where blasting takes place, as it is relevant for this research. The night shift activities are equally important as they influence morning shift; however, testing the suitability of the ECPM in one shift, will be sufficient to prove its suitability for a mining stope.

The sequence of activities involved in a mining stope for the morning shift include the following:

1. The miner reports to the office for duty, and looks at the communication from night shift, at the end of shift he has to write a message to night shift.
2. Before proceeding, underground a lamp and rescue pack are taken from the lamp room; and replaced at the end of shift.
3. The means of transportation to underground workings done using a cage, chairlifts or walking.
4. The team meet at the waiting place, and there are discussions about safety matters and the daily plan.
5. Thereafter, the team proceeding to the actual working place, entering by “entry examination” procedure, assessing all areas to ensure that the working place is safe for workers to commence duties.
6. The face is then prepared, drilling takes place, and then charging up with explosives and connecting done.
7. The face is then blasted and the team travels back to the surface.

4.2. Results
The project has a planned schedule of 08:30:00 (H: M: S) termed “best practice” represented in “blue” in Figure 4.1: Planned Vs Actual Durations which include all the activities involved to achieve the objective and all the other mining stopes in red. There are obvious discrepancies between the planned schedule and the actual project schedule for the five mining stopes, Table 4.1: The Percentage in excess of planned durations indicate that only one panel has an actual project duration that is only 1% over the planned (21M 24N 13N 1#). This attributed to lesser events experienced by the working place, further explanation provided below (4.2.2.). The remaining four panels take on average of 32% more time than planned; these results indicate the failure of the project to be completed on the planned schedule. The contributing factors to
this challenge are investigated further in this research. Event chain methodology will be used in identifying, and managing events and event chains that affect the project schedules.

**Figure 4.1: Planned Vs Actual Durations**

**Table 4.1: The Percentage in excess of planned durations**

<table>
<thead>
<tr>
<th>Working Place Name</th>
<th>% more than Planned Durations</th>
</tr>
</thead>
<tbody>
<tr>
<td>17C 107 5N 12#</td>
<td>36%</td>
</tr>
<tr>
<td>21M 24N 13N 1#</td>
<td>1%</td>
</tr>
<tr>
<td>12 C 77N 10N 10#</td>
<td>28%</td>
</tr>
<tr>
<td>22C 93N 13N 14#</td>
<td>53%</td>
</tr>
<tr>
<td>15C 24N 6N 1#</td>
<td>12%</td>
</tr>
</tbody>
</table>

The results presented in Figures below, represent the data collected through the observations carried out in a form of motion time study. A comparison between planned durations for each activity and actual durations for five working places is done to determine the extent of the effects on activity durations.
4.2.1. Panel 22 C 93N 3N in 14#

The results indicated in Figure 4.2: Morning Shift Activities for 22C 93N 3N 14# shows that less time is spent on entry examination than planned, only 73% of the planned duration is used. Also on temporary support and face preparation, only 44% of the planned time is used. In contrast, drilling takes 56% more time than planned, while the explosive activity takes 127% more time than planned. The actual travelling time equals to the planned time at the beginning of the shift, but 313% more time than planned is used on travelling out at the end of the shift.

![Figure 4.2: Morning Shift Activities for 22C 93N 3N 14#](image)

4.2.2. Panel 21 M 24N 13N in 1#

The results in Figure 4.3: Morning Shift Activities for 21M 24N 13N 1#, indicate that in this panel, 58% more time is used than planned on travelling in, and 50% more time used on travelling out. The entry examination and face preparation activities have the least time spent, with only 61% and 27% consumption of the planned time spent respectively. Drilling in this stope takes 16% more time than planned.
4.2.3. Panel 12 C 77N 12N in 10#

The results in Figure 4.4: Morning Shift Activities for 12C 77N 12N 10# indicates that less time spent on the “entry examination” and “face preparation” activities, only 45% and 86% of planned time used to carry out these activities. While drilling takes 56% more than the planned time and explosive activity takes 127% more time than planned.
4.2.4. Panel 15 C 24N 6N in 1#

The results indicated in Figure 4.59: Morning Shift Activities for 15C 24N 6N 1# indicate more time spent on travelling in and out of the working place, 52% and 51% more than planned respectively. The “entry examination” and “face preparation” activities both take up to 71% and 33% of planned durations respectively. Drilling takes slightly longer than planned, 8% more. The explosive activities take more time than planned, at 62% more time than planned.
Figure 4.59: Morning Shift Activities for 15C 24N 6N 1#

4.2.5. Panel 17 C 107SN 5N in 12#

The results indicated in Figure 4.6: Morning Shift Activities for 17C 107S 12# indicate that travelling in and out takes longer than planned 65% and 106% than planned respectively. The panel entry examination takes 81% more time than planned. However, the face preparation activity still takes less time than planned, 77% of the planned duration is used. Drilling takes more time 21% more time than planned. Furthermore, the explosive activity takes 53% more time than planned.
4.3. The results discussions

The overall results on the activity “office activities in and out” indicate that this activity is not included in the best practice schedule; observations revealed that while the procedure requires a miner to report to the office daily, the planned schedule does not include office activities. However, this attributed to the fact that the planned schedule does not consider the activities performed by the miner as the supervisor of the team, but considers activities performed by the team as a whole. Durations for this activity for all working places are below 00:15:00 (H: M: S), this is due to the communication system between night shift and day shift, a book is kept in the office.

The overall results on the activity “travelling in and out”, which commence from the time spent waiting for cage until arriving at the waiting place. Durations recorded for all working places ranges from 00:30:00-00:57:00 (H: M: S), this is higher than the 00:30:00 stipulated by the planned schedule. This indicates delays in terms of the cage arrival, and slow walking to the waiting place.

The results for the activity of “entry examination”, which commence from the waiting place to the panel; indicate a range of 00:41:00-01:51:00, this is lower that the planned 01:30:00, however, there are questions to be asked about the panels that spend only 00:26:00 and
00:41:00 (H: M: S) on this activity. These results indicate that the entry examination procedure is not carried out properly as required. This is a crucial activity for the protection of the health and safety of people working on a panel, if this activity improperly done, that can result in series injuries or even fatalities resulting from Falls of Ground.

The overall results on the activity “temporary support and face preparation” indicate the ranges from 00:25:00-01:18:00 (H: M: S), while the planned is 02:30:00. There is a series concern about all panels as they manage to complete this activity in just 51% of the stipulated time. These results indicate that the procedure to carry out this activity is not followed; some of the steps are skipped to push for the finish line. This activity is also important for the health and safety of workers, it has potential to cause injuries and fatal if not done appropriately.

The overall results on activity “drilling” for all working places range from 03:15:00-05:17:00 (H: M: S), this higher than the planned 03:00:00. The minimum-recorded time of 03:15:00 is justifiable; however, the highest time of 05:17:00 is not justifiable. It indicates a problem affecting all working places is causing delays; this problem linked to the technology used for drilling, and the rate of absenteeism by drillers.

The “explosive” activity is a combination of charging and connecting up, the overall results for all working places indicate a range from 01:25:00-03:25:00, while the planned time is 01:30:00. The minimum-recorded time of 01:25:00 is acceptable, but the highest recorded time of 03:25:00 indicate a problem that is causing delays; this problem linked to the availability of material and the number of people available to charge up.

4.4. Events Analysis and Management

According to Mndzebele (2011) management of events is the process of investigating the potential events, with the end aim of reducing the likelihood of their occurrence or their impact on the project (Mndzebele, 2011). Furthermore, the process allows for identification, ranking, analysis, and evaluation of events, so that project value creation occurs (Cooper, et al., 2014)

4.4.1. Event Identification

Events identification is the first step in events management; this step encourages mental engagement within the project in looking for potential events (Munier, 2014). There are many tools used to identify risks in a project among others brainstorming, scenario analysis, interviews and other technique, which promotes event identification. In this case, other technique are used, events identified through practical observations of activities within the project and recorded in a checklist, recorded events indicated in Figure 4.7: The frequency of
Event Occurrence. The events identified to dominate in most of the working places were absenteeism, low compressed air and Half-level meeting; the “low compressed air” attributed to the common technology used pneumatic drills powered by compressed air. Absenteeism is a common problem in industries that rely on employees to carry out the activities; conventional mining is more dependent on the human factor to operation. The Half-level meeting, safety meeting, conflict resolution and intendant go slows represents the differences in a team and the team spent trying to settle them. Conflicts are common when humans are working together to achieve a goal; the meetings are platforms to resolve these conflicts. The chairlift breakdown and DDT breakdown, are events seen to affect only two specific working places; this is because not all working places require the use of chairlifts for travelling, it is only one working place. The DDT breakdown only affects one working place; this is because only that working place uses this machine for the installation of roof bolts. The late blast activity was observed to affect one particular working place, which is also affected by the material store, which is far. The frequency of occurrence of all the events was recorded, as indicated in Figure 4.7: The frequency of Event Occurrence, as per observations for 12 shifts. These events have resulted in activity delays ultimately project delays; this has resulted in discrepancies between the planned project schedule and actual durations.

![Frequency of Event Occurrence](Image)

*Figure 4.7: The frequency of Event Occurrence*
After event identification, their probability of occurrence should be determined, followed by their ranking of importance regarding potential damage (Munier, 2014). The probability occurrence is estimated using the frequency of occurrence through the use of Equation 2.1: Probability Formula, the results are indicated in Figure 4.8: Probability of Event Occurrence.

*Equation 2.1: Probability Formula*

\[
\text{Probability} = \frac{\text{Number of favourable outcomes}}{\text{Number of possible outcomes}}
\]

*Figure 4.8: Probability of Event Occurrence*

An event, by its very nature, more often has a negative impact on the project. However, the size of the impact varies in terms of project duration, cost or some other critical factor. In order to estimate the impact of events on the project if the event occurs (Munier, 2014). A scale of 1-10 scale used, 1 assigned to the little impact and a 10 for catastrophic impact using (Anon, nd), the results are indicated in Figure 4.9: Event Severity Estimation.
4.4.2. Event Ranking

Events ranking is a qualitative evaluation used to acquire information about the threat and its performance; more often, an event matrix is used (Munier, 2014). However, in this case a ranking formula is used:

*Equation 2.2: Risk Ranking*

\[
\text{Event Ranking} = \text{Probability} \times \text{Severity}
\]
Figure 4.10: The event ranking

The results in Figure 4.10: The event ranking indicates the ranking of each event; this based on the probability of occurrence and the severity of impact on the project. Absenteeism ranked 62% and considered the event with the highest potential to cause project failure. DDT is a machine used to drill in support, its breakdown ranked at 48%; making it the second highest ranked event; it affects drilling and ultimate project delay. Followed by, low compressed air at 44%; it causes delays in drilling and triggers other events such as late blast or project failure.

Other events have potential to trigger on other event forming an event chain; absenteeism leads to resentment amongst team members, as members feel overloaded with work, although it is legal to be absent from work but team members do not see it that way. Furthermore, low compressed air will also lead to resentment towards the supervisor, as the team expects him/her to do something to resolve the issue of compressed air, as it is beyond the team’s reach. This will demotivate the team, more time spent on meeting to try to resolve conflicts and ultimately result in late blast as the project will experience late starts.

The breakdowns, listed as chairlifts and DDT machinery are events that occur randomly and are isolated as not all panels use chairlifts for travelling or use the DDT machinery for support installation; this is the case also with the material store being far. All these events can trigger
the late start of the project, which will result in the late finish and late blast; also, can result in conflict and more meetings.

Absenteeism, DDT and Chairlifts breakdown and low compressed air are identified as critical events due to their high rankings reflecting their high potential to cause other events and ultimately causing project failure.

Figure 4.11: Actual Event Chain Diagram indicates the relationship between all the events identified and all activities within the project. The planned schedule of the project 08:30:00 (H: M: S) is indicated in black, and the actual duration (12:30:00), has been affected by events. All event indicated some events trigger other events forming an event chain.

4.4.3. Event Quantification

Event quantification is the process of evaluation the critical events and developing data that will be needed for decision making about these events. Furthermore, it measures the cumulative impact of the critical events on the project schedule. The quantification is a quantitative assessment of the value of the events and its effect on the project output. The event may affect a single activity and sometimes more than one activity, therefore, their effect on the project
requires understanding. This will assists in revealing the economic loss or duration lost due to the occurrence of critical events; however, this research only considers the impact on the project duration, hence termed Duration Cumulative ($D_{\text{cum}}$), see Equation 2.3: Cumulative Duration.

\[ D_{\text{cum}} = \sum_{i=1}^{n} (D_i' - D_i) \times k_i \]

In order to determine the cumulated duration due to the events, a sum of all affected activities in a project considered, as the cumulated duration results from impacts of all affected activities. The effects on activities in a form of delays is visible when compared to the planned activity durations, however, correlation between each activity’s duration and the project duration must be performed; so that the event’s effect on activities and the whole project is estimated. The correlations performed using a Spearman’s Rank-Order Correlation represented by k in the formula, which is the nonparametric version of the Pearson product-moment correlation; it measures the strength and direction of association between two ranked variables (Statistics, 2013), in this case the each activity duration correlated with the project duration. The planned duration for each an activity represented by $D_i$, and the actual duration which is affected by an event is represented by $D_i'$.

The results from the cumulated durations in percentage format presented in Figure 4.12: Cumulated Duration for each affected activity these results indicate that the critical events resulted to cumulated durations for several activities. Drilling and Explosives activities suffered major delays, this is concluded based on the high percentage of cumulated durations.
Figure 4.12: Cumulated Duration for each affected activity

4.4.4. Project Monitoring and Performance

Project measurement and monitoring is focused on monitoring the event behaviour compared to the predictions made, initial analysis are continuously updated using actual updated information. These analysis performed during the project, can be used to recalculate the probability of event occurrence, and the actual impact; a new project schedule can be generated. However, the application of this principle is continuous through the project; therefore, if an activity is partially completed and events occurs three approaches listed in Section 2.7.6 apply.

This project performance is concentrated on efforts to reduce the project durations by improving the efficiency of each activity. All information gathered indicated that the efficiency of the activities reduced by the occurrence of events, therefore, the mitigation plan requires implementation to deal with the events. The improvements will emerge as a direct result of the mitigation plan presented in Figure 4.13: Improved Project Durations, the duration cumulated due to the occurrence of events recovered and the project duration reduced.
4.4.5. The Mitigation Plan

Event mitigation plan is the process of taking steps to reduce adverse effects of events on the project and performance enhancement occurs when the mitigation plan is properly implemented, it is made up of four response strategies, the event avoidance, event acceptance, and event transfer and event limitation. Event avoidance occurs when the event avoided by removing the source or executing the project in a different way, while still aiming to achieve project objectives. Event acceptance adopted when the cost of managing a certain type of an event accepted, because the event is inadequate to warrant the added cost it will take to avoid it. Transferring an event involves finding another activity that can bear the liability of the event should it occur as the severity will be less. Event limitation is the prevalent response for the ECPM, it is a strategy the employs both avoidance and acceptance; it reduces the probability and/or impact of an adverse event to an acceptable threshold; by removing the source or executing the project in a different way (Herrera, 2013). The implementation of the mitigation plan will ensure that critical events are prevented from occurring. Recommendations on how to mitigate against the specific critical events identified in this project are provided on Chapter 6; this will result in the improvement of efficiency in processes and an increase in productivity.

Figure 4.13: Improved Project Durations

4.5. Summary

The application of the ECPM in a mining stope has proven to be a straightforward and easy process; guided by the principles of the methodology. Although unpopular in the mining industry, it is popular in many industries including large corporations and government agencies
especially construction industry. The results presented in this Chapter are quantifiable and show improvement in the durations of activities a mining stope. The results indicate that the efficiency of operations improved by the reduction of time spent in each activity through the application of the Event Chain Project Management methodology.
5. CONCLUSION

This research has managed to select a project management methodology for a mining stope, the ECPM, which can provide operational excellence. The ECPM methodology has proven to be capable of dealing with internal risks in a mining stope, which affects the mining stope schedule. It has managed to improve the efficiency of operations by reducing the time spent in each activity, improve productivity by reducing the project duration, and costs were reduced in the process.

The ECPM methodology through a proper risk management process is able to identify events using different techniques, analyse them through qualitative and qualitative means; and quantify the amount of time wasted by the risks, thereafter, mitigate against the risk impacts through mitigation strategies. A proper risk management tools in a project enables decision makers to prioritize competing requirements, this ensures that the resources allocated where required. Furthermore, recognized as an important exercise in order to achieve better performance of a project (Cooper, et al., 2014).

Efficiency measures how well and productive resources are used to achieve project goals, in this case how well is the project allocated time used. The presence of risks within an activity reduces the efficiency of carrying out the activity, because of the time wasted by risks. Elimination of the risk will allow for effective use of the allocated time; thus the efficient use of project duration. However, the improvement in efficiency in this project is only limited to project duration, and not linked to the quality of the product produced; that constitute as a limitation for this research. Further research is required to test the methodology’s ability to improve on the quality of the product produced or service rendered at a specific duration.

The implementation of the ECPM’s mitigation plan ensures that all the time wasted by risks recovered, that reduces the project duration. As stated by Baratta (2006), the three factors of triple constraint theory, time, costs and scope relate in a defined and predictable way. If one variable changes, then another must change in a defined and predictable way; in this case, the variable which will change is the duration of project, this will influence the costs to also change in the same way as the duration.

This research managed to use project management in breaking the boundaries created by the traditional ways of management; ways that lead to professionals believing that projects and operations run parallel and do not link, this research has confirmed that operations can be improved using project management (Joslin & Muller, 2016)
6. RECOMMENDATIONS

The recommendations pertaining to the actual plan on how to deal with the specific critical events identified in this project provided. Absenteeism in this case, refers to the unscheduled absence of employees from the workplace, it is unscheduled, and precautionary measures are not in place. It has potential to hurt the business, due to the drop in production but constant or increasing costs. These employees are a financial burden to the business and work load burden to other employees. This event forces the team to adjust and stretch their strengths in order to cover the gap; this can have severe consequences on both safety and production (Folger, 2016). This event affects the efficiency in the project and the employee’s safety. Absenteeism among other has deepened Lonmin’s operational and financial woes in the first quarter of 2017, it has significantly reduced the production output for the quarter (Mckay, 2017). According to Gouws (2015), there is a positive relationship between absenteeism and physical workplace conditions; therefore, improved working conditions will discourage absenteeism. The hours spent underground by employees Figure 4.1 indicate that there is no time for employees to rest, this result in fatigue and sickness, which encourages absenteeism.

Compressed air is a source of power for the pneumatic machinery used for drilling, however, its efficiency is the lowest compared to other power sources like electricity and hydropower; its power decreases with long distances that come with risks of leakages. However, its versatility has resulted in its use in a variety of pneumatic equipment’s, which requires its sharing. According to Hassan (2011), the use of compressed air in mines can be optimised if mines adopt control philosophise which works best for them, this include the setting of compressors pressure such that it is allowed to cut back. Drilling is the main activity, which requires compressed air, therefore during the drilling time, the guide vanes fully opened and the compressors will run in full capacity to cover the demand and closed when drilling ends. Furthermore, a mine that uses one compressor must increase the number of compressors when faced with “low compressed air” challenges.

The breakdowns experience with DDT machinery and the chairlifts are a failure of a machine to function or an occurrence in which a machine stops working. According to Kumar (2013) breakdowns can be prevented by a good maintenance system, which increases machine availability and productivity; moreover, deals with root causes of breakdowns.

The area of concern identified in the project are health and safety related activities; health and safety in mines is still the mining industry’s biggest challenge, although there was a slight
improvement in overall fatalities of 5% between 2015 and 2016. However, there are concerns regarding the increase in the falls of ground related fatalities, which seemed to be decreasing over years, with the introduction of interventions (Chamber of Mines, 2017). This research has revealed that health and safety related activities seem to be neglected, “entry examination’ and “temporary support and face preparation” only take on average 61% and 35% of the total allocated duration for the 12 shift in which data was collected. Entry examination is a process of assessing if the working place is safe and rectifying any deviations to ensure that workers are safe. The rushing of this process will compromise the safety of workers, moreover, this raises concerns with the attitude of workers and supervisors concerning health and safety matters, therefore, further research is required to understand these happenings.
7. REFERENCES


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