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Improving the Productivity of the Styldrift Platinum Mine using the Theory of Constraints.

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A research proposal submitted to the Faculty of Commerce, Law and Management, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Business Administration

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DECLARATION

I declare that this report is my own unaided work. I have read the University Policy on Plagiarism and hereby confirm that no plagiarism exists in this report. I also confirm that there is neither copying nor is there any copyright infringement. I willingly submit to any investigation in this regard by the School of Mining Engineering and I undertake to abide by the decision of any such investigation.

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ABSTRACT

The purpose of this research was to apply Theory of Constraints (TOC) to identify constraints affecting the Styldrift mine's productivity and develop strategies on how TOC can be used to improve productivity in operations. Due to limitations in resources, the study was focused only on one crew.

To identify the constraints limiting production at Styldrift mine, time and motion studies were conducted for a period of a month. The data was collected from direct observations as well as end of shift production reports. Control charts were then used to summarise the observations of the time and motion studies for each critical activity in each shift. The data from the Control charts was then analysed to identify the constraints.

From the Control Charts, it was observed that the main constraint limiting productivity at the crew was the issue of blockages, as it contributed the most (42%) to the factors affecting production. After identifying the main constraint, a root cause analysis was conducted using TOC's Current Reality Tree (CRT). The root cause analysis identified the mine's cost cutting drives, the role of the union, long working hours, the mine's local empowerment policies, and the utilization of the axess rig for other task other than the installation of secondary support, as the core problems leading to the blockages. To develop strategies to solve these core problems, the TOC's Evaporating Cloud (EC) thought process (TP) tool was applied to come up with more optimal solutions to the identified problems. A Future Reality Tree (FRT) was then constructed using the EC.

This research illustrated how the TOC's thought process tools such as the EC, CRT and FRT can be applied in the mining context to identify constraints limiting productivity and develop strategies to exploit and eliminate those constraints. It however did not manage to illustrate explicitly how the five focus steps of TOC can be applied to improve productivity in the mining context. This is an area further research can focus on.

DEDICATION

I dedicate this Research Report to my family, notably:

My wife, Mukani, my father, Prosper, and my late mother, Venancia.

ACKNOWLEDGMENTS

I want to thank my supervisor, Dr O. Oro, for his outstanding commitment to supervising my research project. His swift responses to any updates I made completing this research less frustrating. His constructive feedback made me more positive in wanting to complete this applied research project.

I am grateful to the Styldrift management for enabling me to carry out this research on their mining site and giving me adequate time to pursue my MBA, including completing this research. I would like to also thank my wife for the support she has given me while I undertook this research work.

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Percent	%

LIST OF ABBREVIATIONS

TOC	Theory of Constraints
EC	Evaporating cloud
CRT	Current Reality Tree
FRT	Future Reality Tree
TMM	Trackless Mobile Machinery
UDE	Undesired Effect
TP	Thought Process

GLOSSARY

Face - the tunnel end, or underground workstation where current mining activity is taking place.

Trackless Mobile Machinery- Underground machinery that is not track (rail) bound used to carry out production activities in a mechanised mining operation.

Roof Bolter – TMM whose primary function is to install primary support (underground roof bolts installed to prevent fall of ground)

Axess Rig- TMM whose primary function is the installation of underground secondary support (cable anchors installed after primary support in bad ground conditions to prevent the tunnel from curving in (fall of ground)).

Drill Rig – TMM whose primary function is the drilling of a face after support is installed.

Blockage – A blockage refers to failure of an activity happening due to queuing or having to wait for a face or place to work or perform the activity.

Starvation - Starvation refers to failure of an activity happening due to lack of resources, e.g., a shortage of input material, or shortage of labor.

Control Charts– the research instrument used to record observations of the critical daily activities, including the time activities start, and their duration, and which activities did not occur, and reasons why they started late, took longer than planned or did not occur.

Crew 3 – the name of the production crew that was being observed in this research.

Undesired Effect - problem

Injection - solution

1. INTRODUCTION AND RESEARCH BACKGROUND

1.1 Statement of purpose

This research report is a case study of how Theory of Constraints (TOC) can be applied to improve the productivity of the Styldrift platinum mine. It aims to achieve this by applying TOC to identify bottlenecks affecting the Styldrift platinum mine's productivity and then investigating and analysing how the identified bottlenecks can be exploited to improve productivity in the mining operation.

1.2 Background of the study

In this modern era, companies compete globally for market share. A company's competitiveness is measured by how much market share it can obtain in comparison with its competitors among other metrics. It obtains this market share through possessing a competitive advantage over its rivals. Most companies obtain this competitive advantage, through differentiating their products, based on quality and brand equity, or through competitive pricing (Tilton, 2002).

To gain competitive advantage over their rivals, companies should be able to understand and lay out their growth strategy, through having a clear understanding of their external environment, as well as their own internal structures. For instance, the mining sector is unique in that, while other industries compete on pricing or through differentiating their products to gain a market share, mining companies produce homogenous products (minerals e.g., gold, platinum etc.). These homogenous products sell at the same prices, which are set on international markets. Thus, mining companies cannot compete on pricing nor differentiating their products. To gain competitive advantage, mining companies compete using costs of production. In other words, the lower the cost of production a mining company has, the more competitive it is in the industry (Eggert, 2010).

One strategy a mining company can use to lower their production costs is through ramping up production. This is because the higher the production levels, the more the mining firms can benefit from economies of scale. Thus, to gain a competitive advantage, it is critical for mining companies to develop and implement strategies that can help them continuously improve their productivity and lower their production costs. One such methodology is known as the Theory of Constraints (TOC). TOC focuses on finding the weakest link in the production chain. These weakest links are known as bottlenecks or constraints in the system (Simsit, Gunay, & Vayvay, 2014).

TOC was developed by Eliyahu Goldratt during the 1980's as a management philosophy. It states that the goal of a company is to make money now and in the future. According to Naor, Bernardes & Coman (2013) this stated goal has been refined over the years to state that the goal of a company is to "increase shareholder value". For a company to increase shareholder value it must increase the throughput of its operation, while reducing its inventory and lowering its operating expenses. TOC focuses on identifying, exploiting, and removing bottlenecks in the system. The operations' bottleneck is the place or process in the system that causes limitations in the rate of throughput, this is also known as the system's constraint. Identifying and eliminating the system's bottleneck is the main concept behind TOC (Naor, Bernardes, & Coman, 2013)

TOC is still in the early stages of adaptation in South Africa. The mining industry is one of the sectors that have been early adopters of TOC in their mines to ensure continuous improvement in their operations. For example, Sasol has been using TOC to identify system bottlenecks in some of their mines. On one of the studies which was contacted on their mine it was found that by applying TOC principles and focusing on the constraints of the mining operation, the net cashflow and value to shareholders will increase. However, they identified that there might be some risk of incurring costs if focus is placed on a perceived constraint that might end up not being the actual bottleneck of the system. It is therefore important, when applying TOC principles, to be able to clearly understand and use a methodology that can accurately identify the real bottleneck in the system and not just the noise. (Ramasu, Sobiyi, & Akinlabi, 2017)

This research aims to unpack the Theory of Constraint to improve the understanding of its methodology and applicability in the South African context using Styldrift platinum mine as a case study. There are a total of 16 production crews on the mine. This study zooms its focus on one of the production crews. The production crew at the mine which was selected for the study is called crew 3 and is referred as such in the study.

Styldrift mine has not been consistent in meeting its production targets. This report aims to investigate the core problems limiting Styldrift mine from achieving its targets, using TOC as a methodology.

1.3 Research problem

Styldrift mine, a relatively new mechanized platinum mine in South Africa is currently having production challenges. Over the past two years it has consistently failed to achieve its production targets. This has resulted in an escalation of its unit cost of production and a persistent fall in its profitability. This study argues that TOC could be applied effectively to improve the productivity of the company's operations by identifying its operational bottlenecks and device strategies to remove them to ensure improvements in its productivity.

TOC was chosen as a method to conduct this study because it is one of the well-known theories in the business improvement field. It has been used to improve the performance of operations across various industries, using various techniques which include the 5 Focus steps, buffer management, and the thought process tools such as evaporating clouds, and Current Reality Trees. Numerous top global organizations have adopted TOC as a management philosophy. However there has been an identified gap in TOC's successful adaptation in developing countries, particularly on the African continent. Part of the reason is due to a lack of understanding and experience in TOC methodologies and applications by managers in developing countries. This is the gap this research aims to fill by highlighting the applicability of TOC in a developing country context, using a platinum mine in South Africa as a case study.

1.4 Research objectives

- To apply TOC to identify bottlenecks affecting the Styldrift platinum mine's productivity.
- To investigate and analyse how TOC can be used to improve productivity in the mining operation.

1.5 Research Questions:

- What are the core problems limiting Styldrift mine from achieving its monthly production targets?
- What strategies can be used to improve the monthly productivity of Styldrift mine?
- Can Theory of Constraints be successful applied as a methodology to identify the bottlenecks limiting productivity, and to formulate strategies that can be used to improve productivity at Styldrift mine.

1.6 The study significance

Styldrift mine employs nearly 5000 people directly, and thousands more indirectly through its supply chain. The surrounding communities also rely on Styldrift mine for their survival as its mine workers support the local economy. Moreover, it is a significant contributor to the national treasury through the taxes it pays and is also a major foreign exchange earner in the country. Styldrift mine is also responsible for funding the maintaining of the local infrastructure including roads, waterworks, local schools, and clinics, as well as supporting local entrepreneurs.

For the past two years Styldrift mine has been failing to meet its production targets. If Styldrift mine continues to fail to meet its production targets and is not profitable, there is a huge risk that it might be closed or put on care and maintenance. This could have a serious impact on tens of thousands of people, and entire communities that depend on it for a livelihood. It is therefore critical that successful strategies are developed and implemented to ensure the sustainability of the mining operation through productivity improvement. If the TOC developed strategies proposed in this research study are adopted, the mine's productivity can improve and in turn this can reduce the risk of the mine being closed.

1.7 Delimitations of the study

a) This research used primary TOC principles in its analysis and did not use other process improvement techniques such as six sigma and lean.
b) This research focused on TOC applications specifically to an underground mechanized mining environment.
c) This research focused its research only on one section of the mine, namely crew 3, due to resource constraints and the availability of data.
d) This research focused primarily on application of TOC to improve productivity in the section, and not directly on cost reduction applications.

1.8 Assumptions

The research was conducted in one section of the mine. The assumption is that the constraint that was identified in that section is representative of the constraints of the whole mine, and the recommendations given to eliminate the section's constraint is applicable to the entire mine.

1.9 Chapter Outline

This report has the following structure. In **Chapter 1** a brief background on the importance of good operations management in ensuring companies remain competitiveness is given. This is followed by a brief introduction to the concept of TOC and its application. This is followed by outlining the research problem, setting out the research objectives, and the rationale for the research. The scope of the study is then outlined. The research assumptions are then outlined.

In Chapter 2 the literature review is undertaken on TOC and how it can be applied to business operations. In the literature review, TOC is also compared to other management philosophies such as Six Sigma and Lean. Practical examples of mining operations where TOC has been applied successfully on mines in South Africa are given. The analytical framework is also outlined to justify why TOC was suitable for use in this research. This includes outlining the theoretical framework in detail.

In Chapter 3 the methodology that was applied to conduct the research and achieve the outlined objectives is outlined. This methodology was informed by the literature review. In Chapter 4 the time and motion study results conducted on the mine to identify the constraint are presented. The chapter ends by an analysis of these results to identify the bottleneck from the results. Chapter 5 then presents the development of strategies that can be applied to eliminate the identified constraints. Chapter 6 gives conclusions from the report and Chapter 7 then give a summary of the recommendations.

2 LITERATURE REVIEW AND THEORETICAL FRAMEWORK:

2.1 An Introduction to Continuous Improvement applications and Theory of Constraints

Since the advent of the industrial revolution in the early 19th century businesses have been striving to improve the prospects of their business survival, competitiveness, and have aimed to gain profitability through implementing various forms of continuous improvement initiatives (Rajini, Nagaraju, Nara, & Narayanan, 2018). In the quest to continuously improve their operations, businesses began to try out different philosophies in operations management including, Total Quality Management, lean manufacturing, six sigma, and theory of constraints. The common factor amongst all these operations management philosophies was the finding that they all require functional integration and systems thinking. This involves a holistic approach to analysing a business operation and understanding how the different constituent functions and parts in the system, interact together to achieve the common greater goal of the organisation. To achieve this integration and synchronisation of cross functions in the system, managers of the different functions needed to speak in a common language. This is where the different operations management theories came into play (Gupta & Boyd, 2008).

Initially it was thought that by making improvements across all functions or parts in the system, it would lead to an improvement in the overall company performance. However, practice has shown that significant improvements made in different departments or functions in an organisation have on many cases resulted in only slight improvements in the overall performance of the organisation. This phenomenon led to some operations management academics to investigate why such cases occur. One such operations management academic was Eliyahu Goldratt, who developed the thinking process of Theory of Constraints (TOC), with the aim of trying to enhance the analysis and understanding of such phenomenon. Goldratt's Theory of Constraints (TOC) tries to examine and explain why the phenomenon whereby the summation of local improvements in different functions in the system does not result in an improvement in the company performance as whole happens. (Kishira, 2018)

To explain this phenomenon, TOC uses the concept of system bottlenecks. To understand bottlenecks, it is important to understand the variabilities and interdependencies of different functions or activities in an organisation. Each activity of one function in the system depends on another activity in the organization. These links between different activities in the organisation can be symbolised as chains in the system, each flow of work linked to like a chain.

Figure 1 below shows an illustration of such variabilities and interdependencies in an organisation. The illustration shows workflows that can represent different activities across functions such as different departments, and work centres, with the workflow going from left to right. The capacity of each work function is varying from (20 to 15 to 10 to 12 to 16) units per day (Kishira, 2018).

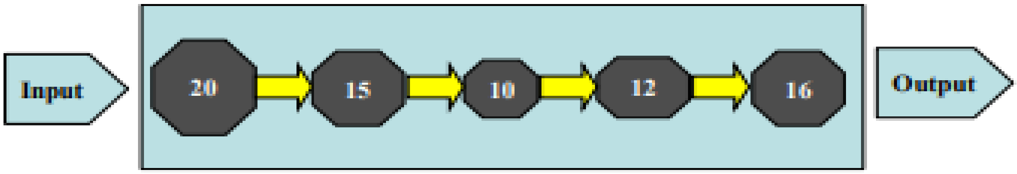


Figure 1: System with variabilities and interdependencies (Kishira, 2018)

From the illustration of the system workflow above the output will not be able to exceed 10 units/day. The work function with the capacity of 10 units/day is therefore the bottleneck of the system. A fundamental step in continuous improvement using TOC is therefore the identification of the function or workstation where the is a bottleneck. Once the bottleneck has been identified, focus should then be placed on ensuring capacity on the bottleneck is improved. An improvement in the capacity of the bottleneck will ultimately result in the improvement in the system’s output. However, increasing the system’s capacity is not always easy to implement.

For example, the bottleneck can be an expensive equipment, or personnel that cannot be replaced or increased in the short term (Kishira, 2018). In this instance it is important for operations managers to find ways to exploit the constraint in the short term. For example, if the bottleneck is personnel, while looking for a permanent solution like recruiting a scarce skill, or training them, which might take a long time, the organisation focuses on supporting the current personnel to improve the bottleneck. This can be achieved for example by taking less critical tasks off their desk that other members can do, so that they have more time to focus on the critical tasks only they can perform. By ensuring that other employees are focused on supporting the bottleneck, this can result in a significant improvement in the system's output, within a shorter period, and before any other resources can be added into the system. It is a common understanding that any system that has variabilities and interdependencies, like the one illustrated above, must have a bottleneck somewhere along the chain (workflow). This approach of focusing resources on the bottleneck than trying to improve everything at once, can therefore be more effective and efficient (Mycue, 2018).

For a systems approach to management, focus must be made on the constraint philosophy championed by TOC. However, since the word bottleneck was often misunderstood and misinterpreted, Goldratt opted to use the term "constraint" instead in developing the "Theory of Constraints". The logic being that focusing on improving non-constraints will not result in improvements in the performance of the system. Furthermore, resources are limited, using these limited resources in the organisation to improve non-constraints is a waste, and it also takes away these resources from improvement of the constraint. Goldratt stated that TOC reduced to one word is FOCUS. In other words, engage in what is necessary to do, and do not perfume what is not important to be do. TOC has evolved to a stage where it is not only applied to improve production in an operation but anywhere in a system where there are variabilities and interdependencies (Kishira, 2018)

Within an organisational system constraint, can be defined as anything that is limiting that system to experience greater performance as related to the goal of the company (Ukey & Sawaitul, 2021). Making a non-constraint improvement can thus be likened to a mirage, as it won't have any effect on the strength of the chain, or performance of the system. (Mycue, 2018)

2.2 Unpacking Theory of Constraints

The theory of constrain (TOC) is one of the operations management philosophies that is used as a business improvement methodology (Naor, Bernardes, & Coman, 2013). TOC is based on the fundamental principle that a business operation is viewed as a system comprising of links on a chain. Each part on the system chain has a certain capacity to process input and produce output, and in every chain, there is at least one link in the chain process that will be limiting the throughput of the entire system. This is regarded as the weakest joint along the chain and is known as a bottleneck or constraint. This constraint can either be physical or nonphysical. Examples of physical constraints can include availability of machinery or raw material, personnel, and processes. The nonphysical constraints may include low morale, lack of training, culture etc. Identifying the constraint in a system can be likened to a clinical diagnosis of an ill patient. Once the constraint has been diagnosed, the next step is to plan the treatment, and implement the treatment plan. In operations management, this treatment process involves identifying what change is essential, and what is the ideal state to change to, and how to effect the desired change. (Mathu, 2014)

TOC can be used in various organizational systems, including project management, production, supply chain management and logistics. As TOC is built on the foundation that any system has a weakest link, there are a lot of studies available in literature that have been conducted focusing in different areas where TOC can be applied. These studies have given rise to different definitions of TOC, however the common factor among all these definitions in literature is that of systems having “constraints”. The premise of TOC starts by defining the “Goal” of a company. It states that the company’s goal is “to make money now and in the future”. Broadly speaking, the goal of any company is to increase shareholder value. A constraint can therefore be defined as the main obstacle preventing a company from achieving its “Goal”. (Simsit, Gunay, & Vayvay, 2014)

2.2.1 The Five Focus Steps of TOC

To make money and increase shareholder value, a company must increase its throughput and reduce its operating expenses and inventories. The throughput at the bottleneck limits the system’s performance. To improve an operation’s performance in summary, the first step, according to TOC is to identify the constraint in the system. One of the key indicators of a constraint in the system is a place in the system where there is a queue next to the process. The second step in the process of improving the operation's performance is exploiting the constraint. This is done by finding ways to support and improve the efficiency of the system at the constraint without adding major resources or expenses. This process is known as exploiting the constraint. (Nave, 2002)

The next step is to subordinate, whereby the constraint is exploited to its maximum capacity. As part of the subordinating process the pace of the other subordinate processes in the system are synchronized to operate at the same capacity or speed as the constraint. This implies that some individual processes will not be operated at their full productivity levels to benefit the system. Usually, the processes before the constraint are the ones that require subordination, as the processes that are after the constraint are already producing below capacity, as they must wait on the constraint part of the system. (Simsit, Gunay, & Vayvay, 2014)

The fourth step in the TOC methodology is to elevate. This step occurs when the production levels of the system, overall, is still not to the required levels, resulting in further improvements being required. At this step, the company will now be considering implementing investments to add more resources or make major changes to the constraint. These changes may include reorganizing the company, or capital expenditure. The step of elevating the constraint is whereby decisions are made to take whichever actions are required to remove the constraint. Once this constraint is successfully eliminated, there will be a new constraint on another part in the system. To eliminate this new bottleneck in the system, these outlined TOC steps need to be followed again. This is done by repeating the same process of identifying the constraint, exploiting the constraints, subordinating, and elevation in a process of continuous improvement. These five steps are known as the "Five Focus Steps". (Nave, 2002)

2.2.2 The Drum-buffer-Rope Analogy of TOC

Another theoretical dimension that TOC presents to manage the constraint in a system and address the "How question" is the concept of the drum-buffer-rope. The drum symbolizes the production rate of the system. The drum sets the rhythm of the workflow of activities along the production system. The buffer is meant to give a cushion from fluctuations (starvations) in the system caused by shortage of material. These cushions help to maintain full utilization in the system despite the fluctuations, resulting in maximization of throughput. The rope symbolizes a flow of communication that transmits information from location of the buffer to the person tasked with scheduling. The rope signals to the schedular to release activities into the system using the rate at which the buffers are consumed in the system. (Naor, Bernardes, & Coman, 2013)

A simplified example of an organisational system is a platinum mine which produces refined platinum and sell it to Japanese car manufacturers to use in catalytic convertors. The Japanese manufacturers (market) will buy 10kg’s of platinum a week. However, the mine has the capacity to produce 12kg’s of platinum per week. Therefore, the constraint in this system is the market demand. According to TOC, the production rate should be at the same pace as the constraint, which in this case is the market. If the mine continues producing 12kg’s of platinum while the market demand for its platinum is 10kg’s per week, it will end up with unsold stockpiles of platinum, or might be forced to sell the platinum at a bargain discount price.

The above example helps illustrate the importance of using the drum-buffer-rope analogy in operations management using TOC. The constraint, in this case the market, acts as a drum, that beats at the rate the system should follow. The buffer is material that cushions the constraint from the fluctuations in the system. in this case, the buffer can be a stock of a couple of kg’s of platinum kept at hand, to cushion the market from fluctuations in production. The rope is a mechanism in place that is used to signal the depletion of buffers cushioning the constraint, so that more material buffers can be released. In this case the rope signals for a kg of platinum to be input into the system whenever a kg of platinum is sold. This results in the buffer being kept at a constant level. In the example above, the mine manager must focus their effort on increasing marketing and sales of their platinum product. Improving the efficiency of the mine’s production line will be a waste of effort, as the mine can already produce more platinum than it can sell. (Blackstone, 2010)

2.2.3 TOC approach to Inventory management.

In TOC, inventory is an important measure and is one of the key focal components of the drum-buffer-rope approach to buffer management, production planning and scheduling. TOC is viewed like a low-inventory operations management methodology, instead of being a no inventory system. According to TOC, the main function of inventory that is productive is for protecting the system's throughput through buffer management. However, having too many inventories can become counter-productive and cause a reduction of throughput. The reasons why too many inventories are counter-productive are listed below (Gupta & Boyd, 2008):

- Too many inventories clutter the system and make it difficult to physically move around things.
- Tracking things becomes more difficult, which can result in production disruptions as it can take time searching for material or reproducing material that cannot be located.
- Having too much inventory is a symptom that resources are being tied up in producing more that required, instead of being utilized where they are required to support the system's throughput, and
- Too many inventories can increase the lead time.

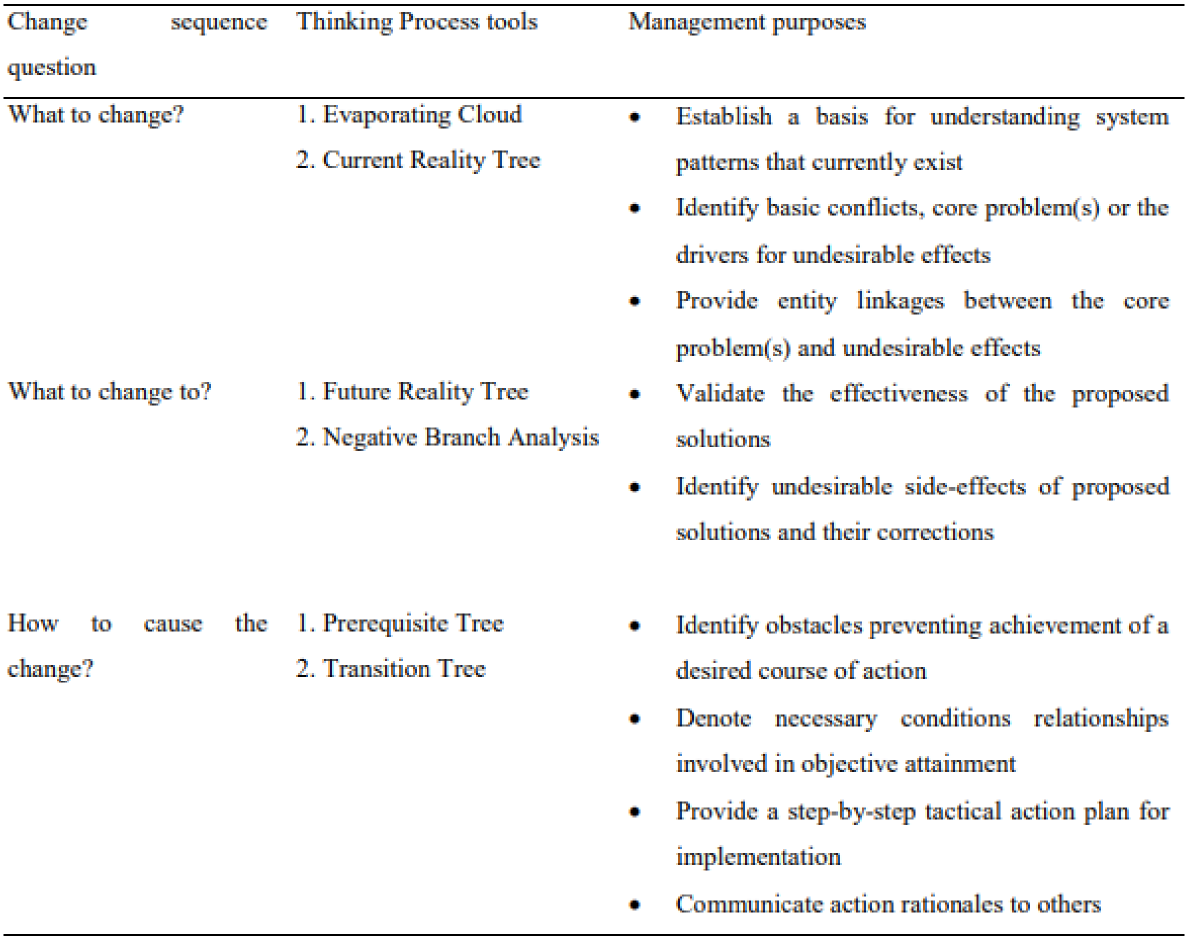
However, if inventory becomes too low, this can threaten the system's throughput. This is because having too little inventory might lead to starvation of the system constraint, as there would be nothing cushioning it to fluctuations on input material it must work on. This can result in an increase in throughput time and lead time, resulting in disappointed customers due to failure to meet shipping schedules. A certain level of inventories is required to act as buffers, particularly in front of the system constraint. (Gupta & Boyd, 2008)

2.2.4 The TOC Thinking Processes.

To ensure continuous improvement in operations managers must continuously scan and adapt to the constantly changing operating environment. The following 3 questions are asked to manage changes using TOC, namely: what is it that requires to be changed, what is the ideal state that can be changed to, and how this change can be achieved. TOC uses the “Thinking Processes” as logic-based tools to guide management in finding answers to the above questions (Sanjika, 2010). These Thinking Process (TP) tools are comprised of cause-and-effect tree diagrams constructed using logical steps to identify the symptoms of the problems (in TOC these are called undesired effects), and then to find the causes of these undesired effects (UDEs). TP’s then assist the manager to determine how to eliminate these root causes, and to formulate a roadmap required to ensure an improvement in the system’s performance. (Mason-Jones, Davies, & Thomas, 2022)

TP tools are therefore used as a TOC framework to help managers understand current situations affecting a system. TP’s also help in formulating strategies that are effective in achieving the set goals and in the implementation of improvement efforts in the system. Table 1 below gives a summary of the different uses of TP tools in continuous improvement:

Table 1: TP, TOC tools that can be used by management for continuous improvement.



Change sequence question	Thinking Process tools	Management purposes
What to change?	1. Evaporating Cloud 2. Current Reality Tree	• Establish a basis for understanding system patterns that currently exist • Identify basic conflicts, core problem(s) or the drivers for undesirable effects • Provide entity linkages between the core problem(s) and undesirable effects
What to change to?	1. Future Reality Tree 2. Negative Branch Analysis	• Validate the effectiveness of the proposed solutions • Identify undesirable side-effects of proposed solutions and their corrections
How to cause the change?	1. Prerequisite Tree 2. Transition Tree	• Identify obstacles preventing achievement of a desired course of action • Denote necessary conditions relationships involved in objective attainment • Provide a step-by-step tactical action plan for implementation • Communicate action rationales to others

(Sanjika, 2010)

Figure 2 below gives a summary diagrammatic illustration of the TOC TP tools. These TP tools, are used to answer the 3 fundamental questions in TOC, namely what to change, what to change to, and how to cause the change?

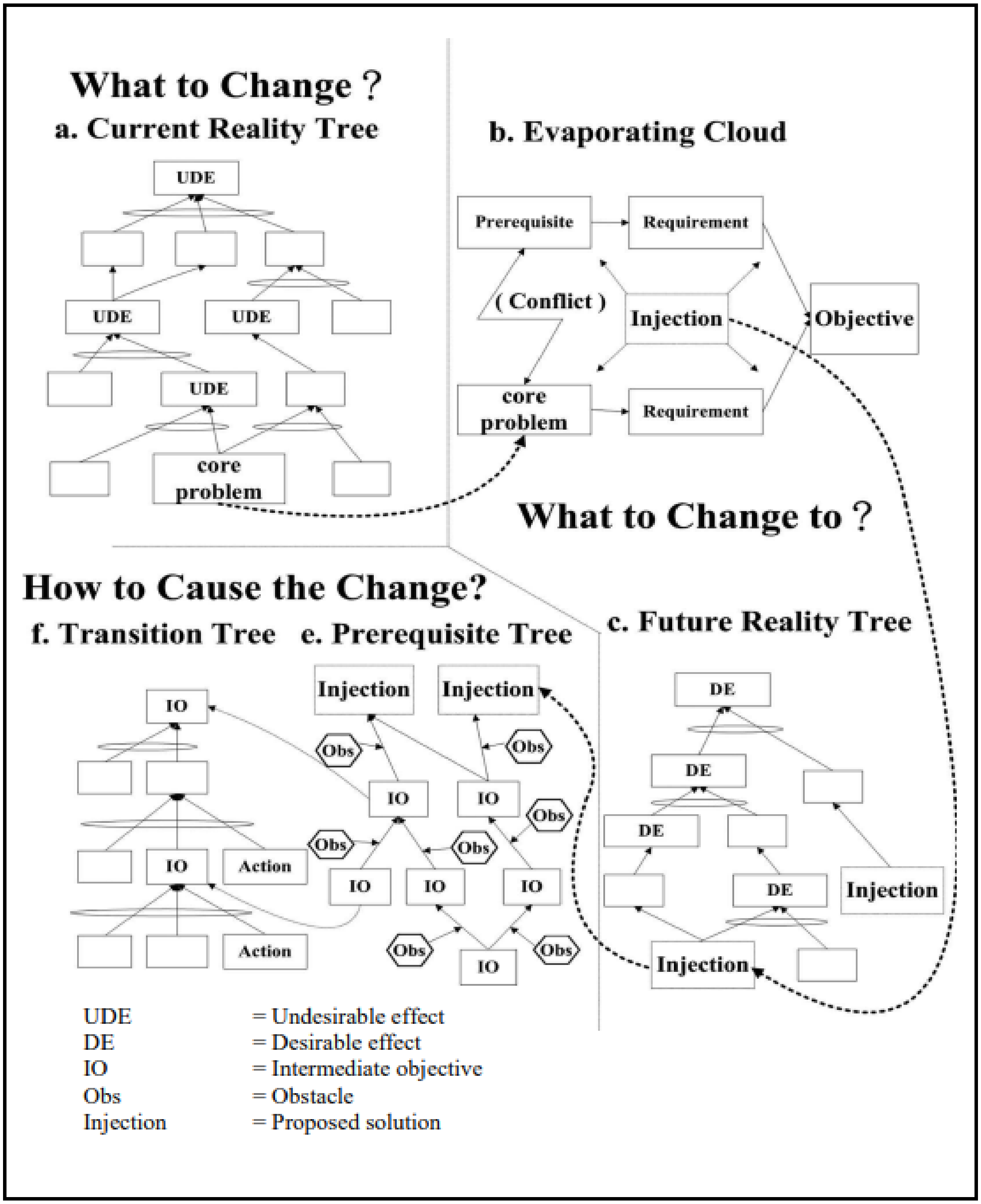


Figure 2: TOC T's illustrations and terminology (Sanjika, 2010)

2.2.4.1 Current Reality Tree as a TP

The first step in improving an operation is to identify what to change. The Current Reality Tree (CRT) is a tree diagram that is used as a TP tool to identify the system's core problems through the application of cause-and-effect logic. The following steps can be used when developing a CRT (Sanjika, 2010):

- Define the scope, by identifying the team's sphere of influence and area of control.
- Write down a list of UDE's (symptoms) indicating the existence of the problem in the system.
- Form casual links between the identified UDE's.
- Construct a cause-and-effect connection validating the UDE's, and
- Use these cause-and-effect chain for the identification of the root causes of the system's underperformance and main problem (Mason-Jones, Davies, & Thomas, 2022).

Figure 3 shows an example of a CRT. A CRT in TOC can be understood as applying the logic of cause and effect, read from the bottom going upwards. As can ban be seen in figure 3 below CRT in figure 3 will therefore be read as "if the engine can't turnover, then the vehicle cannot start. These are symptoms (UDE's) of the underlying problem. To add validity other branches can be added to the CRT through forming logical relationships between the UDE's. In this the entry "the battery is dead" was added to explain why the engine is not turning over (Sanjika, 2010). Similarly, the entity that the lights were left switched on, and the car didn't automatically switch off the lights; were used to explain why the battery died. These will more likely be considered as the root cause of the problem. (Blackstone, 2010)

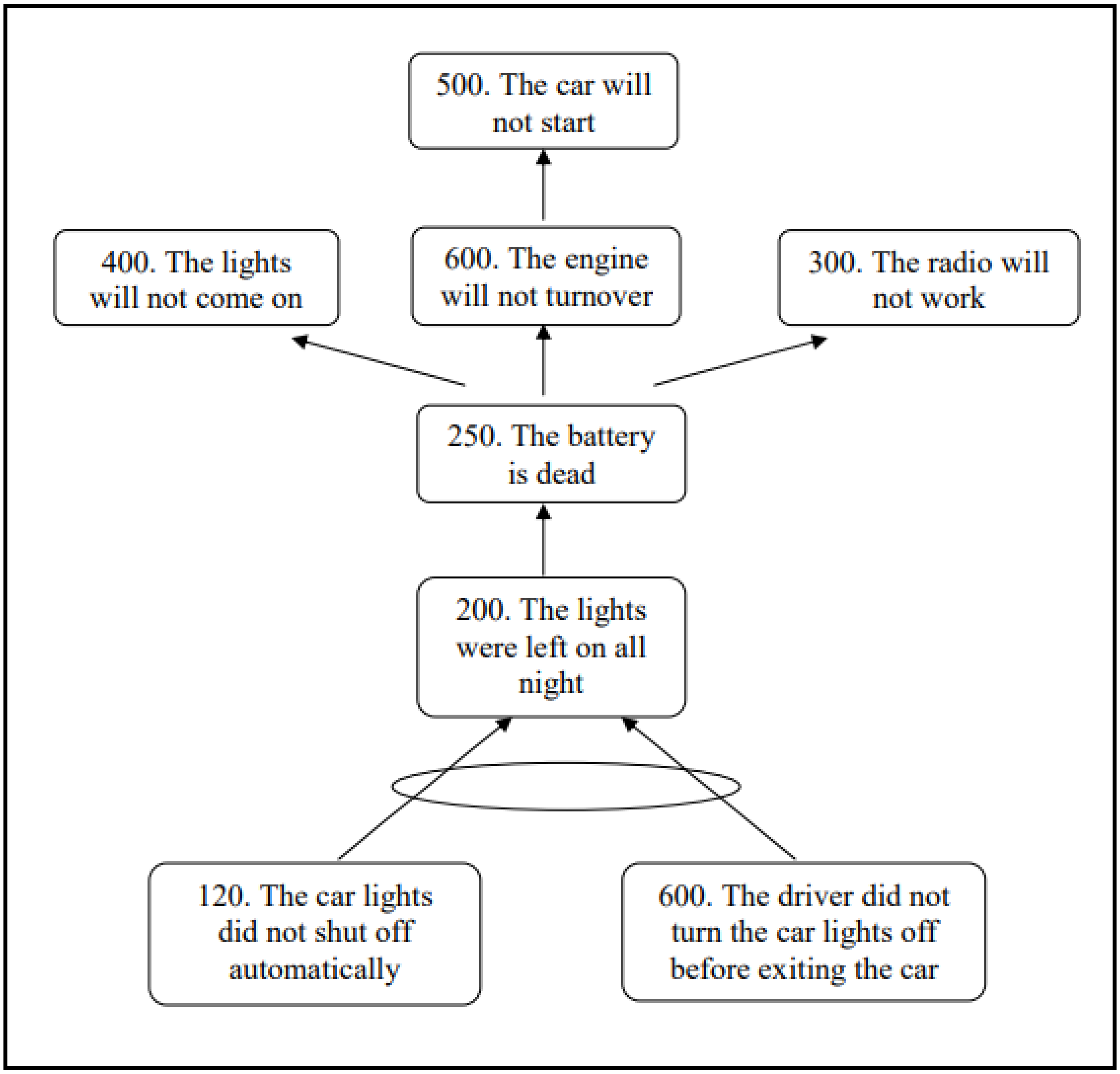


Figure 3: Completed Current Reality Tree (Sanjika, 2010)

2.2.4.2 Evaporating Cloud (EC)

Once the question what to change has been identified through the CRT, the second step of the TOC thought process is to answer the question of “what to change to”. There is however often conflict in resolving system problems. Operation managers often find themselves having dilemmas when coming up with solutions to identify problems, often having to make compromises. The Evaporating Cloud is a TOC TP diagram used to resolve conflict once the root problem has been found. It was developed to resolve dilemmas or conflicting scenarios where there are no acceptable compromises. The EC process achieves this through an analysis of both sides of the conflict and then developing a win-win solution. TOC claims that the EC has the advantage of having the ability to be used as a tool to resolve a conflict entirely, without the need to make a compromise. It can bring to forth new ideas and offer creative solutions. (Sanjika, 2010)

Figure 4 shows an illustration of a EC. When constructing an EC, the starting points is to identify the objective that is desired, this is essentially the opposite of identifying the root problem using a CRT. Once you have defined the desired objective, the next step is to determine the requirements and prerequisites for those requirements. The prerequisites can be described as the conditions necessary to respectively achieve the objectives and requirements. Because the 2 pre-requisites are in conflict, the objective appears unattainable. To resolve the conflict and attain the objective without making a compromise will involve exposing the underlying assumptions behind this prerequisite condition (Blackstone, 2010).

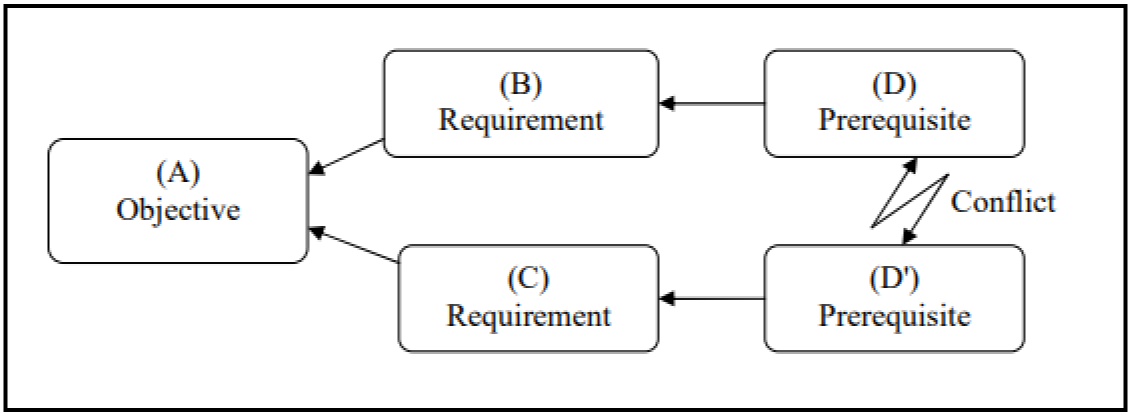


Figure 4: An Evaporating Cloud template (Sanjika, 2010)

The following step requires determining the requirements represented B and C and prerequisites (D and D'). Prerequisites and requirements are critical factors in achieving the objective and the requirements, respectively. This logic is now ready to verify the necessary conditions. Therefore, the diagram can be interpreted as; we must have prerequisites D and D', to have requirements B and C respectively. Since there is a conflict between prerequisites D and D', it implies that objective (A) can seem difficult to attain. To resolve the conflict would thus need the assumptions behind the critical factors be exposed, challenged, and made invalid. (Sanjika, 2010)

Figure 5 illustrates an example of application of an EC. In this example the objective of the EC is to become a good manager. To achieve this objective, there are two conditions that are necessary (requirements) namely to continuously reduce waste, and to continuously increase workflow. For both objectives to be achieved, both requirements must be achieved. It is a known fact that people act in accordance to how they are measured. The implication is that the prerequisite of reduction of waste is through using efficiencies as measurement matrices. However, to ensure sustained flow increase, all workstations must be subordinated to flow at the same pace as the constraint. This may imply that locally some workstations would not be operating at their most efficient levels. However, if these workstations are allowed to run at more efficient levels this would result in a buildup of work in the progress inventory at the constraint. The main function of an EC is to unpack these underlying assumptions. In this case the assumption that "a resource that is standing idle is a waste". Breaking this assumption is key to resolving the conflict between using efficiency as a measurement or not. For example, this assumption might be replaced by a new approach stating that workstations that are non-constraints should be measured against the pace of the constraints. (Blackstone, 2010)

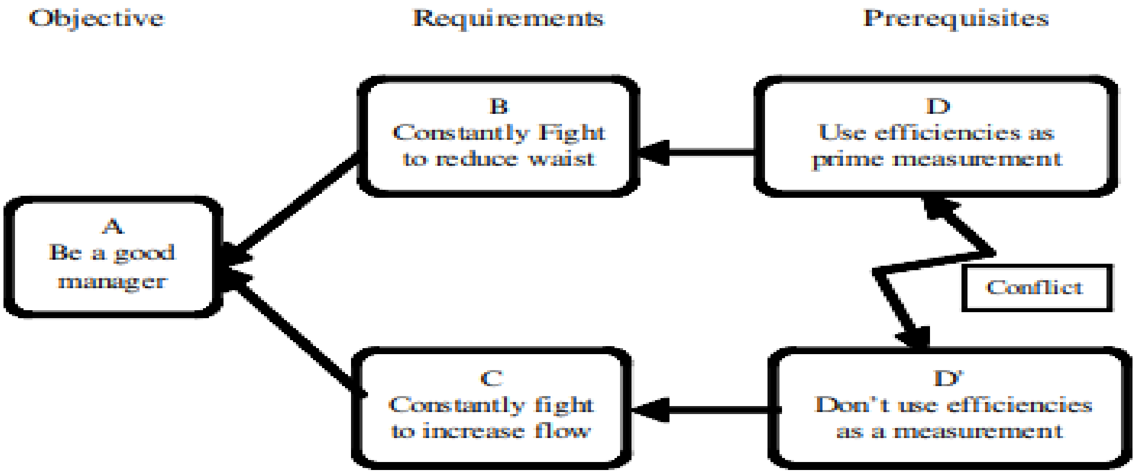


Figure 4. The generic conflict of operations managers.

Figure 5: An example of an Evaporating Cloud (Blackstone, 2010)

2.2.4.3 Future Reality Tree (FRT)

The FRT is a TOC Thought Process (TP) tool that is applied after the Evaporating Cloud (EC). Its purpose is to also help develop a suitable solution to the core system problems that are identified through use of the Current Reality Tree. The FRT is used to test the robustness of the solution proposed using the EC tool to make sure that implementing that solution can really resolve the identified problem without creating a negative performance impact in the future consequently. Ideally, the FRT is constructed through s group effort, where people are allowed to criticize the proposed solutions. The benefit of this is an improve communication, acceptance and understanding of the solution by those affected by the problem. Building a FRT as a team helps to reduce the probability of overlooking potential problems that can result from implementing the proposed solution. One of the advantages of building the FRT is that it allows the suggested solutions to get tested before any resources can be committed to implementing them. It also helps develop actions that can be used to prevent the occurrence of negative consequences that can result from implementing the proposed solution. It also improves the chances of gaining support for the implementation of the proposed solution. (Sanjika, 2010)

2.3 Investigating how TOC can be used to improve productivity in operations, through identifying and eliminating constraints.

The TOC methodology has been proven effective in literature through empirical studies. These empirical studies have shown that when TOC is properly implemented it can indeed improve the performance of a company. TOC has garnered further support to its effectiveness as it has been adopted and implemented successfully by several Fortune 500 companies (Naor, Bernardes, & Coman, 2013).

TOC has the potential to transform countries' economies through its implementation to help industries maximize their operations' performances. While TOC has become widely used as a business solution to improve operations of companies in developed countries, it is yet to be fully grasped or embraced in developing countries. South Africa has been one of the developing countries that has been leading other African countries in the application of TOC to develop the performance of its industries. However, there remains a gap which requires to be filled to fully maximize on the benefits of applying TOC.

One of the companies in South Africa that has applied TOC to improve its operations is Lonmin. For instance, in 2014 TOC was introduced to Lonmin's Rowland mine. This was an intervention measure after the mine had been consistently underperforming in terms of production throughput. After the introduction of TOC, there was a 5.1% increase in the mine’s production output as illustrated in figure 6 below. Figure 6 below shows a comparison in production output before and after TOC was implemented on the mine. As can be seen from the diagram, on the left-hand side there was a decreasing trend in production output, and on the right-hand side it shows a reversal of the trend after TOC was applied. (Ramasu, Sobiyi, & Akinlabi, 2017)

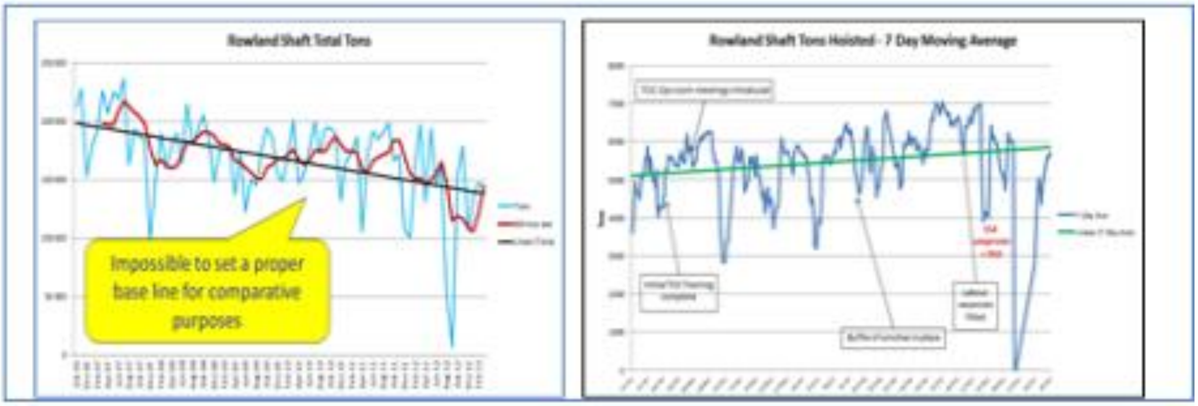
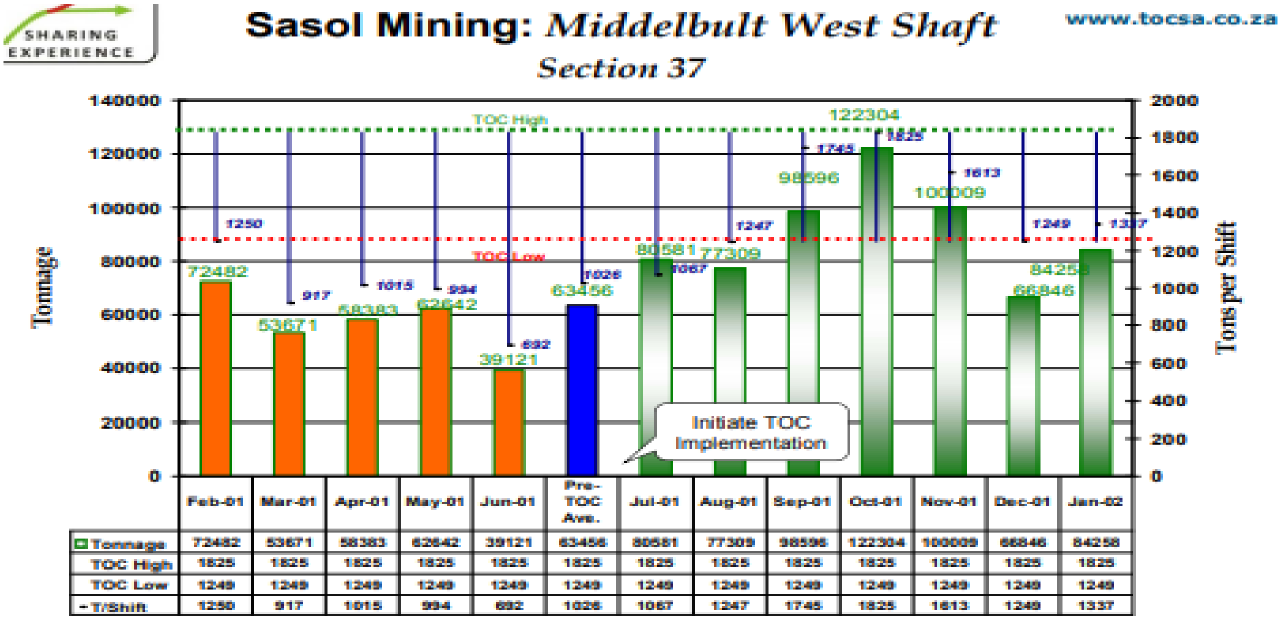


Figure 1. Rowland Shaft Lonmin mine production output [23]

Figure 6: Rowland Shaft performance before and after TOC was applied. (Ramasu, Sobiyi, & Akinlabi, 2017)

There are several other examples of how TOC has been applied successful to turnaround the performance of South African mining companies, whether in coal mining or hard rock mining, mechanized operation, or conventional mining operation. One such example is Sasol Mining, which introduced TOC to its Middelbult West Shaft resulting in a quick turnaround in the mine’s operational performance. The results are illustrated in table 2 below, which shows the production outputs before TOC was implemented, and the production outputs after TOC was implemented.



	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Pre-TOC Ave.	Jul-01	Aug-01	Sep-01	Oct-01	Nov-01	Dec-01	Jan-02
🟩 Tonnage	72482	53671	58383	62642	39121	63456	80581	77309	98596	122304	100009	66846	84258
TOC High	1825	1825	1825	1825	1825	1825	1825	1825	1825	1825	1825	1825	1825
TOC Low	1249	1249	1249	1249	1249	1249	1249	1249	1249	1249	1249	1249	1249
- T/Shift	1250	917	1015	994	692	1026	1067	1247	1745	1825	1613	1249	1337

Figure 7: Sasol mine before and after TOC was introduced.

2.4 A Comparison of TOC with other Business improvement methodology.

A methodology can be defined as a set of structured activities or guidelines that can be used to assist people to undertake research, a methodology is a set of principles for the method used in the research. Each methodology can be broken down into techniques, such as the Thinking Process tools used in TOC (Stamm, Neitzert, & Signh, 2010). Below are brief comparisons between the most popular methodologies used in business improvement of operations:

2.4.1 Six Sigma

One of the most popular business improvement methodologies is called Six Sigma. It was developed in the 1980s by Bill Smith who was an engineer at Motorola with the aim of addressing the company's systematic problems in delivering customer expectations. Six Sigma aims to ensure quick tangible results through eliminating process variations that can result in cost savings. (Stamm, Neitzert, & Signh, 2010)

Six sigma is a uses statistical data analysis to gain an understanding of fluctuations in a system with the aim of being able to reduce errors and defects in the process. The main assumption of six sigma is that the output of the system process should improve when variations of different elements are reduced. The six-sigma methodology includes five basic steps namely:

1) Defining- this step involves defining the process by trying to understand the operation and the challenges it is facing. The result of this process is the identification of the current output situation as well as the process elements.
2) Measuring- the next step is to measure the process. This step involves verifying the measuring systems and conducting data collection.
3) Analysing - the next step in the process is to analyse the data. This involves converting the raw data into meaningful information that can give insight into the system's processes.
4) Improving- the next step is then to improve the system's processes by developing solutions to the identified problems and making the necessary changes to the processes. The results of these changes are measured allowing the company to make an informed judgement on whether the effected changes are sufficiently beneficial or further sets of changes are required.
5) Controlling- once the desired changes are affected and the system's processes are performing at the desired levels, they processes are monitored closely to ensure that there are no unexpected consequences of the changes and everything is under control. (Nave, 2002)

As highlighted earlier with its Motorola roots, Six Sigma was initially focused on application in the manufacturing industry. However, overtime Six Sigma has gained acceptance and popularity in other sectors such as in the hospitality, food, health, and services industries. Because of its emphasis on quality management and its use of quantitative measuring methods, with performance goals that are clearly defined, Six Sigma is now a widely recognised strategy for business improvement. It has specialised teams of practitioners, with rankings such as green belt and black belt, depending on proficiency. (Pacheco D. A., 2013)

2.4.2 Lean thinking

Lean Manufacturing has its roots in studies which were done by scholars on the Toyota manufacturing methodologies. One of the scholars who conducted the studies defined Lean Manufacturing as systems approach to remove waste. Alternatively, this methodology was called the Toyota Production System. its aim was to reduce production and setting up time, integrating of suppliers, take advantage of synergies in the whole business process, removing of waste, and generating of buy in across all levels in the business operation. (Stamm, Neitzert, & Signh, 2010)

The two most important principles for Lean manufacturing are Just in Time and autonomation. The just-in-time principle implies to an optimal flow of the system whereby the correct components arrive at the production line at the exact time and quantities required. In ideal situations, this will result in zero levels of inventory. The second principle of autonomation (or Jidoka) refers to a situation where machines in the system can immediately stop whenever the system processes are out of sync. In more recent publications Lean (or the Toyota Way) also incorporates the importance corporate culture as highlighted in figure 8 below. Toyota manufacturing emphasises using making lean structure and systems, as well as encouraging organisational learning. Toyota's success was also attributed to its corporate culture and management system where emphasis was put on respect for people, long term thinking, and leaders taking the responsibility to mentor. (Stamm, Neitzert, & Signh, 2010)

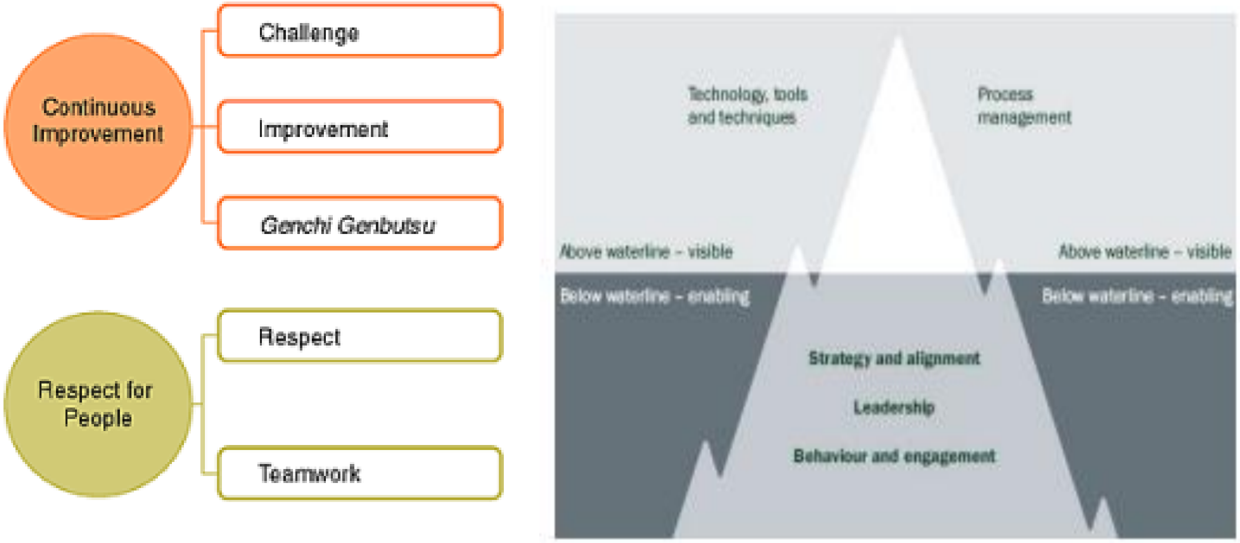


Figure 8: Main components of The Toyota Way main elements and Hines' iceberg model of a sustainable Lean organization (Stamm, Neitzert, & Signh, 2010)

As mentioned previously, the lean process improvement methodology aims at removing waste in the system's processes. Waste is defined as anything that is not essential in producing the service or product. The Lean methodology uses 5 basic steps namely:

1) Identifying value- the first step in the lean methodology is to evaluate on what features of the product create value. Value is defined as the aspects of the product that meet the need of customers at a given time and price.

2) Identifying value streams- once the value features are identified, the activities that contribute to the creation of this value component of the product are identified. Then decisions are made on whether it is necessary to keep some of the activities that don't directly add value to the product. The impact of the necessary activities that don't directly add value to the product is kept to a minimum. The remaining nonvalue adding activities that are not necessary are phased out of the system's processes. (Nave, 2002)

3) Improving flow- once the activities that add value to the product and that add no direct value, but are necessary are identified, the effort is now directed at improving the flow of these activities in the system. Flow refers to the unhindered movement of the service or product in the system till it reaches the customer. Examples of

flow hinderances are batch processing and queuing of work in progress. These ties up money and resources that can be utilized elsewhere in the organization and can act as a cover to system constraints and other wastages.

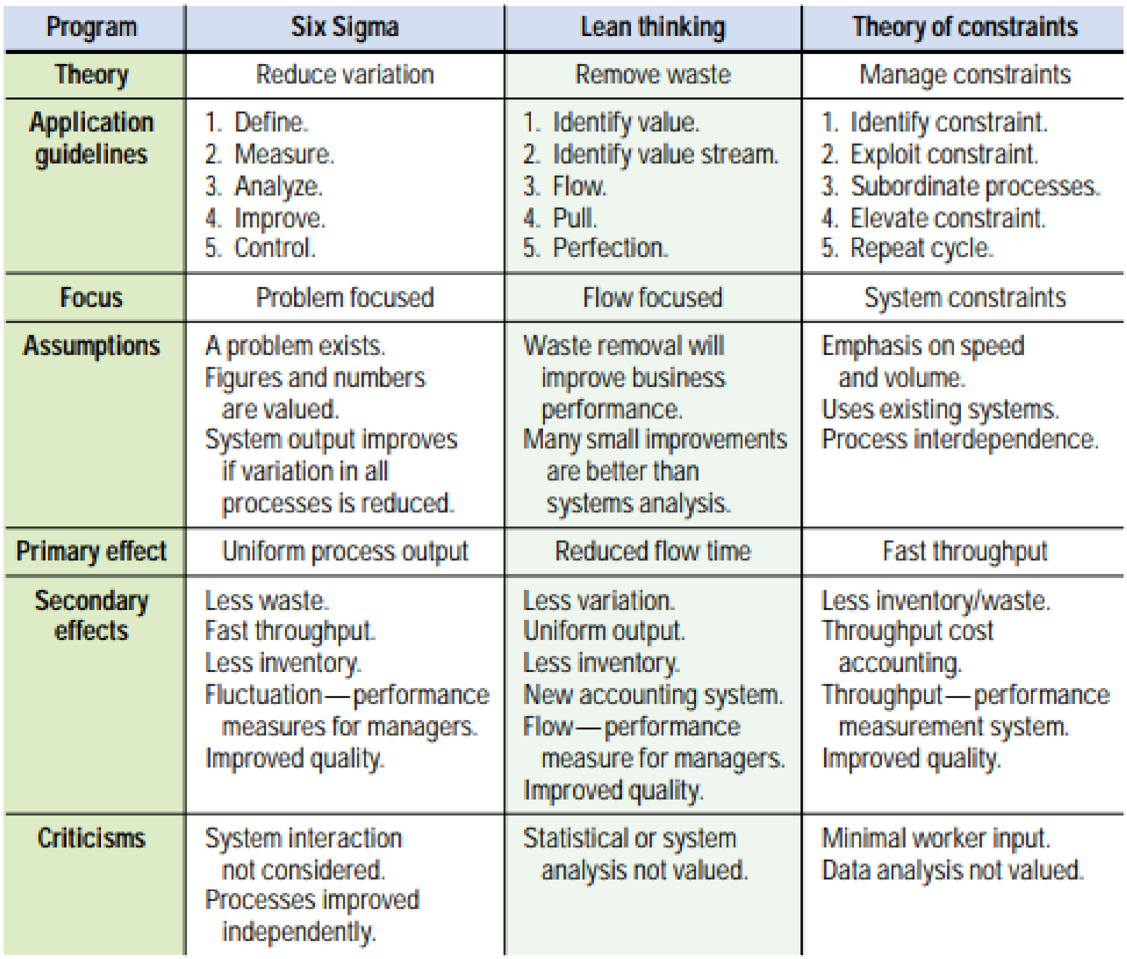
4) Allowing customers to pull- When the wastage in the process is removed and the hinderances to flow is also removed, the effort is now directed to allowing the customer to pull the product through the system's process. The system must be able to respond by providing the service or product only at the time it is required by the customer.

5) Working towards perfection- the final step in the lean methodology is to continuously try to remove the nonvalue activities and improve the flow in the system and ensure customers' needs are delivered at the quantity and time they are required. (Pacheco D. d., 2015)

2.4.3 TOC vs Six Sigma vs Lean Thinking

While TOC focuses on managing constraints, lean thinking primarily focuses on removing waste in the system, and six sigma aims to reduce variations. Figure 3 below gives a summarized comparison between TOC and Six Sigma and Lean thinking (Pacheco D. d., 2015):

Table 2: A comparison of TOC vs Six Sigma vs Lean thinking



Program	Six Sigma	Lean thinking	Theory of constraints
Theory	Reduce variation	Remove waste	Manage constraints
Application guidelines	1. Define. 2. Measure. 3. Analyze. 4. Improve. 5. Control.	1. Identify value. 2. Identify value stream. 3. Flow. 4. Pull. 5. Perfection.	1. Identify constraint. 2. Exploit constraint. 3. Subordinate processes. 4. Elevate constraint. 5. Repeat cycle.
Focus	Problem focused	Flow focused	System constraints
Assumptions	A problem exists. Figures and numbers are valued. System output improves if variation in all processes is reduced.	Waste removal will improve business performance. Many small improvements are better than systems analysis.	Emphasis on speed and volume. Uses existing systems. Process interdependence.
Primary effect	Uniform process output	Reduced flow time	Fast throughput
Secondary effects	Less waste. Fast throughput. Less inventory. Fluctuation—performance measures for managers. Improved quality.	Less variation. Uniform output. Less inventory. New accounting system. Flow—performance measure for managers. Improved quality.	Less inventory/waste. Throughput cost accounting. Throughput—performance measurement system. Improved quality.
Criticisms	System interaction not considered. Processes improved independently.	Statistical or system analysis not valued.	Minimal worker input. Data analysis not valued.

(Pacheco D. A., 2015)

Lean aims to remove hidden waste from the system. The hidden waste can be in the form of overproduction, transportation waste, production of defective products, unutilized resources, excess inventory, waiting time and waste of motion. TOC focuses on achieving the goal. To achieve the company's goal the Current Reality Tree (CRT) is used, as well as evaporating clouds, and Future Reality Tree (FRT). To implement the process improvements, the five focus steps are used. Six sigma aims to improve system processes by reducing variations in the system. (Rajini, Nagaraju, Nara, & Narayanan, 2018)

2.4.4 Similarities between TOC, Lean and Six Sigma methodologies.

While TOC and Lean are different approaches to business improvement in operations management, they share similarities. For example, the goal in both approaches is to increase profits. They both value delivery to customers, and they prioritize quality. Both methods aim to streamline operations and increase system capacity. They both aim at reducing inventory and workforce. They both offer techniques to control workflow, which is determined by the pull from market demand. In TOC this is symbolized by the drum-buffer-rope, while in lean they state there must be a downstream signal received for the production feature to be pulled sequentially. The six-sigma methodology is quite distinct from TOC and Lean methodologies to business improvement, as it focuses on reducing defects and variations in the system to improve operational performance. However, like TOC and Lean, six sigma also aims to minimize waste and increase throughput. (Pacheco D. A., 2015)

2.5 Conclusion

TOC is one of the management philosophies that can be used in operations management for business improvement. This theory focuses on managing systems constraints. TOC assumes that the system processes are interdependent in a way that can be likened to a chain. The constraint is the weakest link in the chain. The primary effect of applying TOC principles and eliminating the constraint is achieving a faster throughput. The secondary effect of applying TOC is having less inventories held up in the system. The main criticism of TOC is that it involves minimum input from workers. Empirical evidence has shown that after TOC was applied to mining operations, the mines experienced an improvement in their performance. This research will add to this empirical evidence supporting the effectiveness, by testing the effects of TOC on a mechanized platinum mining operation in South Africa.

This research also identified gaps in that most of the previous research has focused on conducting studies on each methodology as silos. However, though these various process improvement methodologies discussed above are different approaches, they share similar characteristics. They also have their own individual strengths and weaknesses. There is room to do more research on how these strengths of each method can be combined and synergised together with the aim of better optimising operational performance.

2.6 ANALYTICAL FRAMEWORK

Research problem: A relatively new mechanized platinum mine in South Africa is currently having production challenges. Over the past two years it has consistently failed to achieve its production targets. This has resulted in an escalation of its unit cost of production and a reduction in its profitability. This report aims to apply TOC to identify the bottlenecks in its operation and come up with strategies to remove these bottlenecks to ensure improvements in its productivity.

Proposition: That TOC can be applied successfully to improve the production performance of the South African mechanized platinum mine.

Below is an analysis to justify why TOC can be chosen as a framework and applied successfully to improve the production performance of a mechanized mining company in South Africa:

2.6.1 Theoretical Framework introduction: Theory of Constraints (TOC)

The world is becoming increasingly competitive, and businesses need to improve their performance and become more efficient to remain competitive. TOC is a management methodology which offer a way to enable continuous improvement in a company's operations. In operations management TOC is one of the most well-known theories used for business improvement. TOC was created to solve systematic problems applicable to various industries including production, project management, distribution, finance, and marketing. It uses Thinking Process (TP) tools to identify the root causes and solve problems. (Sukalova & Ceniga, 2015)

TOC has demonstrated a long track record of successfully being applied to improve the business performance of companies. For example, Avery Dennison experienced a 20% increase in profit, 32% decrease in the waste materials, and 47% increase in customer satisfaction within 18 months of introducing TOC applications. Ford Motors experienced a reduction in delivery time by 65%, and a reduction in mistakes by 50%. After introducing TOC, Motorola managed to decrease its production time by 20% and increased its throughput by over 100%. Boeing managed to reduce its stock levels by 60% and increase its throughput by 50%. Pharmacia, after introducing TOC, managed to decrease its delivery time by 60% while increasing its packing rate by 30%. Numerous global firms have also adopted the TOC, these include Hewett Packard, Delta Airlines, Intel, Bell Laboratories, General Motors, Proctor & Gamble. (Okutmus, Kahveci, & Kartasova, 2015)

Even though TOC has been widely adopted by many businesses in developed countries, it remains to be fully embraced or grasped by businesses in developing countries. This is the gap this research aims to fill, by demonstrating its applicability to the African context, using a South African mine as a case study. A couple of South African mining companies have adopted TOC. These include Lonmin and Sasol. For instance, in 2014, after Lonmin's Rowland mine introduced TOC, the mine improved its productivity output by 5.1%. Sasol experienced a turnaround in its production performance, after it applied TOC to its Middlebult mine. (Ramasu, Sobiyi, & Akinlabi, 2017) However, due to lack of understanding and experience in TOC methodologies and applications, there is still a wide gap to be filled to enable businesses in African developing countries to fully maximize the benefits of application of TOC. The following segment aims to provide a theoretical breakdown and analysis to support how TOC can be used to successfully enable performance improvements in business operations across various industries and applications.

2.6.2 Framework of Theory of Constraints application in Buffer Management

According to TOC, there are 3 primary factors that negatively affect the attainment of project targets namely: Parkinson's Law, Student Syndrome and Bad Multitasking. Bad multitasking refers to the situation where work on a particular task is stopped before its completion, to engage in work on another task that is considered more important or urgent. The negative effect of this is that it results in a reduction in efficiency as one must remember details of the task they hadn't completed when they return to complete the task later. Furthermore, the stopped task also delays other dependent tasks, resulting in the delay of the overall project. Thus, bad multitasking can result in the delays having a domino effect in the delay of the project. Student Syndrome refers to the phenomenon where majority of people tend to work on a task at a deadline’s last moments. This is like students who tend to start studying just the night before the exam. In essence Student Syndrome refers to the human nature tendency to procrastinate. Parkinson’s Law describes the phenomenon where people tend to spread the work on tasks to fill up the time provided to complete the task. This is because people want to look busy all the time. (Kuo, Hsu, Li, & Chao, 2021)

Theory Constraints provides a methodology for overcoming these 3 primary factors that negatively affect projects. For example, to minimize Bad Multitasking effects, the business operation can decrease the number of available tasks in the work pipeline. This is because having too many tasks on someone’s desk can create a lot of opportunities for Bad Multitasking. When people focus on the critical chain, it helps reduce the number of active project tasks. When Bad Multitasking is reduced workers can remain focused on the critical tasks and perform them faster and more efficiently. When the most critical parts of the project have been completed, the other tasks which had been frozen can be reactivated and completed much faster. This will ultimately result in a significant reduction in the time it takes to complete the overall project, and an increase in the number of tasks completed on time. (Izmailov, Korneva, & Kozhemiakin, 2016)

To reduce both Student Syndrome and Parkinson’s Law, TOC proposes cutting the internal buffers of each task, to reduce the estimated time allocated for the completion of each activity and shifting these time buffers to the end of the project. This is illustrated in figure 9 below. The time allocated to complete each task is made shorter, by cutting out the internal individual time buffers of each task and shifting the buffers to the end of the project. This can result in the reducing of the negative impact of Parkinson’s law and Student’s syndrome on project completion. (Izmailov, Korneva, & Kozhemiakin, 2016)

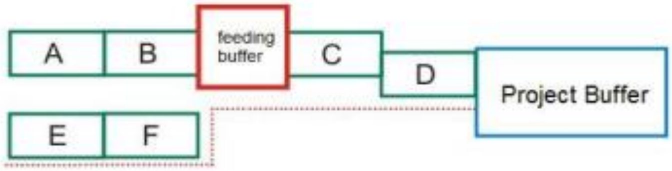


Figure 9: Buffers (Izmailov, Korneva, & Kozhemiakin, 2016)

TOC explains how buffers can be used to improve efficiency in project management. Time buffers placed at the end of a project will help ensure any delays during any task completion in the project can be absorbed by the time buffers. Fig 10 below shows how project managers can track the proportion of work completed on the critical path of a project, and the proportion of the time buffers consumed. When the buffers of the project are consumed at a faster rate than the work being completed on the project's critical path, the graph enters the red zone, this will mean the project is at an increased risk of running late. When the buffer and the critical task are moving at the same pace, the graph will be in the yellow zone. In a case where work is being competed at a faster rate than the buffers are consumed, the graph will be in the green zone. This color coding can help a project manager be able to pick up which projects are progressing well, and which ones are is in danger. It is critical for the project managers to be able to understand the root problem causing a delay of critical tasks in the project, to take the required action to bring back the project to yellow and green zones. (Izmailov, Korneva, & Kozhemiakin, 2016)

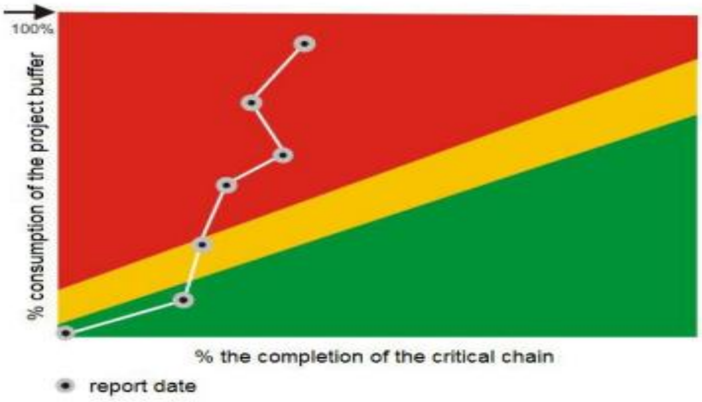


Figure 10: Consumption of project buffers vs Completion of critical task

2.6.3 Framework for Theory of Constraints application in Systems Improvement

At first TOC was applied mainly in project management and production operations. However, as time went on, it has evolved to be applied in other fields like, logistics, hospitality, and cost and management accounting. According to TOC, as discussed earlier, every task resembles a piece in a chain, and each chain has a weak link. The chain's strength is dependent on its weakest link. Thus, to improve the strength of the chain, focus must be placed on strengthening the weakest link. To strengthen the weakest link is equivalent to removing the constraint, which will result in an improvement in the entire system. According to TOC there is always a constraint in any business, limiting the firm from achieving its goals. Once that constrain is removed, another constraint will emerge, and must again be eliminated. This continuous identification and elimination of system constraints is known as a process of ongoing improvement. The system constraints themselves can be capacity constraints, logistical constraints, marketing constraints, supply chain constraints, administrative constraints, or behavioral constraints. (Okutmus, Kahveci, & Kartasova, 2015)

As discussed earlier, TOC uses tree diagrams collectively known as Thought Process (TP) tools to effect positive change in business operations. TOC uses TP tools to identify what to change, the ideal state to change to, and how to effect the change. These TP tools, as described earlier, include the evaporating clouds (EC), current reality trees (CRT) and future reality trees (FRT) and are used in TOC as analytical tools. For instance, the CRT, is used to map cause-and-effect linkages that can lead to the identification of the root cause resulting in the performance constraint. (Davies, Mabin, & Balderstone, 2005)

Below is a breakdown of some of the main conceptual frameworks and tools used in the application of TOC for systems improvement. This includes an analysis of the TOC's 5 Focus steps, and TP tools.

2.6.1 Frameworks of TOC's Key Tools

2.6.1.1 The 5 Focus Steps

The 5 Focus steps are used in TOC to improve the operation's performance. Step 1, in the 5 focus steps is identifying of the system's constraint. Sep 2 is to decide on ways to exploit the constraint. Step 3 is the subordination of all other things to the decision from made from step 2, whereby the constraint is exploited to its maximum capacity. Step 4 in the TOC methodology is elevating the constraint of the system by making whichever action is required to remove the constraint, including bringing in more resources. Once this constraint is successfully eliminated, there will be a new constraint on another part of in the system. Thus, the fifths step in the 5 focus steps is to return to the first step and identification of the new constraint and repeat the steps again. (Nave, 2002)

These 5 focus steps were proposed by Goldratt to enable a process of ongoing improvement, were a constrain is eliminated, and the next one is identified and eliminated continuously. There is however criticism that the 5 focus steps are over simplified representations of the reality. For instance, though it represents 5 step sequences in theory, in practice, the number of steps and decisions that must be made to ensure effective performance improvement are greater, both in number and complexity. Some academics are highly critical of TOC, stating that its nothing new, and argue that implementing TOC might result in an over focus on some problems while other issues are ignored. However, the criticism does not seem to invalidate the 5 focus steps themselves. The main shortcoming identified of the 5 focus steps is the linear sequential process of the 5 focus steps that lack of clarity on the decisions required to be taken, to enable an organisation from moving from one step to the next. (Pretorius, 2013)

However, other TOC techniques have been devised to address this. For instance, the Thought Process (TP) tools such as the Evaporating Cloud, and Current Reality Tree aim to guide practitioners of TOC in making logical judgements and decisions. Table 4 below gives a summary of the theoretical framework characterising the TOC's 5 focus steps.

Table 3: Framework characterizing the TOC's 5 focus steps (Davies, Mabin, & Balderstone, 2005)

Methodology/Technique	**TOC/ 5 Focus Steps**
What does it do?	It is used for identifying and managing constraints in a process of continuous improvement
Ontology (Assumptions)	There are constrains or barriers in the system limiting performance
Epistemology (Representation)	The process of finding and analyzing constraints affecting the system's performance.
Epistemology (Required Information)	Opinions, facts that are objective, logical relationships, informed judgement, expected outcomes, actions required to achieve the outcomes.
Epistemology (Information Sources)	Real world observations, opinions, and judgements
Axiology (Users)	Participants e.g., workers, stakeholders, implementors and decision makers
Axiology (Purpose)	To improve system performance

2.6.1.2 Evaporating Clouds (EC)

TOC's ECs are described as thinking tools that enable conflict resolutions to facilitate better decision making in the implementation of TOC strategies for operations performance improvement. The EV achieves this uncovering the underlying assumptions causing the conflict, and then developing inputs that can dismantle these assumptions. By visualizing and verbalizing the conflicting scenario, the different needs the conflicting actions are trying to fulfil and the shared goal that they are trying to satisfy, the EC helps to clearly define the conflict at hand. Figure 11 below shows a breakdown of how an EC is constituted. (Gupta & Kerrick, 2014).

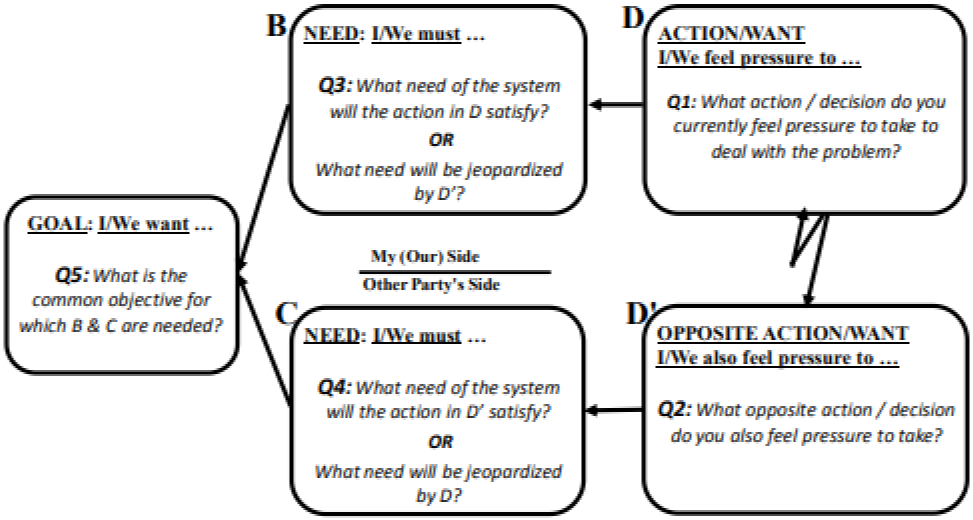


Figure 11: Five entities evaporating cloud structure (Gupta & Kerrick, 2014)

As illustrated in figure 11 above, the EC is made up of 5 constituent structures. The conflicts it aims to resolve are everyday conflicts managers can face in running an operation. These can be conflicts between two departments or people, or internal conflicts the managers experience within themselves when making decisions. Table 5 below gives a summary of the framework characterizing TOC's EC.

Table 4: Framework characterizing the TOC's Evaporating Clouds (Davies, Mabin, & Balderstone, 2005)

Methodology/Technique	**TOC/ Evaporating Clouds**
What does it do?	Applied to provide an explicit presentation of people's conflicting views.
Ontology (Assumptions)	Stakeholders hold conflicting views, each underpinned by underlying assumptions
Epistemology (Representation)	Diagram which showcases seemingly opposed viewpoints, each with underlying assumptions held by each stakeholder.
(Required Information)	Different viewpoints by stakeholders, options, stakeholders' interests.
Epistemology (Information Sources)	Discussions, interviews, debates and arguments by participants, reasoning by analyst.

Axiology (Users)	Analysts, participating stakeholders.
Axiology (Purpose)	Used to synthesis divergent viewpoints, and help in the understanding of different viewpoints, and how they result in conflict, and come up with actions to resolve the conflict

2.6.1.3 Current Reality Tree (CRT)

The CRT is used in TOC to establish what to change. After which a new reality of what to change to can be envisioned by creating a FRT. Figure 12 below demonstrates a CRT template. It highlights the problem symptoms or undesired effects (UDEs) affecting production, and a series of casual cause and effect relationships that help in the identification of the root causes or core constraint in the system.

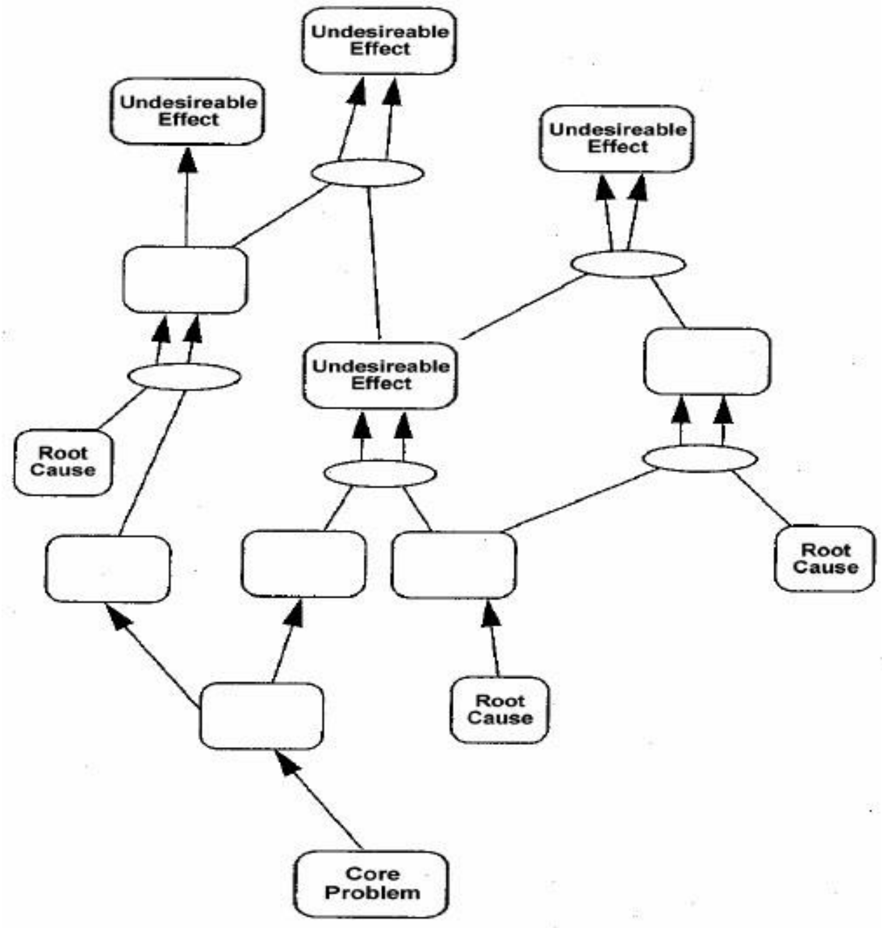


Figure 12: CRT template (Matchar, Patwardhan, & Sarria-Santamera, 2006)

To create a CRT diagram, the first step is to identify the most relevant or apparent UDE’s, then explore other relevant UDE’s. It concludes by listing the root causes that resulted in the UDE’s. the CRT explores the casual relation between UDE’s and their root causes to identify the system constrain. Table 6 below summarizes the framework characterizing TOC’s CRT.

Table 5: Framework characterizing the TOC’s Current Reality Tree (Davies, Mabin, & Balderstone, 2005)

Methodology/Technique	**TOC/ Current reality Tree**
What does it do?	Used to find root causes, and show their linkages with the problem symptoms
Ontology (Assumptions)	There is a cause-and-effect relationship between the symptoms and the root problems
Epistemology (Representation)	Logic relationship between cause and effect linked by arrows
Epistemology (Required Information)	Information patterns, subjective opinions, objective facts, judgements, cause-and-effect linkages
Epistemology (Information Sources)	Real world observations and measurements, judgement, and analysis of the data.
Axiology (Users)	Management consultants, stakeholders, decision makers, facilitators, analysts.
Axiology (Purpose)	Search for root causes of system problems

2.6.1.4 Future Reality Tree (FRT)

A FRT is a TOC TP tool used to have a visualization of the future state. Its purpose is to answer the question of “what to change to”. A FRT is a logic-based thinking tool that helps the practitioner find solutions to remove the identified UDEs, replacing them with desired effects (DEs), once implemented. These proposed solutions in the FRT are known as injections. A FRT is thus a series of cause-and-effect relations that connect the recommended injections with the DE’s. The FRT has a similar structure to a CRT but is different in that instead of identifying problems (UDE’s) it proposes actions (injections) that can lead to ideal future state (DE’s). Figure 13 below shows a template of a FRT. To construct an FRT, the starting point is to outline the CRT, namely the UDE’s and the underlying root causes. The first element of the FRT is then the proposed solutions (injections) created to address these root causes. After outlining these injections, the FRT is then build up into the DE’s. (Visual Paradigm, 2023)

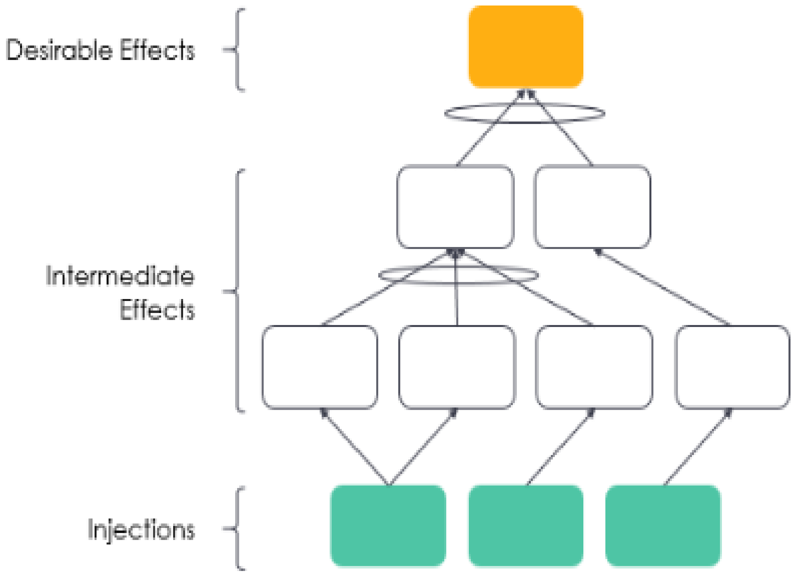


Figure 13: FRT Template

Figure 14 below illustrates an example of a FRT. In the CRT the UDE that was identified was low customer satisfaction. One of the root causes was found to be low staff morale. The other cause of low customer satisfaction was poor customer services. These were caused by slow response times and unhelpful solutions offered to customers. Thus, in the FRT which is read from the bottom up. Injections are offered as solutions to the identified root causes. For instance, an increase in salaries is proposed to boost staff morale, that will in turn lead to improved customer satisfaction, which is the DE. Offering improved training for staff is also proposed as an injection to enable an improvement in the helpful solutions staff will provide to customers, which would improve customer service and ultimately the customer satisfaction. Providing A standardized template for answering commonly asked question is also offered as an injection that can reduce the response time to customer's queries. This would in turn result in the DE of improved customer satisfaction.

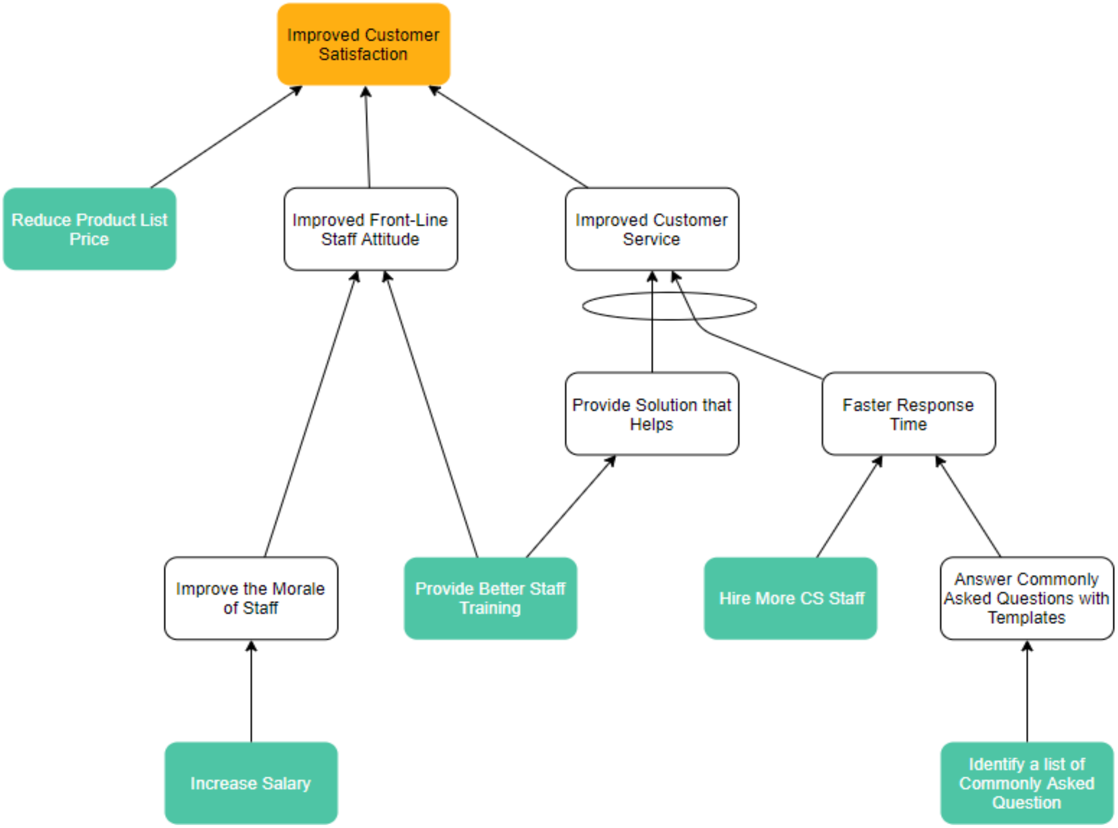


Figure 14: Future Reality Tree Example (Visual Paradigm, 2023)

Table 7 below gives a summary of the framework characterizing the TOC's FRT discussed above. As stated above, a FRT is a construct of cause-and-effect relationships used in TOC to answer the question of, "what to change to".

Table 6: Framework characterizing the TOC's Future Reality Tree (Davies, Mabin, & Balderstone, 2005)

Technique	**TOC/ Future Reality Tree**
What does it do?	Used to predict the effects and consequences of carrying out the proposed actions to fix the identified problems
Ontology (Assumptions)	Problems have been identified, actions have been proposed, there is a logical linkage between cause and effect.
Epistemology (Representation)	Logic Relationships between Cause and effects represented by arrows
Epistemology (Required Information)	Logic relations, subjective opinions, objective facts, informed judgements
Epistemology (Information Sources)	Real world observations and measurements, judgements
Axiology (Users)	Business consultants, analysts, facilitators, stakeholders, decision makers.
Axiology (Purpose)	Show how actions proposed lead to the desired outcomes

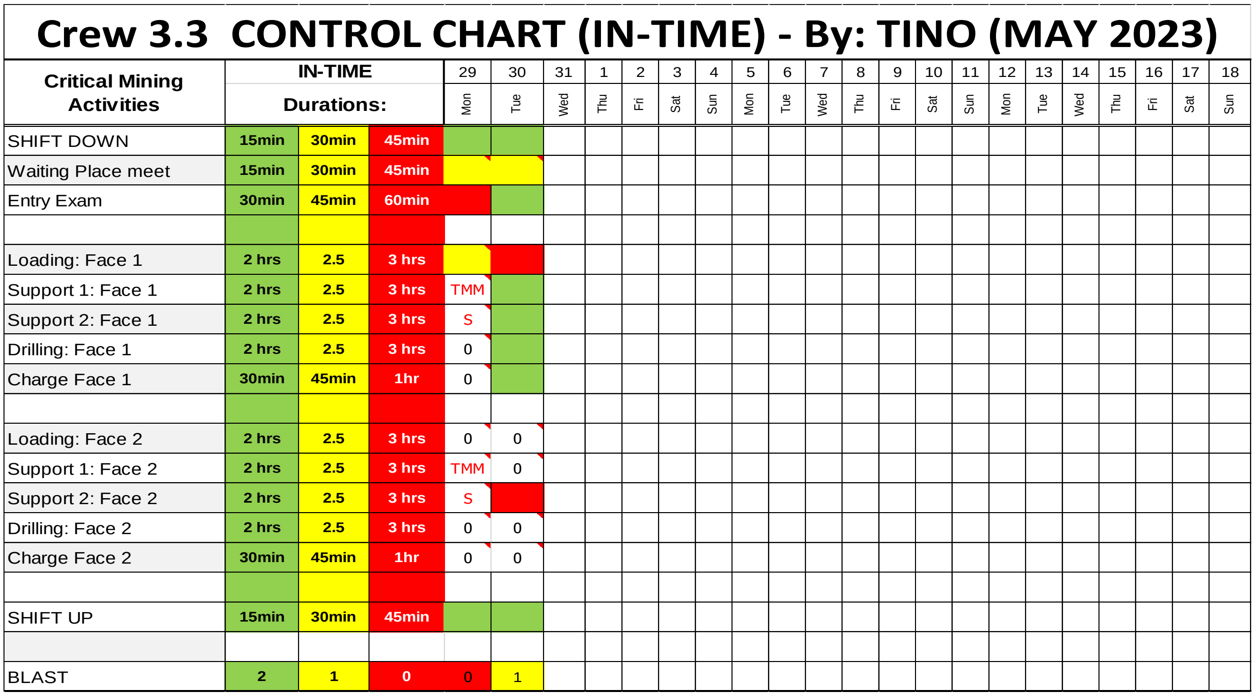
2.6.2 Conclusion of Research Framework

In this research the TOC is used in conducting the study on how to improve the productivity of a South African mechanized mine. TOC was chosen as a method to conduct this study because it is one of the well-known theories in the business improvement field. It has been used to improve the performance of operations across various industries, using various techniques which include the 5 Focus steps, buffer management, and the TP tools. TOC has a long track record of being successfully implemented to improve business operational performance across various industries. Numerous top global organizations have adopted TOC as a management philosophy. However there has been an identified gap in TOC's successful adaptation in developing countries, particularly on the African continent. Part of the reason is due to a lack of understanding and experience in TOC methodologies and applications by managers in developing countries. This is the gap this research aims to fill. By highlighting the applicability of TOC in a developing country context, using a platinum mine in South Africa as a case study.

3 RESEARCH METHODOLOGY

3.1 Research approach

The study was conducted at Styldrift mine. Due to limitations in resources, including human resources, the study only focused on one crew. This study was done by using production data collected during the study, on condition written permission is granted from the company to use such data. Control charts were used to record the data. Two types of control charts were used to record the production data used to investigate the bottleneck limiting production in the crew. Namely the “in time control chart”, and the “on time control chart”. The “in time” control chart investigated the time or duration it takes to complete each of the critical tasks required to be performed during the shift. Any task which is completed within the allocated duration of time is marked as green, any activity that takes less than 30 minutes longer than the allocated time is marked as yellow, any activity which does takes more than 30min longer than the allocated duration is marked as red. This color cording helps to identify the activity that is taking the longest more frequently, to help with identification of the constraint.



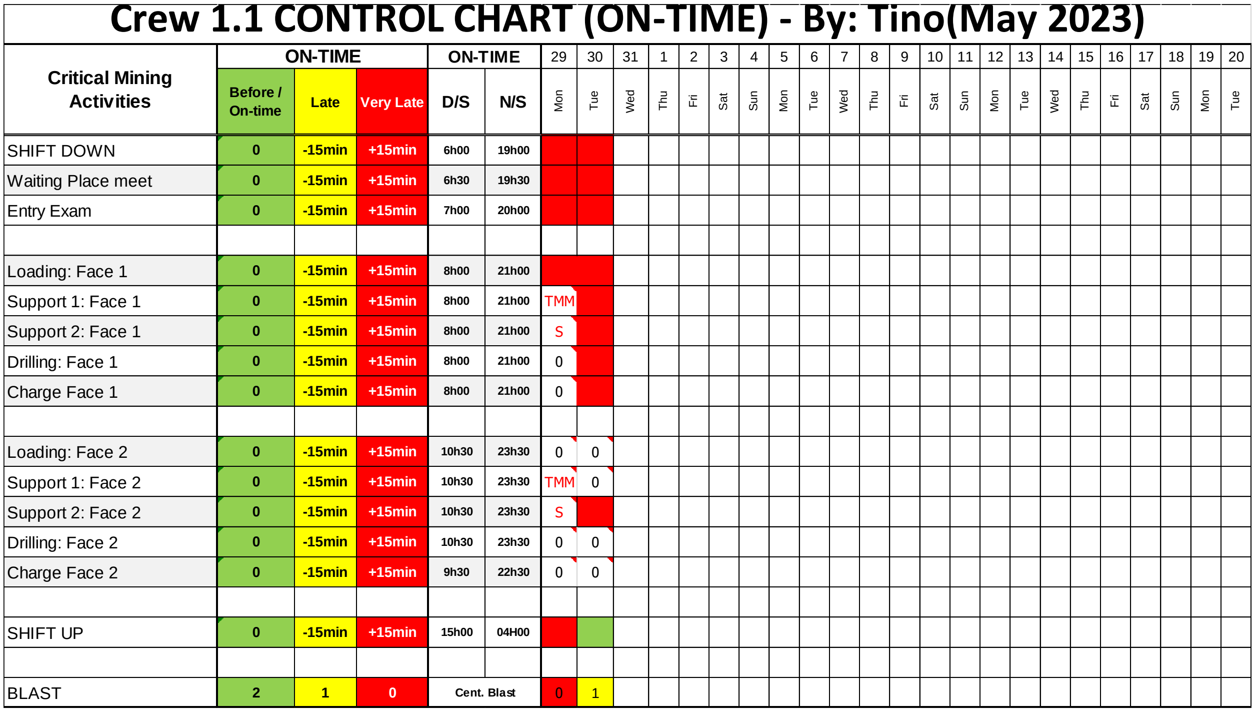
Crew 3.3 CONTROL CHART (IN-TIME) - By: TINO (MAY 2023)

Critical Mining Activities	IN-TIME Durations:			29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
SHIFT DOWN	15min	30min	45min	🟩	🟩																			
Waiting Place meet	15min	30min	45min	🟨	🟨																			
Entry Exam	30min	45min	60min	🟥	🟩																			
	🟩	🟨	🟥																					
Loading: Face 1	2 hrs	2.5	3 hrs	🟨	🟥																			
Support 1: Face 1	2 hrs	2.5	3 hrs	TMM	🟩																			
Support 2: Face 1	2 hrs	2.5	3 hrs	S	🟩																			
Drilling: Face 1	2 hrs	2.5	3 hrs	0	🟩																			
Charge Face 1	30min	45min	1hr	0	🟩																			
	🟩	🟨	🟥																					
Loading: Face 2	2 hrs	2.5	3 hrs	0	0																			
Support 1: Face 2	2 hrs	2.5	3 hrs	TMM	0																			
Support 2: Face 2	2 hrs	2.5	3 hrs	S	🟥																			
Drilling: Face 2	2 hrs	2.5	3 hrs	0	0																			
Charge Face 2	30min	45min	1hr	0	0																			
	🟩	🟨	🟥																					
SHIFT UP	15min	30min	45min	🟩	🟩																			
BLAST	2	1	0	0	1																			

Figure 15: In-time Control Chart illustration

The second chart that was used is the “on time” control chart illustrated in figure 16 below. The on-time control chart was used to track what time each critical activity during the shift was starting. Any activity which starts on-time is color coded as green, any activity that starts between 0-15 minutes is marked as yellow. Each activity that starts more than 15 minutes late is marked as red. These time allocations are based on the TOC buffer management methodology discussed in the research framework chapter.

An explanation is given on each activity that is color coded red, to help identify the core problems. Furthermore, if any activity did not take place at all, an explanation was given on why the activity did not take place. The reasons why an activity did not take place can be divided into two main groups, namely due to starvation or due to blockage. Starvation refers to failure of an activity happening due to lack of resources, e.g., a shortage of input material, or shortage of labor. A blockage refers to failure of an activity happening due to queuing or having to wait for a face or place to work or perform the activity.

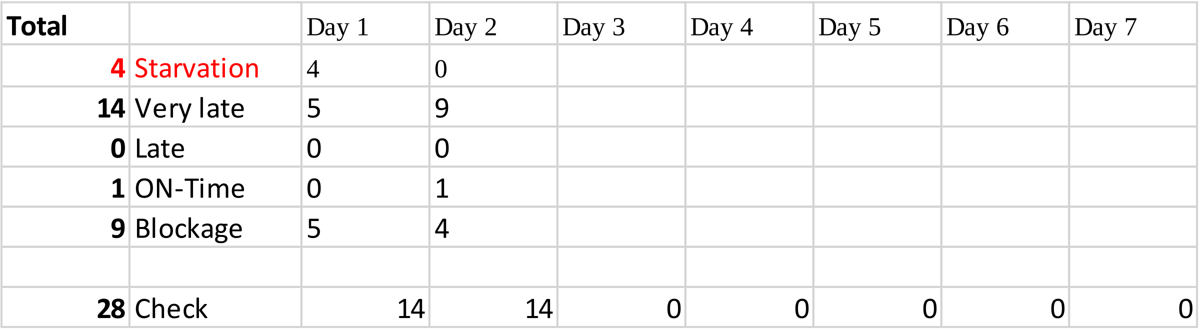


Crew 1.1 CONTROL CHART (ON-TIME) - By: Tino(May 2023)

Critical Mining Activities	ON-TIME			ON-TIME		29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Before / On-time	Late	Very Late	D/S	N/S	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue
SHIFT DOWN	0	-15min	+15min	6h00	19h00	🟥	🟥																					
Waiting Place meet	0	-15min	+15min	6h30	19h30	🟥	🟥																					
Entry Exam	0	-15min	+15min	7h00	20h00	🟥	🟥																					
Loading: Face 1	0	-15min	+15min	8h00	21h00	🟥	🟥																					
Support 1: Face 1	0	-15min	+15min	8h00	21h00	TMM	🟥																					
Support 2: Face 1	0	-15min	+15min	8h00	21h00	S	🟥																					
Drilling: Face 1	0	-15min	+15min	8h00	21h00	0	🟥																					
Charge Face 1	0	-15min	+15min	8h00	21h00	0	🟥																					
Loading: Face 2	0	-15min	+15min	10h30	23h30	0	0																					
Support 1: Face 2	0	-15min	+15min	10h30	23h30	TMM	0																					
Support 2: Face 2	0	-15min	+15min	10h30	23h30	S	🟥																					
Drilling: Face 2	0	-15min	+15min	10h30	23h30	0	0																					
Charge Face 2	0	-15min	+15min	9h30	22h30	0	0																					
SHIFT UP	0	-15min	+15min	15h00	04H00	🟥	🟩																					
BLAST	2	1	0	Cent. Blast		0	1																					

Figure 16: On-time Control Chart illustration

As the data was being collected and recorded into the control charts each day, a summary of the progressive results was presented for analysis. Figure 17 below gives an illustration of the daily summary of performance recorded, indicating the number of activities that were not performed due to starvation and the number of activities not performed due to blockages, as well as the number of activities that started on-time, on each day, and the number of activities which occurred late, and very late. By tracking these parameters, any improvement in performance could be tracked, on a daily, weekly, and monthly basis. This data was then converted into graphs to aid in visualizing the trends in productivity.



Total		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
4	Starvation	4	0					
14	Very late	5	9					
0	Late	0	0					
1	ON-Time	0	1					
9	Blockage	5	4					
28	Check	14	14	0	0	0	0	0

Figure 17: Summary of Data of activities obtained from control charts.

3.2 Research design

This research applied the TOC methodology. The first part of the research was focused on identifying the constraint. To identify the constraints, time and motion studies were conducted on site to identify the activity taking the longest to complete, or taking the longest to start, or not being completed the greatest number of times. Control charts were used to track these time and motion studies each month the study is being carried out. At the end of the months, the control chart was analysed based on which activities took the longest most frequently, and which activities started very late most frequently, to help identify the constraint. The control chart was used to identify activities which did not occur due to starvation, and which had a long queue in front of them, as this indicated the location of the bottleneck. Once the constraint is identified, strategies were then be developed to ameliorate these constraints, by making the necessary changes, without adding any significant resources in the system.

3.3 Data collection methods

Data was collected through observations conducted on site, more specifically through time and motion studies. The data collected was then used to identify the constraint and to develop strategies used to exploit the constraint. Observations from time and motion studies were objective and pragmatic, as time is easily quantifiable, and is a suitable metric to identify a constraint. It is also easy to physically identify, through motion studies, where queueing is occurring.

This study was carried out over a two month. The first month was used to collect data that was used to identify the constraint and second month to develop the strategies to exploit the identified constraint.

3.4 Population and sample

3.4.1 Population

The mine is divided into a total of 16 production crews, each allocated an equal number of personnel, equal set of machinery, equal budget, and similar area size to mine. The production target for the mine is divided equally amongst the 16 crews. For instance, according to the mine's business plan, the mine's monthly production target is 200,000 tonnes of ore. This production target is divided equally amongst the 16 crews, meaning each crew must produce approximately 12,500 tonnes of ore per month. Thus, one crew can be representative of the entire mine's system, as the crews are designed as similar work units.

This proposed research methodology can be replicated by anyone, by using the same tool illustrated above, namely the use of control charts, to monitor and track which activities are taking the longest to complete (using In-Time Control Chart), which activities are starting later than scheduled more frequently (using the On-Time Control Chart), and what is the main reason why some activities fail to take place at all (whether its starvation issues, such as shortage of material/labour, or blockage issues, such as queuing). By using these control charts, this study can be replicated, and applied to any production crew.

Due to the size of the mine, limited time to visit all sections to conduct time and motion studies, the research only focused on one crew on the mine. The assumption is that the findings from the study of the crew are representative of the systemic problems of the mine.

3.5 The research instrument.

Time and motion studies were conducted through observing and recording the time it takes to start and end each activity in the mining cycle. A sample of the control charts and tables to be used to track these results was illustrated above.

3.6 Procedure for data collection

Data was collected through personal site observations of each activity in the mine cycle. Further data was collected through end of shift reports. These gave a summary of the performance of each activity in the mining cycle for each shift within the duration of the study, and reasons why activities started very late, or took longer than planned, or why they did not take place at all.

3.7 Data analysis strategies and interpretation

Descriptive analysis was used to analyse the data collected from time and motion studies. This data was tabulated and presented graphically for better understanding.

3.8 Possible limitations and challenges of the study

The limitation of the study is that the constraint identified in the crew under investigation might be different from the constraints experienced in other crews. However due to limited access to data, and limited resources and time, it was not possible to make observations on activities occurring on the entire mine.

3.9 Quality Assurance

The data collected was signed by the team leader/miner in charge of the section as well as the operator responsible for the activity being studied. This ensured that the data collected has been verified by the subjects who are part of the study. The data collected was primary data collected directly from the source/site.

3.10 Ethical considerations

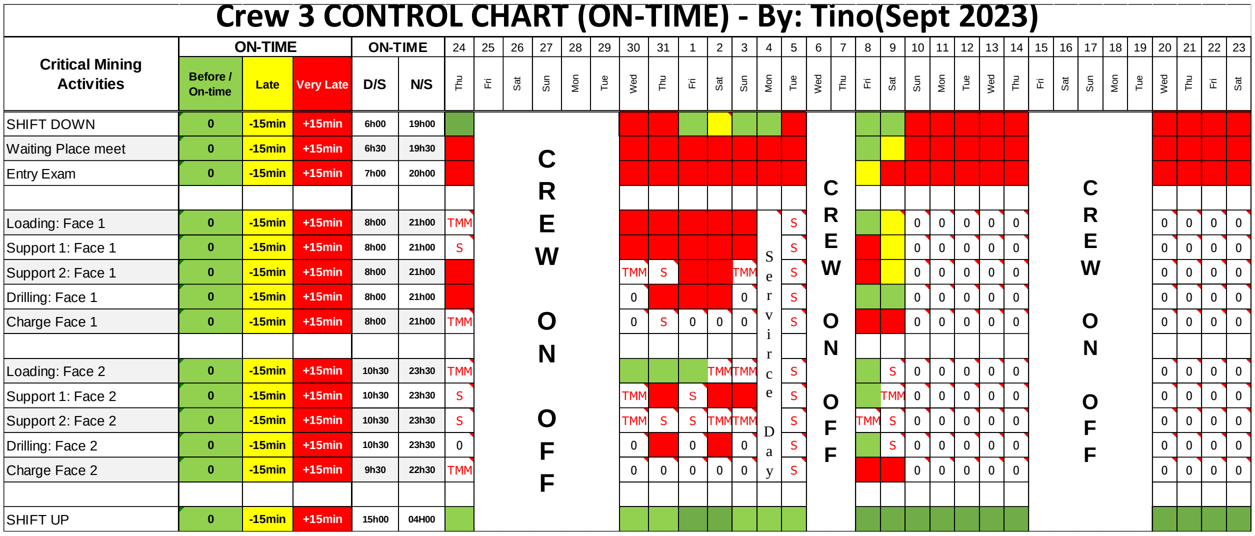
Approval was requested from the mining company before data was collected. Any person who was part of the study, was informed and their consent requested before the research was undertaken. There was no disclosure of any names in this research, to protect the confidentiality of participants in the study.

4 DATA COLLECTION AND ANALYSIS

4.1 Data Collection and Analysis

To identify the constraints limiting production at Styldrift mine, time and motion studies were conducted for a period of a month. Factoring in the 12 off days for the crew being studied in the September production month, plus 1 day for scheduled maintenance, the effective shifts the time and motion studies were undertaken were 18 shifts (between the 24th of August and the 23rd of September). The data was collected from direct observations as well as end of shift production reports, particularly from the miner in charge of the crew. Control charts were then used to summarise the observations of the time and motion studies for each critical activity in each shift. These control charts were created as excel spreadsheets. In each cell of the control chart representing an activity, in addition to the colour coding, detailed comments were added to explain the reason the activity was delayed, did not take place, or why it took long to complete.

Figure 18 below shows a snapshot of the On-time control chart used to capture the observations from the time and motion studies. The colour coding makes it easy to quickly pick up areas of concern. For instance, a cell filled with a red colour code shows that the activity started very late (more than 15 minutes from planned start time). An uncoloured cell with a red ‘S’ or ‘TMM’ symbol shows that the activity did not take place due to starvation. A starvation in the system is a result of a shortage of resources in the system. This can be in the form of unavailability of labour, materials, or unavailability of machinery due to breakdown (TMM). An uncoloured cell with a black ‘0’symbol in the control chart indicates an activity not taking place due to a blockage in the system. The blockage can be caused by there not being a face or workstation available for an activity to take place. This results in the activity having to queue or wait for a workstation or face to become available. The data on the On-time Chart can then be used to identify the constraints in the system. The In-time Chart was placed in the appendix (figure 30).



Crew 3 CONTROL CHART (ON-TIME) - By: Tino(Sept 2023)

Critical Mining Activities	ON-TIME			ON-TIME		24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Before / On-time	Late	Very Late	D/S	N/S	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
SHIFT DOWN	0	-15min	+15min	6h00	19h00	🟩	CREW ON OFF					🟥	🟥	🟩	🟨	🟩	🟩	🟥	CREW ON OFF		🟩	🟩	🟥	🟥	🟥	🟥	🟥	CREW ON OFF					🟥	🟥	🟥	🟥
Waiting Place meet	0	-15min	+15min	6h30	19h30	🟥						🟥	🟥	🟥	🟥	🟥	🟥	🟥			🟩	🟨	🟥	🟥	🟥	🟥	🟥						🟥	🟥	🟥	🟥
Entry Exam	0	-15min	+15min	7h00	20h00	🟥						🟥	🟥	🟥	🟥	🟥	🟥	🟥			🟨	🟥	🟥	🟥	🟥	🟥	🟥						🟥	🟥	🟥	🟥
Loading: Face 1	0	-15min	+15min	8h00	21h00	TMM						🟥	🟥	🟥	🟥	🟥	Service Day	S			🟩	🟨	0	0	0	0	0						0	0	0	0
Support 1: Face 1	0	-15min	+15min	8h00	21h00	S						🟥	🟥	🟥	🟥	🟥		S			🟥	🟨	0	0	0	0	0						0	0	0	0
Support 2: Face 1	0	-15min	+15min	8h00	21h00	🟥						TMM	S	🟥	🟥	TMM		S			🟥	🟨	0	0	0	0	0						0	0	0	0
Drilling: Face 1	0	-15min	+15min	8h00	21h00	🟥						0	🟥	🟥	🟥	0		S			🟩	🟩	0	0	0	0	0						0	0	0	0
Charge Face 1	0	-15min	+15min	8h00	21h00	TMM						0	S	0	0	0		S			🟥	🟥	0	0	0	0	0						0	0	0	0
Loading: Face 2	0	-15min	+15min	10h30	23h30	TMM						🟩	🟩	🟩	TMM	TMM		S			🟩	S	0	0	0	0	0						0	0	0	0
Support 1: Face 2	0	-15min	+15min	10h30	23h30	S						TMM	🟥	S	🟥	🟥		S			🟩	TMM	0	0	0	0	0						0	0	0	0
Support 2: Face 2	0	-15min	+15min	10h30	23h30	S						TMM	S	S	TMM	TMM		S			TMM	S	0	0	0	0	0						0	0	0	0
Drilling: Face 2	0	-15min	+15min	10h30	23h30	0						0	🟥	0	🟥	0		S			🟩	S	0	0	0	0	0						0	0	0	0
Charge Face 2	0	-15min	+15min	9h30	22h30	TMM						0	0	0	0	0		S			🟥	🟥	0	0	0	0	0						0	0	0	0
SHIFT UP	0	-15min	+15min	15h00	04H00	🟩						🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩	🟩						🟩	🟩	🟩	🟩

Figure 18: Crew 3 On-time Control Charts

Table 7 below gives as summary of the number of times activities were affected by starvations, blockages, and very lates. It is key to note that out of the effective 18 days (250 critical activities observed), critical activities only started on-time 31 times, representing 12% of the times. Out of those 31 times activities were observed to start on-time, 18 of the times it was attributed to the shift up (knocking off time). Factoring out shift up, the effective time critical activities started on time was 5.6% of the time.

Table 7: Summation of On-time Control Chart observations

Total		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18
35	Starvation	7	3	3	2	2	3	10	1	4	0	0	0	0	0	0	0	0	0
72	Very late	4	5	8	6	8	5	3	3	3	3	3	3	3	3	3	3	3	3
7	Late	1	0	0	0	1	0	0	1	4	0	0	0	0	0	0	0	0	0
31	ON-Time	2	1	2	3	1	2	1	7	3	1	1	1	1	1	1	1	1	1
105	Blockage	1	4	1	3	2	4	0	0	0	10	10	10	10	10	10	10	10	10

From figure 19 below it can be shown that 56% of the times critical activities did not occur at all, due to Blockage (42%) and Starvation (14%). Activities started very late (more than 15 minutes behind schedule) 29% of the time and were late 3% of the time (within a delay of less than 15min). It can therefore be observed that biggest constraint limiting productivity at the crew observed was the issue of blockages, as it was the highest contributing factor (42%) amongst the factors affecting production.

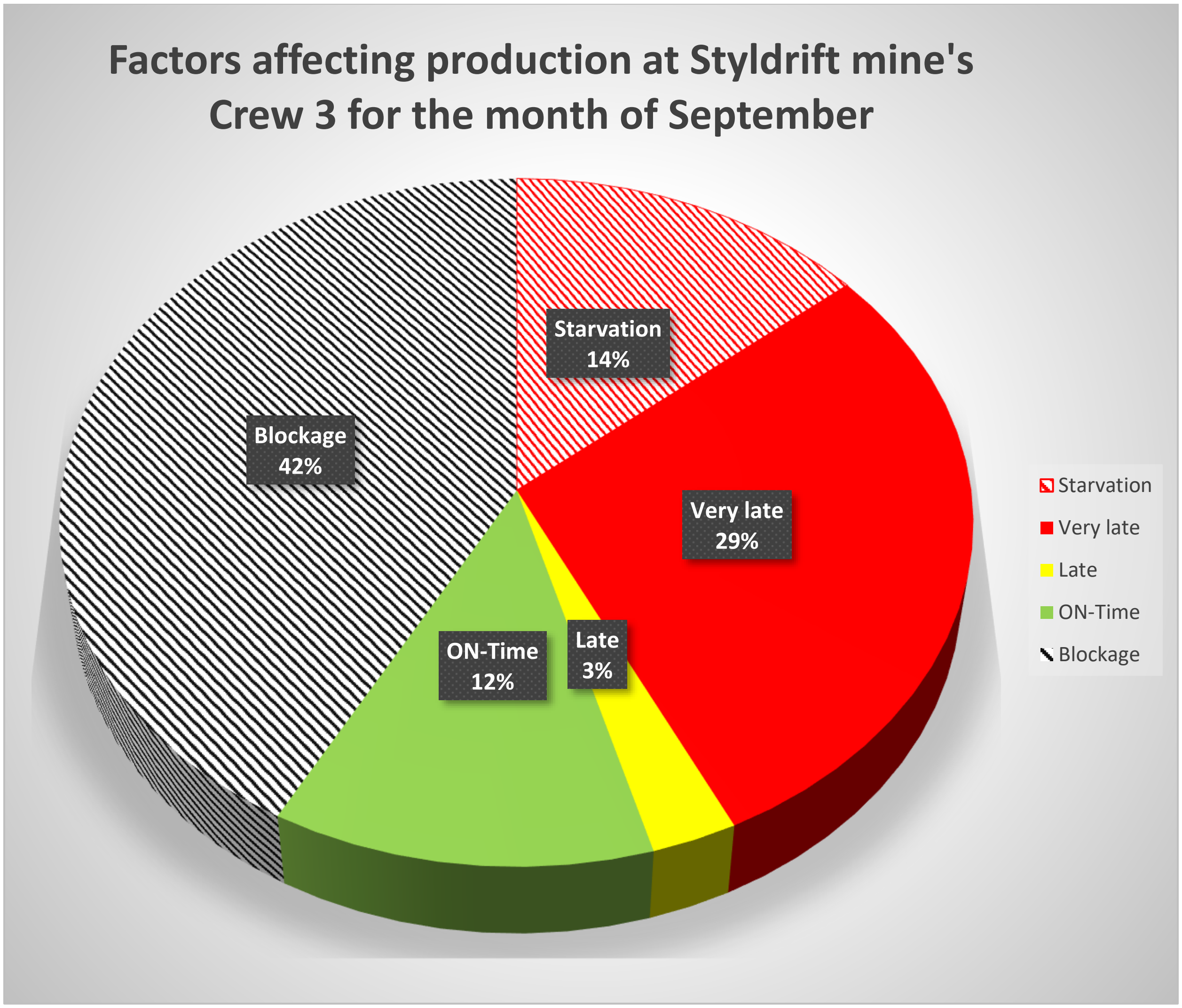


Figure 19: Factors affecting productivity at Styldrift mine’s crew 3 for the month of September.

By analyzing the control chart in figure 18 it can be observed that blockages increased significantly in the second half of the month of September compared to the first half. By splitting the analysis of the observations into two parts, namely observations made on the first half of the September production month, and observations made on the second half of the production month, a deeper understanding of root problems affecting productivity at the crew can be observed and a cause-and-effect analysis can be done. Table 8, table 9 and table 10 in the appendices give a more detailed breakdown analysis of the factors that affected the production activities at Styldrift mine’s crew 3 in the production month of September 2023.

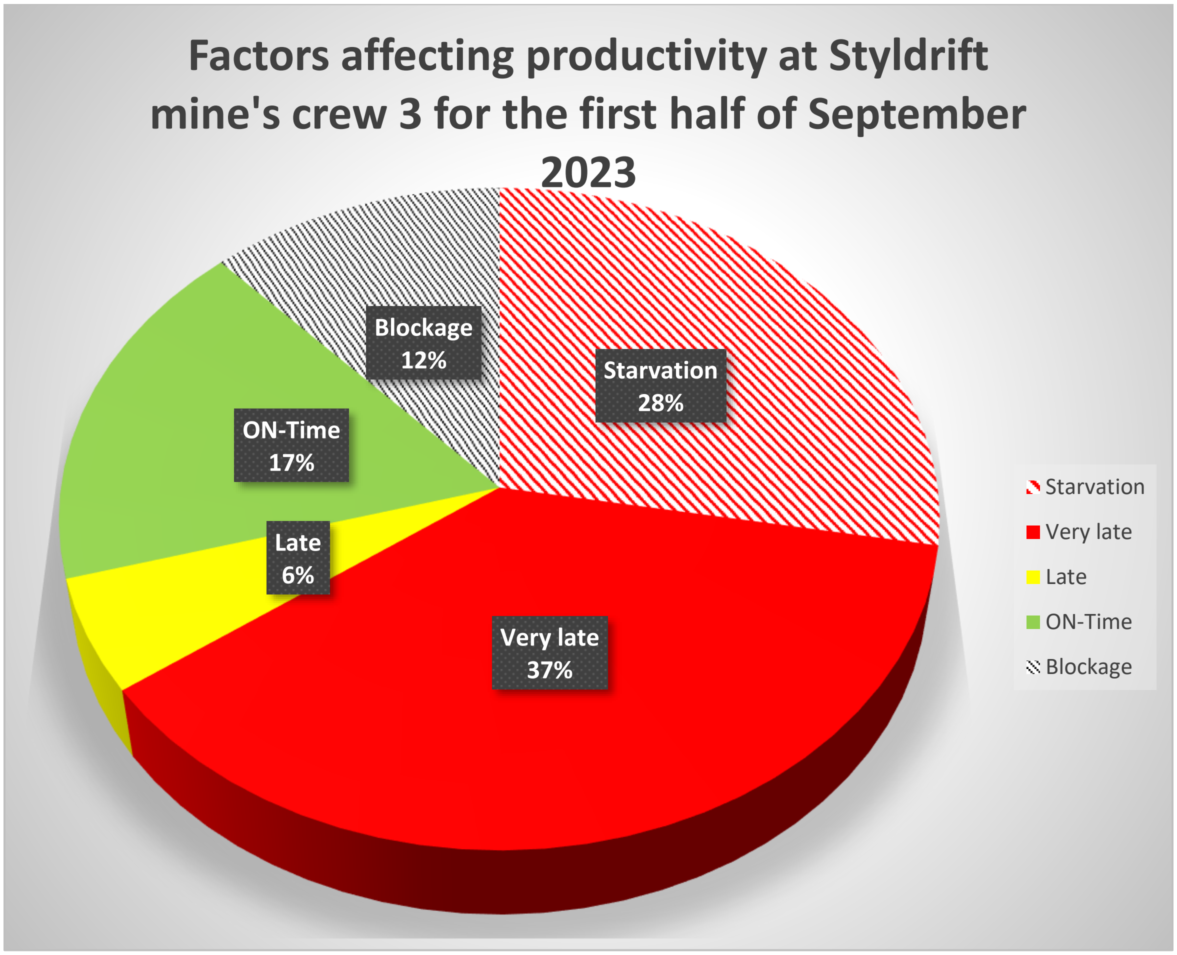


Figure 20: Factors affecting productivity at Styldrift's crew 3 in the first half of the September production month.

From figure 20 above, during the first half of the September production month (between the 24th of August and 9th September 2023), it can be observed that critical activities did not take place 40% of the time mainly due to starvation (28%) and blockages (12%). Out of the times the activities occur, 62% of the times the activities occurred very late. Table 8 in the appendix gives a detailed description of the factors that affected productivity in the first half of September at crew 3. From figure 18 the biggest activities which did not occur more frequently was the installation of secondary support of the second face (written in the control chart as support 2: Face 2), which did not occur 100% of the time.

The reason the activity did not take place 45% of the times was due to breakdowns, 22% of the time was due to the long time it took to complete work at first face (Face 1), 20%

due to unavailability of operator, and 11% of the times it was due to there being no miner at work. It can therefore be derived that the bottleneck or constraint limiting production in the first half of September 2023 was installation of secondary support on face 2. This is because the activity occurred 0% of the time and thus had the least frequency of occurrence. As is shown in table 8 in the appendix, the main reason that this activity failed to take place was due to starvation 76% of the time (45% due to breakdowns, 31% due to unavailability of workers).

Figure 20 below shows the factors affecting productivity at Styldrift mine’s crew 3 for the second half of the of September 2023. It can be observed that the main factor affecting productivity was blockages. From figure 18 above it can be clearly seen that in the second half of the production month, from the 10th of October, virtually production came to a complete standstill. This was due to blockages. The reason for the blockages was a safety stoppage due to a serious accident which occurred at crew 3 on the 10th of September due to a major fall of ground. Because of the fall of ground accident, the Department of Mineral Resources and Energy issued a stoppage of production in the entire mine while investigations were being conducted to the causes of the fall of ground accident. This safety stoppage affected production for the remainder of the month as no mining activities were permitted during the investigation.

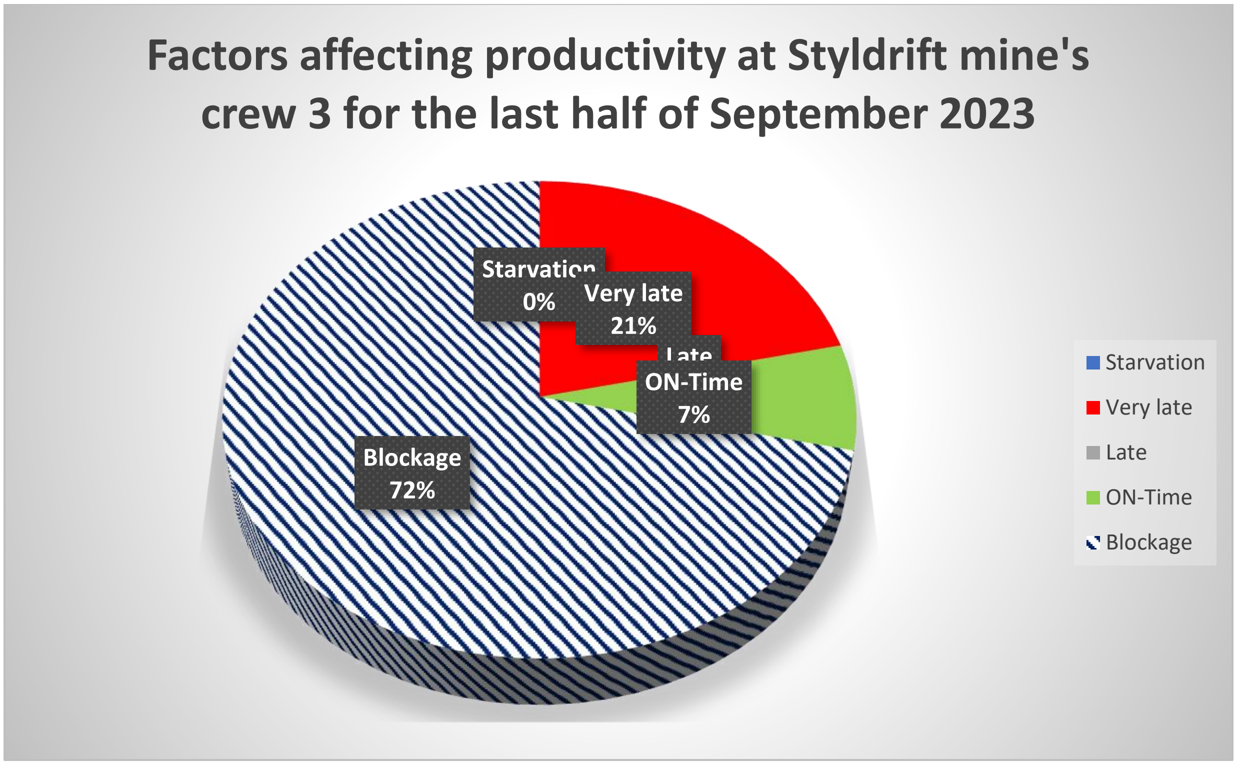


Figure 21: Factors affecting productivity at Styldrift mine's crew 3.

4.2 Current Reality Tree (Identifying the Constraint)

As has been previously discussed in the theoretical framework chapter, the first step in improving an operation is to identify what to change. The Current Reality Tree (CRT) is a tree diagram that is used as a thought process tool to identify the system's core problems through the application of cause-and-effect logic. The CRT highlights the problem symptoms which are also known in TOC as the undesired effects (UDE's) that are affecting productivity. The CRT then links these UDE's in a series of cause-and-effect relationships with the aim of identifying the root causes of the identified constraint in the system (Davies, Mabin, & Balderstone, 2005).

As has been started earlier, the biggest factor which impacted productivity in the month observed in the study was blockages that were a result of safety stoppages caused by a fall of ground incident. The investigation of the fall of ground incident found out that the fall of ground was caused because of inadequate installation of secondary support at crew 3. From the observations made above using control charts, it can be derived that the main contributing factor which led to the secondary support at crew 3 falling behind was due to starvation. As previously stated, the main contributing factors to starvation (76%) were unavailability of machinery (45%) and the unavailability of labour (31%). Figure 22 below shows a current reality tree (CRT) diagram of the scenario.

During the study it was derived that the main contributors to unavailability of labour was due to the high rate of absenteeism, as well as a high turnover of machine operators. One of the factors found to contribute to absenteeism was fatigue as currently production crews must work 10-hour shifts that run continuously for 7 days at a time. The other main cause of absenteeism was found to be the current culture at the mine were operators, particularly those hired from surrounding local communities believe that they can get away with being absent from work, this culture has been facilitated by a lack of consequence management at the mine. This is because there is a lack of successful disciplinary action for such behaviour. When supervisors try to take action, the operators seek protection from the union. Because of fear of retribution, supervisors now tend to avoid enforcing disciplinary actions against operators.

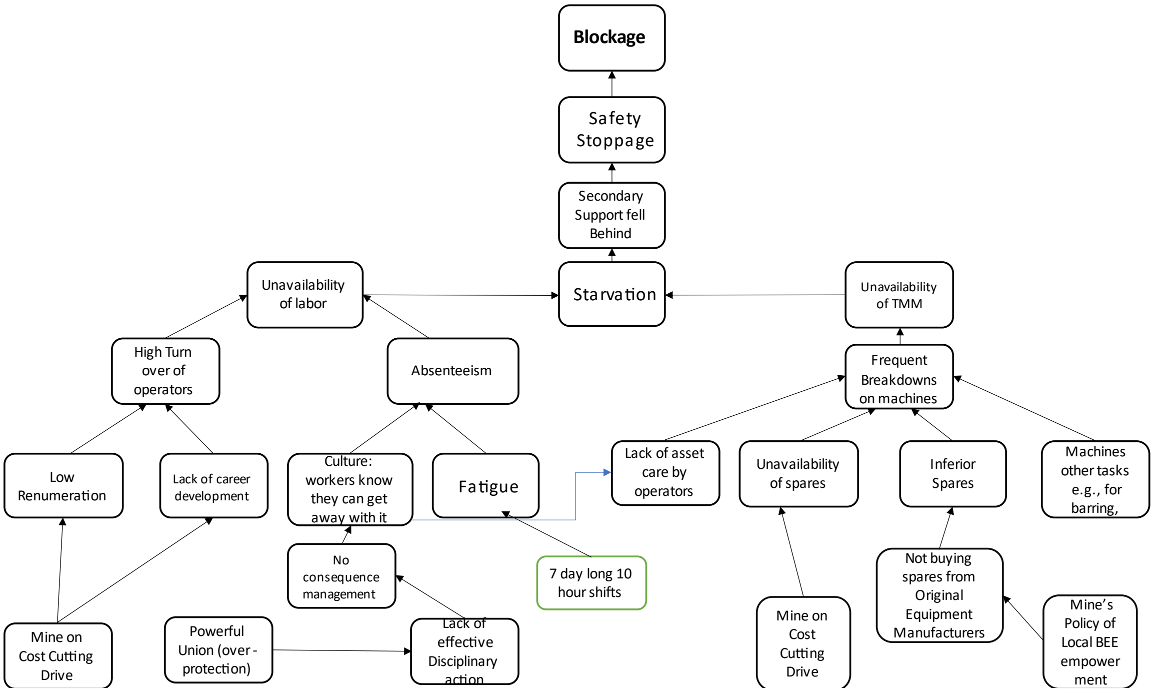


Figure 22: Current Reality Tree analyzing the root causes leading to the identified constraint limiting production.

The other cause of high unavailability of labour was due to the high rate of turnover of operators. This can be attributed to the high demand for TMM operators in the platinum mining industry. For instance, in the past few years new mining operations have opened or expanded operations in surrounding areas. This includes Eland mine, Bakubung mine, and Booysendal which have been on active recruitment drives in the past year. A significant number of Styldrift's TMM (machine) operators have as a result resigned to take up higher offers from these mines. This trend also negatively affected crew 3 as one of its best operators who was responsible for installing secondary support resigned in the middle of the month.

The other contributing factor to this high turnover of operators is also a lack of career progression and skills development at Styldrift. In its pursuit to cut costs, Styldrift's management implemented a directive to freeze all development training and promotions in the company. This directive has contributed to a loss of some moral from operators.

The main contributing factor to secondary support falling behind was however derived to be unavailability of TMM (45%). The underlying contributing factor to the unavailability of TMM was the frequent breakdowns experienced on the axess rigs (TMM for install secondary support). It was observed that some of these breakdowns are caused by lack of proper asset care by operators. This is found to be linked again to the culture at the mine of lack of accountability as operators know they can get away with it. For instance, operators are required to do a pre-use checklist inspection of their machines before they use them. However often operators don't do so and can use a TMM without checking the oil or diesel levels. This can often lead to avoidable breakdowns.

Another contributing factor to the frequent breakdowns is the issue of the unavailability of spare parts, which affects the time it takes to fix breakdowns. The unavailability of spare parts can be attributed to the current cost cutting measures being implemented at the mine. For instance, more layers of control have been added to the process of ordering parts to an extend that at one point to get a simple and frequently consumed part like a hydraulic hose, artisans had to first wait to get the engineer's signature. This process is cumbersome and leads to delays in fixing machines as the engineer is not always on sight to sign for these orders of spares.

Operators and artisans have also been complaining about the quality of spares. They state that the parts sourced from local suppliers are inferior in quality compared to the ones sourced directly from the original equipment manufacturer (OEM). For instance, some parts which are designed to last for months before they are replaces now sometimes only last for a weeks or days. This ends up resulting in a higher frequency of breakdowns. One of the reasons managements has given to why local suppliers are used instead of the OEM is the mine and government's policy on local empowerment.

While the above-mentioned challenges with availability of machinery is a widespread issue on the mine which affects all TMM, the unavailability is worse on the axess rig TMM which is used to install secondary support. One of the factors that causes this higher rate of unavailability of axess rigs is that, since in addition to being used to install secondary support, the axess rigs are also used to perform other tasks that include doing mechanical barring, drilling camera holes, and drilling service holes. The task of mechanical barring is particularly damaging for the machine, as the machine was not primarily designed for this purpose. The tasks of mechanical barring using an axess rig often results in big rocks falling on the boom of the axess rig while the machine is barring them down. This often results in the damaging of hydraulic hoses amongst other damages that can be encountered by the axess rig during the process.

5 STRATEGIES THAT CAN BE APPLIED TO ELIMINATE THE IDENTIFIED CONSTRAINTS.

5.1 Evaporating Cloud (EC)

The previous chapter ended with a detailed description of root cause analysis using the Current Reality Tree (CRT) TOC thought process (TP) tool. The purpose of the CRT was to identify “what to change” or the root problems that resulted in identified constraint of blockage. This chapter will be aimed at answering the question of “what to change to”. In other words, strategies will be developed in this chapter that can be applied to eliminate the identified constraint. This will be achieved using the TOC TP tools, namely through using the Evaporating Cloud (EC) and the Future Reality Tree (FRT). As was mentioned in the theoretical framework chapter it is often not easy to come up with solutions to the identified underlying problems, as there are often conflicts or dilemmas encountered in the decision-making process which often results in managers having to make compromises. The EC was designed to be used as a tool to resolve these conflicting scenarios in a situation where no acceptable compromise is apparent. The EC achieves this by ensuring that both sides of the conflict are critically analyzed, and then developing win-win solutions.

5.1.1 Resolving Costs Cutting impact on productivity

As was highlighted in previous chapter, one of the biggest factors leading to secondary support falling behind which resulted in a blockage constraint in the system was due to the mine’s cost cutting measures. These cost cutting measures resulted in a series of undesired effects that lead to the blockage. For instance, as part of the cost cutting measures there was a freeze on the development and upskilling of workers. There was also a freeze in salary increases resulting in the mineworkers’ salaries being lower than those offered by neighboring mines. This ultimately resulted in low morale amongst workers, as well as high turnover of operators. This resultantly contributed to low availability of workers, which negatively contributed to the activity of installing secondary support falling behind. The cost cutting measures also contributed to prolonged breakdowns, as often at times spare parts were not readily available, negatively affecting the availability of TMM.

The most apparent solution to the above-mentioned problem is to increase spending to ensure that spare parts are more readily available. The mine can also make more funding available to ensure renumeration for the mine's workers is competitive, and reopen training and development programs for workers, to reduce turnover of personnel and boost morale. However, as can be seen from the EC in figure 23, this solution will be in direct conflict with the current strategy of the mine of implementing widespread cost cutting measures on the mine's operations.

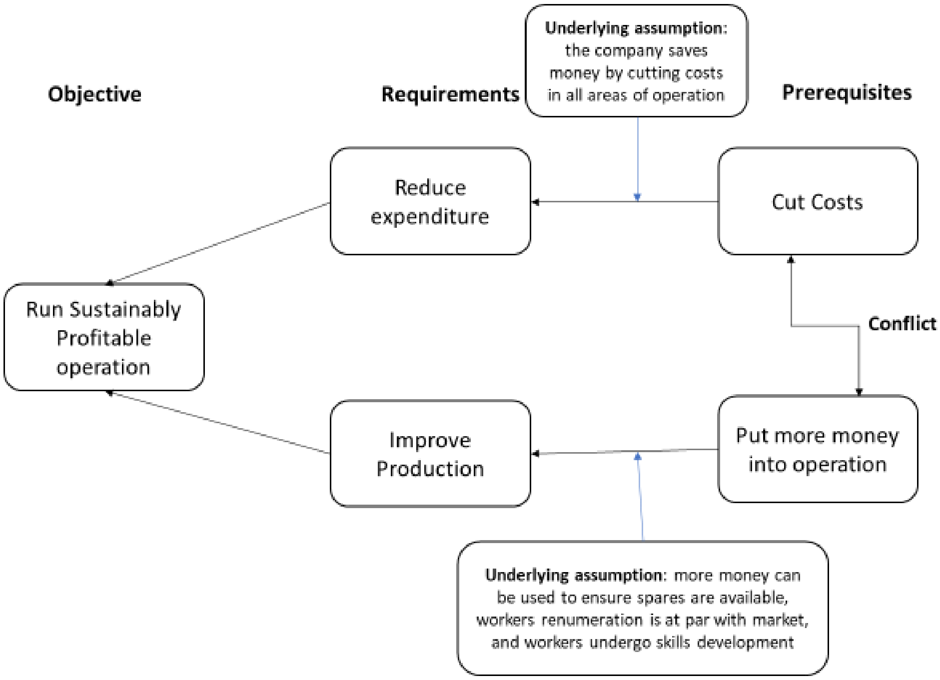


Figure 23: EC on the conflict of the mine cutting costs vs putting more money into the operation.

One solution that can be able to address both sides of the conflict is by challenging the underlying assumption that widespread cost cutting measures will lead to a more sustainably profitable operation. Sometimes it is clear by trying to save costs, the mine ends up paying more. For example, by trying to save costs on remuneration and training and development of its employees, the mine will end up spending more on recruitment of new employees with likely less experience and skills, as the experienced operators will go to other mines offering better pay and development opportunities. Again, by restricting the purchase of spare, the mine will end up being affected by longer downtimes, reducing production revenue of the mine.

On the other hand, increasing expenditure can often result in wastages in the system. Investing in personnel's development may not always result in lower turnover, as the upskilled workers can then decide to market themselves to other mines once they obtained the skills. Increasing renumeration may not always translate to improved moral and lower turnover, for example if the other conditions of employment such as work/life balance are not addressed.

As a possible solution to address this conflict, one alternative solution can be to improve the supply chain efficiency in the system to ensure that the needed spares are made available just in time when they are needed, without necessarily having to raise costs. This solution can be achieved by implementing more prudent inventory management systems for TMM spares. For example, the must be an automated system in place at the mine to track the inventory of spares, to ensure they are kept at an acceptable level. Whenever inventory is lower than acceptable, an automatic signaling and ordering must be activated without delay. This solution ensure that the needed spares are made available, without having to significantly increasing spending, and as a result lead to an improvement in availability of TMM.

To address the issue of high turnover of workers, the mine can introduce a merit system where employees compete for a chance to be placed in a development program. The development program selection criteria should be transparent and set up in such a way that it incentivizes workers to apply themselves more in their work. The mine can also review its labor to see where it has excess labor in the system and cut those labor costs. The extra money it saves from streamlining the operation by cutting surplus labor can then be used to increase the remuneration of the remaining critical personal at competitive rates. This can help reduce the high turnover without having to increase expenditure significantly.

5.1.2 Dealing with the issue of the Union Interference

The issue of the Union is a sensitive matter, especially given the history of the country, particularly in the mining sector, where mineworkers were often exploited and treated unfairly. Therefore, it is important for management and the union to find ways to work hand in hand, without undermining each other's role in the success of the mining operation. The current situation at the mine is such that the mine's supervisor feels like they cannot discipline their subordinates due to the interference from the union. On the other hand, the union also feels that if supervisors are allowed to exercise their power without the union getting involved, the subordinate employees will be disadvantaged.

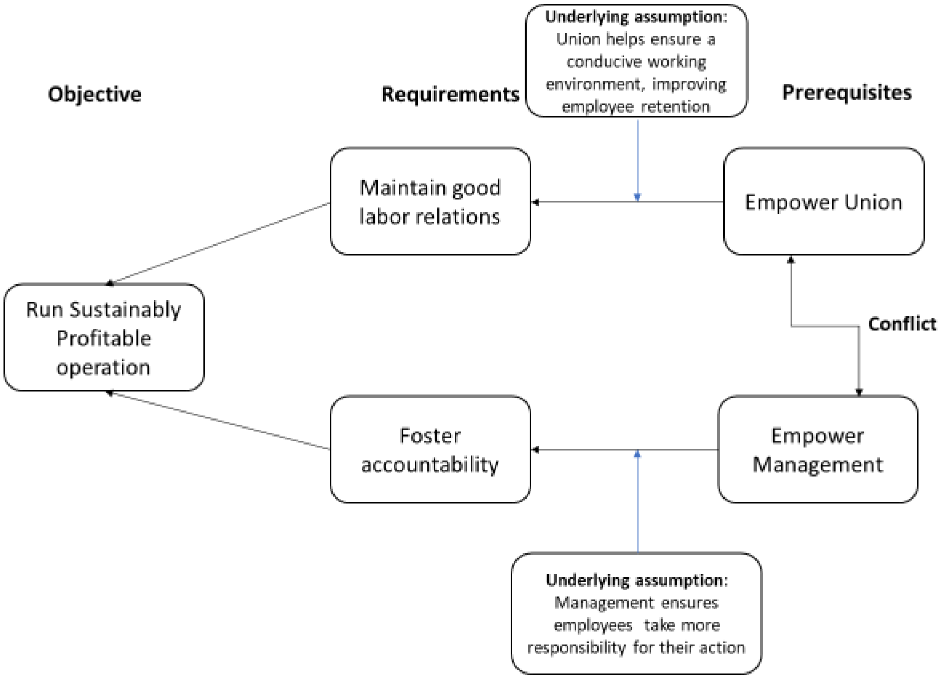


Figure 24: EC on the dilemma the mine faces on empowering the union vs empowering management.

However, what is clear is that there is currently a culture of lack of accountability at the mine. This has affected the performance of the operation, as often employees are absent from work, or don't do proper asset care, as they know there are no real consequences for their actions. Figure 24 above illustrates the conflict the mine's leadership encounters when attempting to address the problem of union interference. On one hand, the mine's leadership wants to empower the union to maintain good labor relations. On the other hand, the mine’s leadership wants to empower management to foster a culture of accountability. Both serve a critical role in ensuring a sustainably profitable operation.

To resolve this conflict, without compromising either the role or power of the union and of management one solution can be to equip line management with labor relations guidelines. This will enable the line supervision to correctly follow the required disciplinary steps to ensure a higher rate of successful disciplinary process. It has been observed that most disciplinary actions initiated by line supervision fail because of failure to follow proper procedures. For example, before a supervisor can issue a final written warning to a subordinate, the correct procedure is to first prove in writing that they have attempted to first coach or counsel the subordinate, then if there is no change in behavior of subordinate the supervisor must then give a first written warning, before issuing the final written warning. Once the supervisor has clearly shown than he followed the correct disciplinary guidelines, the union will not have ground to block the disciplinary action taken by supervision. On the other hand, a system must be put in place to ensure that mine supervisors are also integrated into the union structures to ensure a balanced approach from the union with regards with their role in labor relations.

5.1.3 Dealing with the issue of sourcing inferior spares from local suppliers

One of the key contributors to the low availability of TMM was found to be inferior TMM parts which tended to break more frequently that designed or planned. It was common knowledge at the mine that since the mine switched from ordering spares from the OEM to local suppliers the quality of spares has deteriorated. However, when management was asked why not switch back to the OEM, they stated that sourcing from local suppliers is in line with the mine’s policy on empowering local businesses and communities.

Figure 25 below shows an EC break down of the dilemma the mine faces between sourcing spares from OEM or sourcing them from local suppliers. To be a sustainable and profitable operation, on one hand the mine is required to source reliable spares, on the other hand the mine is required to honor its social responsibility contracts of supporting local businesses.

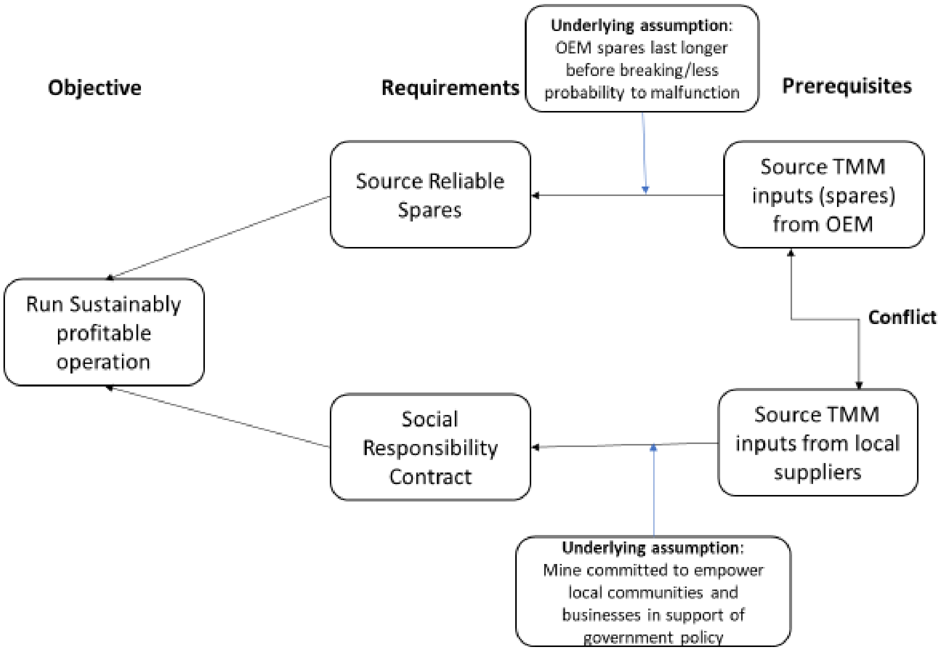


Figure 25: EC o dilemma of sourcing spares from OEM vs local suppliers

One solution could be for the mine to invest in the development and upskilling of local suppliers to a level where they can compete with bigger international suppliers on both price and quality. It can then claim tax rebates for these initiatives in developing local industries. Another alternative is to use OEM to supply the spares, as they already have the required expertise and capacity to deliver on quality and price. The mine can then contract and partner with local enterprises to assemble those spares, with training from the OEM, and be contracted to service the TMM after undergoing extensive training with the OEM. In this way, the mine can be able to ensure quality or reliability in the spares it gets, and at the same time meet its social responsibility requirements.

5.1.4 Dealing with the issue of utilizing the axess rig only for installing secondary support.

As highlighted in the CRT in the previous chapter, one of the contributing factors to the frequent breakdown of the axess rig is that the machine is utilized for other activities other than the installation of secondary support. For instance, the axess rig is also utilized regularly to perform mechanical barring. It is also utilized to drill service holes, and to drill camera holes. These activities, particularly mechanical barring makes the machine susceptible to damages as rocks often fall on top of the boom while the machine is barring the rocks down. The machine primarily designed to perform this task is a scaler, but the mine does not have scalers, thus utilizes the axess rig to perform this task.

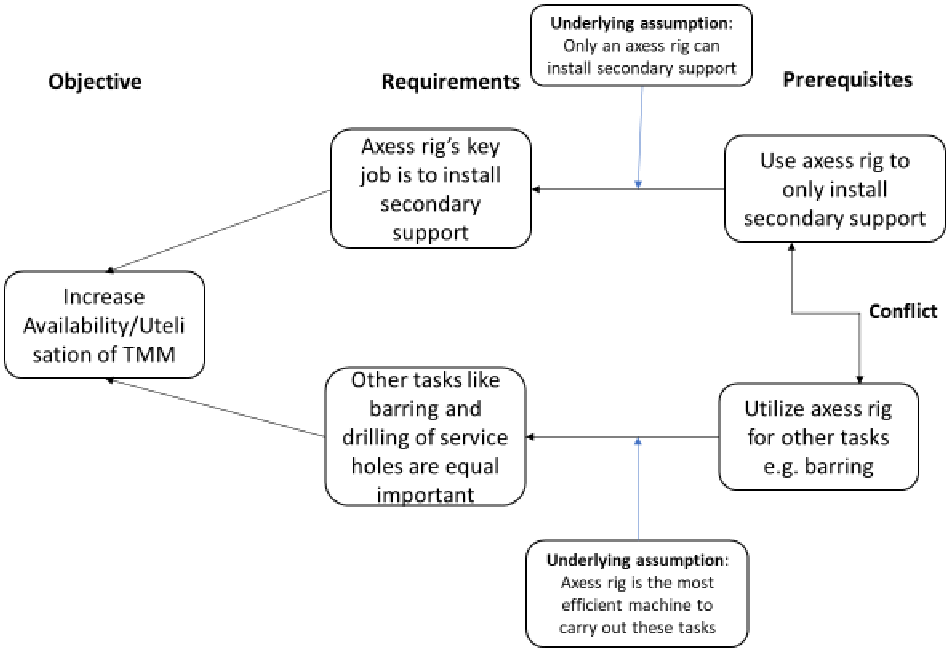


Figure 26: EC of dilemma of utilizing axess rig for only installing secondary support vs also performing other tasks.

Figure 26 above shows a breakdown of the dilemma of utilizing axess rig for only axess rig to install secondary support and utilizing the axess rig to perform other tasks. As a solution to the above problem, one option in the short term would be to utilize the axess rig to do the tasks only it can perform. The other tasks which the axess rig was being utilized for, but which can be performed by other machines can then be assigned to those other machines, thereby exploiting the constraint. For instance, mechanical barring can be assigned to be done by a drill rig, freeing up more time for the axess rig to install anchors and at the same time reducing the axess rig's risk of encountering breakdowns while doing mechanical barring. Service holes which were being drilled by the axess rig can be assigned to be done by a roof bolting machine, further freeing up more time for the axess rig to spend installing secondary support. The axess rig can then focus on primarily installing secondary support and drilling camera holes as it is the only machine which can perform these tasks. In the long term the mine can consider acquiring scalers which are machines designed primarily to do mechanical barring.

5.1.5 Dealing with the issue of long working hours

One of the root causes of unavailability of labor was the current long hours workers must do resulting in fatigue, and in turn leading to a high rate of absenteeism at the mine. One option to reduce fatigue is to reduce the working hours of workers. However, this solution conflicts with the mine's other business objectives. For instance, the mine is planned to operate continuously 24hrs a day, 7 days a week. This results in workers having to work 10hours or more a day, in 7-day long shifts before they can go on off. Figure 27 below shows the analysis of conflict management faces on whether to make the shifts shorter or keep them as is.

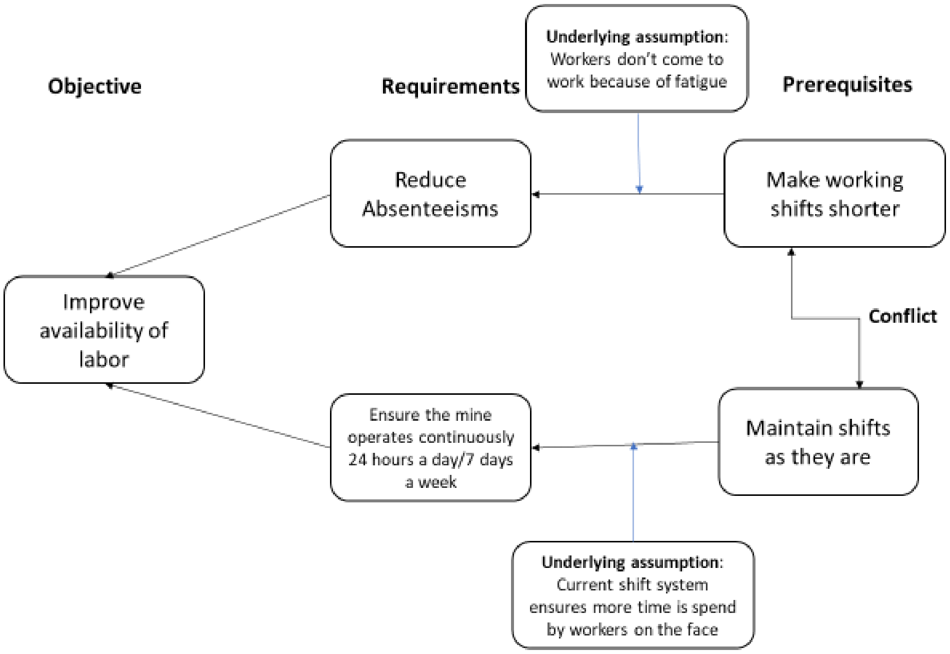


Figure 27: EC on the dilemma the mine faces on whether to make shifts shorter or maintain shifts as they are.

A more optimal solution to this conflict will be to keep the shifts as they are but introduce fatigue breaks during the shifts. Currently there are no allocated fatigue breaks given during the shift, where workers can have breakfast or lunch during the shift. The employees are only expected to stop the machine when they are done with their planned tasks for the day. The mine can investigate introducing two 30min fatigue breaks during the shift, one at break time, the other at lunch time. This can help reduce the fatigue currently being experienced by the workers, which can in turn be linked to be contributing to the high levels of absenteeism being experienced at the mine. Not only can giving workers allocated fatigue breaks during the shift contribute to a reduction in absenteeism, but it can also improve productivity of workers during the shift.

5.2 Future Reality Tree (FRT)

As was stated in the theoretical framework chapter the FRT is a TOC Thought Process (TP) tool that is applied after the Evaporating Cloud (EC). The function of the FRT is to also help develop a suitable solution to the core system problems that are identified through use of the Current Reality Tree. The FRT is used to test the robustness of the solution proposed using the EC tool so as to make sure that implementing that solution can really resolve the identified problem without creating a negative performance impact in the future as a consequence. (Sanjika, 2010) These proposed solutions in the FRT are known as injections. A FRT is thus a series of cause-and-effect relations that connect the recommended injections with the DE's. The FRT has a similar structure to a CRT but is different in that instead of identifying problems (UDE's) it proposes actions (injections) that can lead to ideal future state (DE's).

Figure 27 below shows a FRT created from the EC to provide solutions for the root problems found using the CRT. The FRT gives a summary of the proposed solutions (injections) recommended to achieve the desired effects (exploit and eliminate the constraints) currently being experienced at Styldrift mine.

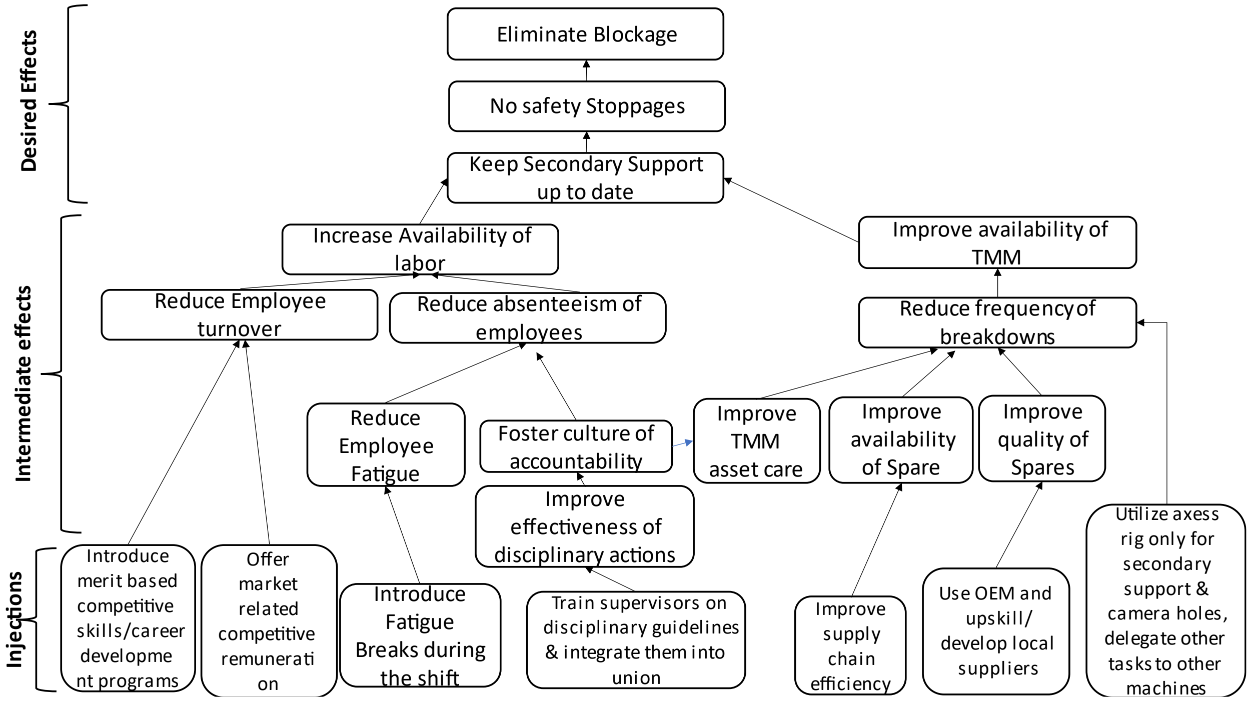


Figure 28: FRT on how production can be improved at Styldrift mine

6 CONCLUSION

In this section an overview of the key areas covered by this study are given. The research's objectives were to apply TOC to identify the constraints affecting Styldrift mine's productivity and develop strategies that can be used to improve productivity at the mine. To identify the constraints, time and motion studies were carried out at the mine's crew 3. According to TOC a constraint can be defined as being the weakest link in the chain. From the time and motion studies it was observed that the constraint limiting productivity at the crew was the issue of blockages, as it contributed the most (42%) to the factors affecting production.

After identifying the constraint, a root cause analysis was conducted using TOC's CRT. From the CRT analysis it was derived that the direct cause of the blockage, was due to safety stoppages which were a result of the activity of installation of secondary support falling behind. Further analysis from the time and motion studies derived that the reason the activity of secondary support fell behind was mainly due to starvation (76% of the time [45% due to breakdowns and 31% due to unavailability of labor]).

The main contributing factors to breakdowns on the axess rig included the unavailability of spares at the mine, which was linked to the mine's cost cutting drive. The use of the axess rig to perform other tasks such as mechanical barring and drilling service holes, in addition to its primary task of the installation of secondary support, also contributed to the high frequency of breakdowns on the machine. The low quality of spares ordered from local suppliers also contributed to the high frequency of breakdowns, as the spares often malfunctioned or broke in a shorter time frame than planned. The sourcing of spares from local suppliers instead of the OEM can be attributed to the mine's policy of local empowerment and drive to support local businesses. The other contributing factor to the high frequency of breakdowns was the be a lack of asset care by operators, which can be attributed to a lack of effective consequence management at the mine, in part due to the union's protection of workers.

The other core reason secondary support fell behind was attributed to the high unavailability of labor, due to a high turnover of the mine's machine operators and a high rate of absenteeism at the mine. The high turnover of personnel at the mine was attributed to the low renumeration rates at the mine compared to neighboring mines, and a lack of career development at the mine which in turn was linked to the mine's cost cutting drive. The high rate of absenteeism at the mine was attributed to fatigue, which was a result of long working hours, and the current culture of lack of accountability. The lack of consequence management was attributed to a lack of effective disciplinary action and union protection.

To develop strategies to solve these root causes of the identified constraint, the TOC's EC thought process tool was applied to come up with more optimal solutions to the identified problems or UDE's. A FRT was then constructed using the solutions developed using the EC.

This research report illustrated how the TOC's thought process tools can be applied in the mining context to identify and solve productivity constraints. For instance, this research illustrated how EC's can be applied to enable resolution of various conflicting scenarios found in the mining context and facilitate better decision making in developing strategies to improve productivity. This was achieved by using the EC to unpack the underlying assumptions that cause the conflict, and then developing inputs that can dismantle these assumptions. This research illustrated how verbalizing the conflicting scenarios, and visualizing the different needs the conflicting actions are trying to satisfy in pursuit of a shared goal, can lead to a more optimal solution to the identified problem. Using the FRT has the advantage of addressing the negative consequences of a proposed solutions before implementing them.

7 RECOMMENDATIONS

One way to exploit the identified constraint of blockage is to ensure the axess rig is only utilized for the tasks it can perform, while other tasks like doing mechanical barring can be delegated to be carried out by other machines. In addition, it was also recommended that to improve the quality of spares the mine should invest in the development and upskilling of local suppliers to a level where they can compete with bigger international suppliers on both price and quality. Alternatively, the mine can also source spares directly from the OEM, as they already have the required expertise and capacity to deliver on quality and price. The mine can then contract and partner with local enterprises to assemble those spares, with training from the OEM, and be contracted to service the TMM after undergoing extensive training with the OEM.

To improve the availability of spares the mine should improve the supply chain efficiency in the system to ensure that the required spares are made available just in time when they are needed, without necessarily having to raise costs. This solution can be achieved by implementing more prudent inventory management systems for TMM spares.

To increase availability of labor the mine should introduce fatigue breaks during the shifts as this can help reduce fatigue. Introducing a merit-based system where employees compete for a chance to be placed in a development program can also help reduce the rate of employee turnover, and at the same time encourage enhanced productivity amongst workers. To reduce turnover, the mine should offer its employees market competitive renumeration packages. One way to fund increased renumeration without raising costs is for the mine to review its labor complement and cut excess labor in the system and streamline its operation.

To foster a culture of accountability the mine should equip line management with labor relations guidelines. This will enable the line supervision to correctly follow the required disciplinary steps to ensure a higher rate of successful disciplinary process. On the other hand, a system must be put in place to ensure that mine supervisors are also integrated into the union structures to ensure a balanced approach from the union with regards with their role in labor relations.

The recommendation to retrain mine supervision on disciplinary guidelines put into question the mine's governance effectiveness, particularly on the capacity of line supervision it hires. Further research must be conducted to investigate the impact of the capacity of mine supervision in ensuring governance effectiveness. The role of the union on the mine appears indistinct. Ideally the union should not be interfering with organizational management processes. It is therefore further recommended that further studies are conducted on the role of unions in the mining industry and their impact on the sustainability of the mining industry' operations.

This research underestimated the importance of generating buy-in from the decision makers in an organization to influence their attitude towards adopting the analysis and research findings. To implement and test the TOC's five focus steps required buy-in from management and the mine's decision makers. This proved to be a slow and difficult process for the researcher as he was not in a position of influence.

Due to these limitations, the above-mentioned recommendations could only be made available to the mine's management, who are the decision makers, but could not be implemented or tested by the researcher in the given context and timeframe. To encourage buy-in, ideally a FRT must be constructed through a group effort, where team members including the people affected are allowed to give different inputs to the proposed solutions. This has the benefit of enhancing collaboration and understanding of the proposed solutions by the people affected by the identified problems and the people who have the power to implement the proposed solutions. It is therefore recommended that future research be done in a collaborative manner involving conducting workshops with the affected people to enhance the successful implementation of the proposed solutions.

While this research managed to illustrate how the TOC thought process tools such as the EC, CRT and FRT can be applied in the mining context to identify constraints limiting productivity and develop strategies to exploit and eliminate those constraints, it did not manage to illustrate explicitly how the five focus steps of TOC can be applied to improve productivity in the mining context, due to the above mentioned factors. This is an area further research can focus on.

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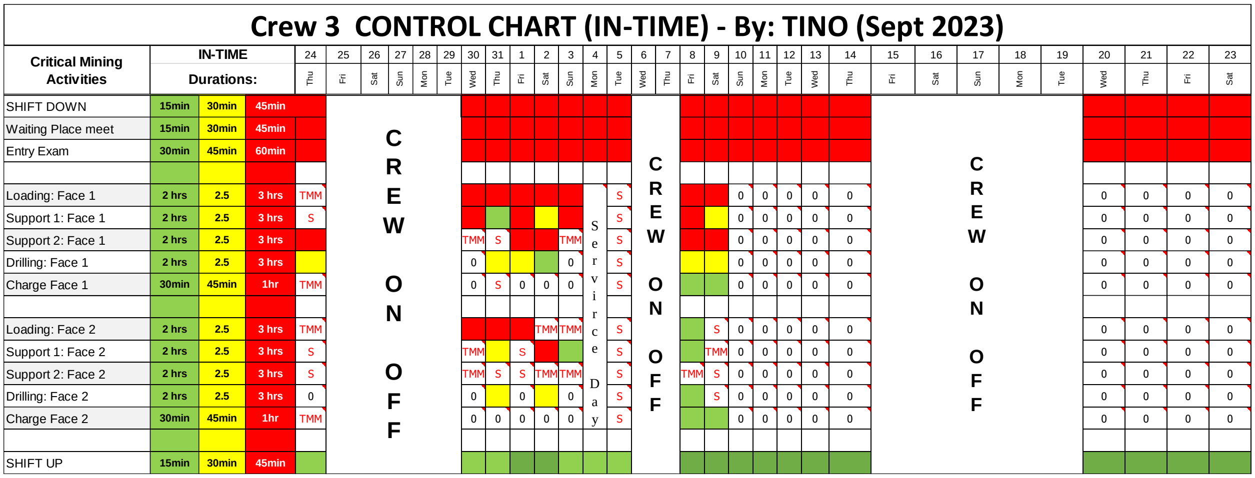
APPENDIX

Table 8: On-time chart analytic breakdown for the first half of the month of September 2023

On-time chart analytic breakdown for the first half of the month of September, 2023		
Activity	**Main Factor Affecting Activity**	**Cause of the problem**
SHIFT DOWN	38% of the time activity started very late	this was due to late blasting from previous shift
Waiting Place meet	the activity occurred very late 78% of the time	50% of the time it was due to late cage, 50% of the time it was due to delay by miner checking panels
Entry Exam	89% of the time activities occurred vey late	62.5% of the time it was due to late and prolonged safety meeting. 37.5% of the time it was due to late shift down
Loading: Face 1	55% the activity started very late; 22% activity did not take place	50% of the times the activity did not take place was due to breakdowns, 50% of the times activity did not take place was due to miner being absent
Support 1: Face 1	55% the activity started very late; 22% activity did not take place	50% of the times the activity did not take place was due to no material, 50% of the times activity did not take place was due to miner being absent
Support 2: Face 1	44% the activity started very late; 44%	50% of the times the activity did not take place was due to breakdowns, 50% of the times activity did not take place was due to the being no operator or miner at work

	activity did not take place	
Drilling: Face 1	44% the activity started very late; 33% activity did not take place	67% of the times the activity did not take place was no face being available (blockage), 33% of the times activity did not take place was due to the being no miner at work
Charge Face 1	22% the activity started very late; 77% activity did not take place	57% of the times the activity did not take place was no face being available (blockage), 14% of the times activity did not take place was due to the being no miner at work, 14% due to breakdown, 14% due to machine being utilized for other tasks
Loading: Face 2	50% of the times activity did not take place	60% of the times the activity did not take place was due to breakdowns, 20% of the times activity did not take place was due to the being no miner at work, 20% due to no unavailability of operator
Support 1: Face 2	33% the activity started very late; 55% activity did not take place	40% of the times the activity did not take place was due to breakdowns, 20% was due to the being no miner at work, 20% due to no shortage of material, 20% due to late finish of first face
Support 2: Face 2	100% of the times activity did not take place	45% of the times the activity did not take place was due to breakdowns, 22% due to long time it took to complete work at first face, 11% of the times it was due to the being no miner at work, 20% due to unavailability of operator
Drilling: Face 2	22% the activity started very late, 67% of the time activity did not take place	67% of the times the activity did not take place was no face being available (blockage), 16% of the times activity did not take place was due to the being no miner at work, 16% was due to poor planning by miner

Charge Face 2	22% the activity started very late; 77% activity did not take place	71% of the times the activity did not take place was no face being available (blockage), 14% of the times activity did not take place was due to the being no miner at work, 14% due to breakdown
SHIFT UP	the activity occurred very late 100% of the time	the activity occurred very late 100% of the time



Crew 3 CONTROL CHART (IN-TIME) - By: TINO (Sept 2023)

Critical Mining Activities	IN-TIME			24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Durations:			Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
SHIFT DOWN	15min	30min	45min	🟥	CREW ON OFF					🟥	🟥	🟥	🟥	🟥	🟥	🟥	CREW ON OFF		🟥	🟥	🟥	🟥	🟥	🟥	🟥	CREW ON OFF					🟥	🟥	🟥	🟥
Waiting Place meet	15min	30min	45min	🟥						🟥	🟥	🟥	🟥	🟥	🟥	🟥			🟥	🟥	🟥	🟥	🟥	🟥	🟥						🟥	🟥	🟥	🟥
Entry Exam	30min	45min	60min	🟥						🟥	🟥	🟥	🟥	🟥	🟥	🟥			🟥	🟥	🟥	🟥	🟥	🟥	🟥						🟥	🟥	🟥	🟥
	🟩	🟨	🟥																															
Loading: Face 1	2 hrs	2.5	3 hrs	TMM						🟥	🟥	🟥	🟥	🟥	Service Day	S			🟥	🟥	0	0	0	0	0						0	0	0	0
Support 1: Face 1	2 hrs	2.5	3 hrs	S						🟥	🟩	🟥	🟨	🟥		S			🟥	🟨	0	0	0	0	0						0	0	0	0
Support 2: Face 1	2 hrs	2.5	3 hrs	🟥						TMM	S	🟥	🟥	TMM		S			🟥	🟥	0	0	0	0	0						0	0	0	0
Drilling: Face 1	2 hrs	2.5	3 hrs	🟨						0	🟨	🟨	🟩	0		S			🟨	🟨	0	0	0	0	0						0	0	0	0
Charge Face 1	30min	45min	1hr	TMM						0	S	0	0	0		S			🟩	🟩	0	0	0	0	0						0	0	0	0
	🟩	🟨	🟥																															
Loading: Face 2	2 hrs	2.5	3 hrs	TMM						🟥	🟥	🟥	TMM	TMM		S			🟩	S	0	0	0	0	0						0	0	0	0
Support 1: Face 2	2 hrs	2.5	3 hrs	S						TMM	🟨	S	🟥	🟩		S			🟩	TMM	0	0	0	0	0						0	0	0	0
Support 2: Face 2	2 hrs	2.5	3 hrs	S						TMM	S	S	TMM	TMM		S			TMM	S	0	0	0	0	0						0	0	0	0
Drilling: Face 2	2 hrs	2.5	3 hrs	0						0	🟨	0	🟨	0		S			🟩	S	0	0	0	0	0						0	0	0	0
Charge Face 2	30min	45min	1hr	TMM						0	0	0	0	0		S			🟩	🟩	0	0	0	0	0						0	0	0	0
	🟩	🟨	🟥																															
SHIFT UP	15min	30min	45min	🟩						🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩	🟩						🟩	🟩	🟩	🟩

Figure 29: In-time Control Chart for the September Production month

Table 9: Analytic breakdown of the In-time Chart of the 1st half of the September 2023

Analytic breakdown of the In-time Chart of the first half of the September, 2023		
Activity	**Main Factor Affecting Activity**	**Cause of the problem**

SHIFT DOWN	100% of the time activity took longer than planned	this was mainly because of the long-time workers take to travel from the shaft bank to the waiting place (on average taking more than 45min)
Waiting Place meet	100% of the time activity took longer than planned	this mainly since the crew must wait for the miner to check the working places before he can issue the job and safety instructions
Entry Exam	100% of the time activity took longer than planned	this is because it takes on average more than 30min to do an entry examination on one panel. The miner must do an entry examination on an average of 6 panels or more per shift.
Loading: Face 1	100% of the time activity occurred it took longer than planned	loading one panel takes on average more than 3-4hrs. This is because of the long tramming distance from face to tip.
Support 1: Face 1	57% of the time activity occurred it took longer than planned	this was mainly due to frequent small breakdowns during activity, e.g., broken shank, burst hydraulic hose, etc.
Support 2: Face 1	100% of the time activity occurred it took longer than planned	this was mainly due to frequent small breakdowns during activity, e.g., broken shank, burst hydraulic hose, etc. and anchors always being behind in each face

Drilling: Face 1	100% of the time activity occurred within the planned duration	100% of the time activity occurred within the planned duration
Charge Face 1	100% of the time activity occurred within the planned duration	100% of the time activity occurred within the planned duration
Loading: Face 2	100% of the time activity occurred it took longer than planned	loading one panel takes on average more than 3-4hrs. This is because of the long tramming distance from face to tip.
Support 1: Face 2	25% of the time activity occurred it took longer than planned	this was mainly due to frequent small breakdowns during activity, e.g., broken shank, burst hydraulic hose, etc.
Support 2: Face 2	100% of the times activity did not take place	100% of the times activity did not take place
Drilling: Face 2	100% of the time activity occurred within the planned duration	100% of the time activity occurred within the planned duration

Charge Face 2	100% of the time activity occurred within the planned duration	100% of the time activity occurred within the planned duration
SHIFT UP	100% of the time activity occurred within the planned duration	100% of the time activity occurred within the planned duration

Table 10: Analytic breakdown of the In-time Chart of the second half of the September 2023

Analytic breakdown of the In-time Chart of the second half of the September, 2023		
Activity	**Main Factor Affecting Activity**	**Cause of the problem**
SHIFT DOWN	100% of the time activity took longer than planned	this was due to safety stoppage
Waiting Place meet	100% of the time activity took longer than planned	this was due to safety stoppage
Entry Exam	100% of the time activity took longer than planned	this was due to safety stoppage

Loading: Face 1	100% of the time activity took longer than planned	this was due to safety stoppage
Support 1: Face 1	100% of the time activity took longer than planned	this was due to safety stoppage
Support 2: Face 1	100% of the time activity took longer than planned	this was due to safety stoppage
Drilling: Face 1	100% of the time activity took longer than planned	this was due to safety stoppage
Charge Face 1	100% of the time activity took longer than planned	this was due to safety stoppage
Loading: Face 2	100% of the time activity took longer than planned	this was due to safety stoppage
Support 1: Face 2	100% of the time activity took longer than planned	this was due to safety stoppage
Support 2: Face 2	100% of the time activity took longer than planned	this was due to safety stoppage
Drilling: Face 2	100% of the time activity took longer than planned	this was due to safety stoppage

Charge Face 2	100% of the time activity took longer than planned	this was due to safety stoppage
SHIFT UP	100% activity took place in time	100% activity took place in time