A project management approach for a mining stope

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Continuously increasing costs and weakening commodity prices have forced mining companies to focus on improving their efficiency in order to enhance production rates. Because of this, more companies are treating their daily mining operations as a project for the purpose of achieving this goal. This paper focuses on an underground stoping panel project where platinum group metals (PGMs) are extracted using conventional drill-and-blast mining methods. A conventional stope can be classified as a project due to its uncertain and unpredictable characteristics, many variations, and a large number of interdependencies. These interdependencies may be minor linked activities with characteristics that tend to increase the risk of failure. The 'project management approach' to be applied to this case study should consider the risks associated with each event and be able to serve as a method to avoid disruption caused by unforeseen events. In project management, specific methods are applied to achieve objectives. In this study the critical chain project management (CCPM) approach and the event chain project management (ECPM) approach are compared to determine which is more applicable for use in an underground stope. The aim is to improve the efficiency of day-to-day stoping activities using a project management approach. The day-to-day operations are guided by a definite goal – achieving the most effective blast. This approach will improve project planning, therefore assisting in preparation for any uncertainty.

INTRODUCTION

Platinum group metals (PGMs) are South Africa's second largest export revenue generator, and the PGM sector provide approximately 136 000 direct jobs and 325 000 indirect jobs (DMR, 2014). PGMs are mined using both conventional and mechanized methods. Conventional mining involves the extraction of the reef by drilling using hand-held pneumatic machines followed by blasting, and the process is labour-intensive; while the mechanized methods involve drilling and blasting using mobile trackless machinery. It is often assumed that mechanization cuts labour costs and increases productivity. However, Lonmin, the world's third-largest platinum producer, said it would revert to conventional mining methods because mechanization, which was introduced in 2004, had failed to improve productivity and reduce costs (Mail & Guardian, 2012). The efficiency of the conventional method in relation to mechanized mining was confirmed using the analytic hierarchy process (AHP) (Muswingini *et al*., 2008). The mining method involved in this study is the conventional breast mining method, shown Figure 1. In this mining method, development is done prior to stoping to provide access to the orebody; mining is then continued perpendicular to the raise line developed on-reef.

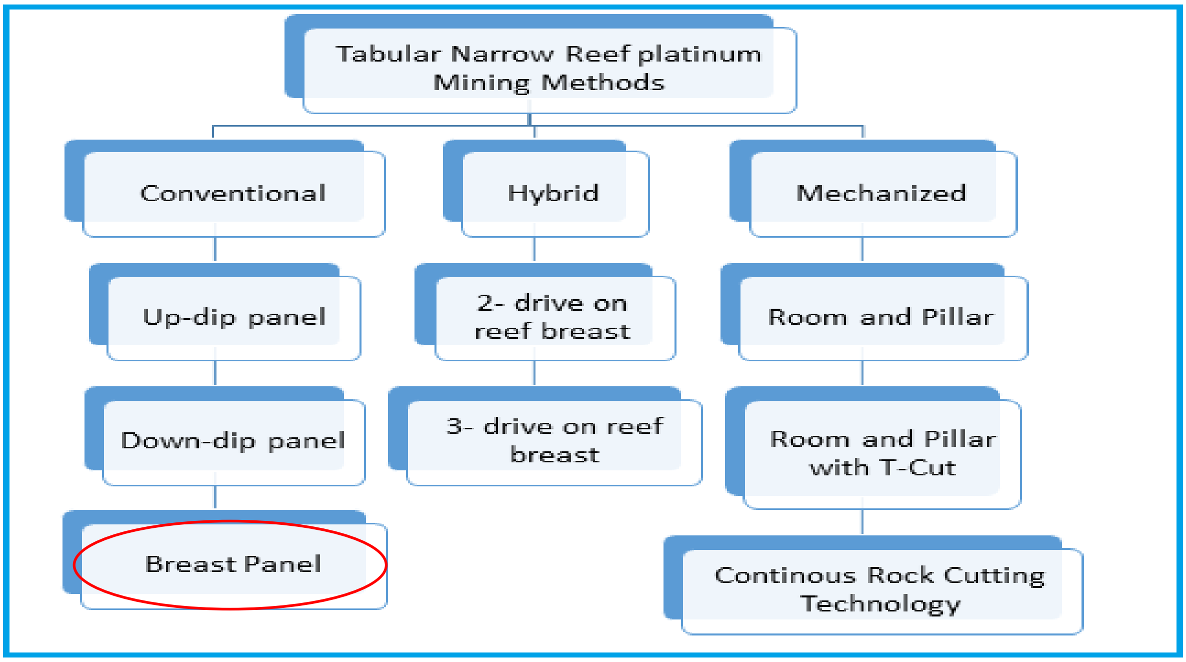

Figure 1. Classification of underground platinum mining methods in South Africa (Musingwini et al., 2003).

Although the conventional mining may be the most prevalent method for narrow tabular orebodies, it does have its own set of challenges such as low performance and labour instability. This study will focus on performance, which is 'the accomplishment of a given task measured against pre-set known standards of accuracy, completeness, cost, and speed' (Valicek *et al*., 2014). In this case study, the set standard would be an effective blast per shift. Effectiveness takes into consideration quality, cost, and timeliness. This case study compares the applicability of the critical chain project management (CCPM) approach and the event chain project management (ECPM) approach for improving the extraction performance in a stoping section. A conventional underground stope falls under the sphere of a 'project' due to its unpredictable characteristics, variation, and a large number of interdependencies (Phillis and Gumede, 2009). These unpredictable characteristics create uncertainty, which is why project management might be an ideal approach to employ.

PROBLEM STATEMENT

A case study was previously done in the application of the CCPM methodology in a platinum mine, and it was shown that there was visible improvement in the results presented (Phillis and Gumede, 2009). However, the sustainability of the methods has come into question given the current performance of the same platinum mine. This company achieved an average face advance of 17 m/ month in 2009 when the CCPM method was successfully applied. The overall performance subsequently deteriorated, and currently (2016) the average face advance per month is only 11 m. The successful application of CCPM at the mine was short-lived. Research on the CCPM methodology cannot provide insight in cases of sustained application of this technique and there is clearly resistance towards the CCPM environments (Verhoef, n.d.).

METHODOLOGY

An analysis was done on the application of CCPM at the mine in 2009. An official from the mine was then interviewed to gain an understanding of how to progress the approach. A literature review of the

CCPM and ECPM techniques was conducted to obtain a better understanding of the two approaches. Lastly, the applicability of the two methodologies to a mining stope was compared.

BACKGROUND

A project is a unique, transient endeavour undertaken to achieve planned objectives, which could be defined in terms of outputs, outcomes, or benefits. Project management is the application of processes, methods, knowledge, skills, and experience to achieve the project objectives (Meredith and Samuel, 2012). Project management must reconcile two conflicting, but equally important, aspects of a project, which are the need for speed in delivery and the need for reliability in delivering quality results. A project is usually deemed to be a success if it achieves the objectives according to the acceptable criteria within an agreed timescale and budget (Advance Project Management, n.d.). Projects mostly fail to achieve set objectives due to lack of respect for Parkinson's and Murphy's laws. Parkinson's Law states that 'work will expand to fill (and often to exceed) the time allowed', while Murphy's Law states that 'whatever can go wrong, will go wrong'. The project management approach employed in this project should identify, and protect the project against, inevitable uncertainties, which are trigged by the aforementioned laws and have the potential to cause project failure (Focused Performance, n.d.). In a project like a mining stope, the analysis of cost and duration becomes increasingly complex due to the multiple risks and uncertainties inherent in the project (Virine, 2006). CCPM is an approach concerned with elimination of project failures due to the Parkinson's Law, while ECPM is more concerned with Murphy's Law.

CCPM is an approach aimed at planning, executing, and managing projects that emphasizes the availability of resources (people, equipment, physical space) required to complete project tasks. This approach was developed by Goldratt (n.d.) in response to many projects being dogged by poor performance manifested in longer-than-expected durations, frequently missed deadlines, increased costs in excess of budget, and substantially less deliverables than originally promised. CCPM works well for projects in which activities have volatile times, and this is the case for most activities which rely on human skills. It combats the human elements that delay completion of tasks, leads to a change in the organization, and changes the way in which project workers fulfill their work (Verhoef, n.d.).

The key aspects of CCPM are that it:

- Involves a cultural change concerning how to manage projects and evaluate team members
- Avoids multi-tasking, especially while on the critical chain
- Protects against inherent uncertainty by aggregating all safety time at the end of the project rather than building it into individual task estimates
- Concentrates on the constraint of the project: the longest chain of dependent tasks or resources (dependency can either be the standard CPM finish-start dependencies or resource dependencies) (Cook, 1989).

The ECPM approach is regarded as the next level of advancement following the critical path and critical chain approaches (Raj Jat, 2016). It is an uncertainty modelling and schedule network analysis technique that is focused on identifying and managing internal and external events and event chains that affect the project schedule. It comes from a notion that 'regardless of how well a project schedule is developed and resources are allocated, some internal or external events may occur that will alter it' (Intaver Institute, 2011).

The six basic principles of ECPM are:

- Moment of event and excitation
- Event chains
- Event chain diagram and state table

- Monte Carlo schedule risk analysis
- Critical event chains and event cost
- Project performance measurement with event and event chain (Intaver Institute, 2011).

These aspects and principles drive the application of each approach.

DISCUSSION AND ANALYSIS

Resource Allocation

The principles of applying CCPM in project execution are as follows:

- Resources working on a critical chain activities are expected to work continuously on a single activity at a time. They do not work on several tasks in parallel or suspend their critical chain activity for other work
- Resources are to complete the task assigned as soon as possible, regardless of the schedule
- If a task is completed ahead of schedule, then work can start immediately on the next activity (Raz, Barnes, and Dvir, 2011).

The abovementioned principles are in contrast with what is actually happening on the ground. Firstly, the optimistic model, which assumes that all resources will be available at all times and can be used whenever required, is not always possible in a practical scenario; absenteeism is one of the biggest challenges threatening the mining industry. Secondly, even if a task is completed before its planned completion time, the time gained cannot be utilized for the next activity because the activity has to wait until it is scheduled to start; this usually happens because resources allocated for the next activity may not be available earlier.

Phillis and Gumede (2009) observed that time is mostly wasted when workers do not focus on their own assigned tasks (multitasking). The CCPM approach supports the notion that each employee should focus on his/her own work, and further, uses resource buffers to identify and ensure availability of resources on the critical chain. The resource buffer does not occupy any time in the project network, it is an information tool to alert the project manager and the resources performing the work of the impending necessity to work on a critical chain task; CCPM focuses only on the critical chain of the project (Leach, 2013).

In the application of ECPM, Monte Carlo simulation is used to estimate resources to be allocated in a project. Monte Carlo simulation is a computerized mathematical technique that accounts for risk in quantitative analysis and decision-making (Palisade, n.d.). The technique can be used to estimate the impact of any risk or event in a project through duration estimates, the costs of a project, and the resources required in a project. It uses a range of possible values taken from reliable historical data to create a more realistic picture of what might happen in the future. Multitasking observed at the platinum mine can be recorded as an event and a mitigation plan introduced to deal with it. When the planned resources are assigned to the project and there is further need for re-assigning due to an unforeseen event, then re-assigning of resources is classified as an event. Events can be used to model different situations with regard to resources, like temporary leave, illness, and vacation (Virine, 2006).

CCPM focuses mostly on the workforce as a resource. However, in a stope the resources required to achieve a blast are not limited to the team members – equipment and logistics also contribute to achieving the project objective.

Duration Estimates

The CCPM approach works well for projects in which tasks have volatile times. This is the case with most activities that rely on human skills (Camy, 2013). CCPM assumes that all task durations in a project are overestimated by a certain safety factor, and that the actual duration will be expanded to fill the allocated time (Parkinson's Law). This 'safety factor' is actually meant to deal with any uncertainty that may arise, but in most cases it is wasted by workers through their ’student syndrome’ behaviour. CCPM combats the human element of activity delay, like procrastination, due-date focus, and multitasking. CCPM further states that original duration estimates are such that there is 95% likelihood of completion, and that they should be reduced to a completion likelihood of 50%. Figure 2 graphically portrays this concept. The difference between the new estimated project duration and the original duration is termed a buffer (Raz, Barnes, and Dvir, 2001). A buffer is something that reduces a shock or forms a barrier between incompatible or antagonistic things. In this case, it will be time allocated to absorb any unforeseen event that is likely to affect project activities. There are three buffers in a CCPM project – the project buffer, feeding buffer, and resource buffer. A project buffer is placed between the last task and the project completion date on the critical path, while the feeding buffer is placed between the last task on a non-critical chain and the critical chain (Intaver Institute, 2011).

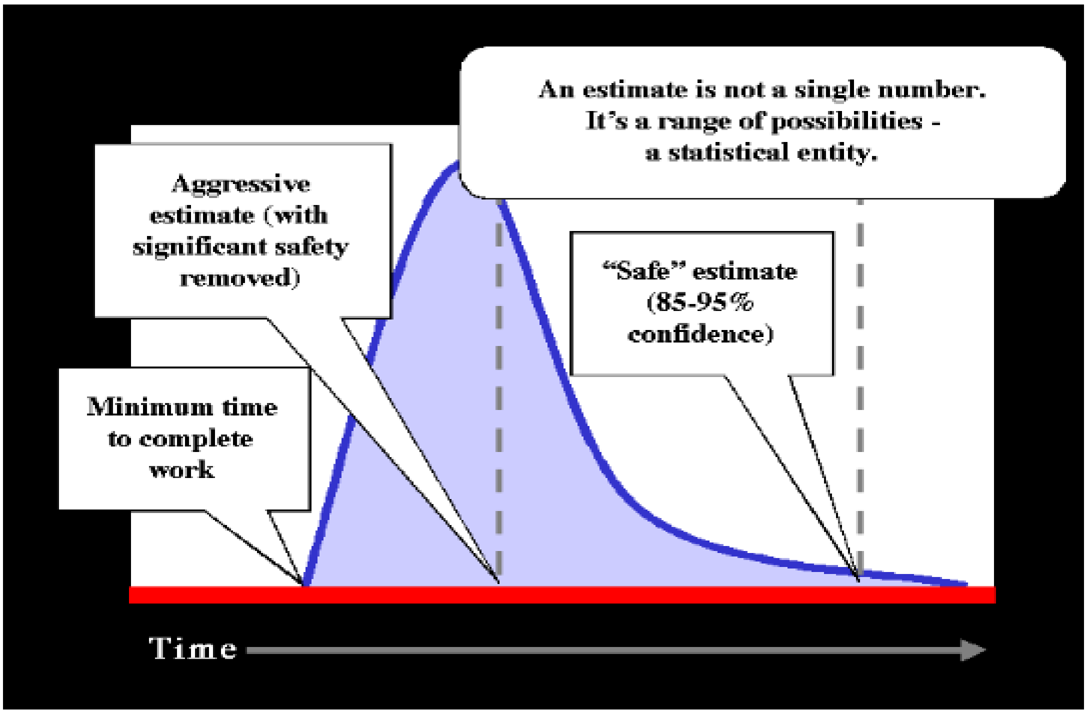

Figure 2. Duration estimates in CCPM (Focusedperformance, n.d.)

Buffers that were previously hidden have been pooled and made explicit (note that pooling the buffers does not increase the total duration of the project). However, it is assumed that by pooling together the safety margins of the individual tasks, protection against uncertainty is improved. Contrary to the noble intentions, this approach results in all gained time being lost because even if an activity is completed sooner than planned, the time cannot be utilized for the next activity. Furthermore, the delays are passed on in full as there is no intention to deal with the risk, but rather to absorb the impact. The project is likely to finish late even if there are enough buffers. Figure 3 explains the buffer in the project schedule.

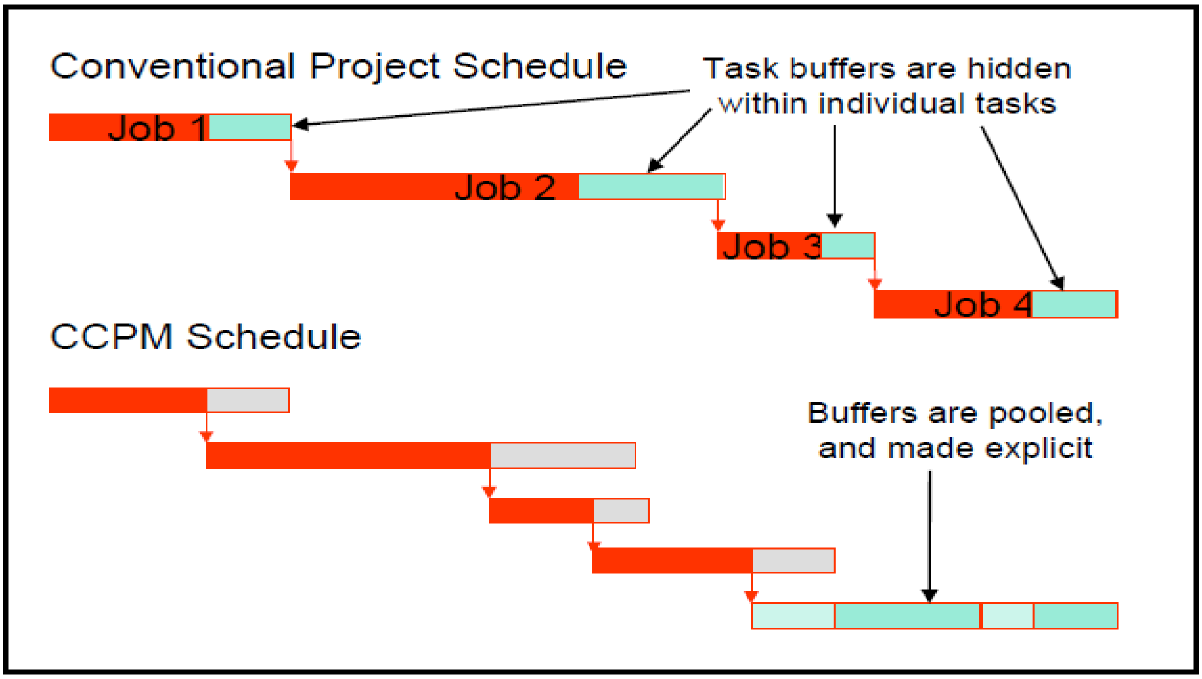

Figure 3. CCPM schedule with buffers (Raz, Barnes, and Dvir, 2001).

The ECPM approach attempts to mitigate the negative effects of motivational and cognitive biases, which influence estimates of the durations of activities in a project. ECPM recognizes that some durations are estimated based on 'best-case' scenarios; however, unfortunately that is not a true reflection of what is likely to happen on the ground, as unforeseen events might occur that change the scenario to the 'worst'. These unforeseen events are referred to as risks or events; they have the ability to prevent, delay, or stop an activity, possibly leading ultimately to project failure. An activity will be performed differently in response to an event. This state is called excitation (Figure 4), and the original state is called the ground state. In ECPM, excitation indicates that something has influenced the manner in which an activity is performed, and the activity may require different resources or take longer to complete. ECPM focuses on identifying and managing the events and event chains that are likely to affect the duration of the project. It seeks to ensure that duration estimation takes into account the occurrence of events, assuming that there is always 50% probability of an event occurring. It uses techniques to improve the accuracy of the duration estimation by using reliable historical data and continuously updating the information, through Monte Carlo simulation (Intaver Institute, 2011).

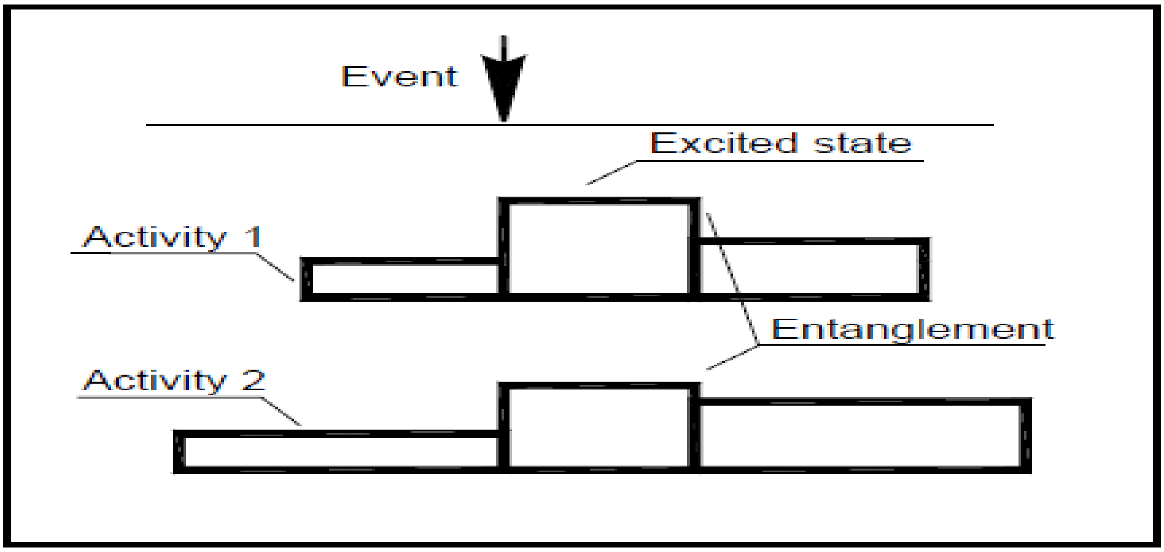

Figure 4. The influence of an event on an activity (Intaver Institute, 2011).

Hypothetical Application of CCPM and ECPM on Project Duration Estimate

As an example, the platinum mine's best practice schedule as stated in Phillis and Gumede (2009) (Figure 5) will be used as the basis for the following discussion to further elaborate how CCPM and ECPM are applied in duration estimates of a mining stope project..

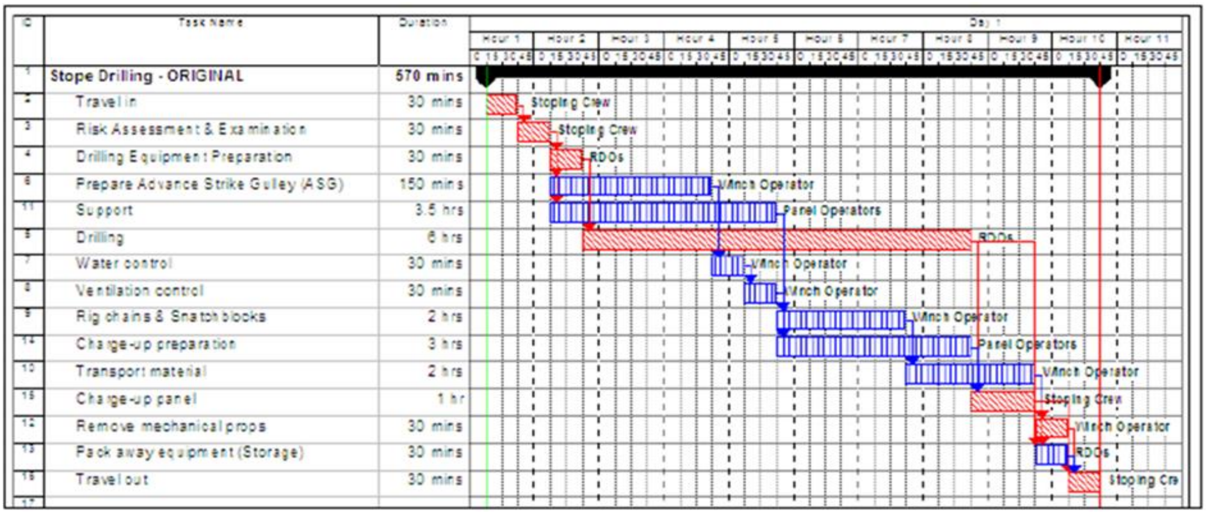

Figure 5. Best-practice: stoping activity schedule (Phillis and Gumede, 2009).

The original duration estimate is 9.5 hours. In the application of the CCPM approach, the durations of the all the activities listed in Figure 5 will be reduced by 50%. The project duration is thus reduced to 4.75 hours (Figure 6). The 50% reduction is assumed to be the 'safety factor' which was initially added in each activity to deal with uncertainties. The accumulated safety factors will then be moved to the end of all activities, where they constitute a buffer (Figure 6).

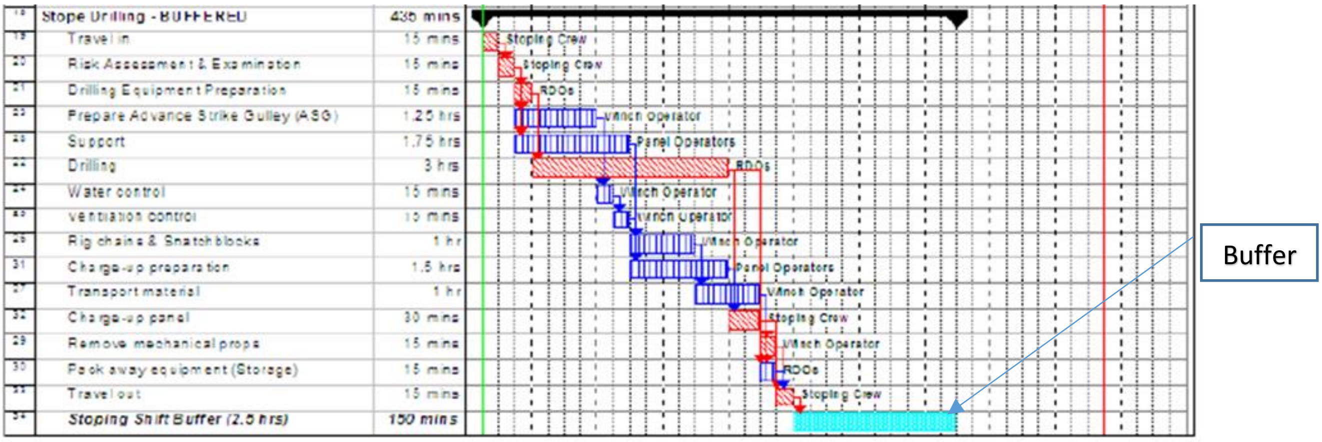

Figure 6. Activity schedule on CCPM (Phillis and Gumede, 2009).

The application of ECPM ensures that all possible events are taken into consideration when estimating project durations. ECPM uses the Monte Carlo simulation to achieve the abovementioned goal, and the simulation will provide a more accurate duration for the project. The Monte Carlo method requires a range of possible values, therefore the output will also be a range. The total duration of the project will be considered and not the durations of individual activities. Firstly, the CCPM-estimated duration of 4.75 hours will be used as the 'optimistic duration', then the best-practice schedule of 9.5 hours will be used as the 'most likely duration', and finally the 'pessimistic; value, which was ~~were~~ estimated to be 12 hours based on historical data collected at the mine. The range of possible outcome is between 4.75 hours and 12 hours, therefore random values were generated and run 500 times in the simulation. The results (Figure 7) indicate that instead of the 9.5 hours from the best-practice schedule and the 4.75 hours from the CCPM estimates, the more accurate duration estimate, which takes into account the risks, is 10.5 hours for project completion. This is because when the 500 runs were done, the results indicate that 10.5 came out 500 times.

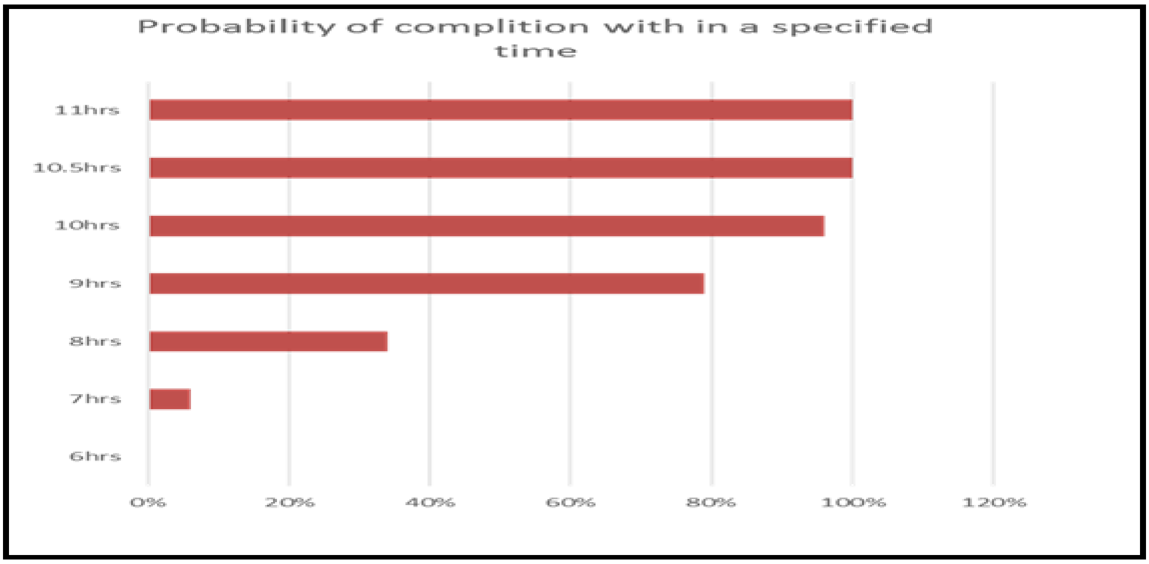

Figure 7. Monte Carlo simulation results.

Response to Risk/Uncertainty

Risk response is the process of developing strategic options and determining actions to enhance opportunities and reduce threats to the project's objective (Project Management Institute, n.d.) In a project like a mining stope, the analysis of duration and success rate becomes increasingly complex due to the multiple risks and uncertainty inherent in the project. The main challenge is to determine how to visualize the complex relationship between the risks and the mining activities; only then are we more empowered to deal with the events and events chain. The approach employed should firstly seek to define the uncertainty and risks; this will assist in the understanding the potential impact. Secondly, to mitigate the impact of the event. Lastly, to be proactive in analysing the probability of the next occurrence of the event, so as to strive to prevent the occurrence. It has been said that the way in which uncertainties in a project are managed is core to the improvement of project performance, defined as completing the project faster and with better reliability regarding the promised final project due date.

A mining stope is very complex because of the risks inherent in the project, which are likely to multiply. As an example, in the platinum mine's practice schedule (Figure 5), drilling was taken as an activity to be influenced by an event; the event was identified as a shortage of compressed air, which is very common in mines that use compressed air as a source of power. The event lengthens the drilling time from 6 hours to 7 hours (Figure 8).

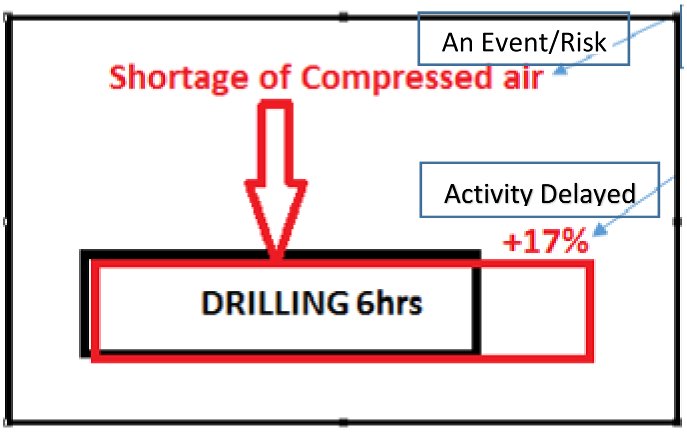

Figure 8. Impact of event on activity.

Due to the complexity of this project, it is highly likely that events will automatically trigger other risks, forming an event chain. An event chain can significantly affect the project by creating ripple effects through the project, and possibly ultimately causing project failure (Figure 9) (Virine, 2006).

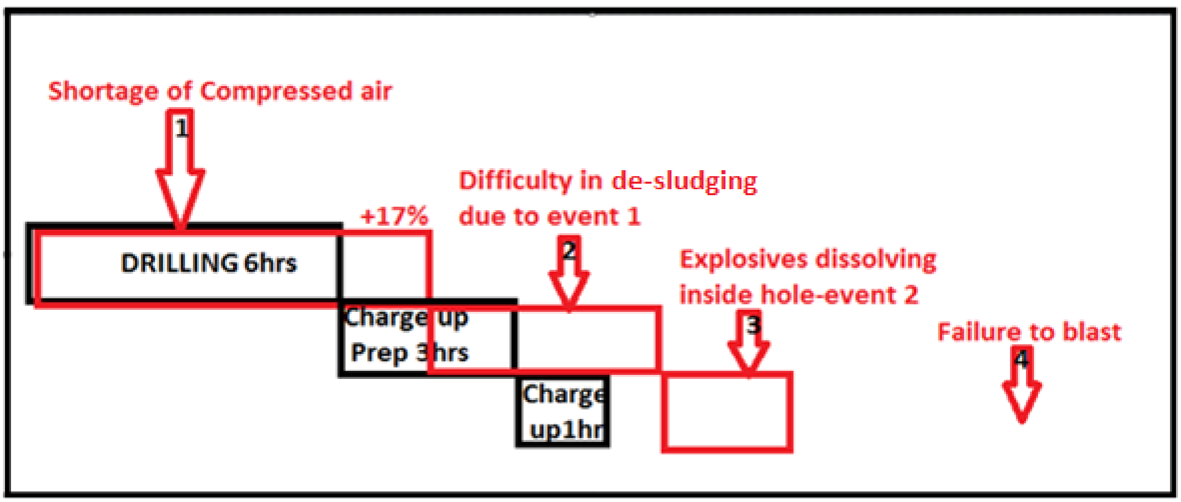

Figure 9. Effects of event chain on activities.

The CCPM approach uses the 'buffers' to mitigate the impact of any events on the project. The impact of variation and uncertainty is managed within the project. A buffer allows focus, simplifies priorities, and provides an early warning regarding the state of the project. In principle, the size of the project buffer and of the feeding buffers should reflect the amount of protection required against the uncertainty as regards the sum of the durations of the tasks on the critical chain and the feeding chains, respectively. Planning and actions depend on how much the buffer has been consumed or replenished by an activity performance; which gives direction on when to act. As long as there is some predetermined proportion of the buffer remaining, all is considered to be well. Only when the buffer is consumed to a certain degree is the flag raised for action (Focusedperformance, n.d.). The disadvantage of this approach in dealing with uncertainty is that one has to wait until the impact of the risk on the activity before acting. The impact might be so severe that it will be too late for the project to be saved. The approach is reactive, as illustrated in Figure 10.

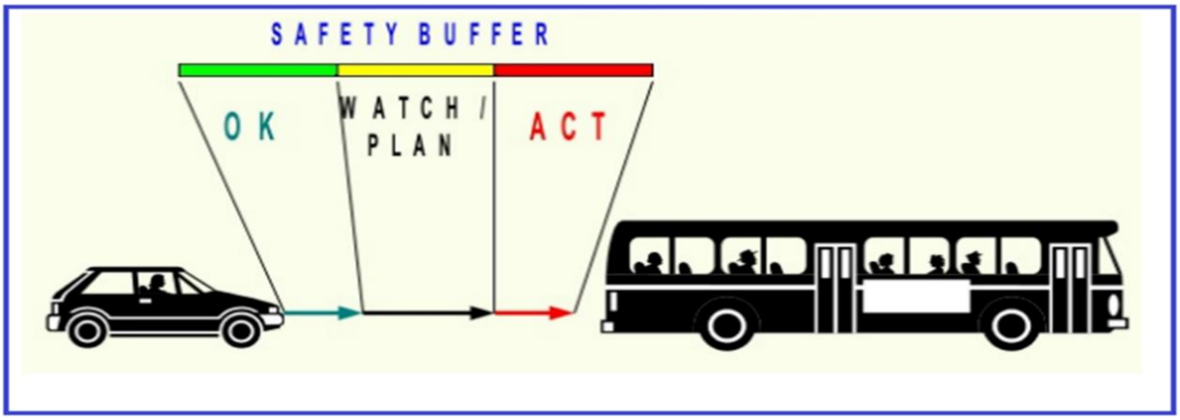

Figure 10. CCPM's response to a risk act (Focused Performance, n.d.).

In the application of ECPM through Monte Carlo simulation, the project schedule has been increased to accommodate the risks within the project. This should raise concerns, as no company wants to increase the duration of any project as that will result in increased costs and consumption of resources. The ECPM method has a built-in mitigation plan that ensures mitigation against any event or event chain; this will result in duration gains as the risk impact will be reduced.

Mitigation plans are an activity or group of activities that augments the project schedule; the plan is to assign the mitigation command to the event or event chain so that it will be triggered when the event occurs, as shown in Figure 11 (Virine, 2006).

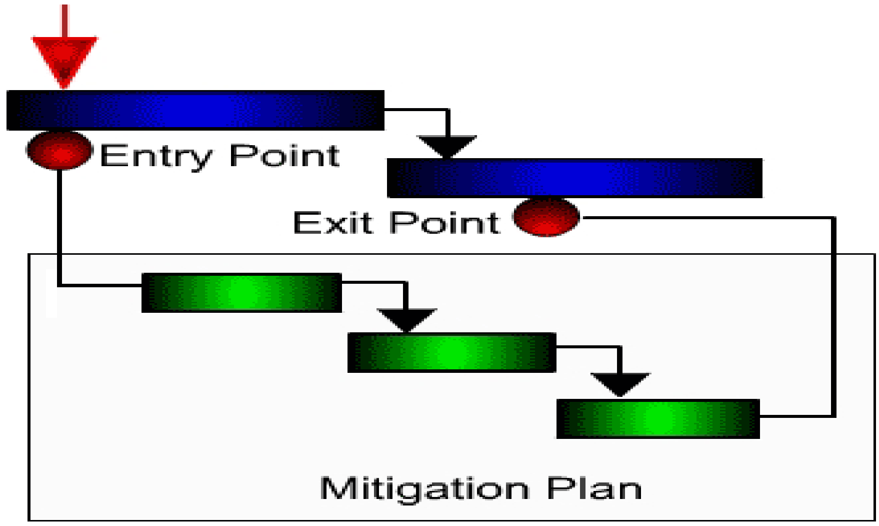

Figure 11. Mitigation plan triggered to buffer an event (Virine, 2006).

The mitigation plan is made up of four response strategies – risk avoidance, risk acceptance, risk transfer, and risk mitigation. Risk avoidance is when the risk can be avoided by removing the cause of the risk or executing the project in a different way while still aiming to achieve project objectives. Unfortunately this is not always possible. Risk acceptance is adopted when it is not possible or practical to respond to the risk by the other strategies, or a response is not warranted by the importance of the risk; this may result in project failure. Transferring risk involves finding another party or activity that is willing to bear the liability of the risk should it occur, with the aim of reducing the severity. This response can be applicable in the project. Risk mitigation is the prevalent response of ECPM. It reduces the probability and/or impact of an adverse risk event to an acceptable threshold; it is a combination of avoiding and accepting the risk. (Project Management Institute, n.d.). The mitigation plan has the ability to avoid project failure by increasing the chances of meeting the project's objectives. As an example, the mine accepts that 'load shedding' is an event that might occur at any time, and has the potential to cause project failure; therefore, a standby generator is installed to ensure that the risk impact is avoided.

Influence of the Approaches on the Workplace Culture

In an interview with the official on the platinum mine, the author asked what was the progress of the CCPM approach on the mine. The official stated that '*the application was stopped as the approach had challenges*'. This can be attributed to the fact that the application of CCPM leads to change in the organization, and changes the way workers fulfil their work. Implementation of CCPM requires a redesign of working processes and it touches on the habits of an organization. Verhoef (n.d.) conducted a study of the reasons why project workers resist working according to the principle of critical chain project management. It was discovered that workers resist adapting to the CCPM approach. They find it hard to disassociate from traditional principles and, to some extent, they appear to easily fall back into old patterns. The study further states that although the implementation of the CCPM approach often goes reasonably well, there are worries concerning long-term sustainability, and currently there is no published literature that shows evidence of long-term sustained success of CCPM. This approach sets out to change organizational behaviour in order to achieve integral performance, but falls short in managing worker expectations and perceptions, and it appears that there is some resistance to the changes brought by this approach. Resistance to change is a natural and normal human response. The type of culture change that comes with the CCPM approach, and might be detrimental to a team in a mining stope, is the fact that *workers working on a critical chain are expected to work continuously on a single activity at a time; they do not work on several tasks in parallel or suspend their critical chain activity for other work*. This is intended to prevent multitasking and avoid the consequences of Parkinson's Law. It also adversely impacts the emphasis on teamwork in a mining stope, as teamwork is a process of working collaboratively with a group of people in order to achieve a goal (Verhoef, n.d.).

The application of ECPM in a project is 'invisible'; workers will not even know that the approach has been implemented. Information is collected to obtain reliable historical data to use, and any event that causes a delay in the activity is recorded. All records are used to change the project schedule, but that information is only for the supervisors. The information will assist the supervisor to be more prepared for any event, and he/she will shape up a mitigation plan that will ensure that the impact of the events is reduced or prevented. All workers will continue with normal work. Multitasking can also be recorded as an event and the supervisor will put a mitigation plan in place to prevent it.

CONCLUSION

Projects usually fail due to Parkinson's Law and/or Murphy's Law. These threats exist even in a mining stope. A mining stope as a project requires an approach that is flexible and sustainable to ensure that the inherent risks are continuously dealt with.

CCPM has proven to be not flexible enough for application to resource allocation in a mining stope, as it does not facilitate teamwork in the form of multi-tasking. Teamwork has always been the key factor for successful teams in mining stopes. Furthermore, CCPM only focuses on labour as a resource, but does not consider other factors such as logistics and the equipment required for a successful stoping project. The resource buffer is only an information tool used to give warning when the critical chain of resources becomes depleted. ECPM, on the other hand, uses a quantitative technique to ensure that the planning of resources is accurate; this prevents resources from running out during project execution. If there is an event that leads to resources running out, then the event is reported and adjustments are made to the allocation of resources; the information captured will assist in preventing repetition of the event in the future.

CCPM reduces all activity durations by 50%. This is regarded as a safety factor, and the difference between the new shortened project duration and the original duration (the buffer) is meant to deal with any uncertainty. This will not work in a project like a mining stope, as the durations of activities are estimated using, amongst others, factors such as the level of technology, the equipment, and the logistics involved in the activity. The safety factor is not included in these factors due to the unique nature of the project. Therefore, the 50% reduction in the estimated duration is impractical and cannot be achieved. The application of ECPM in duration estimates uses a quantitative technique to ensure mitigation against the effects of motivational and cognitive biases, which adversely influence the estimation of the durations of activities in a project. Furthermore, the method ensures that events are taken into consideration when duration estimates are made.

CCPM takes a reactive approach to risks. As illustrated in Figure 10, actions to mitigate any risk can be instituted only when the impact, in the form of a delay, has consumed all the time allocated to buffer the project against uncertainty; the buffer is the only protection against any event. ECPM, in contrast, takes a proactive approach to risk in that there is a mitigation plan to reduce the severity of the impact. Although the duration estimates have been stretched to include the events, the mitigation plan will ensure that the events are dealt with and do not impact the activities; the time allocated for events will always be regained.

The success of activities in a mining stope depends mostly on the team members. Therefore, the project management approach should take into consideration the human factors involved in the project. It has been shown that the introduction of ECPM assists the team to achieve set project objectives, while CCPM changes the culture and is often not welcomed by the team members due to their inherent resistance to change. Taking all these factors into consideration, ECPM is the more appropriate project management approach for a mining stope.

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