



# A case study on stoping shift buffering at Impala Platinum: A critical chain project management perspective

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## Synopsis

Conventional stoping in hard rock mining is largely considered an operational environment. This paper suggests that stoping falls within the realm of a project management environment typified by uncertainty, variation, and large numbers of interdependencies. Stoping was then equated to a micro-project with many simultaneous activities that had to be executed accurately using finite resources within limited shift durations in order to reach specific goals.

Critical chain project management (CCPM) principles were applied to the stoping activities, and the results showed that the number of blasts per panel can be significantly increased by successfully moving the distribution of work as close as possible to the start of shift. Critical chain principles also assisted in facilitating re-focusing and teamwork among stoping crews as well as between day- and night-shift crews. The main recorded success was in managing inherent protective capacities/local contingencies/fat/buffers that are found in all projects.

The impact on mine health and safety (MHS) was significant as individual operators and crews became convinced that they could perform all stoping tasks (activities) without compromising accuracy or speed.

## Keywords

buffers, critical chain, stoping shift.

## Introduction

Despite all the advances in the field of project management, a good number of projects are invariably delivered with compromised basic deliverables of time, budget (cost), and content (which includes quality). In some quarters it has been institutionally accepted that projects will always be late. For a field with a number of publications comparable to most established fields, the following extensively quoted statistics of IT project failure rate<sup>1</sup> do not justify the cause—only quantitative quotes are referenced.<sup>†</sup>

- The Bull Survey: major findings were:
  - 75% of projects missed deadlines
  - 55% of projects exceeded budget
  - 37% of projects were unable to meet project requirements (content).

- The Chaos Report: This was commissioned in 1995 by the Standish Group in the USA and revealed the following:
  - 53% of the projects cost over 190% of their original budget
  - 31% of projects were cancelled before completion
  - 16% of projects met their project deliverables.

Leach<sup>2</sup> postulates that more than 30% of projects are cancelled before completion. After analysing 18 projects in the mining industry, Vallee<sup>3</sup> concludes that 78% of the projects had non-delivery issues.

These are just a few selected surveys that are available in the literature, and only the quantifiable bottom-line results are referred to. It is also worth mentioning that the academic debate on the statistical correctness of the above findings has been ignored because the paper is biased towards the bottom-line project management deliverables of time, budget, and content. In a typical mining scenario, bottom line results will manifest in the form of:

- Missed annual business plans
- Missed holing dates in development and stoping activities of the mining process
- Continuously shifting the shaft-commission dates
- As will be proved later, lost blasts.

A number of valid reasons are given to justify the missed deliverables, and a majority of these explanations have something to do with the uncertainties that seem to befall all projects. In the following subsections, this paper will describe the application of a relatively new project management

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methodology in South Africa. This new methodology places emphasis on the management of the uncertainties that always accompany projects.

### Critical chain project management

The critical chain project management (CCPM) philosophy was introduced to the commercial world in the late 1990s by an Israeli philosopher Eliyahu M. Goldratt. Simply stated, it is a theory of constraint (TOC) way of managing projects.

The key aspects of CCPM are that it:

- Pays detailed attention to resource contention during the scheduling process
- Limits and discourages bad multi-tasking
- Takes into account the tendencies of people to procrastinate getting down to work or to divide work evenly throughout the estimated duration of work
- Uses the as-late-as-possible (ALAP) scheduling process
- Acknowledges the inherent existence of uncertainties in projects and attempts to quantifiably manage them through a process known as 'buffer management' (Leach, 2004<sup>2</sup>; Newbold, 1998<sup>4</sup>; Goldratt, 1998<sup>5</sup>).

### Critical chain methodology

- *Scheduling phase*—The scheduling phase of CCPM is basically the same as that for critical path scheduling. In fact, without resource contention, the critical path is the same as the critical chain. The major difference is that in CCPM the project due date is set and protected/buffered against uncertainties. In simple terms, all task durations are halved prior to resource levelling. The remaining half of the task durations are ploughed back into the project plan as a protection of the project due date, which is known as the project buffer. This whole process of halving task durations is carried out so as to eliminate the adverse human behaviours that can interfere with task execution. The critical chain is then identified as the longest chain of dependent events taking into account the resource contention<sup>2</sup>.
- *Execution and monitoring phase*—In CCPM, resources are forced to prioritize tasks that are on the critical chain. 'Bad multi-tasking'<sup>†</sup> is eliminated by releasing—as a rule of thumb—only three tasks per resource at any given time. The project monitoring phase during execution involves monitoring the amount of buffers consumed *vis-à-vis* the percentage of the critical chain completed<sup>5</sup>. The practical application of these principles is described in the following section.

### CCPM application: case study on stoping shift buffering

#### Case study background

Although Impala Platinum's average monthly stoping produc-

<sup>†</sup>Bad multi-tasking may be considered as working on many concurrent tasks/paths that have an adverse effect on lead times, although effort and touch time remain unchanged.

tivity was 17m/month, its leadership was concerned that the overall stoping performance had plateaued and was starting to deteriorate. Impala Platinum, through its Best Practice Department, initiated an Accelerated Productivity Improvement programme (API) aimed at improving the overall productivity of the organization. It is a noteworthy observation that a metre improvement in productivity of the whole organization translated to a more than R1 billion increase in annual sales in the 2007 financial year (turnover of R17 billion at 17 metres per month). In addition, improving stoping productivity is a fundamental step towards achieving annual business plans.

The API programme started with an industrial engineering study at Impala No.12 shaft for the period between October 2006 and January 2007. The objective of the study was to identify the reasons for the fact that some stoping crews' performance were falling short of their monthly targets/blasts. It was anticipated that the causes of lost blasts could broadly be classified into three areas:

- *Input constraints*—system limitations caused by under-resourcing of human, physical, information, and/or financial inputs
- *Output constraints*—system limitations caused by the inability to move the broken rock from the stopes
- *Capacity constraints*—constraints in capacity that meant that it was not possible to complete all the stoping tasks in the available shift time.

The focus of the study was on the stoping capacity constraint, and only the day shift (drilling) will be discussed here. Inbound and outbound logistics and development (including construction and equipping) studies were also conducted, but these do not form part of this paper. The project team used both qualitative and quantitative research methodologies.

### CCPM application methodology

The project team used the following methodology, which is based on research, correlation and implementation:

#### Stoping research study at Impala No. 12 shaft

Initially the project team did not know what the stoping capacity constraints were, other than management hypotheses. The project team set out to gather as much relevant data during time and motion studies.

Competent observers tracked selected stoping crews for both the day and night shifts and observed time from start of shift (SOS) to end of shift (EOS) and motion from shaft bank to bank.

The study was conducted on four panels, two of these being benchmark panels and the other two comparison panels.

#### Comparing and correlating the study results with best practice

The stoping resource schedule as shown in Figure 1 reveals the following:

- Time and motion studies average performance of the operator tasks were completed faster when compared to the time allowed in the best practice—stopping resource schedule.

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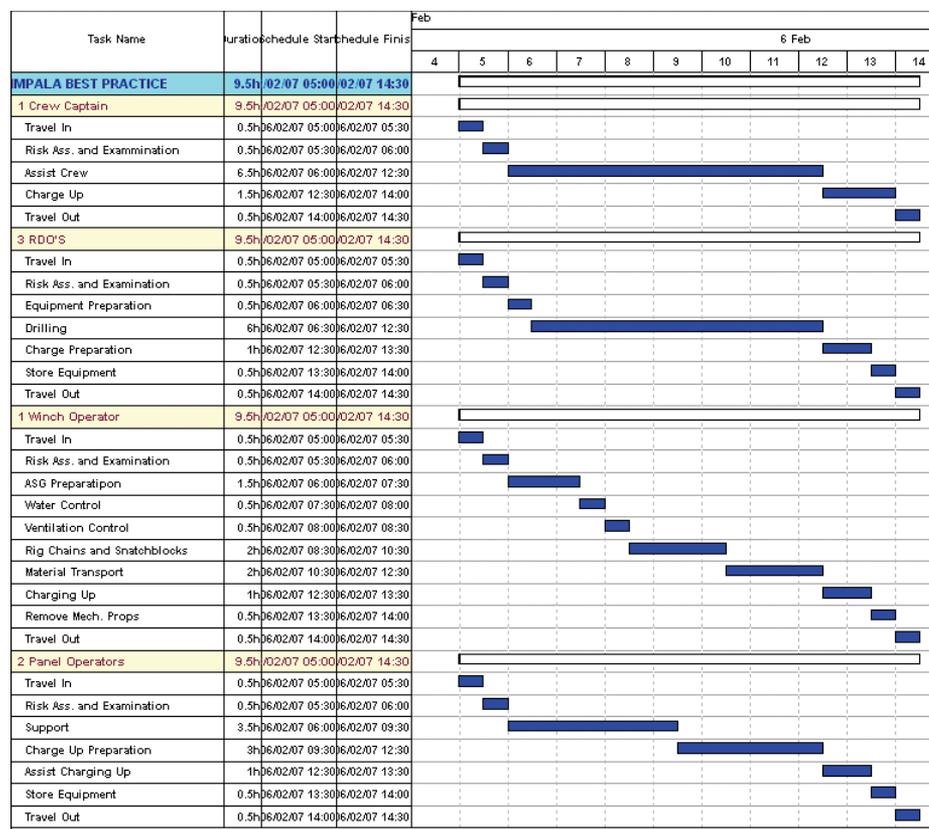


Figure 1 – Best practice – stoping resource schedule

- Individual operators that constituted the stoping crews were efficient, as all operators were proficient in their best-practice-assigned responsibilities/jobs.
- It seemed that the main problem was the lack of the integration of all the stoping activities. This phenomenon was realized only when the project team observed the holistic motion of the stoping crews throughout the shift *vis-à-vis* the goal of each stoping-shift, i.e. 'A safe, quality blast per day, every day'.
- The resource-based nature of the stoping schedule encouraged each crew member to concentrate on his particular tasks and ignore the global goal. For instance, when one of the three rock drill operators (RDOs) completed their tasks, that particular RDO simply packed up and left the rest of the crew behind. The faster crew member did not stay on to assist other crew members complete the stoping schedule and achieve the goal. Also, all crew members became proficient, with a low reliance on the crew as a unit, i.e. individual operators did not find protection from the system.
- In the best practice schedule the focus on the resources and the integration of the resources was implicit. As such, crews divided all the work among operators, as evenly as possible. Miners would then drive continuous improvement of the efficiencies of each crew member in anticipation that, when added together, all the individual efficiencies would result in goal achievement.
- Idealizing tasks and/or resources meant that much emphasis was placed on finishing each task on time as

the best way to achieve the goal.

The shortcomings listed above indicated that the original best practice resource schedule as shown in Figure 1 had to be complemented with a best practice activity schedule (as seen in Figure 2) in the following manner:

- Shifting focus from the resources to the tasks/activities
- Making the schedule integration explicit (divergent and convergent points).

This solution was incomplete as it did not address stoping risks such as:

- Resource variation such as availabilities (e.g. absenteeism) and efficiencies in relation to stoping productivity
- Uncertainty caused by the erratic nature of the causes for failure to blast (lost blasts) and protection against things that could go wrong
- Resistance to change, shown in the crew's attitude to doing each and every task accurately, because each stoping task is an act of MHS.

CCPM methodology was then applied to the stoping activity schedule, with the main objectives including:

- Protection of the crew from uncertainties that result in lost blasts
- Facilitation of crew re-focusing on co-operation and teamwork
- Facilitation of the development of control charts (crew dashboard, a tool for crew synchronicity)
- Derivation of a single measure for behavioural change.

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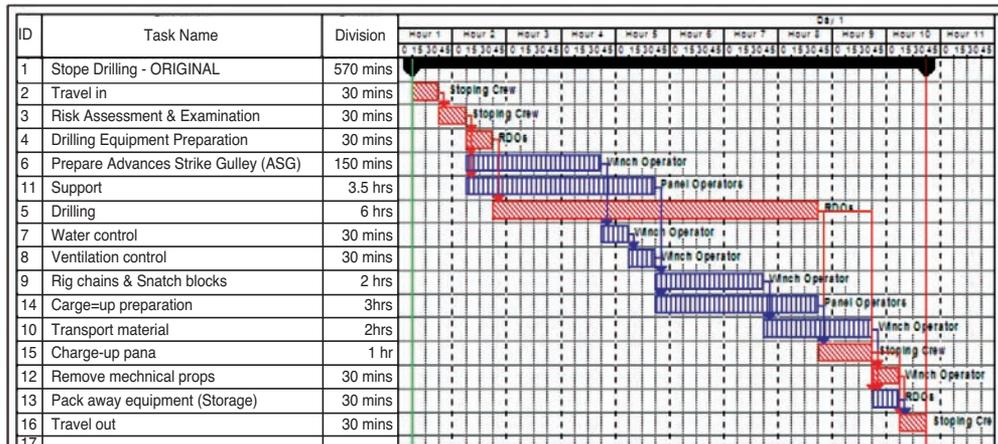


Figure 2—Best practice—stoping activity schedule

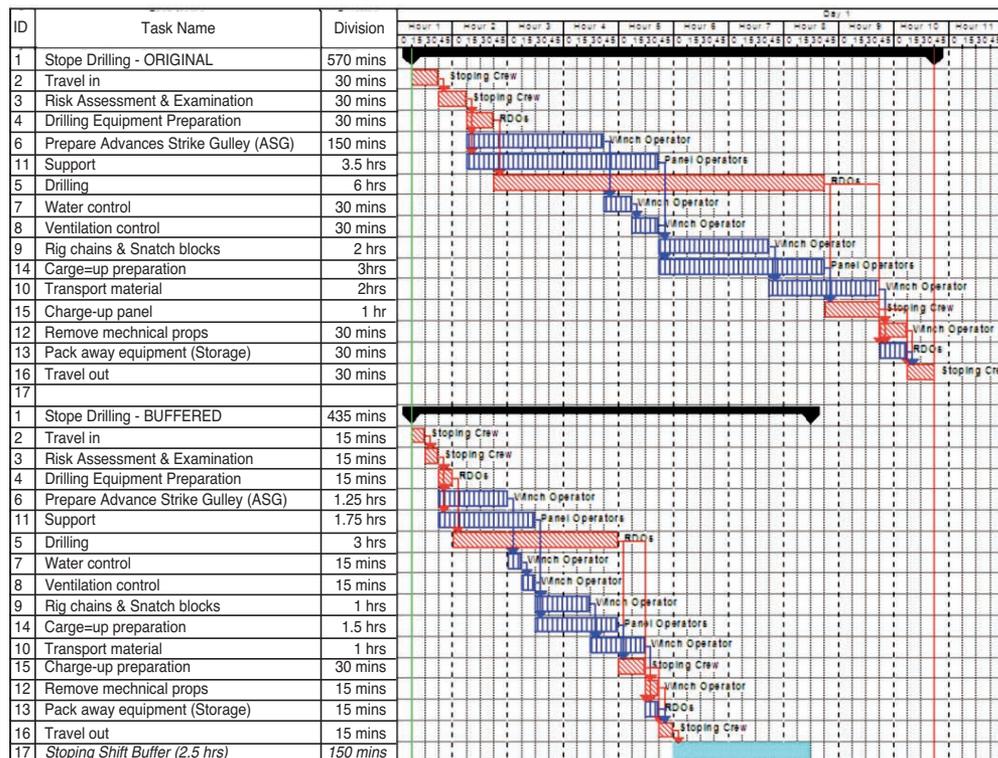


Figure 3—Impala Platinum—stoping production cycle on CCPM

Figure 3 illustrates the stoping activity schedule on CCPM, i.e. with resource allocation and buffering. The red bars indicate the actual critical chain while the blue bars are floating paths/tasks, each with their own buffers shown in light blue.

The buffers provided the opportunity to schedule floating tasks/paths as-late-as-possible (ALAP). The implications for MHS were that the entire crew could focus on the start-of-shift procedure. The crews were rationalized with due regard to waiting place procedure, risk assessment, and stope examination, which formed part of an MHS campaign at that time. Only when this (SOS procedure) was completed did the

crew split up to take on specific tasks, as may be seen in Figure 3. Promoting teamwork and protecting the shift from lost blast, was more important than the convenience of individual operators. The CCPM stoping schedule was then implemented.

Implementation of the CCPM schedules at Impala No. 11 shaft included a buy-in process to ensure the active collaboration of the shaft leadership, line management and crews, which is obviously a critical success factor. The elements that had to be emphasized as part of the buy-in process are set out below:

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- It had to be ensured that the operators understood the logic of CCPM and were convinced that the overall blast protection took priority over task protection. This meant that management clearly understood and accepted that the halved estimates might never be achieved; and that if the halved-estimates were not achieved the management and/or the miner would not penalize operators.
  - It was explained that the other halves of the time estimates would be pooled to the end of the shift (project) in a way that protects the shift, albeit at the expense of the halved estimates. It had to be over-emphasised that the project as a whole was protected.
  - The crews were informed in simple terms of what was required. For instance, to eliminate the Student Syndrome and Parkinson's Law, the soccer analogy was presented to the crews and emphasis was placed on the fact that as a soccer team, the crew should score all their goals in the first half of the shift and then spend the second half defending.
  - Stoping, being a daily repetitive micro-project carried out in uncertain ambient conditions (underground), called for a dashboard that had to be tracked and updated in real time. This assisted in influencing crew behaviour through the provision of timely warnings of schedule deviations. As a consequence crews could self-adjust or rationalize themselves in accordance with the required crew work rate.
  - The miner (given a project manager role) was given a control chart to monitor the adherence to the schedule (as seen in Figure 4). Updating the control chart meant that the miner could maintain a holistic view of the shift.
- Control charts also helped to empower the miner as he was now managing rather than operating. This new mode of operation was also independently monitored and tracked for a period of four months.
- All of Impala No. 11 shaft crews were then adopted as the population universe (i.e. target population for the pilot implementation). The project team had potential access to all 95 crews, but only 20 crews were involved in this case, which represented 21% of the population universe. The selection of the sampled crews was non-random, because the shaft leadership identified the worst-performing crews (locally termed 'Intensive Care Unit (ICU) Crews' for the pilot implementation.
- Only 67% of the sampled data was used for deriving statistical graphs; the remaining 33% was not considered due to:
- Data being beyond the target sample (e.g. when the crews were sweeping, cleaning, and installing support during the production shift)
  - Ukhozi internal quality checks
  - Extra production shifts.

CREW PERFORMANCE CONTROL CHART																	
SECTION :			PANEL :			CREW NO :											
MINER (Day):			MINER (Night):			UPM INTERGRATOR (Day):											
No.	Task Name	Responsibility	Dur. (Min)	From	RED	YELLOW	GREEN	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 6	8th Shift Recon.	Actual	Budget	Variance
COMMENTS/REMARKS																	
<b>BLAST</b>					NO	Partial	YES										
<b>STOPE DRILLING</b>					330	330	330										
1	Travelling to Workplace	Crew	15	1hr	45	30	15										
2	Waiting Place Procedure	Crew	15		45	30	15										
3	Risk Ass. and Examination	Crew	15		45	30	15										
4	Face Prep & Marking	Crew	15		45	30	15										
5	ASG Preparation	Crew	30		60	45	30										
6	Equipment Preparation	RDOs	15	0.5hr	45	30	15										
Equipment Prep Feeder Buffer					15	15	10	5									
7	DRILLING	RDOs		3hrs	540	360	180										
8	ASG	RDOs			NO		YES										
9	Face	RDOs	180		NO		YES										
10	Sidewall	RDOs			NO		YES										
11	Drilled rig holes (Cleaning setup)	RDOs			NO		YES										
12	Pump Water (Control)	Winch Operator	30	2.5hrs	120	60	30										
13	Ventilation control	Winch Operator	30		120	60	30										
14	Rig chains & Snatchblock	Winch Operator	15		45	30	15										
15	Material Transport	Winch Operator	75		225	150	75										
Services Feeder Buffer					75	75	50	25									
16	Set-up Support	Panel Operator	15	2.5hrs	45	30	15										
17	SUPPORT	Panel Operator	120		360	240	120										
18	Decommission Support	Panel Operator	15		45	30	15										
Support Feeder Buffer					75	75	50	25									
20	Charge Up Preparation (Setup)	Panel Operator		0.5 hrs	60	45	30										
21	ASG	Panel Operator	30		NO		YES										
22	Face	Panel Operator			NO		YES										
23	Sidewall	Panel Operator			NO		YES										
Feeder Buffer					15	15	10	5									
24	CHARGING	Miner		1hr	135	90	45										
25	ASG	Miner	45		NO		YES										
26	Face	Miner			NO		YES										
27	Sidewall	Miner			NO		YES										
18	Remove Temporary Support	Panel Operator	15		45	30	15										
28	Decommission Panel	Crew	15		45	30	15										
Day Shift Buffer					165	165	109	54									

Figure 4—Stoping production cycle—control chart example

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The plan was to improve the ICU crews and make them the best performing crews. The success of the ICU crew was expected to be imitated by other crews and spread to the whole shaft in this way. The implementation results and analysis are presented in the succeeding subsection.

### Results analysis

During the implementation of API, Impala also introduced a new bonus system, namely the 'Ama Ching-ching' bonus, which suggests that some of the improvements in production could be attributed to this new system. However, it is worth mentioning that the project team was offering a unique product by promoting the concentration of work in the first half of the shift so as to eliminate the Student Syndrome and Parkinson's Law. The project team had proposed/hypothesized that the number of blasts per panel could be increased significantly by shifting workflow distribution to the first half of the shift.

With that in mind, the project team measured this paradigm shift as it was the only parameter that could be attributed to CCPM. The paradigm shift was tracked through a comparison of monthly workflow distribution curves of the relevant crews. Monitoring the behavioural change before and during the implementation of the revised CCPM schedule involved gathering data underground in the form of time and motion studies and conducting statistical analyses. These analyses were carried out by:

- Subdividing the allocated times for the activities on the best practice schedule into hourly intervals (as indicated in Table I)
- Extrapolating results from time and motion studies to determine the number of times in which each activity was completed within the CCPM best practice schedule's allocated time per shift, and calculating cumulative frequencies
- Plotting cumulative frequency and percentage probability distribution curves as illustrated in Figures 5 and 6
- Calculating areas under the probability distribution curves within a specific period to obtain the amount of work completed.

Only the results of one of the crews (BA44) are given in this paper.

The above statistical analysis methodology was adopted from Walpole *et al.* (1993)<sup>6</sup> and Gumede *et al.* (2007)<sup>7</sup>.

Figure 5 shows the percentage-frequency-density distribution of crew BA44's completion of different tasks at section 114 on level 13. The probability distribution of completing different tasks is the area below each graph. In analysing Figure 5 there is a gradual increase in the area below the graphs midway during the shift for the period between February and May. This is illustrated by the consistent shifting of graphs towards the left from February to May, indicating a gain in percentage probability. As an illustration, in February, crew BA44 completed 47% of their day shift production cycle midway into the shift, as seen in the area under the black curve.

For the same period in May, the same crew completed 57% of their tasks—i.e. the area under the green curve—compared to 62% in April. This signifies a significant change in paradigm, as the crew concerned achieved a 10% increment in concentrating the work during the first half of the shift.

Table II summarizes the percentage distributions for all the crews that were monitored during the implementation, and there is a clear indication that crews gradually concentrated their efforts at the beginning of the shift (a paradigm shift).

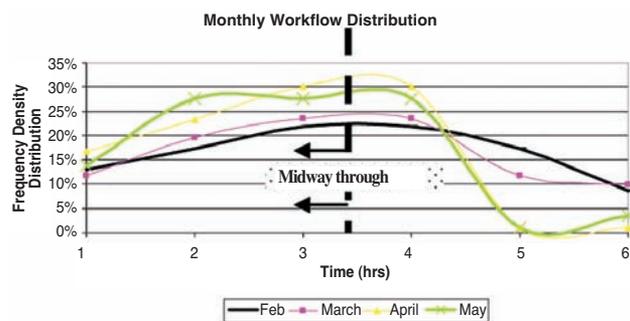


Figure 5—Monthly workflow distribution of completed critical tasks

Table II

### Percentage distribution of completed work

Month	February	March	April	May	June
Average % probability	47%	49%	57%	56%	54%

Table I

### Hourly interval activities on Impala Platinum's original best practice schedule

Time (h)	Tasks
0	Start of Shift (SOS)
1	Travelling to workplace, waiting place procedure, risk assessment and examination, face preparation and marking
2	ASG preparation and drilling
3	Drilling
4	Drilling
5	Drilling and charging-up
6	Decommissioning of shift
7	End of shift (EOS)

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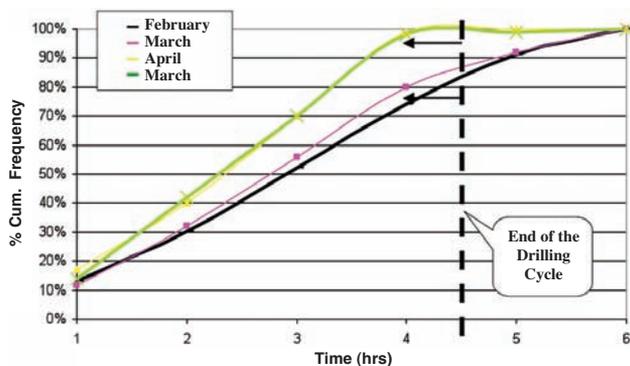


Figure 6—Workflow cumulative frequency distribution

An analysis of crew BA44 from the perspective of the probability of achieving a blast is given in Figure 6. In this case it was assumed that whenever crews completed their drilling tasks they would definitely achieve a blast. External causes for blast failures were ignored (e.g. material or equipment shortages and the unavailability of stopes). The comparison was pegged at the end of the drilling task on the best practice schedule.

Using the CCPM best practice schedule, the drilling task was scheduled to finish after four-and-a-half hours. Also, assuming that the crew always charges up after successfully completing the drilling task, the following conclusions can be drawn:

- In February crew BA44 had an 80% chance of achieving its target, while the same crew had almost a 100% chance of achieving its target for April and May 2007.

Table III summarizes the cumulative frequency distributions for all the crews that were monitored during the implementation.

Figure 7 demonstrates the overall performance of one of the sections that the project team worked on (section 114). In this particular section there was an approximately 45% improvement in production during the CCPM implementation.

### Conclusions

The partial and holistic application of the CCPM methodology on the stoping production cycle has proven to be relatively simple to practise, and the bottom-line results are evident and quantifiable. Some of the advantages that the project team and client experienced were:

- a. Keeping the entire stoping crew focused on the goal (crew synchronicity)
- b. Facilitating crew co-operation and teamwork (rationalizing of resources)
- c. Miner empowerment by inducing the miner to manage, in spite of the fact that the majority of miners believed that they were more effective operating instead of project managing
- d. Application of simple CCPM principles that led to significant improvements on daily stoping

Table III

### Overall cumulative frequency distribution

Month	Feb	Mar	Apr	May	Jun
% Cumulative Frequencies	82%	88%	96%	95%	94%

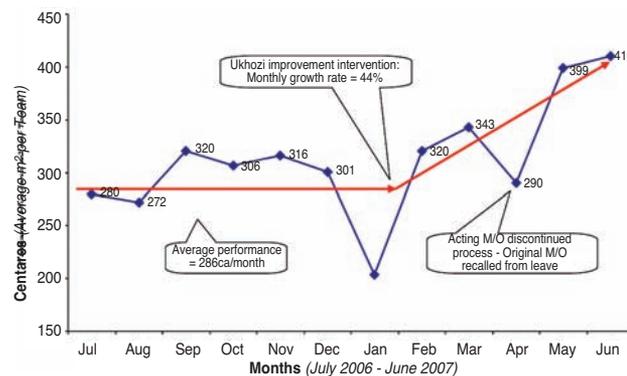


Figure 7—Impala Platinum No. 11 Shaft—section 114 performance chart

performance and, ultimately, an improvement in returns on equity (ROE)

- e. Emphasis being placed on accuracy instead of speed (which was inevitable) as the root cause of effective health, safety, quality, cost, production, and morale management at the stope face.

### Acknowledgements

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