



Can buffer stores improve productivity?

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Synopsis

The management of critical resource inventories is an important productivity lever and a significant risk factor—risk in the sense that poor resource availability lends itself to disempowerment of workers, unsafe work practices, wasted spending (high unit costs), and poor quality of work (including mining waste/rework). Most underground platinum mines experience lost blasts that directly lead to reduced productivity. In most surveyed shafts, 30% of lost blasts can be attributed to shortages of critical material and/or equipment. The problem is prevalent despite the existence of conventional transitory surface and underground stores. This paper discusses the introduction of buffer stores as a complementary materials storage system in order to improve health and safety in mines as well as reduce lost blasts. Both quantitative and qualitative results have shown that buffer stores result in dramatic improvements in productivity and are readily acceptable by stakeholders.

Keywords

Buffer stores, lost blast.

Introduction

The availability of physical resources (such as materials, equipment, plant and machinery assets) is an important contributor in mining productivity. Plant and machinery resources receive close attention as they normally go through a rigorous mining engineering process to determine their availability and they form part of the responsibility of the engineering departments in mines. Unfortunately, physical resources such as material and equipment do not receive the same attention because they form part of the overwhelming responsibilities of mining production line management. The effects of poorly managed physical resource inventories manifest themselves in varying ways:

- Congested mining logistics, especially inbound
- Overstocking of redundant resource inventories
- Stock-outs of critical resource inventories
- Overloading on maintenance

- Excessive resource costing
- Underachievement of production performance.

A detailed literature search revealed a distinct absence of published information on the buffer stores. Empirical tests of the solution also revealed that most in-house inventory management systems were absent or ineffective, despite senior management's belief to the contrary. This paper addresses a need for a simple and practical resource management methodology aimed at simultaneously leveraging productivity and mitigating and eliminating the risks associated with inventory stock-outs.

The research emphasized the availability of critical inventories. The determination of the criticality of inventories is shaft specific (or mine specific). Non-critical material in this context refers to paint, nails, bolts and nuts. The paper cannot cover the entire supply chain and/or all procurement aspects of those resources; instead it focuses on the constraints of distribution flow from centralized stores (mine warehouses) through shaft systems onto the mining face. Physical resources inventories are referred to as 'inventories' for the rest of this work.

Status quo: distribution of inbound inventories

This paper is concerned with the maintainability of mining—in particular, inbound logistics—as it relates to the distribution of inventories. The systematic management of shaft inventories is achieved through existing enterprise resource planning (ERP) systems; for example, Systems Applications Programs (SAP). The full benefit of ERP systems has not been realized because information and

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communication technologies have not been extended to the hard rock mining face. Therefore, tracking inventory movements in most shafts demonstrates that the influence and relevance of most ERP systems is limited to shaft surface where such technology is available. Once the inventories enter the shaft distribution flow it becomes difficult to answer the following basic distribution questions:

- ▶ How many rockdrills, say, must be held as inventory in-by the waiting place?
- ▶ How many rockdrills are held as inventory in underground stores?
- ▶ How many rockdrills are available throughout the mine?

The unavailability of critical inventories leads to serious safety compromises to mining. For instance, the unavailability of one drilling machine may cause stopping crews to compromise drilling of the advance strike gully.

Figure 1 is a schematic representation (not to scale) of a platinum shaft arrangement. It intends to demonstrate the complexity of inventory distribution systems (inbound logistics) that results from the network of rails, rolling stock and rigging that cater for the entire shaft. Managing constraints of a single distribution flow is relatively easy compared to the network below where there are interdependent constraints (Figure 1).

Figure 2 highlights the number of interdependencies affecting the throughput of inventories from the centralized mine stores to an underground workface.

The significance of Figure 2 is that the availability of inventories at the mining face reduces as the number of interdependencies increases. Ideally, inventories distributed to shafts must be shuttled to the underground store, as soon as they are delivered to the shaft. Transitory containers are kept on surface, as a way to mitigate the effects of disruptions to distribution by external factors such as truck breakdowns and vendor unreliability. Both mine stores and underground stores are described in detail in the following subsection.

Mine central stores (warehousing)

Most mines have a centralized store system. Information about replenishment and buffering of material flows from the mining personnel to the shaft accountant. Normally, orders are placed on the ERP system. Inventories are made available to shafts and include of factors such as ordering, manufacturing, delivery and distribution times. The shaft accountant has access to the ERP system and is responsible for the whole distribution management of inventories from the central store. The notable advantages of a centralized store system is that the mine can use economies of scale as leverage for competitive pricing from vendors, as well as reduce duplication and exposure to fraud. Centralized stores provide the first buffer between the mine and the external suppliers.

Shaft transitory stores

The shaft surface stores are usually neither decentralized stores nor back-up stores, but transitory stores. These stores are commonly used for the reception of material from central stores before this material is transported to the working places. The intention is for material to change hands and be

moved to underground stores. Material received on surface is placed onto designated material cars that shuttle to the underground stores. The shaft also has daily schedules that cater for inventory flow—such as:

- ▶ *Day shift*—mainly for underground explosives
- ▶ *Afternoon shift*—mainly for transporting empty material cars from underground to surface
- ▶ *Night shift*—mainly transporting loaded material cars to replenish underground stores.

Underground stores

Ideally, underground stores serve to buffer material and equipment flow to the working place. These stores are located in cross-cuts in a manner that facilitates unloading and reloading of material cars, while reducing the distance that operators must travel. The location of the stores also allows for rigging of mass material through the use of technology, such as mono winches.

The problem with the status quo

Mining is a highly uncertain environment as a result of many untimely disruptions that adversely affect material flow. Disruptions do not occur in a neat and sequential manner, and the times between cause and effect is relatively long. Also the impacts of these disruptions, such as long replenishment times, are easily transmitted throughout a mine's interdependent distribution network. Furthermore, the nature of mining is that any line manager who reports inventory stock-outs as the cause for lost blasts (failure to blast) makes an admission that consequently implicates himself. Such implication is subject to disciplinary action, among other things, which means that inventory-related lost blasts are not reported.

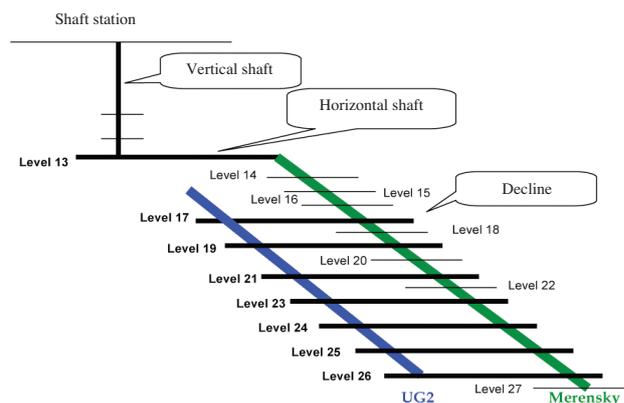


Figure 1—A typical platinum mine shaft arrangement

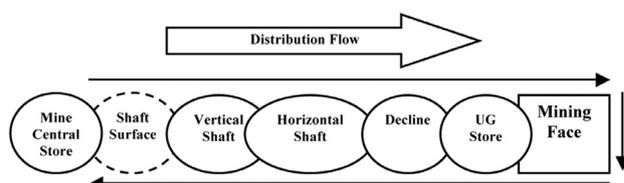


Figure 2—Simplified mine distribution chain

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As a result, the lost blast data that relate to inventory stock-out are invariably unreliable. The effect is that the impact of the inventory problem is not fully comprehended, especially where techniques such as the Pareto analysis are used to guide operational strategies. Thus senior management have a false sense of security.

The unavailability of critical inventories disempowers management and more so operators from fulfilling their purpose. It stands to reason, therefore, that individuals begin to invent innovative ways of ensuring that they have what they need for the foreseeable future. Unfortunately, this behaviour shifts emphasis to personalities—the one with the most charisma tends to get the ‘lion’s share’ at the expense of the meeker personalities. The power of those who get the lion’s share includes the ability to move themselves to the front of inventory queues.

A summary of observations made while monitoring inventory flows is listed below. Observations are based on empirical versus theoretical evidence from Anglo Platinum’s Townlands Shaft and Impala Platinum Shafts (10, 11, E&F, and 1). Experience on this subject was also drawn from major capital mining projects such as shaft sinking of both vertical and decline shafts.

Shaft stores

Most shaft stores were characterized by the following observations:

- Shaft transitory stores do not have an explicit and systematic management of inventories
- There is a shortage of material cars on surface for loading inventories
- Material car cycle-times from surface to underground stores are too long because of the coupled nature of the inventory system
- Often material cars are overloaded
- Bank attendants normally complain about the heavy material cars that they push
 - There are high levels of absenteeism among bank attendants
 - Bank attendants feel overworked
- No dedicated mining human resources for systematic tracking of material/equipment.

Underground stores

Most underground stores were characterized by the following observations:

- Many underground stores are either non-existent or dysfunctional
- Most stores do not have critical material and equipment
- Lost blasts due to inventory stock-outs are not reported
 - Line management fear the fact that they implicate themselves in lost blasts
 - Common practice is to ‘steal’ inventories from one another, especially during odd-shifts, Sundays and public holidays.

Impact on the mine as a whole

Observations have shown that the absence of reliable inventory in underground stores has adverse effects on morale, which affects on productivity and further reduces

morale, typical of a negative spiral. Miners, driven by original need (such as bonus and ambition), often elect to carry out the following actions:

- Create their own individual and localized back-up inventories through:
 - Unauthorized storages in panels—using material cars, hiding, stealing
 - Arbitrary overordering of inventories, which are often left behind with crew moves
 - Redundancies of back-up inventories because, depending on the amount of paranoia, even operators hide equipment
 - Misallocation of inventories, which is costly from a financial and planning perspective because there may be enough inventories in the system but these might be held in the wrong places
 - Disregarding planned maintenance, especially of rock drills, because of the slim chances of it returning to the same crew.
- Compromise safety by, for example:
 - Not drilling the advanced strike gully or not installing support units in the event of rockdrill shortages
 - Ignoring the start-of-shift procedures—in the event of unavailability of a drilling machine, crews are bound to rush through procedures.
- Compromise quality:
 - In the event of unavailability of a drilling machine crews tend to increase the spacing between holes, thus compromising fragmentation and loading cycles.

These problems affect most mines, especially as they get deeper. Further aggravation may be experienced when the same single shaft must contend with production as well as a major capital project.

The following section discusses the methodology behind buffer store. It hypothesises that the core problem lies in mismanagement of stores resulting in lost opportunity to buffer the effects of disruption of inventory flow. The solution—buffer stores—considers the why, what (content), when, where and how inventory flow buffering must work.

The solution: buffer store methodology

The purpose of buffering critical inventories distribution flow is to improve productivity at the face. Therefore, there are three factors that formed the basis for the hypothesis testing:

- Reliability of the system (stores availability and cost effectiveness)
- Accuracy of inventories required at the face (accuracy of forecasts)
- Reduced replenishment durations (increased response times).

Reliability of buffer store system

Conceptually, a buffer focuses on cushioning the impact of ‘things that can go wrong’ as opposed to focusing on reducing uncertainty. As such, buffer stores are required to protect at the intersection between the mining face and the distribution system—recommended as a shift supervisor’s responsibility. In addition, a shaft buffer store on surface

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provides protection internally from effects of external disruptions—recommended as a mine manager’s responsibility. Shaft bottom buffers (horizontal shaft buffers) protect the underground workings from disruptions to inventory flow affecting the vertical shaft; a decline shaft buffer store provides corresponding protection—the recommended responsibility of the shaft logistics officer. The number and placement of buffer stores is site specific, but the concept is generic.

Accuracy of inventory forecasts

The methodology applied for increased accuracy of forecasts is based on ‘statistical aggregation’. Statistical aggregation considers that the fluctuations at the underground buffer stores are much more volatile than when those buffer stores inventories aggregate; in fact, variation at aggregate will reduce by the square root of that at the source. This means that consumption depends on the number of storage points in the system. In this instance, if the surface store were servicing four underground buffer stores, then the accuracy at the surface buffer store is twice (square root of 4 is 2) as good as the accuracy at the underground buffer stores (Goldratt, 19991; Schragenheim *et al.*, 2009).

For a hypothetical mine such as that depicted in Figure 3, rock drills will be buffered as follows, starting at source and working backwards:

- Underground buffer stores:
 - An underground buffer store services both stoping and development
 - For demonstration purposes, let the number of rock drills consumed from one store be 49
 - Therefore the rock drills stored as buffer in each underground store will be the square root of $49 = 7$ rock drills.
- Applying the same principle to the decline, horizontal and vertical shafts will ultimately provide the shaft buffer:
 - Buffer of rock drills in the decline shaft buffer store the square root of $14 = 4$

- Horizontal shaft buffer will be the square root of $4 = 2$ rock drills
- Shaft buffer will be the square root of $(14 + 2) = 4$ rock drills.

For the scenario above:

- The total number of rock drills at the face = 196
- Conventionally, the mine’s budget allows an additional 30% inventories held in the distribution pipeline
 - Total number of rock drill inventories = $196 \times 130\% = 255$
 - Total number of rock drills in the pipeline is 59
- Buffer stores total rock drill inventories = 42
- Implementing buffer stores shown in Figure 3 results in a 30% reduction in rock drill inventories
- Cost benefits, logistics benefits, and morale benefits cannot be overemphasized
- Replenishment response times translate into improved productivity.

Control charts

The system is incorporated into accessible control charts (Figure 4), where material and accessories that are used for drilling are recorded on control charts. Depending on the importance of the material and reliability of supply, simple rules are formulated for line management according to the colour codes of the control chart.

Considering the previous example (Figure 3):

- Underground store A will be accorded a green status if there are at least nine rock drills in the store
- The same store will be accorded a yellow status if there are at least seven rock drills and this next rule is obeyed
 - The shift-supervisor must be aware of the situation and must initiate the reordering/supply process
- The red status will be accorded to the stores if they have at the most five rock drills and these next two rules are obeyed
 - The status is elevated to the mine overseer
 - The shift supervisor and miner track the situation daily.

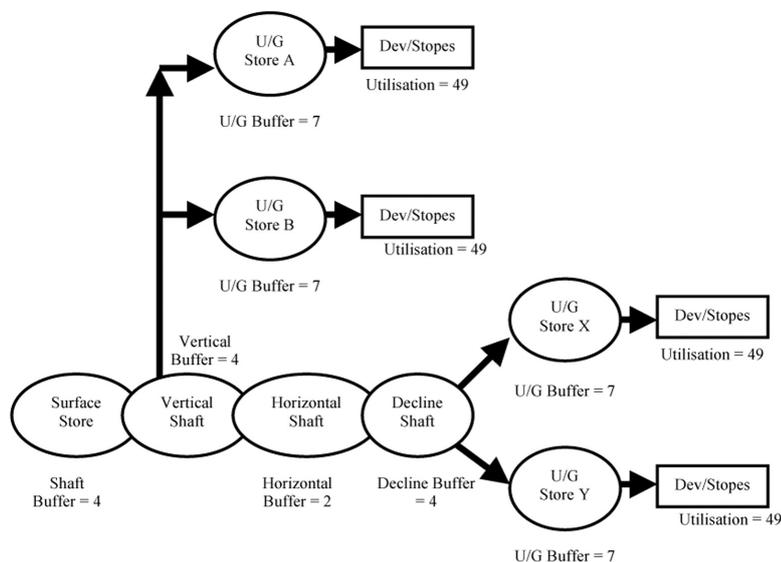


Figure 3—Inventory distribution chain in a hypothetical shaft

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MEASUREMENTS		Now	TODAY	WEEK	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 6	Shift 7	Shift 8
CRITICAL EQUIPMENT AND SPARES BUFFERS	Responsibility											
MAKING SAFE												
Pinch Bar 1.2m + Gaskets		3	5	7	●	●	●	●	●	●	●	●
Pinch Bar 1.5m + Gaskets		3	5	7	●	●	●	●	●	●	●	●
Pinch Bar 1.8m + Gaskets		3	5	7	●	●	●	●	●	●	●	●
1.8kg Hammer		3	5	7	●	●	●	●	●	●	●	●
Shovels		1	2	3	●	●	●	●	●	●	●	●
DRILLING												
Rock Drills		5	7	9	●	●	●	●	●	●	●	●
Hand held drill steel(0.9m)		5	7	9	●	●	●	●	●	●	●	●
Hand held drill steel(1.5m)		5	7	9	●	●	●	●	●	●	●	●
Hand drill steel (1.8m)		5	7	9	●	●	●	●	●	●	●	●
Rootbolters/in-stope		3	5	7	●	●	●	●	●	●	●	●
Cheetah Saw		1	2	3	●	●	●	●	●	●	●	●
Manifold (2 Inch)		1	2	3	●	●	●	●	●	●	●	●
Manifold (4 Inch)		1	2	3	●	●	●	●	●	●	●	●
Machine Lubricator Container		1	2	3	●	●	●	●	●	●	●	●
Manifold (4 Inch)		1	2	3	●	●	●	●	●	●	●	●
Machine Lubricator Container		1	2	3	●	●	●	●	●	●	●	●
Airlegs												
Short Airleg (1.5m)		5	7	9	●	●	●	●	●	●	●	●
Long Airleg (1.8m)		5	7	9	●	●	●	●	●	●	●	●
Airleg extension		5	7	9	●	●	●	●	●	●	●	●
Hoses and valves												
Mining hoses (12 mm Diam.)					●	●	●	●	●	●	●	●
Mining hoses (16 mm Diam.)					●	●	●	●	●	●	●	●
Mining hoses (25 mm Diam.)					●	●	●	●	●	●	●	●
Mining hoses (30mm Diam.)					●	●	●	●	●	●	●	●

Figure 4—An illustration of a store control chart

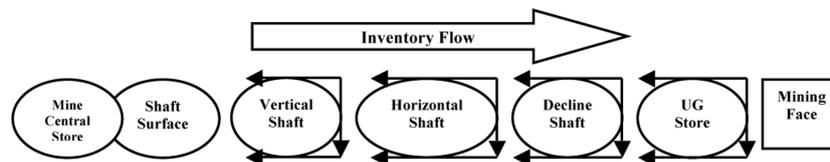


Figure 5—Decoupling of shaft inventory flow

- ▶ The store operator’s responsibility will be to update daily all transactions at underground stores and update daily the preceding half-level and shaft stores
- ▶ The same principles are applied to shaft (decline and vertical) and section stores with the mine manager monitoring only shaft surface buffers.

Reduced replenishment time

Distribution management of inventories as applied to mining is the systematic management of all inbound and outbound requirements that are needed for a particular shaft. Two of the most important parameters of distribution management are distribution capacity and inventory management. Distribution management strategies are normally classified into two categories: push-based and pull-based management systems.

In a push-based system inbound requirements and replenishment are pushed into working areas on the basis of forecasted consumption and, as such, inventory levels are adjusted according to forecast. This is normally applicable for new material and accessories, such as a new support regime.

In a pull-based system inbound requirements and replenishment of these are demand driven; that is, inventory levels are adjusted according to the level of consumption.

In general, operations use both strategies. The emphasis in this work is on the application of a pull-based system. Some of its salient features include:

- ▶ Inventory levels controlled according to actual consumption
- ▶ Continuous improvement of the speed of replenishment
- ▶ Replenishing in smaller batches
- ▶ More frequent replenishment.

Applying the pull-based system to shaft inventory flow will result in the set-up shown in Figure 5. Figure 5 shows a now decoupled shaft inventory flow previously demonstrated in Figure 2 as the status quo. In Figure 5 the decoupling is effected from the vertical shaft to limit logistical interdependencies between stores. In some instances it is effected from the decline shaft.

Typical and valid responses to this concept include:

- ▶ Rehandling of inventories:
 - Decoupling of the system means that each segment must be viewed separately without losing holistic benefits
 - Buffers stores stability means that fewer, accurate inventories flow as a top-up
 - There is less utilization of rolling tock
 - There is dramatically reduced congestion of rolling stock
 - The cleaning of blasted stocks is dramatically increased
 - Productivity increases dramatically
 - Operating costs reduce dramatically
- ▶ Security of inventories:
 - Stores are properly constructed
 - Stores are manned to increase store availability
 - Store operator works on hand-to-hand exchanges of inventory
- ▶ Cost of inventories:
 - Buffer stores are not decentralized stores—no large capital injection is necessary
 - Buffer stores are not back-up stores, with inventories locked away
 - Inventories are ordered on what is actually consumed

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- No arbitrary average ordering takes place
- Buffer stores are stocked in sequence from closest to the face toward shaft buffers store—and with the costs saved
- Operators and line management relinquish their own uncontrolled buffers
- There is a dramatic increase in productivity, with reduced inventories
- Stores, store operators and inventories pay for themselves.

In conclusion, buffer stores increase reliability of the system because the direct impact of disruptions become localized within stores without the entire distribution network being necessarily affected. Replenishment times are reduced because of shorter rolling stock cycles. The buffer store methodology is based on pull strategies, which dramatically increase the accuracy of forecasts.

The sequel to sound logic is application.

Buffer store implementation—empirical testing

Buffer store implementation is executed in two phases. Phase 1 addresses the institution of buffer stores, and phase 2 deals with buffer store management. This process is highly dependent on stakeholder buy-in, which is done top-down before proceeding to the mining face.

Phase 1—Instituting buffer stores

This phase involves:

- Establishing buffer stores, starting with workplace buffer stores, and progressing towards the shaft surface is important for re-establishing operator confidence in the (buffer) stores, that is, decline shaft, horizontal shaft and shaft (surface) buffer stores—the point where inventories aggregate
- Ensuring that buffer stores are established with adequate capacity, and with due regard to rock drill operators who must carry their equipment to and from
- Ensuring that buffer stores have a dedicated store operator
- Developing critical material/equipment control charts
- Decoupling logistical interdependencies to reduce replenishment durations increases reliability of buffer stores
- Limiting rolling stock shuttling between buffer stores and thereby decongesting the shaft schedule.

Phase 2—Buffer store management

This phase involves:

- Generating buy-in from store operators
- Exercising control chart visual intelligence, where shift supervisors are able to determine status of inventories at a glance
- Store operators ordering inventories according to consumption and control charts improves accuracy of forecast
- Monitoring and tracking progress and including buffer stores into internal occupational health and safety audits
- Awarding bonuses and penalties to encourage ongoing improvement.

The above innovation was piloted at Anglo Platinum's Townlands Shaft and Impala Platinum Shafts (10, 11, E&F, and 1) using the process set out immediately below:

- A desktop study on lost blast analysis was carried out to determine the extent of critical material shortages. In the event that the data from this study were unreliable, an independent study was carried out by the project team.
- Establishing buffer stores was carried out in collaboration with the shaft management (including the shaft accountant) as most buffer stores were operating as transitory stores. The buy-in process also included the shaft management's agreement to have a dedicated store operator, which was important because most underground store operators were already incorporated into stoping crews that were manning stores on a part-time basis only. The shaft management and store operator were also given basic training in using a store control chart and the accompanying rules.
- In some mines that have a combination of vertical and decline shafts, a horizontal shaft buffer store was instituted to cushion the logistical risks associated with such a shaft system
- A shaft surface buffer store was established so that it could act as a buffer between the mine and logistical delays from central stores and suppliers
- The amount of inventory needed was established for each store.

The whole implementation period averaged two weeks per level and the results are discussed in the next subsection.

Results

Figure 6 presents the measured lost blast analysis for one stoping crew. Lost blasts attributed to shortage of critical material amounted to 33% and this was consistent for most of the crews participating in the pilot studies. Only this lost blast analysis results are discussed because it is a relatively small shaft and the project team was permitted to carry out parallel lost blast analysis. It was also during this parallel run that the project data confirmed that lost blast analysis data due to inventory shortages from the source was inaccurate. However, such a discovery was understandable against the backdrop of the human factors alluded to earlier on.

Implementation of the inventory-buffering methodology completely eliminated lost blasts that were the result of material shortages. In one instance, eliminating the lost

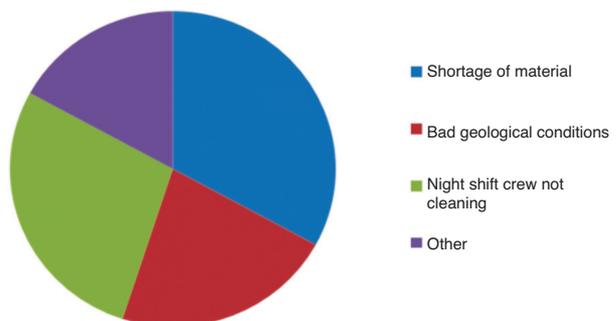


Figure 6—Effect of material shortages in production

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Impala Platinum - E&F Shaft

Capital Development - Blasting Performance

21 May - 21 June 2008

Overall Performance	Crew No.					Total	Target	% Achieved
	KC26D	KC15D	GB16D	IB25D	IB16D			
Jan	21	7.8	21.6	6.4	23.3	80.1	101	79%
Feb	5	12	24.1	7	17.9	66	93.7	70%
March	17.2	16.9	20	14	12	80.1	89.2	90%
April	0	14.2	19	12.7	22.9	68.8	76.6	90%
May	6.4	12.4	25.2	8.4	25.4	77.8	95.4	82%
June	35.2	17.6	31.5	28.2	33	145.5	130.5	111%
Total	84.8	80.9	141.4	76.7	134.5	518.3	586.4	88%
Target	127.3	56.6	148.3	107.9	146.3	586.4		
% Achieved	67	143	95	71	92	88		

Improvement Calculation	
3 month ave.	5 month ave.
80%	82%
112%	
102%	
140%	
57% Var. on Ave.	
70% Improvement	

NB: Ukhozi was re-deployed to these workplaces/crews from 21 May - 21 June

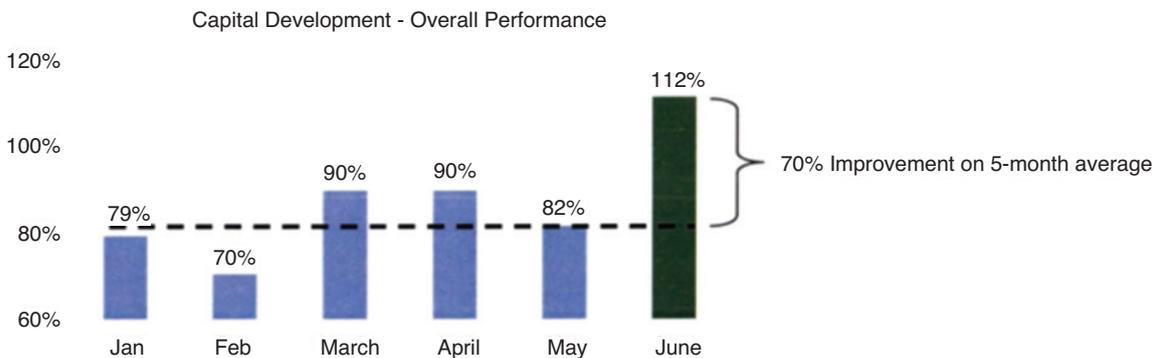


Figure 7 – Productivity at Impala Platinum’s E and F Shaft for the period January to June 2009

blasts due to material shortages contributed to a 70% improvement in monthly targets and this result is in line with TOC predictions made by Goldratt, 1999³. The other instant benefits were cost saving and improved communication (refer Figure 7).

The main contributor to cost saving was the fact that line management and mining crews no longer ordered arbitrarily and, instead, ordered only what was consumed. In addition, all shaft personnel developed trust in the inventory management system and ceased to institute their own buffers as a result of this new trust. Damaged equipment and planned maintenance specifications were adhered to and duplication of critical material numbers was also significantly reduced.

Through the use of control charts, communication between line management was more effective and focused, as emphasis was placed on the red and yellow items. This also assisted in freeing up time for line management to focus on other productivity matters.

Conclusion

The systematic management of inventory in a shaft is one of most important productivity levers. Managing inventories in most mining shafts has deteriorated from the ideal to an arbitrary basis, with negative effects on productivity and, in particular, on morale, production, occupational health and safety, quality, and cost.

Buffer stores (institution and management) are a simple and practical innovation that leverages productivity, while

mitigating/eliminating risk by regulating the distribution flow of inventory to where it matters most—the face.

Effective buffer stores management is achieved when:

- The buffer store system has absolute reliability (i.e. established infrastructure and resource deployment)
- There is an increased response time to inventories replenishment
- There is an improved accuracy of forecast replenishment (only top-up buffers, no arbitrary ordering).

Implementation occurs in a surprisingly short space of time with the correct buy-in and active collaboration from top management. Experience has shown dramatic improvements in productivity (number of blast) of up to 70% in just one month, where inventory stock-outs measured 33%. The morale boost was unprecedented as these teams experienced the fruits of their labour in the form of a bonus.

Acknowledgement

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