APPLICATION OF HIGH PRECISION MINING FOR OPTIMISING LOAD AND HAUL OPERATIONS AT KANSANSHI MINE, ZAMBIA

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ABSTRACT

Mining of copper and gold at Kansanshi is done in the Main and North West pits using hydraulic excavators and a mining fleet of haul trucks. In the recent past, there has been reduced truck deployment, increased truck and shovel waiting time, reduced production and reduced grade/quality of ore delivered to crushers. Therefore, there is need to improve productivity and optimise operations in mining, loading and hauling. This paper focuses on the use of High Precision Mining (HPM) through use of Wenco's dispatching algorithm to achieve the best utilisation of all mining equipment and maximise production.

The study involved establishing the precise bucket positioning, production rates, cycle times and monitoring the material type and quality /grade of ore delivered to the crushers. This was done by using BenchManager which relies on the motion of the Global positioning System (GPS) antenna scribing an arc as the excavator is rotated to determine the equipment's centre of rotation by placing the bucket with the teeth flat on the ground (anywhere) and taking the rover and measuring left and right tooth on the outside of the teeth and taking note of the coordinates, first eastings then northings and lastly the elevation. With the tolerance of X=0.5m, Y=0.5m and Z=0.5m, it was noted that the events of a bucket mining out of the assigned polygon were reduced to about 50cm in distance from 34% to 15% and from 10% to 8% in terms of mismatches.

The use of precision mining has led to reduced mining cost of about 10.3$/BCM, improved fleet/production reporting, high grade of the material delivered to the crushers of about 75% from the previous 65%. These results indicate that there is a strong business case for implementation of a Wenco fleet monitoring and dispatch system at the mine

Keywords: *High Precision Mining, Loading and Hauling optimisation, fleet, bucket positioning*

INTRODUCTION

Kansanshi copper and gold mine is located approximately 15 km north of Solwezi in North Western Province of Zambia and 18km south of Democratic Republic of Congo border. Currently, the mine has two open pits in operation; the Main and North West. In future, both pits will be merged to form a single large open pit. It is expected that the Main Pit will reach a depth of 295 metres while the North West Pit will reach a final depth of 160 metres by December 2031 (KMP, 2019).

In order to improve productivity and optimise operations, the mine is implementing High Precision Mining (HPM) based on WENCO. This technology uses high precision GPS on fleet (shovels/trucks) to improve both bench elevation and ore quality control (Trainor, G.F., 2012)

Geology of Kansanshi

The Kansanshi Deposit occurs within the northwest-trending Kansanshi antiform, which exposes rocks of the Kansanshi mine formation in its core (GRD Miniproc Limited, 2002). The Kansanshi antiform hosts four major stratigraphic units, which structurally, from top to bottom are described as follows: Upper Dolomite – the sequence comprises dolomite and dolomite marble and can be described geologically as pale brown-grey to medium grey, fine grained, saccharoidal and iron-free dolomite; bearing schist; Kansanshi Mine Formation – this formation consists of interlayered phyllite, schist, marble and calcareous schist and Lower Pebble Schist Formation – this unit is calcareous biotite schist, locally garntiferous that contains up to 10 % of exotic clasts. Figures 1 shows the Kansanshi geology plan view of North West and Main pit.

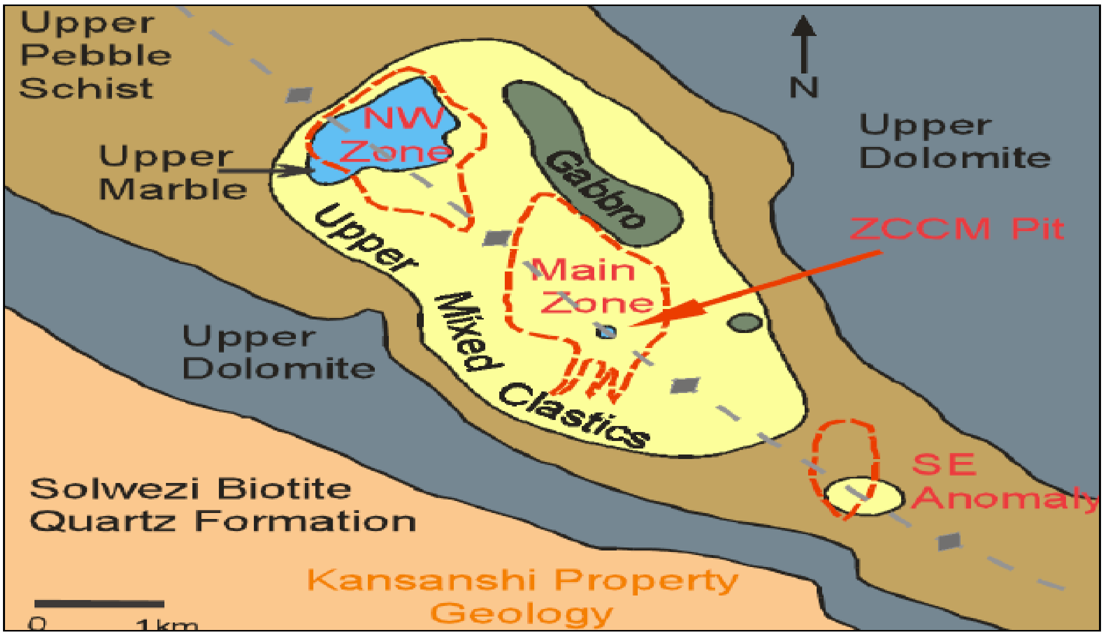


Figure 1: Kansanshi Geology Plan View (GRDMiniproc Limited, 2002)

The Application of High Precision Mining

There are many companies in the world providing mine fleet management systems (Askari-Nasab, 2017). Some of the more popular ones are: Modular Mining Systems; Jigsaw; WENCO, Dynamine Micromine Pitram system and Caterpillar with CAT® MINESTAR™ FLEET are the next leaders of mine fleet management systems (Askari-Nasab, 2017). Peculiar features of automatic control systems used in mining transportation include the fact that they were developed with a wide use of computer aids, and computer-based solutions of tasks bound to the theory of linear and dynamic programming were used as an algorithm of optimal control of transportation (Semykina, 2018)

Modular mining fleet management system: The system leverages three mathematical programming models; Linear Programming (LP), Dynamic Programming (DP) and Best Path (BP) to maximise overall truck productivity by maintaining and updating a real-time model of the mine equipment, locations, and haulage roads (Modular Mining, 2021). The modular model studies allow controlling shift turnaround and implementing the strategy of dump trucks distribution along all pit sites, modeling trips to loading terminals with changing the transportation route (Semykina, 2018)

Jigsaw hexagon mining's fleet management system-Jigsaw Jmineops is used commonly to optimise the real-time scheduling and dispatch of mobile mining equipment. Information provided by the fleet management system (FMS) gives greater control of operations and production. Jmineops optimises and centralises equipment tracking, dispatching and diagnostics, ensuring that activities and operators can be directed, material movement can be confirmed and machine health can be monitored (Hexagon, 2021). Jmineops has the following characteristics: independence, universal software platform; ability to harness any industry standard IP-based wireless network; identical on-board SQL databases & office server that replicate in real-time; distributed database architecture; instantaneous data relay; real-time compliance control and automated cycle logic (Askari-Nasab, 2017).

Micromine pitram is a fleet management and mine control solution that records manage and processes mine site data in real-time. As a scalable solution, it is suitable for underground and surface mine construction, development and production. Pitram records data related to equipment, personnel and materials, providing an overview of the current mine status and therefore enabling improved control over operations. Greater control allows sites to increase production, reduce costs and improve safety and business intelligence. Pitram's sophisticated yet intuitive functionality makes it ideal for any mining environment. It has been implemented at more underground sites than any competitor product, and is increasingly popular with sites using automated practices (Pitram, 2021). Pitram also has enhanced 3D visualizations and integrates with tagging and positioning system to provide control room operators with "near real –time information", reducing reliance on radio communication (Dean, 2021).

Caterpillar's MineStar is an integrated mining information system, developed by Caterpillar, Incorporation and its alliance partners. The system allows for tracking of machine health, productivity, machine and material movement, and drill management. It also includes Computer Aided Earthmoving System, CAES® and an advanced truck assignment program. MineStar® has the capability of linking machines in the field to MineStar® office systems, as well as to other mine information systems. Caterpillar's alliance partners, Mincom and Trimble Navigation, have provided office software, radio infrastructure software and GPS technology, respectively (Ataman, 2001)

In this paper the algorithms behind the commercial mine fleet management systems mentioned above have not been compared to establish which one works better than others. (Askari-Nasab, 2017), observed that the algorithms behind many commercial mine fleet management systems are proprietary information, and therefore the companies do not want to disclose the logics to the public domain. Consequently, a comparison of the optimality of the fleet management solutions has not been made.

Dispatching system- A general review

(White, J.W. and Olson, J.P., 1986), proposed a short-term production planning system which consisted of two Linear Programming (LP) models. The solution to the first LP model determines the optimum production rate of the shovels, which is then used to link the first LP model with the second. The solution to the second LP model allocates the volumes of the haulage capacity to all available haulage routes by maximising production per unit of haulage resources.

(Maran, 1987), showed that 60% of the total costs incurred in surface mining can be attributed to loading and hauling operations. According to (Ataeepour, 1999), the rules aimed at minimising shovel idle times perform better than minimising truck waiting times in an under-trucked system. According to (Alarie, 2002) the main forms of truck-allocation are the single stage and multistage systems. (Souza, 2010), developed a hybrid heuristic MILP algorithm based on a combination of two metaheuristics to minimise number of trucks required to meet production target and required material quality. (Xiao-Yu Sun, 2011) indicated that fleet size and distances traveled between the loading and unloading points determines fleet efficiency.

(Mena, 2013), proposed a multiple integer knapsack problem to obtain the maximum cumulative fleet production in a fixed time frame. The objective of their model is to assign available trucks to the route requesting trucks according to their operating performance in a truck-shovel system. (Zhang. L and Xia, 2015), proposed a mixed-integer linear programming (MILP) model that determines the trip numbers of trucks hauling between loading sites and dump sites. The objective of their model is to achieve the production target with minimum total truck operating costs in a shift by taking into account of operational and ore grade constraints. (Askari-Nasab, 2017), state that the approaches used to solve the production optimisation problem in the truck shovel dispatching models can be divided into Linear Programming (LP) approach, Non-Linear Programming (NLP) approach, Goal Programming (GP) approach and stochastic programming approach. According to (Bnouacgiri, 2020), there are still many limits to the current algorithms as most models are deterministic.

This paper focuses on the evaluation of WENCO application at Kansanshi Mine for optimising load and haul operations.

WENCO

The primary objectives of WENCO are to maximise production, minimise rehandles, supply the plant, and meet the blending objectives. Efficient algorithms that dispatch trucks in an open pit mine must manipulate a variety of raw data to produce intelligent assignments in all situations. Such raw data include: a haul road network containing locations, elevations, roads and distances; travel times gathered between shovels, dumps, and intermediate signposts; loading intervals of trucks at shovels; dumping intervals of trucks at waste dumps and crushers; material grade information dug at the face and blending targets at dumps; operational status of trucks and shovels and miscellaneous mining constraints such as shovel priorities, dump capacities, truck capacities, and scheduled operator breaks (Trainor G F, 2012).

Owing to the fact that the operation of the mine depends on timely response from the central computer, these algorithms must operate quickly to generate assignments within fractions of a second. Rather than depend on simple algorithms and heuristics to generate such assignments, a realistic approach to truck dispatching should incorporate several rigorous algorithms to provide different parts of the solution.

WENCO consists of three subsystems; Best Path (BP) determination for each change in topography, Linear Programming (LP) for each significant change in a time-dependent variable, and Dynamic Programming (DP) for assignment in real-time as indicated in Figure.2. The BP subsystem generates the shortest paths between all pairs of locations in the mine road network. The LP subsystem takes travel times and optimal routing from BP, as well as information concerning the current pit configuration such as number of ready shovels and trucks; loading and dumping intervals at shovels and dumps; respectively, blending requirements at dumps and crushers; and shovel priorities. The system then sets up the LP constraints. (www.wencomine.com, 2019).

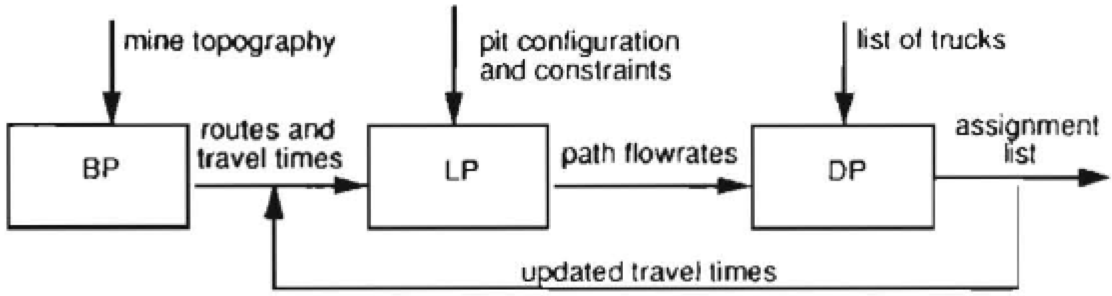


Figure 2 WENCO Algorithm

Solution of the LP model generates the optimal path flowrates in tonnes per hour to minimise haulage requirements for the given pit configuration. Finally, the DP subsystem uses these optimal path flowrates, the list of trucks needing an assignment from a dump to a shovel, and the current travel times and distances to produce an optimal list of assignments for each truck. The DP, called each time a truck requests assignment, produces a list of paths from dumps to shovels ordered by need and assigns trucks to paths. Finally, the system updates travel times using a moving average.

The technology determines equipment activity, location, and time and production information. It offers fleet control, a mine management solution to interface various mine activities; optimise truck deployment and ore grade control; and track equipment location, status, and operators. It offers BenchManager, a Global Positioning System (GPS) solution for precise graphical actual-vs-design feedback and system integration; tracking elevation, gradient, cut/fill, and safety information for dozers and tractors; and digging limits for excavators and backhoes. Using the WENCO system, you can monitor and control dispatching of mine equipment, the grading of material, and analysis of production (www.wencomine.com, 2019). A typical mine site using WENCO includes the components indicated in Figure 3.

The WENCO system features include:

a) Fleet management

A real-time mine map shows the position of equipment at all times identifying areas of congestion, waiting hauling units and waiting loading units (Bristol V. , 2000). The foreman or supervisors can take immediate action to redistribute the equipment and minimize lost production.

b) Automatic dispatching

WENCO’s Automatic Dispatching allows for better utilization of equipment, resulting in greater productivity. Automatic Dispatching determines which loading unit and hauling unit should go to, based on other recent hauling unit assignments, loading unit status, loading unit loading times and travel times to the loading units (Lizote, Y. and Bonates, E., 1987).

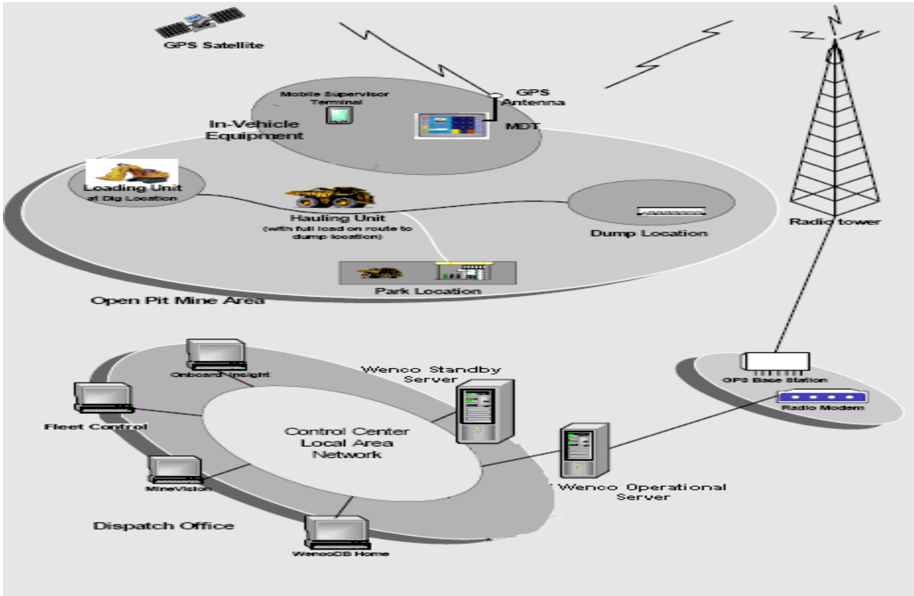


Figure 3 Typical mine site layout for monitoring and control of mine equipment, grading of material, and analysis of production (Courtesy of Kansanshi Mining Plc (KMP), 2019)

The dispatching algorithm maximises production while meeting any operational constraints by continuously analysing the number of required hauling units and indicating to the dispatcher whether an over-trucked or under-trucked situation is present (White, J.W. and Olson, J.P., 1986). In order to assist with the best hauling unit / loading unit balance, the system continuously displays the optimum number of hauling units required for each loading unit (Tan Y. M., 2012). If the loading units have been placed into a dispatch group, the system displays the number of hauling units required for the group (Q. GU., 2008). These numbers are dynamically updated to reflect the 'minute to minute' mining conditions.

c) Blend and stockpile management

Based on quality parameters from the mine plan or laboratory analysis, the system can determine which material has been taken to the crusher or deposited on the stockpiles or even an area within a stockpile. The system maintains and displays the real time ore grade average for each dump location for up to 10 quality parameters. The figures are adjusted with each load dumped or load removed.

Hauling Units can be dispatched automatically to meet grade range targets.

d) Automated data collection

The system automatically collects details about daily operations, eliminating the need to rely on records created manually.

e) Reporting

The WENCO system automatically collects details about daily operations. It can create custom reports on all aspects of the mine's activity and production.

f) Hardware and Software

The WENCO system includes both hardware and software components:

Dispatch Office Computers-Two Microsoft Windows servers and Workstations

In Vehicle computers

MDTs (Mobile Data Terminals): Octagon RMB-C2

Communication Equipment

The specific communications equipment required depends on the mine's requirements. Communication equipment may include: GPS and Radio Antennas; GPS Base Station; Radio Modems and Repeaters and Wireless Network Communications: Motorola MESH

WENCO System Software Components - Microsoft SQL Server; WENCO applications (for example: Fleet Control, Mine Vision, and TireMax) and WENCO services to provide connections between WENCO applications and the real-time system (Wencomine, 2019)

Prior to the introduction of WENCO, Kansanshi mine was using the Modular Dispatch System for production trucking of in-situ polygons while the shift engineers and shift geologists control moved polygons on the pit floor. The Modular Dispatch System created many reconciliation challenges more especially for the geological team. Hence, the introduction of High Precision Mining (WENCO) was meant to eliminate most human controlled aspects such as manual dispatching, operator self-commands on the cabins, survey stakeouts and other negative aspects in the mining and dispatching system of various types of mined materials to predetermined destinations.

In addition, lack of clarity on the quantity of mined ore tonnages or bank cubic meters BCMs), reconciliation and misplacements of material has led to increased mining costs from 10.5 $/BCM to 12.6 $/BCMs or by 4.0% due to: reduced truck deployment, increased truck and shovel waiting time by 42%, reduced production by 6.0% and reduced Grade/Quality of ore delivered to crushers**.** With the in-pit haulage distance increasing from 1335RL to 1195 RL, there is a need to address the above issues. Furthermore, the major elevation and in-pit hauling fluctuation pose a risk to trucks since clearance is compromised. The other challenge is that there are some inconsistencies on the reporting of the fleet performances. This has resulted in the manipulation of figures by some operators at the mine.

The following fleet was studied and evaluated as shown in Table 1.

MATERIALS AND METHODS

Introduction

A non-intervention and quantitative research study was employed in which numerical data was collected in order to determine the behaviour of the loader-truck system. Parameters such as shovel loading time, haul cycle time, capacities of trucks and shovels were determined and quantitatively analysed to determine their contribution to trucks queuing at the loading site.

In order to accomplish the objectives of this research, different methods were used to establish the precise bucket positioning and track elevation on an actively mined block/polygon by using BenchManager which relies on the motion of the GPS antenna scribing an arc as the excavator is rotated to determine the equipment’s centre of rotation. This was done by placing the bucket with the teeth flat on the ground (anywhere) and taking the rover and measuring left and right teeth on the outside of the teeth and taking note of the coordinates, first eastings and northings and lastly the elevation. The coordinates so obtained were filled in the accuracy excel file and then verified to ensure that the distance between surveyed point and the selected point on the screen in the excavator was less than 50cm to achieve a +/-0.3m tolerance. If it was over the tolerance, recalibration had to be done. The above system allows to identify the blast, flitch, polygon, and dispatch material automatically to an agreed destination as per the mining plan as follows:

Table 1 Primary and secondary loading fleet

Fleet Item	Make/Model	Quantity
Shovels/excavators	Liebherr R9250D BH (250 t)	3
	Liebherr R9350D BH (330 t)	4
	Liebherr R9350 ER (330 t)	4
	Liebherr R984C (120 t)	5
	Hitachi EX2500 BE	2
Trucks	Caterpillar 777D	2
	Caterpillar 785D (150 t)	42
	Hitachi EH3500ACii (170 t)	40

a) **Short listing of a block**

i. A blast was chosen where pre and post-blast survey was captured to determine movement and swell factors of ore.

ii. Polygons were then adjusted and published into Wenco.

b) **Scheduling of a block in the mining plan and allocation of diggers.**

The plan allowed for the shortlisted block to be mined with the following verified: One backhoe was to be used on that mining block and was to have the high precision auto dispatching functionality turned on (or multiple excavators that have been agreed upon).

Calibration checks were done on this/these excavators/s – accuracy had to be within 0.5m.

The mining plan required that the following control measures were in place:

i. The Dig-plan surveyed on the pit floor and used by the KMP field assistant was adjusted and the same as the digital data used to control the Wenco High Precision (HP) process.

ii. The Operator utilizing the HP digger was to adhere to the polygon boundaries and cut/fill data was displayed on his Bench Manager screen. Operator was to focus on avoiding loading trucks with buckets from different materials.

iii. The Trainer was to be available across shifts to ensure operators followed floor/boundary rules.

iv. The Person in Charge (PIC) had to ensure that the dozer did not push in material from adjacent blocks into the block which was being mined.

v. If the digger floor required sheeting, the mining engineer was consulted and the number of loads tracked.

c) **Automatic material dispatching validation checks**

i. The high precision system auto detected the material and polygon.

ii. Destinations for the materials was obtained from the Shift Engineers and configured in the system by Dispatch.

iii. As the digger began to load and/or changed material – the Dispatcher validated that the trucks received the right assignments. The data was then reviewed by the Shift Engineer when required.

d) **Exceptions raised while mining**

i. Real time High Precision Exception Report – This report was flagging events when the digger operator mined outside the blast boundary or over mines D flitch. It also provided information when the digger crossed polygon boundaries and when a truck was loaded with two different material types (mixed load). The material changes flagged in the report were supposed to match the data that was provided by the grade controller to Dispatch.

ii. The following items were reviewed before start of trial: toe crest buffer, toe crest slope, dig block damping factor.

iii. Hardware issues – the real time exceptions report flags hardware faults. This needed to be monitored and the digger was to be stopped if a persistent issue was observed.

iv. When a digger breaks down, no other digger was to be used other than the agreed one.

e) **Mining Validation checks**

If the polygon depletion report reached 100% for any polygon within that blast, mining operations stopped until the area was surveyed. This check provided an idea if the load factors being used needed to be adjusted.

f) **Weighing of trucks**

i. A calibration check of the weighbridge was conducted. A rated payload was loaded on to a truck and weighed. Results ideally had to match the rated payload.

ii. Each truck coming from this block was to be weighed, in order to remove any truck size restriction that was needed to be imposed, especially during the rainy season when CAT trucks get into Production faster.

iii. No other trucks from any other blocks were weighed reflecting the priority of this trial and thus reducing error margin.

g) **Checks when B flitch is mined out**

Once B flitch was mined out, the mining of that block was to be stopped and the following checks were carried out:

i. Polygon depletion report needed to be aligned.

ii. Dirty loads dispatching needed to be validated.

h) **Post Mining Survey**

Once the polygons were mined out according to the Polygon/Block Depletion Report, a survey was carried out to see how much material was left in the polygon/block before continuing to mine it. This was used in order to provide a better understanding of truck factors being used. The remaining material, if any was not mined until the 'Control Report' was run and data analysed before further mining continued.

Determination of production rates

Determination of production rates through optimised loading and hauling cycle times (truck shovel waiting times) and fleet performance was done by tracking production performance through cycle time, utilisation, availability and overall productivity of the machines. This took into consideration the queue, load and hanging times. Truck performance/ productivity was determined per truck type inclusive of excavator performance. Use of excel spreadsheet was utilised to compile and compute all relevant key performance indicators (KPIs) under loading and hauling

Monitoring the material type and quality /grade of ore delivered

Bench Manager was utilised in line with dispatch and the physical inspection assisted by the grade controllers to ensure the right polygon/block matched what has was published on Wenco system as mining progresses.

RESULTS AND DISCUSSION

Effects of Precise Bucket positioning

The introduction of BenchManager gives operators the power to cut and fill to design. Figure 4, shows a backhoe bucket and track chain location based on a particular cut back mining to a targeted elevation.

Mining information: Block ID W2_1315_B35; Cutback W2; Blast No. 35; Target Elevation 1320RL; Flitches: b; Material: LG_SUL and Equipment. EX 66

The current mining tolerance on the either flitch is +/-0.5m. The excavator 66 in Figure 4shows that the bucket location during that period of mining was at 1320.91RL. Target elevation to the b-flitch was 1320RL.

Variance= Actual RL –Target RL= = (1320.91-1320) RL=0.91m.

This shows that the digger in this area was over mining by 0.41m. Over mining affects many downstream processes such as ore dilution/loss, reconciliation of mined material being overestimated from planned volumes etc. Achieving the correct RL is very vital in mining. WENCO is currently being utilised to reduce on over mining and mining to correct RLs. The lower the tolerance in the Z-direction, the more precise the RL.

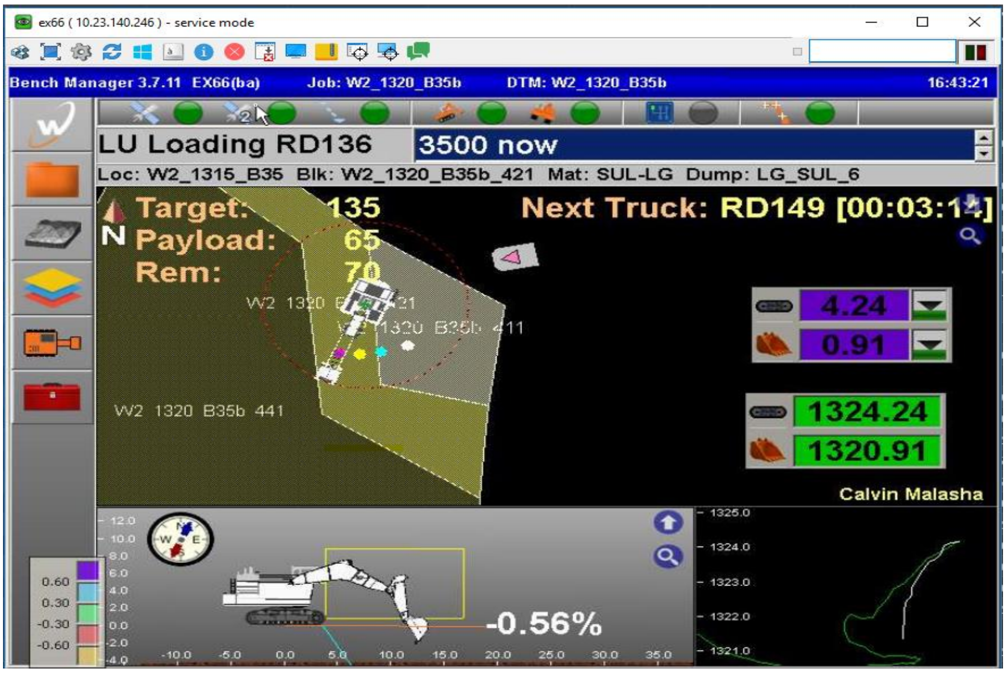


Figure 4: w2_1315_b35_b BenchManager

Figure 5shows a shovel bucket and track chain location based on a particular cut back mining to a targeted elevation of 1275 RL.

Mining information: Block ID M11_1275_B07; Cutback M11; Blast No. 07; Target elevation 1275 RL; Flitches: d; Material: LG_SUL and Equipment. EX 29

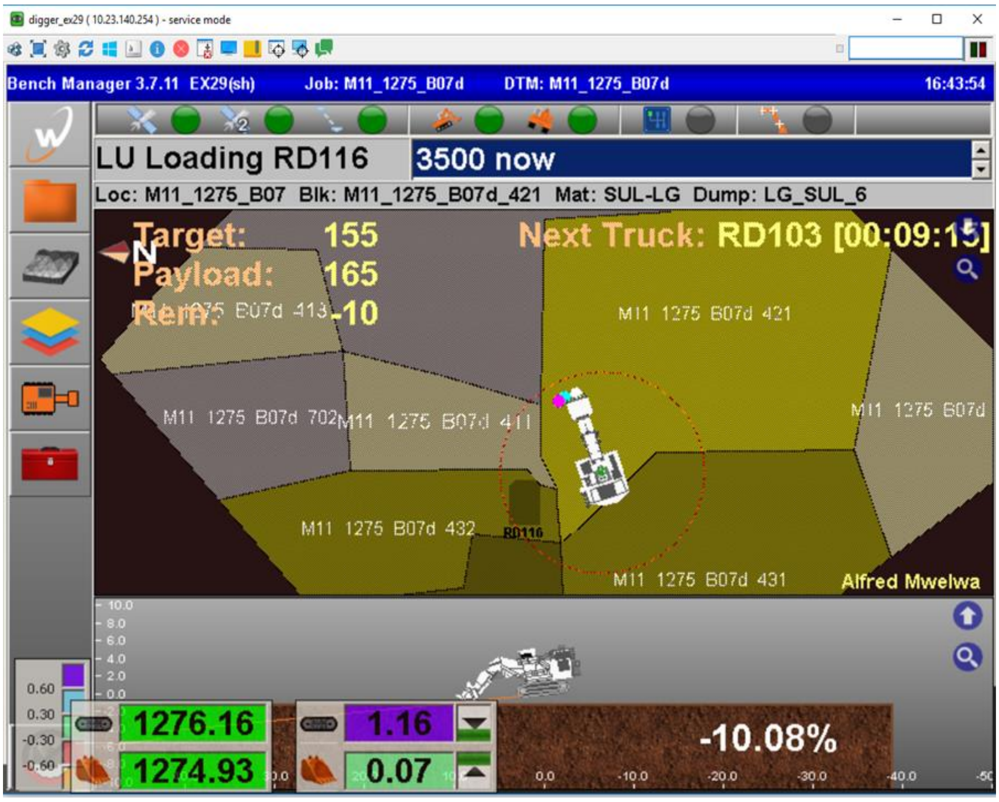


Figure 5: BenchManager view of a shovel (Ex 29)

The bucket location in this case should be almost at the same elevation as the track chains based on the mining location. The three digit number shown in the different colour codes represent the following: First two digits represent material type and last digit is number of assigned polygon. Accordingly, 421 indicated in light yellow represents material type 41 which is low grade sulphide and 1 represents polygon number. 411 shown in light grey is sulphide mineralised waste. Dark grey is waste. Colour code with 431 is medium grade sulphide

Actual bucket location was at 1274.93RL. Target elevation is 1275RL.

Variance = Actual RL – Target RL= (1274.93-1275) RL=-0.07m

This shows that the shovel was under-mining by 0.43m. Under-mining affects other downstream processes along the mine value chain such as reconciliation of mined BCMs and toe that eventually require secondary drilling.

Figure 6, shows Ex 74 which was due for calibration and the initial results. The accuracy centre was 2.12cm and was above tolerance by 324%. Once calibrated, an accuracy centre value was noticed to be within tolerance. Figure 7 shows final validation results

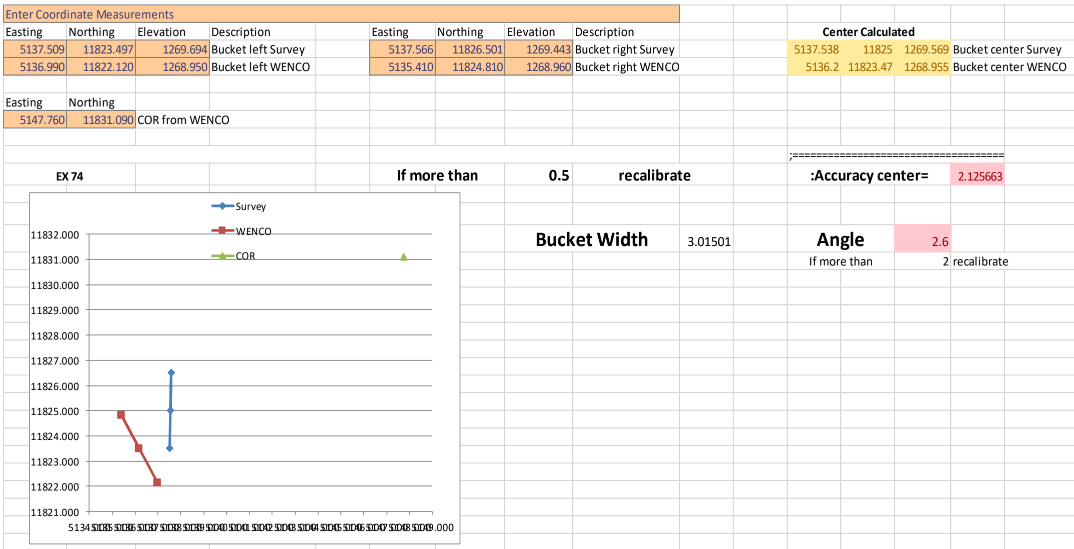


Figure 6 EX 74 Validation results Initial

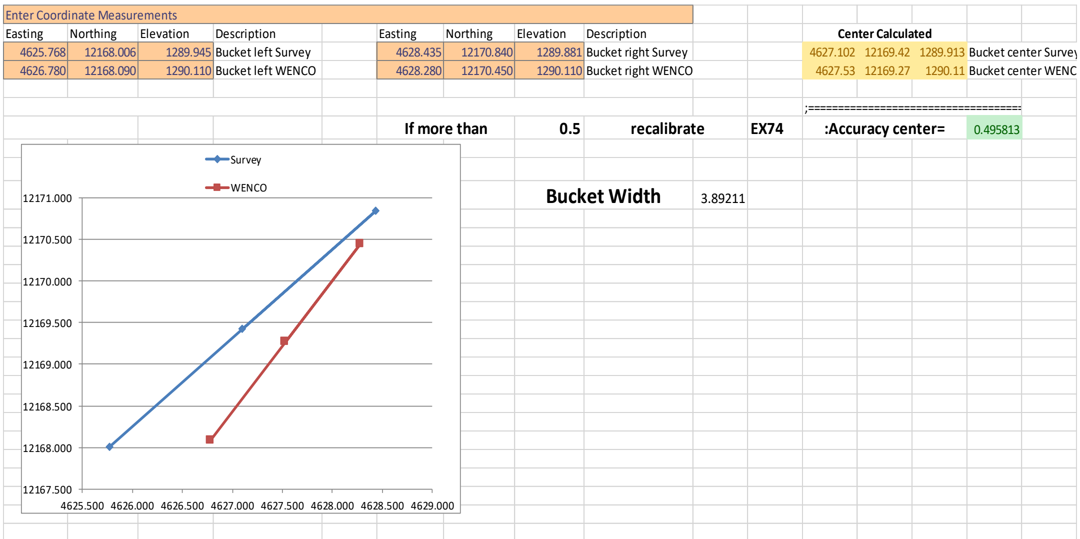


Figure 7 EX 74 Validation results final.

Cycle times and fleet performance

The dispatching algorithm is designed to automatically assign trucks in order to achieve the best utilisation of all mining equipment and maximize production. This minimizes shovel wait, truck wait and truck empty travel times. Budget Haul truck utilisation between January and March remained constant at 70%. From March to May it increased to 85%. Later budget utilisation remained constant at 85 % between May and October and only reduced to 70% in November and December due to rainy season and to some extent non availability of operators and shift change

Using linear programming that examines multiple iterations of equipment configurations, WENCO determines the best plan and then dynamically dispatches trucks to meet plan.

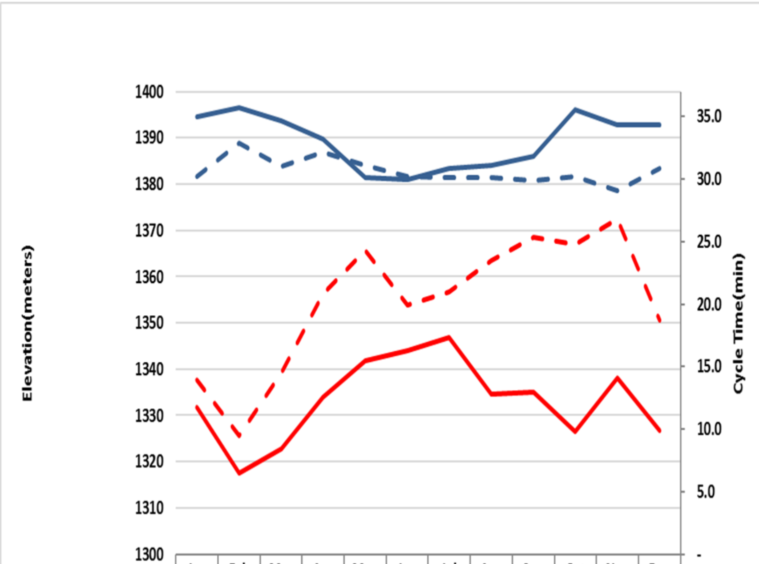
For every assignment, there are two calculations: Schedule and Dispatch

Schedule

This incorporates the mine configurations; Dump location, shovel location, material destination, cycle times and available trucks, as well as any constraints such as maximum crusher dump rate. Using these inputs, the schedule calculates the maximum production achievable. This is expressed in terms of shovel rates or the number of loads per hour the shovels can achieve based on the current mine conditions and setup.

Dispatch

This allocates the trucks in order to best meet the plan.Figure 8 shows Cycle Time Vs Elevations



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual Elevation	1332	1318	1323	1334	1342	1344	1347	1335	1335	1326	1338	1327
Budget Elevation	1338	1326	1339	1356	1366	1354	1357	1364	1369	1367	1372	1351
Actual CycleTime	34.9	35.7	34.7	33.2	30.1	30.0	30.8	31.1	31.8	35.6	34.3	34.3
Budget CycleTime	30.2	32.9	31.0	32.2	31.1	30.2	30.1	30.1	29.9	30.2	29.1	30.8

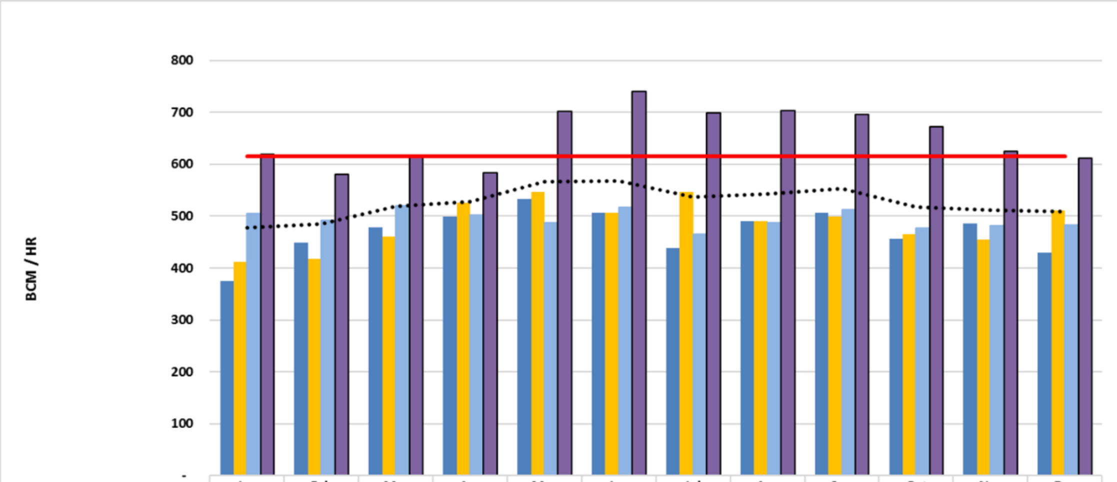
Cutback	Budget	Forcast	Actual BCM	Budget Elev	Actual Elev
m7		104,000	35,695		1230
m11	310,000	891,000	857,898	1308	1308
m12	514,600	775,000	712,490	1257	1252
m13	372,000	364,000	302,654	1419	1449
m14	930,000	315,000	425,254	1375	1394
n9	372,000		41,225	1417	1445
s3		279,000	250,950		1301
s4	372,000	248,000	219,564	1355	1361
w2	372,000	279,000	189,425	1315	1330
Total	**3,242,600**	**3,255,000**	**3,035,155**	**1351**	**1327**

2019	
Budget Cycle Time	Actual Cycle Time
30.6	33.0

Figure 8 Cycle time Vs Elevations

As can be seen from Figure 8, variations in cycle time between actual and budget were generally higher except for the month of May. The variations are attributed to different cutbacks which have different material configuration and dump locations. In Figure8, budget elevations/cycle times relates to the schedule while actual elevations/cycle time relates to dispatch. The variations in cycle time are dependent on exposure of ore based on various cutbacks based on which areas in a particular month have considerable amounts of ore to feed to the crushers.

In instances where challenges such as boulders and mining in boggy areas were encountered, there were increases in the loading times and hauling distances to the prescribed dumping location based on the type of material. In such circumstances, the increase in cycle times led to corresponding reduction in productivity as can be shown in Figure 9.



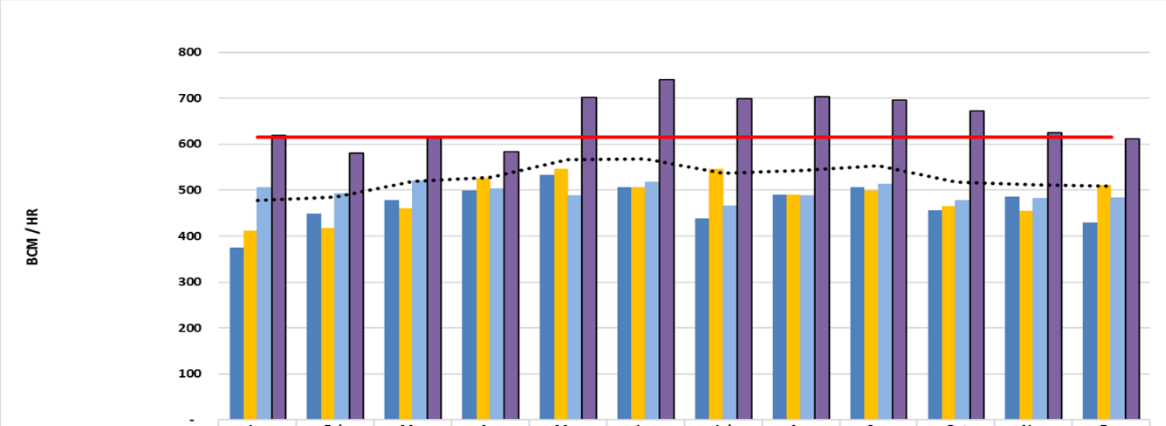
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EX2500-6	376	449	478	499	533	507	438	491	506	456	486	430
LIEBHERR 9250	411	419	461	526	546	507	547	491	499	466	455	511
LIEBHERR 9350	506	491	520	503	488	517	466	487	513	477	482	483
LIEBHERR 9350 E	618	581	617	583	702	740	699	703	696	673	625	612
Budget Productivity	616	616	616	616	616	616	616	616	616	616	616	616
Average Productivity	478	485	519	528	567	568	537	543	553	518	512	509

Figure 9Excavator productivity performance

However, overall productivity on the electric 9350E shovel (Figure 10) was on the higher side across the months based on the mining areas/cutbacks with favourable fragmentation and shorter cycle times.

Material Quality Delivered to the Crushers

Within the algorithm is the ability to specify the ore quality targets that are to be delivered at a certain location. Multiple locations are supported and each can have different requirements. The algorithm knows which shovels are digging in what material types and what qualities are expected at each location and will use these values in the two calculations to schedule and dispatch as described earlier. The schedule calculation determines the rates required for each shovel so that the best material grade can be achieved. Then the dispatch calculation makes its decision to best meet that plan. The end result is the delivery of material coming as close to the middle of the grade ranges as possible.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EX2500-6	376	449	478	499	533	507	438	491	506	456	486	430
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LIEBHERR 9350 E	618	581	617	583	702	740	699	703	696	673	625	612
Budget Productivity	616	616	616	616	616	616	616	616	616	616	616	616
Average Productivity	478	485	519	528	567	568	537	543	553	518	512	509

Figure 10 Excavator productivity performance

The specific benefits realised from the implementation of WENCO's fleet monitoring (high precision mining tool-HPM) and dispatch system at Kansanshi Mine include:Improved productivity of personnel and equipment; Improved content consistency of the material feeding the ore enrichment plant; Increased throughput of the crushers; Availability of statistical data to enable continuous improvement and accountability of mobile equipment operators.

These results indicate that there is a strong business case for implementation of a WENCO fleet monitoring and dispatch system at the mine. The usage of WENCO has resulted in overall improved mine productivity. The reconciliation of the mined BCMs has also improved as misplacement of material (wrong dumping) has dropped drastically from 35% to 10%. Furthermore, the cost of mining has reduced from 12.4$/BCM to 10.3$/BCMs. This observation is supported by WENCO International Mining Systems which has stated that HPM when correctly applied results in high productivity and reduction of mining costs (Wencomine, 2019). Additionally, the use of WENCO has played a major role, as the information is readily accessible to both the operator and dispatchers with the updated topographies (Bristol V. , 2000).

In this study, precise bucket positioning and primary excavators matched designs to the smallest detail of about 50cm. This was made possible by centimetre precise satellite guidance, which sends second by second updates to equipment on board touch screens. Hence, operators simply followed the onscreen guidelines as they cut and filled to design. Previously, lengthy surveys and grade staking were wasting hours of productive time.

In terms of cycle times vs elevations, the following was observed: accurate spotting data was used to check that the loading unit is efficiently loading with minimal waiting times based on the loading and waiting zones demarcated. With the use of WENCO, the excavator cycle time key performance indicator (KPI) was more accurate based on the sensor fittings on an excavator. However, the target load time of 3minutes from the time WENCO was implemented was not ideal even though the loading time has been accurate.

However, the use of WENCO at the mine has also encountered the following practical difficulties: Activating the dispatching tool has been found unsuitable for the complex Kansanshi vein hoisted ore-body which has 13 material types. On a particular blast, there can be a minimum of 5 different material classes that require various dump location. The major challenge is to mine along boundaries of these material classes. If the dispatch system is put into dynamic dispatching, it picks on the las bucket count regardless of whether it is waste or ore thereby increasing mining dilution. This observation is very significant for Kansashi Mine and for other deposits elsewhere in the world with complex geology who would want to use this tool. In Zambia, this is the first time that WENCO as a dispatching tool has been used and evaluated. The other practical difficulty we encountered is that WENCO system is fully dependant on satellite network. This made data capturing difficult if there was interference with satellite network.

CONCLUSIONS

Implementation of WENCO's fleet monitoring and dispatch system has resulted in improved utilisation of mining equipment from 70% to 85 % and production. Based on the study, the following conclusions can be drawn:

1. Establishing precise bucket position with the assistance of the survey team was the most critical in determining the accuracy of mining. The X, Y AND Z coordinates used as a benchmark improved on tracking both the mining elevations and material boundaries to avoid mining dilution as much as possible. With the tolerance of X=0.5m, Y=0.5m and Z=0.5m, it was noted that events of a bucket mining out of the assigned polygon was reduced to a few centimetres of about 50 cm in distance and an alert had to show to rectify this on the X and Y direction.
2. The loading times became more accurate in terms of measurement and reporting. This was defined based on the status of the loading unit and the prescribed load and wait zone by the operator. The loading time in this case was almost in the same network range of 30m distance for both the loading unit and the hauling unit. The interference of dispatch played a huge role as well. With the use of WENCO, the excavator cycle time at KPI was more accurate based on the sensor fittings on an excavator. However, the target load time of 3minutes from the time WENCO was implemented was not ideal even though the loading time had been accurate.
3. Reconciliation of the mined BCMs has largely improved as misplacement of material (wrong dumping) has dropped drastically from 35% to 10%. The use of WENCO has played a major role, as the information is accessible to both the operator and dispatchers with the updated topographies. Except the material delivered to crushers is not as accurate since the bucket loads are fixed.
4. The following challenges however, continue to be experienced with WENCO: Activating the dispatching tool has been found unsuitable for the Kansanshi vein hoisted ore-body which has 13 material types. If the dispatch system is put into dynamic dispatching, it picks on the last bucket count regardless of whether it is waste or ore thereby increasing mining dilution. Additionally, since WENCO system fully depends on satellite network, the mine has in certain instances faced challenges in data capturing once there is interference with satellite network more especially in rain season.

Recommendation

1. Excavator bucket tolerance to be reviewed on the X, Y and Z-axis for results that are more accurate. Preferably +/-0.3< on the Z-Axis to achieve correct results which are: reduced mining dilution, over mining and undermining.

2. Budget cycle time against actual to be revised based on real time study of various mining locations and dumping locations. Determining of optimal waiting and loading zones on each particular digger should also be done.

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Disclosure statement

The authors wish to state that there are no financial/potential conflicts of interest in this study.

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