Arch. Min. Sci. **70** (2025), 1, 29-44

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI: https://doi.org/10.24425/ams.2025.154161

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# PRODUCTION PERFORMANCE EVALUATION OF THE HOISTING SYSTEMS AT AN UNDERGROUND GOLD MINE

The production performance of two hoisting systems operating in series at an underground gold mine was evaluated based on several key performance indicators (KPIs). All the KPIs were lower than the mining industry benchmarks, mainly due to lengthy and recurrent machine downtimes. Frequent breakdowns, power cuts, poor maintainability, and shaft flooding were some of the factors affecting the overall performance of these systems, as captured on the developed Fishbone Diagram. The average cycle times were much longer than expected, and the production rates were significantly lower at a 5% significance level than the requisite 160 tonnes per day. There were mismatches in the throughputs of the hoisting systems, indicating an unbalanced hauling process. Therefore, the current maintenance strategy for the hoisting systems warrants review in order to cut downtime. Alternative power sources are needed to complement electricity from the national power grid. The methods, findings, and data analysis techniques applied in this study can be used for evaluating the performance of mining equipment elsewhere, benchmarking and optimisation functions.

**Keywords:** Production and maintenance performance; hoisting systems; hoist cycle time; mining key performance indicators; Fishbone Diagram; mine productivity

## 1. Introduction

Productivity and efficiency of mining equipment are some of the most crucial determinants of mining costs. According to Paraszczak [1], measuring and benchmarking them is one of the best ways of identifying the possibilities for improvement. The key performance indicators (KPIs) of mining equipment encompass overall equipment effectiveness (OEE), utilisation production efficiency, availability, reliability, maintainability, performance and quality. Mining companies

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should aim for high values of these KPIs regarding capital-intensive equipment to maximise productivity while minimising production costs and shutdowns [1-4].

Effectiveness is the same as producing quality results with the minimum wasted effort. The mining industry's effectiveness commonly refers to the mine machinery and focuses mostly on the equipment availability and utilisation [1,2,5,6]. According to Barringer [7], effectiveness can be calculated from Eq. (1).

$$Effectiveness = Availability \times Reliability \times Maintainability \times Capability \tag{1}$$

OEE is the primary metric of total productive maintenance, with 85% generally considered the world-class benchmark [8-10]. It indicates the contribution of each unit of equipment as a percentage of its potential to add value to the entire system [11]. It aims to identify unproductive time losses within the system, and these time losses affect availability, performance and quality. The and Johnston [12] state that the period in which the OEE is measured for the equipment can be a day, an hour, a shift, a week or whichever period suits the nature of the operation and at the discretion of the investigator(s). OEE is given by Eq. (2), while the main components of OEE are determined from Eqs. (3)-(5) [6].

$$OEE = Availability \times Performance \times Quality \tag{2}$$

$$Availability = \frac{Actual\ Available\ Time}{Total\ Time} \tag{3}$$

$$Performance = \frac{Net\ Production\ Time}{Actual\ Available\ Time} \tag{4}$$

$$Quality = \frac{Valuable\ Production\ Time}{Net\ Production\ Time} \tag{5}$$

Availability refers to the duration of up-time operations and is ideally 85% to 98% for continuous processes [7]. However, the studies surveyed in which this KPI was determined for mining equipment such as rope shovels, dump trucks, loaders, excavators etc., have shown wide variability from this range, with some reporting comparable values [2], while others have reported availability indices below 85% [5,13,14]. This can be easily explained by the uniqueness of each mining operation and numerous other factors such as weather conditions, the type, size, and age of equipment under consideration, skills and competency of operators, ore characteristics etc. among others [10]. In the absence of a universally accepted benchmark of availability for all the various types of mining machinery, it is plausible to use 85% as the threshold value. Availability is the ubiquitous mining KPI because it is easily understood but the choice of input values varies from mine to mine [1].

Reliability aims to reduce the frequency of failures over a given period and is a measure of the probability for failure-free operation during a given interval [15]. Maintainability is defined as the downtime for maintenance or the time taken to complete the maintenance of equipment compared to a datum [7]. Availability, reliability, and maintainability can be calculated from simple mathematical models, but with the right data [1-3,5-8,12,16,17].

Capability measures the productivity of machinery or equipment compared to a set standard and can be defined as the product of efficiency and utilisation [1,7]. Considering that mining is a very capital-intensive industry, equipment utilisation and its estimation are crucial since the mine management team would want equipment to be fully utilised because it assists in getting an early return on investment as well as reducing total production cost [3,8,11,18,19]. Utilisation can be computed easily using Eq. (6).

$$Utilisation = \frac{Number\ of\ Operating\ Hours}{Actual\ Available\ Time} \tag{6}$$

Performance takes into account speed loss, which includes factors that cause the equipment to operate at less than the expected speed. Quality accounts for product loss, and the filling factor of mining equipment is a good estimation of this KPI [6]. While there are many reported applications and benefits of OEE in the mining industry as a KPI, the importance of OEE is only realisable provided its components are measured and examined more meticulously than is the current norm [1-3,12].

### 1.1. Study of underground gold mine hoists

This study focused on an underground mine exploiting a gold reef deposit, using the shrinkage-stoping mining method. The mine has one tramming level and the extracted gold (Au) ore is hoisted to the surface for processing. It currently operates two shafts handling 4.5 g/t and 3.5 g/t Au ores respectively. The two shafts have a design capacity of 200 tonnes per day (tpd) and 160 tpd respectively, for a combined 360-tpd capacity.

However, this paper centres on the shaft with a 160 tpd design capacity, which handles the 4.5 g/t Au ore. The 160 tpd throughput constitutes 44.4% of the total mine production per day. This shaft has two single drum hoisting systems (Hoisting System 1 – $HS_1$, and Hoisting System 2 – $HS_2$). $HS_1$ is an inclined shaft hoist for ore transportation from the 252 m level to the 101 m level. $HS_2$ is the vertical shaft hoist which moves the ore from the 101 m level to the surface. Fig. 1 shows a vertical cross section of the underground gold mine, with shaft number 4

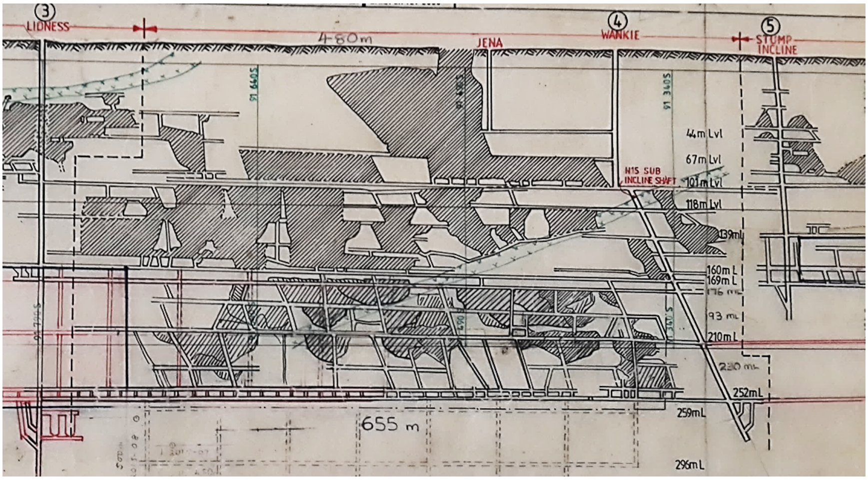

Fig. 1. A cross section of the underground gold mine showing the N15 sub-incline shaft and the Wankie vertical shaft, where $HS_1$ and $HS_2$ operate respectively

or Wankie – N15 being the focus of this study. Hoisting is considered one of the five, autonomously operational subsystems of underground mines [20], with drum hoists being the more popular hoisting technology in some sub-regions of the world compared to friction hoists [21].

The hoisting cycles for these two systems are presented in Fig. 2 and Fig. 3, respectively. $HS_1$ and $HS_2$ are expected to have the same productivity for the whole system to work efficiently, with the expected throughput for each hoist being 160 tpd. Owing to persistent shortfalls in the daily hoisting throughput, it was deemed necessary to evaluate the productivity of these hoists, and identify the challenges and opportunities for their optimal performance. This study evaluated the production performance of these two hoisting systems based on the hoist cycle times, OEE, availability, utilisation, and quality.

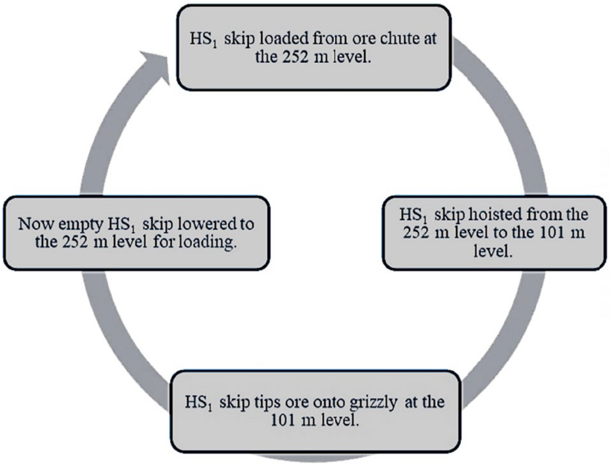

Fig. 2. Hoisting cycle for $HS_1$

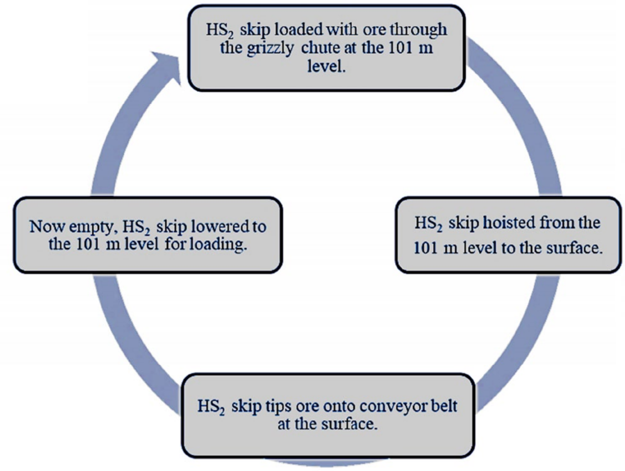

Fig. 3. Hoisting cycle for $HS_2$

### 1.2. Hoist cycle time

The hoist cycle time is the sum of the periods of acceleration, uniform speed, retardation, and rest. It can be calculated from Eq. (7) or (8) [21].

$$T = \frac{H}{V} + \frac{V}{a} + stops + creeptime \tag{7}$$

Where $H$ is the hoisting distance, $V$ is the full line speed of the skip, and $a$ is the average acceleration and retardation.

$$HCT = LD + HTL + OT + HTE \tag{8}$$

Where $HCT$ is the hoist cycle time, $LD$ is the loading time, $HTL$ is the hoisting time of the loaded skip, $OT$ is the offloading time, and HTE is the hoisting time for the empty skip.

The experimental observations were planned based on the three hypotheses:

$H_{0,1}$: There was no significant difference between the actual tonnage of ore hoisted and the target tonnage for both hoisting systems at the 5% level of significance.

$H_{0,2}$: There was no significant difference in the productivity of the two hoisting systems at the 5% level of significance.

$H_{0,3}$: There was no significant difference between the mean cycle time and expected cycle time for either hoisting system at the 5% level of significance.

## 2. Methods

The experimental work consisted of completely randomised observations on-site at the mine and historical data collection. A thorough assessment of production records from the mine database revealed that the mine had its worst run in September of 2023 for 24 days. These 24 days were taken as the worst-case scenario, and subsequently, all production data on the ore tonnages hoisted daily centred on these specific days. The methods used were:

1. Collation of ore tonnage data: The mine records were analysed to collect data on the ore tonnages hoisted over 24 days.
2. Downtime and cause analysis: The mining database was used to collate data on the daily downtimes of the hoisting systems and their associated causes over the same 24 day period. This helped identify factors affecting hoisting performance, which were then classified as direct or indirect hoist system problems. The recorded downtimes were also used for shift analysis.
3. Cycle time measurement and collation from mine records: Time and motion studies were conducted over 5 days to determine the mean or optimum cycle times for each of the two hoisting systems and quantify the contribution of the hoisting cycle elements to the overall cycle time. These 5 days were different from the 24 days used for the productivity evaluation, as the mean cycle times had to be ascertained in real-time through on-site experiments conducted from November 9-13, 2023. The cycle times were measured for different shifts and operators, with a total of 25 cycle times obtained for each hoisting system. Operator details were collected to identify the human influence on cycle time.

The cycle times were measured using a stopwatch as recommended by [21] and recorded in a logbook, then transferred to a Microsoft Excel spreadsheet for evaluation. Hoisting distances we calculated using the elevation data and shaft inclination angle. Subsequently, the average cycle times for the hoisting systems over the 24 days identified earlier were computed from the time logs in the production database at the mine.

4. Shift and shaft analysis: Shift analysis involves evaluating various elements of the shift at different times to calculate the effective shift hours and machine utilisation. This included assessing factors like mine re-entry time, hoisting system management, pre-checks, and external influences. An evaluation of the shaft condition was also conducted to assess how design parameters could affect cycle time and hoisting productivity.
5. Key performance indicator calculation: The availability, utilisation, quality, and overall equipment effectiveness (OEE) were computed for each hoisting system.
6. Data presentation and analysis: The hoisted ore tonnage and cycle time data were presented graphically, while statistical methods like *t-tests* were employed to analyse the performance of the hoisting systems in terms of production requirements and potential improvements. A Fishbone Diagram was developed to categorise the factors adversely affecting the hoisting systems.
7. Improvement opportunities: Realistic opportunities for improving the performance of the hoisting systems were identified based on the holistic consideration of the key machine performance indicators and the causes of hoisting system downtimes.

These methods are aptly summarised in Fig. 4 for expedited visualisation.

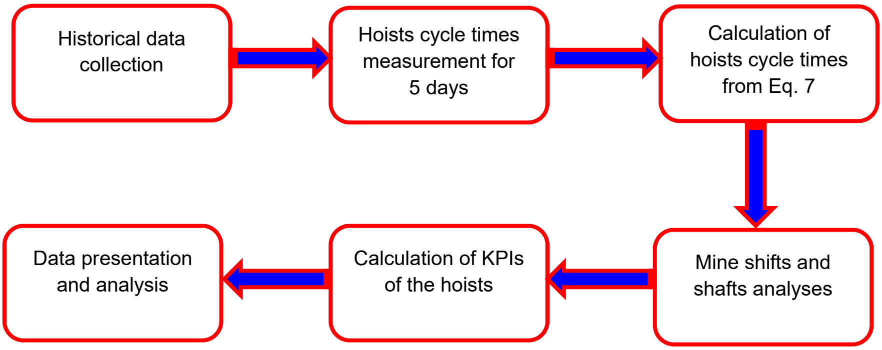

Fig. 4.

# 3. Results

## 3.1. Hoists production performance and downtime analysis

Fig. 5 illustrates the production throughput of $HS_1$ and $HS_2$ hoisting systems compared to the production target of 160 tpd. The days that the two hoisting systems have exceeded the production target correspond with zero downtime, and it can be visualised in Fig. 5 that only $HS_1$ managed this feat once in the 24 days, and it also met the target once. $HS_1$ generally performed much poorer than $HS_2$ over the study period due to more frequent breakdowns, work stoppages due to shaft flooding, and challenges with ore loading and offloading. Inclined shaft hoisting systems are also intrinsically associated with reduced capacity [21].

Fig. 6 illustrates the downtimes for the hoisting systems. Downtime of mining equipment and machinery results in lost production, which in turn increases the cost of production [22]. The horizontal line represents the available operating hours per day. As shown in Fig. 6, on the days where the columns intersect the horizontal line, it indicates that the hoisting systems were non-operational during the scheduled 16-hour production time, and the cause(s) of the downtime could not be resolved within that time frame. If the columns intersect the horizontal line, it implies that zero tonnes of ore were hoisted on those corresponding days, for example, Day 1 for $HS_1$ and Day 3 for $HS_2$.

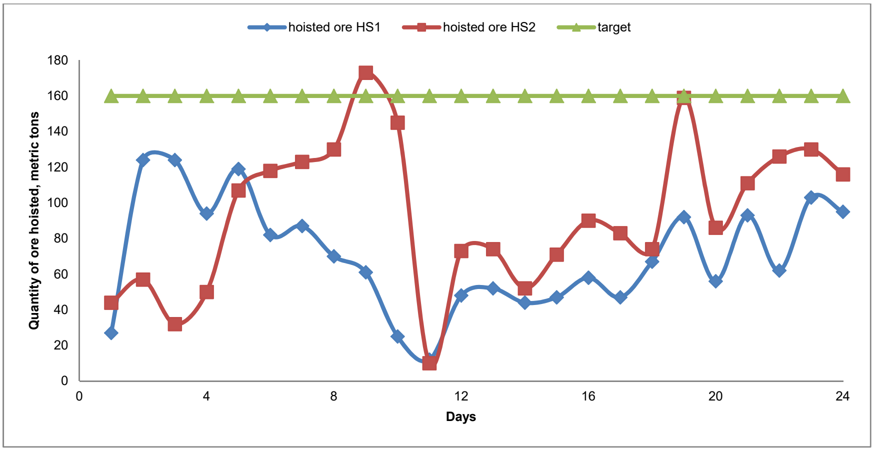

Fig. 5. Daily production for $HS_1$ and $HS_2$ hoists compared to the daily hoisting target

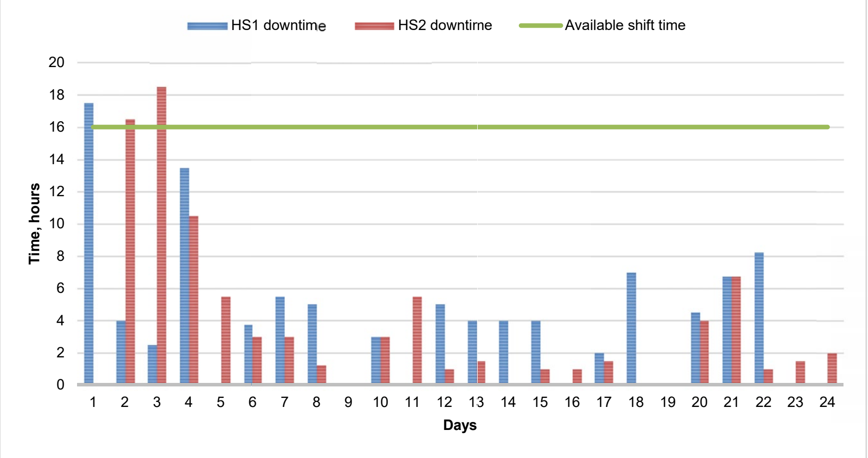

Fig. 6. Downtimes of the hoisting systems

## 3.2. Fishbone Diagram

The causes of the daily downtimes were categorised into four classes and presented on a Fishbone Diagram, a widely adopted quality control tool [23,24], as illustrated in Fig. 7. The recorded downtimes and their associated causes from the mine production database were used to quantify the four elements contributing to the total hoisting system downtime, as shown in Fig. 8.

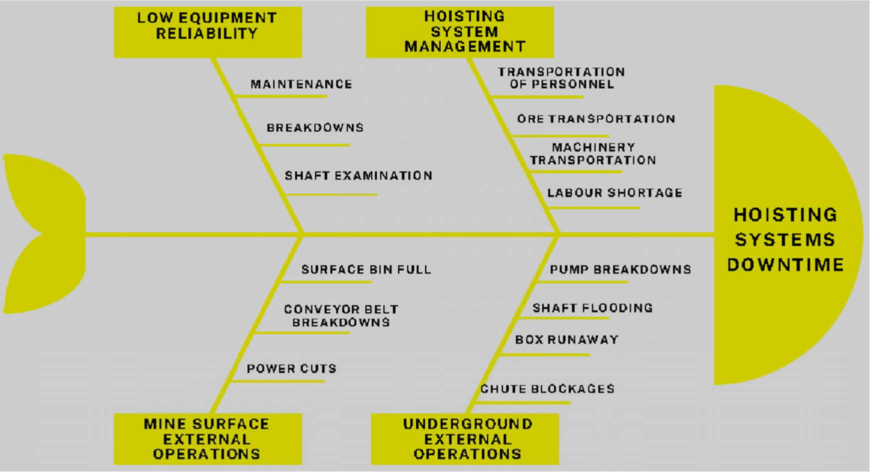

Fig. 7. Fishbone Diagram of the hoisting systems downtimes

Fig. 8 indicates that low equipment reliability, as demonstrated by frequent breakdowns and maintenance shutdowns, was a significant contributor to the total downtime for either hoist-

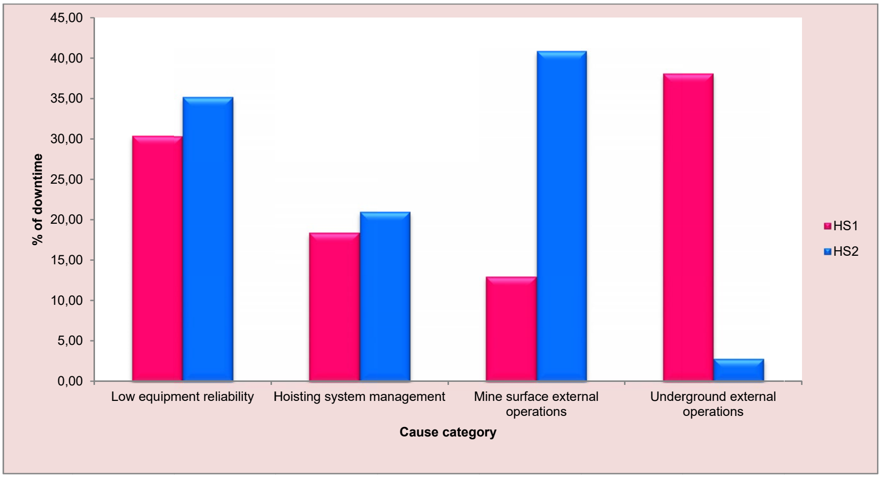

Fig. 8. Downtime causes and associated percentage contributions

ing system. Shaft inspection, which is part of the preventive maintenance plan, also impacted downtime. However, mine surface external operations impacted $HS_2$ downtime the most, while underground external operations impacted $HS_1$ downtime the most. This is easily explained by the fact that $HS_2$ conveys ore to the surface, while $HS_2$ is restricted to feeding $HS_2$. $HS_1$ has much longer downtimes compared to $HS_2$, and the component of downtime responsible is underground external operations, which have relatively little impact on $HS_2$. $HS_1$ is an inclined shaft hoist from the 252 m level to the 101 m level, unlike $HS_2$, which is a vertical shaft hoist from the 101 m level to the surface. Nonetheless, power cuts affect $HS_1$, which explains the contribution of mine surface external operations to the hoist's downtime, as shown in Fig. 8.

Shaft flooding is more pronounced at the lower levels and thus is more likely to affect $HS_1$, whereas if the conveyor belt transporting ore from the bin at the surface or the surface bin is full, $HS_2$ is affected. Power cuts should have the same impact on the downtime for either hoisting system, and Hansel [15] characterises all power failures as catastrophic since they cause unplanned shutdowns. Hoisting system management is also an important contributor to downtime, but the impact can be reduced by better scheduling and optimising the size of the workforce at each hoist. The downtime analysis for $HS_2$ shows that mine surface external operations contribute the most (40.91%) to total downtime, and this was mainly because the surface grizzly was frequently clogged. At times, the surface ore bin would become full (see Fig. 7), necessitating a temporary halt to the hoisting operations. This allowed the dump trucks to transport the accumulated ore to the processing plant located 5 km away from the shaft. This scenario highlights the interdependence between the hoisting operations and the availability of the dump trucks. Whenever the dump trucks experience breakdowns or other operational issues, the impact directly affects the hoisting operations, potentially leading to disruptions and delays.

Equipment failures and unscheduled maintenance are responsible for significant losses in production and unnecessary capital investments in new machinery [3,6]. This is the case for this gold mine as the poor availability of the hoisting systems has severely impacted ore dressing, gold extraction and refining operations in the processing plant, resulting in revenues dropping. There is a need to measure the performance of the maintenance function at this mine. The maintenance performance measurement conceptual framework and indicators developed by Muchiri et al. [25] for the manufacturing industry can be adapted with the relevant modifications to mining operations.

## 3.3. Hoists Cycle Times

The planned cycle time for $HS_1$ is 5 minutes 30 seconds (Fig. 9), but the average cycle time from collected data was 6 minutes 12 seconds. The actual average cycle time is 42 seconds greater than the expected. Since $HS_1$ is an inclined shaft hoist, it is reasonable that its cycle time is longer than for $HS_2$ since the shaft design inherently means retarded hoist speeds [21], and in this case, the travel distance from the loading to the offloading point is also longer. From Fig. 10, loading contributes the most to the cycle time due to the loading mechanism.

Loading from the ore chute was challenging, as the chute gate was often difficult to open when needed. In addition to the chute gate's condition, oversized boulders would occasionally block the chute opening, requiring the operator to use a pinch bar to dislodge them. This added complexity to the loading process and created operational delays.

Oversized boulders are associated with poor rock fragmentation during blasting, and this can be corrected by optimising the drilling and blasting patterns [26-28]. The mining teams at the rock face have to be aware of the top size that can be accommodated by the chute so they design the correct patterns and adhere to appropriate drilling and blasting parameters. A chute design rule of thumb is that its width should be at least equal to 3 times the size of the largest rock fragment to be conveyed to allow the free flowing of the ore [21].

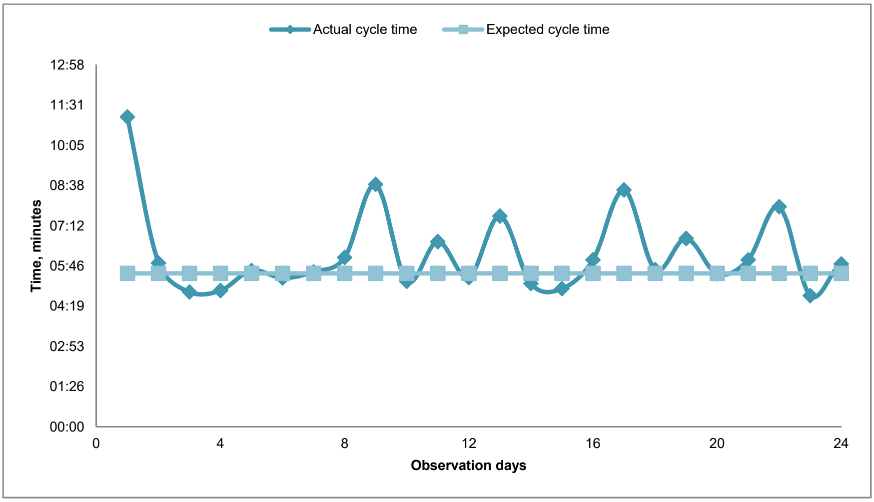

Fig. 9. $HS_1$ cycle time compared to the expected cycle time

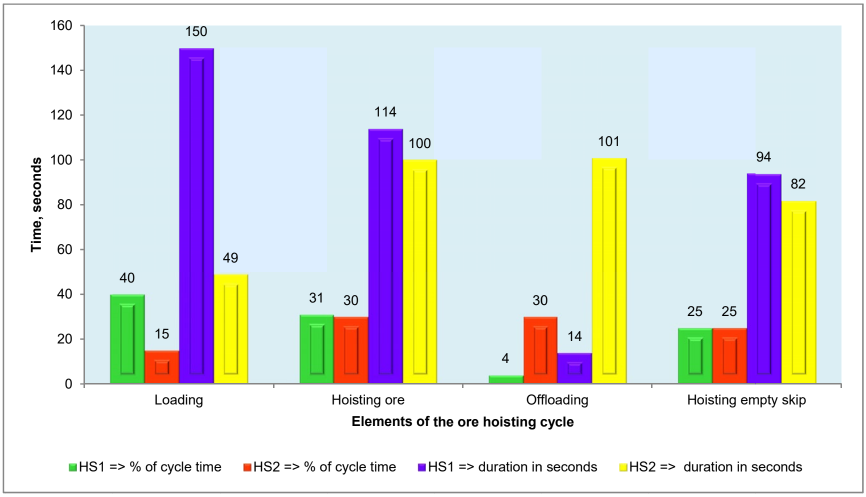

Fig. 10. Contribution of the various hoisting elements to the total cycle time

The planned cycle time for $HS_2$ is 4 minutes 12 seconds (Fig. 11), but the average cycle time from the collected data was 5 minutes 31 seconds. The actual average cycle time is 1 minute 19 seconds greater than the expected cycle time. Ore offloading from the skip contributes the largest percentage of the cycle time, and this affects the hoisting system utilisation [21]. This is a result of the cumbersome manual offloading method, which needs to be optimised [20].

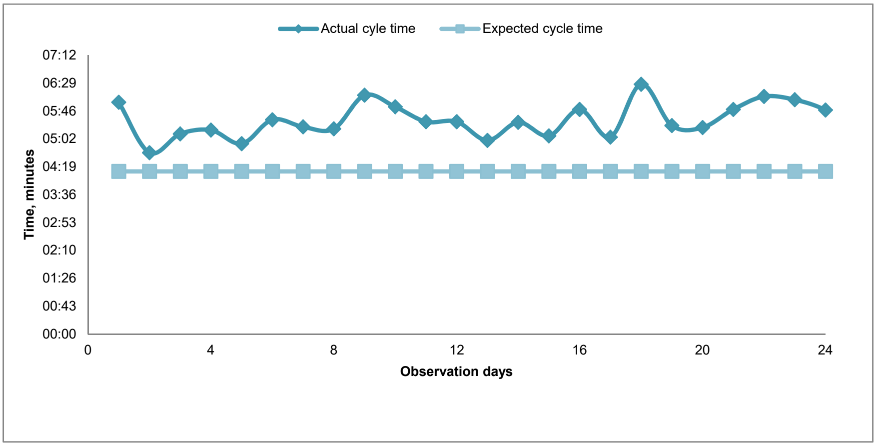

Fig. 11. $HS_2$ cycle time compared to the expected cycle time

## 3.4. Key performance indicators (KPIs)

The calculated KPIs for the two hoisting systems are presented in Fig. 12. The availability of either hoisting system is below the adopted 85% benchmark [2,6]. This is due to the abnormally high downtimes experienced for either hoisting system. One of the most effective ways of increasing equipment's inherent availability is to improve its reliability and maintainability,

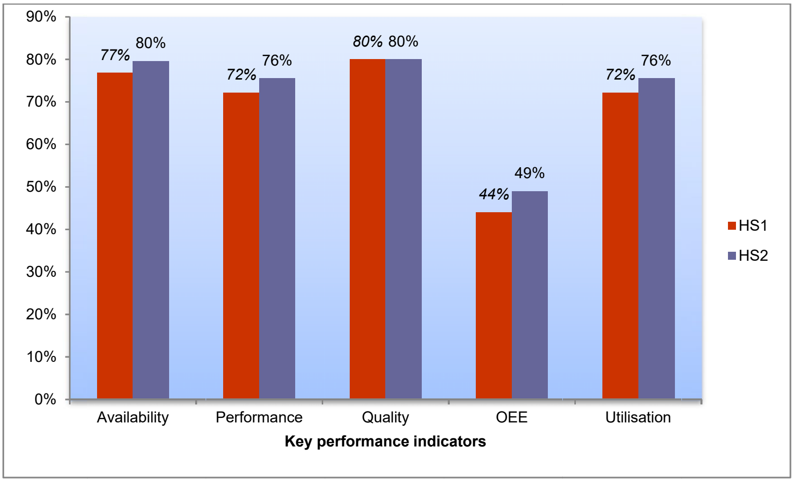

Fig. 12. KPIs of the hoisting systems

either by reducing the number of unplanned shutdowns or by minimising the length of scheduled turnarounds [2,7,15].

The calculated utilisation values of 72.2% for $HS_1$ and 75% for $HS_2$ can be considered normal for the mining industry, but utilisation closer to 100% is desirable and good for productivity. The utilisation of equipment can only be improved and controlled successfully if an appropriate performance measurement system is used [6]. For early return on investment and reduction of production costs, equipment utilisation is very important [2,5,6]. Standby equipment increases the cost of operation, whereas machinery subjected to downtime causes less output. Thus, there is a need to increase the utilisation of the hoisting systems.

The OEEs of 44% and 49% for $HS_1$ and $HS_2$, respectively, are much lower than the industry benchmark of 85% but comparable to those obtainable for a rope shovel or a dump truck [6]. The production performance and availability of the hoisting systems would have to increase substantially to get to this OEE benchmark. When productivity improves, the hoisting systems will yield more output for the same input at no additional cost [3,5,21].

Evaluation of the OEE of a particular machine is usually necessitated by the realisation that its performance is below expectations [6]. OEE helps to identify the problems and opportunities for improving that performance (see Figs. 8-11). The hoisting systems' OEEs are poor because of a matrix of issues depicted in the Fishbone Diagram (Fig. 8), which can only be resolved by coordinated initiatives involving different departments at the mine. The low OEEs of the hoisting systems can be improved by switching from the current Preventive Maintenance strategy to the Total Productive Maintenance (TPM) strategy, which focuses on maximising equipment effectiveness [4,5,8,29].

According to Tomlingson [29], TPM can be implemented easily in underground mines since maintenance technicians are integrated with underground crews, and TPM raises awareness of preventive maintenance among the mineworkers, supervisors, and managers. The merits of TPM and how to implement it are also described in varying degrees in several studies [5,6,8,11,17]. TPM is a proven strategy for maximising OEE in mining [2] and should work for the hoisting systems under consideration [13].

## 3.5. Hypothesis Testing

The *t-test* at a 5% level of significance, together with 95% confidence intervals (CIs) was used to test the three null hypotheses. 95% confidence limits were determined for the data on mean ore hoisted, hoist productivity, and hoist cycle time before running the *t-test* in MS Excel. Confidence limits for the mean are an interval estimate for the mean. Interval estimates are often desirable because the estimate of the mean varies from sample to sample. Instead of a single estimate for the mean, a confidence interval generates a lower and upper limit for the mean. The interval estimate indicates how much uncertainty there is in the estimate of the true mean. The narrower the interval, the more precise the estimate.

### 3.5.1. Hypothesis 1 – Productivity of the hoisting systems

The calculated 95 % CIs for the average tonnages hoisted by the two systems: $HS_1$: CI = (57.2, 83.5) and $HS_2$: CI = (75.5, 110.5). The mean or expected tonnage, i.e. 160 tpd, lies outside and to the right of the CIs (57.2, 83.5) and (75.5, 110.5), indicating that the population mean of ore hoisted by either of these two hoisting systems does not equal 160 tonnes at the 0.05 level of significance. The upper limit of either confidence interval is far below 160 tpd, signifying that these hoisting systems are failing to meet expectations. On this basis, the null hypothesis was rejected.

The decision to reject was supported by a lower-tailed *t-test* conducted to further test Hypothesis 1. The test statistic at the 5% level of confidence was lower than the critical value (2.40) in both cases {$HS_1$ (–0.588) and $HS_2$ (–0.330)}. Therefore, based on the 95% CIs and the *t-test*, the data collected indicated that the actual tonnage of ore hoisted was significantly lower than the target tonnage for either hoisting system.

### 3.5.2. Hypothesis 2 – Steady-state performance of the hoisting systems

The paired two-sample *t-test* is used to determine if two population means are equal [30]. A paired *t-test* simply calculates the difference between paired observations (e.g., $\mu HS_1$ and $\mu HS_2$) and then performs a 1-sample *t-test* on the differences. The absolute value of the test statistic (2.15) is greater than the critical two-tail value (2.01), and thus, Hypothesis 2 was rejected, implying that the two-population means are different at the 0.05 significance level. This indicates that the two hoisting systems are not performing at the desired level of 160 tpd as designed for steady-state operation. Fig. 5 validates the outcome of the t-test and the rejection of this hypothesis.

### 3.5.3. Hypothesis 3 – Mean cycle times of the hoisting systems

The calculated 95% confidence intervals for the mean cycle times of the two hoists are $HS_1$: CI = (05:29, 06:55) and $HS_2$: CI = (05:18, 05:43). The mean cycle time (05:46 for $HS_1$ and 04:19 for $HS_2$), lies inside the confidence intervals ($HS_1$), and to the left of the CIs ($HS_2$). This implies that for $HS_1$ there was no apparent significant difference between the mean cycle time and expected cycle time at the 5% level of significance. However, the opposite is true for $HS_2$, and considering the upper CI, this hoisting system sometimes operates at speeds 01:24 slower than expected. On this basis, the null hypothesis was rejected since both hoists were supposed to satisfy the specified condition.

The decision to reject this hypothesis was supported by a two-tail *t-test* in which the absolute value of the test statistic (2.06), was greater than the critical value {$HS_1$ (0.09) and $HS_2$ (0.60)}. Therefore, based on the 95% CIs and the two-tail *t-test*, Hypothesis 3 was rejected. Figs. 9 and 10 validate this decision, as they depict that the mean cycle times are generally way above the design time. If productivity is to be improved, the mean cycle times need to be minimised. The condition of the hoisting systems is crucial in this regard [15,18,21,31], in addition to how hoisting operations and scheduling are managed [20].

## 3.6. Discussion of the study limitations

This study focused on an underground gold mine, operating a pair of single drum hoisting systems in-line to hoist ore from the 252 m depth to the 101 m depth in a sub-inclined shaft and then from that level to the surface in a vertical shaft at a design throughput of 160 tpd, for a 16 hours per day operation. Both hoisting systems are designed with a single skip, implying that the cycle time is a circuit, i.e. from loading level to offloading level and back to the loading level [21].

Apart from hoisting ore, these hoisting systems also transport waste rock and mine personnel depending on the operating schedule. However, this study was delimited to ore hoisting operations only. As such, the study findings are unique to this particular mine, but the methodologies used and interpretation are of universal applicability. The shaft design parameters, condition of the hoisting systems, operating conditions, competency and skills of the operators running the hoists, and the causes of the hoisting systems downtimes may be unique to this mine, but that does not invalidate the findings of this study. More importantly, the calculated productivity KPIs are comparable to those for other mining projects, which tend to deviate on the lower end from those of manufacturing and chemical processes [5,7,10,12,14].

An important observation though, is that the mine data logging systems are mostly manual, with the mine database being updated from log sheets completed by various operators. Therefore, the accuracy of the historical data may be uncertain, and it could be imbued with random, personal, and systematic errors [1]. Automation of the data logging systems and hoisting systems operation may result in different datasets and subsequently different KPIs.

## 4. Conclusion

The production performance of the two hoisting systems, $HS_1$ and $HS_2$, was studied to find opportunities for improving the KPIs. The availability, performance, reliability, OEE, and utilisation for both hoisting systems fell short of the acceptable mining industry benchmarks. Both hoisting systems were underperforming, despite $HS_2$ performing marginally better than $HS_1$. The hoisting systems have higher downtimes than expected, and the cycle times require optimization. The maintainability of the hoisting systems is poor and contributed more than 30% of the downtime in either case.

A possible fix is switching from the current Preventive Maintenance strategy to a Total Productive Maintenance (TPM) strategy, known to improve equipment reliability and maximise overall equipment effectiveness. Shaft dewatering should be prioritised to reduce downtimes for $HS_1$. Alternative electrical power sources are needed to reduce reliance on the national grid, which suffers frequent power cuts. Overall improvements to the key performance indicators can be done by a range of holistic action plans to solve the problems recorded on the Fishbone Diagram but with a formal system of recording the metrics; inclusive of an implementation strategy, budget, teams and team leaders.

Studies to establish similar and other KPIs of hoisting systems elsewhere are highly recommended, given the limited availability of such literature. Application of Industry 4.0 tools and technologies such as the Internet of Things (IoT), Big Data and Analytics, Digital Twins, Cloud Computing, and Horizontal and Vertical Integration can enable real-time monitoring, evaluation, and troubleshooting of mining equipment and machinery. There are companies vending software, which can be integrated with existing Distributed Control Systems (DCS) or SCADA (Supervisory Control and Data Acquisition) systems for real-time calculation of mining or manufacturing KPIs. The extension of such systems to hoisting systems is recommended for future research and development efforts. They should have predictive capabilities to prevent certain faults, which can lower machine KPIs and improve the safety of both personnel and machinery.

### Acknowledgements

This study was made possible through financial and material support from our university. We are also grateful for the administrative and technical assistance from the management, maintenance and mining teams at the underground gold mine.

## Conflict of Interest

The authors have no conflicts of interest to declare in relation to the content of this article.

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