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Optimization of the overall equipment efficiency (OEE) of loaders and rigid frame trucks in NAMDEB Southern Coastal Mine Stripping fleet, Namibia

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Abstract: This research work investigates optimization of the overall equipment efficiency (OEE) of loaders and rigid frame trucks in Southern Coastal Mine Stripping fleet of Namibia. The objectives of the research were achieved through direct observation and recording in a natural setting. The collected data were duration of various cycle loss times components, loader and truck cycle times. The primary source of data is a time motion study conducted over day shifts. The secondary source is existing data from the mine. The collected data were recorded in print and transferred to corresponding digital spread sheet format in the Microsoft Excel® package for more efficient calculation and analysis. The results of the analyses revealed that OEE estimated for truck operation is 63.12% while that of loader is 24.4%. The estimated availability for truck by OEE is 60.67% while that of loader is 43.30% against the bench mark of 90%, the estimated performance for truck by OEE is 94.58% while that of loader is 59.94% against the bench mark of 90% and the estimated quality for truck by OEE is 110% while that of loader is 94% against the bench mark of 95%. From an availability perspective, queuing and bunching of trucks should be minimized.

Keywords: Optimization, OEE, Loaders, Trucks, Time motion, Availability, Performance and Quality

1. Introduction

Assets have become more expensive to maintain and operate, which has diminished the value of increased production. In a 2009 investigation at the mine, Smart (2009) pointed out that the then present mine operation shortcomings at Southern Coaster Mine (SCM) had diminished desired stripping efficiencies, and that there is a challenge to “upgrade the stripping system”. This challenge still exists from the same roots today and has incited an inquiry by mine management to meet it. However, obtaining a figure of what stripping represents as a percentage of total mining cost at NAMDEB has as in a previous investigation (Smart, 2009), proved futile and instead a hazarded guess that it constitutes close to 50% thereof was used.

Delving deeper into the cost aspect, part of the two major expense areas in any stripping operation are the functions of loading and hauling given typically as, 30 to 50% of the total mining cost and is related to hauling all material types out of the pit or to the waste backfill area (Hartman, 1992). This said, it should give a superior understanding of financial implications optimizing such an operation poses.

Adverse market conditions, environmental regulations and a continually improving focus on safety are causing mine managers to consider creative and proven methods to determine effectiveness of their equipment so they can take necessary steps to increase it and to reduce the total production cost (Elevli and Elevli, 2010). This research is such an attempt at a creative method to determine the effectiveness of SCM stripping equipment with the addition of recommendations to increase this effectiveness.

OEE is a universally accepted method for measuring the improvement potential of a production process with one simple number (OEE, 2012). OEE is also referred to as Overall Equipment Efficiency (Impact, 2012) but for the purpose of this research it will sternly be referred to as Overall Equipment “Effectiveness” and not “Efficiency”. Overall Equipment Effectiveness is a major Key Performance Indicator (KPI) (ATS International, 2010) and an important metric for many companies' initiatives in operational excellence (INS Research, 2012).

As a measurement index, it shows how equipment functions (Zemestani, 2011) and measures the utilization of an asset's productive capacity in terms of three factors—availability, performance (throughput), and quality expressed as percentages of their ideal values (actual output divided by the theoretical maximum output) (Automation World, 2012) and (Williamson, 2012).

2. Methodology

This design was naturalistic as observing and recording ongoing behavior was done in natural settings (i.e. no manipulation of the environment) and rendered vulnerable to effects of overt research by the authors.

Collected data were the durations of various cycle loss times components, and of loader and of haul truck cycle times. This was recorded in print and transferred to corresponding digital spreadsheet format in the Microsoft Excel® package for more efficient calculations and analysis.

The primary source of data is a time motion study conducted over day shifts. The secondary source is existing data from the mine.

The strengths of this methodology are its template format, making it applicable to other sites similar to the one of interest to this paper, and also its ability to provide an idea of the extent of time losses in the loading and hauling cycle. The weaknesses, however, are the biases that could have resulted from the size of sample, the dynamic mining environment, and susceptibility to an overt researching nature (subjects know they are part of a study and there may be various researcher and subject effects).

2.1. Sampling Design

The mine is divided into numerous mining blocks or sites, some active and others not. Those active are catered for by the loading and hauling fleet. The target population for sampling was this fleet, specifically when catering to site G117. Two samplings were made to acquire the necessary data, one for site selection, and another for the recorded loss times and cycle times.

1. The type of sampling used for site selection was a type of non-probabilistic sampling is known as purposive sampling because the site most representative of general production stripping operations (A judgment sample decided at the discretion of mine management) was the sample.

2. The sampling of loss times was simple random sampling so that any loss time experienced by any of the equipment had an equal chance of being selected as there was only one observer. Under the given constraints such as timeframe and available resources, as many samples as possible for cycle times and each loss class were recorded.

Once the sample was selected and data collected, the author computed OEE representatives for the machines and analyzed them.

2.2. Data Collection

The load/haul/dump cycle was studied from January 10 to January 23, 2013. The cycle was analyzed when the L&H team was loading material from site G117 to the dumping area, with only the researcher doing the time motion study. This was performed during the day shift and included short notes of observations that were deemed of importance to the study. As part of the study and prior to and data collection, the researchers first found out how the job was being done. Data collection consists of the bellow two components, a discussion of which follows after:

(i) Time motion study
(ii) Existing data

Prior to any field measurement taken, the cycles (for loaders and trucks) were broken down into operations and operations into loss elements. This was done to avoid redundant work and establish which data already exists and which remains to be measured by lost time study, referred to as measured data. The data for the jobs identified to be measured was then captured by measurement with stopwatch through observation and recording them in the logbook.

With an accurate specification of where the job begins and where it ends snapback stopwatch reading and recording was the method used for stopwatch reading as opposed to the repetitive method. This involved the stopwatch being started at the beginning of each element, and then after reading the time at the end of an element, the watch is snapped back to zero. It starts again for the next element.

The existing data helped produce a benchmark for truck and loader OEE which was then used to compare to that produced by observations. An existing equation was also used in calculating the ideal cycle time needed in calculating speed losses.

2.3. Data Preparation

A simple average of individual OEE scores is insufficient, as it does not take into account the production time of each product. A weighted average, where the weighting is the actual production time, is better, but it does not provide the detailed loss information that comes from Availability, Performance, and Quality, leaving the best option as having the full set of underlying data for each product run (e.g. Total Time, Planned Production Time, Ideal Cycle Time etc), and this is what this section deals with. Although some of the data may come directly from the time and motion study, other had to be derived from secondary data by multiplication or division by relevant variables where appropriate in order to convert the collected core activity times to per shift values. These values have a significant impact on the final resulting times per shift, and were all estimated very carefully from observations on site.

$$T_t = H_s \times N_d \tag{1}$$

Where T_t is the total time taken by the loaders and trucks, H_s is the number of hours per shift, N_d is the number of days in a month.

$$S_{mt} = \frac{D_c + P_c + R}{S} \quad (2)$$

Where S_{mt} is the scheduled maintenance time, D_c is the daily check of the machineries, P_c is the pre-start check of the machineries, R is the refuelling of the machineries, and S is the daily shift of the machineries.

Non- Scheduled time = Estimated Yearly Non-Scheduled time (3)

Idle time without operator = (others) + (tea/lunch break)

Loader waiting time = Average queuing time x Frequency x 30days (4)

Truck waiting time = Average Truck waiting time x shift frequency x 30days (5)

Loading time loss = Mean loading cycle duration - Plan loading time (6)

2.3.1. Benchmark Cycle Time

SCM Haul Curve: $t/h = (203.5 - 53.61 \times (\ln D))$ (7)

Where t = Tons hauled = RFT heaped plan payload capacity of 40t

h = Hour d = Haul distance = 5.8 km (from site G117 to tipping bin area)

Benchmark cycle time = t/1.82 min

Speed loss =Benchmark cycle time -average cycle time (8)

Where

Truck Benchmark cycle time = 21.97 min from Haul Curve

Loader Benchmark cycle time = 37s (obtained from minimum measured loader cycle time)

2.3.2 Quality loss

RFT Quality Loss = Loaded Payload capacity / Full payload capacity (9)

FEL Quality Loss was calculated from the equation (10) as follows

BL = TC/ LBC (10)

Where,

LBC = TC/BL = loader Bucket Capacity or Heaped Capacity

BL = Bucket Loads = 4

TC = Truck Capacity = 24m³

Thus

LBC is = 6 m³, but closest match of available bucket sizes from Komatsu WA600 brochure (Komatsu, 2008) *is 6.4 m³.*

Table 1. *Day Shift Available Time, Existing Data*

ITEM	Equation (where applicable)	Value	Units
Pre-Start Checks (P)		15	minutes/shift
Refuelling (R)		5	minutes/shift
Daily Check (D)		5	minutes/shift
Tea/Lunch (L)		30	minutes/shift
Shift Changes (S)		5	minutes/shift
Others (O)		10	minutes/shift
Hours per Shift (H)		8.33	hours/shift
Total Time (TT)	$= H \times 30 days$	249.9	hours/month
Actual Available Time (AAT)	$= TT - (P + R + D + L + S + O) \times 30 days$	214.9	hours/month
Availability	$= AAT/TT$	85.99%	%

2.4. OEE estimation for Truck Operation

AAT = TT-(Non scheduled time + Scheduled maintenance + Unscheduled maintenance + Setup and adjustment + Idle time + Loader waiting time) (14)

NPT = AAT – (Loading time loss + Job condition loss + speed loss) (15)

OEE = Availability x Performance x Quality (16)

2.5. OEE Estimation for Loader operation

AAT = TT-(Nonscheduled time + Scheduled maintenance + Unscheduled maintenance + Setup and adjustment + Idle time + Truck waiting time) (17)

NPT = AAT–(Propel + Job condition loss + speed loss) (18)

OEE = Availability x Performance x Quality (19)

3. Results and Discussion

Table 2 shows the result of the time lengths for truck operations.

Table 2. *Time Lengths for Truck Operations*

Loss Classification	Description	Time (hours/month)
Total Time	8.33 hours/day x 30days/month	249.9
Non-Scheduled Time	Estimated service hours during day shift (Excel)	27.23
Scheduled Maintenance Time	5 min daily check (/shift) 15 min pre-start check/shift 5min refuelling/shift Total=25min/shift	125
Unscheduled maintenance time	New machines, no breakdown, Confirmed with VMS	0
Setup and adjustment time	5min swift change	25
Idle time without operator	10min others (Bathroom, safety talks, site discussions etc.) 30min tea/lunch break **TOTAL = 45min/shift**	20
Loader waiting time (e.g. time in queue)	Average Truck waiting time x shift frequency x 30days	36.07
Loading Time loss	Mean loading cycle duration - Plan loading time	8.31
Time losses due to job conditions	None within scope of study, but do exist on other shifts (e.g. fog on night shift)	0
Speed loss	Measured cycle time - Standard cycle time	-0.1
Quality loss	40t/36.5t is used *(can also use 40t/32t rated)*	1.10

Table 3 shows the result of the time lengths for truck operations.

Table 3. *Time Length for Loader Operations*

Loss Classification	Description	Time (hours/month)
Total Time	8.33 hours/day x 30days/month	249.9
Non-Scheduled Time	Estimated service hours	27.23
Scheduled Maintenance Time	5min daily check (/shift) 15 min pre- start check/shift 5 min refueling/shift **TOTAL = 25min/shift**	125
Unscheduled maintenance time	New machines, no breakdowns. Confirmed with VMS	0
Setup and adjustment time	5min swift change	25
Idle time without operator	10min others (Bathroom, safety talks, site discussions etc.) 30min tea/lunch break **TOTAL = 45min/shift**	22.5
Truck waiting time (time waiting for truck)	Average Truck waiting time x shift frequency x 30days	76.96
Propel time	Confirmed with VMS as none.	0
Time losses due to job conditions	None within scope of study, but do exist on other shifts (e.g. fog on night shift)	0
Speed loss	Measured cycle time - Standard cycle time	0.37
Quality loss	10t/10.67t	0.94

Table 4 shows the result of the OEE estimation for truck operation.

Table 4. *(OEE Estimation for Truck Operation)*

Total Time (TT)	**249.9**					
Actual Available Time (AAT)	151.6022	Non scheduled time	27.23			
		Scheduled maintenance	12.5			
		Unscheduled maintenance	0	Availability	=AAT/TT	60.67%
		Setup and adjustment	2.5			
		Idle time	20			
		Loader waiting time	36.07			
Net Production Time (NPT)	143.3922	Loading time loss	8.31			
		Job condition loss	0	Performance	=NPT/AAT	94.58%
		Speed loss	-0.1			
Valuable Production Time (VPT)		Quality loss	1.1	Quality		110.00%
OEE (%) =		63.12%				

Table 5. *(OEE Estimation for Loader Operation)*

Total Time (TT)	**249.9**					
Actual Available Time (AAT)	108.212	Non scheduled time	27.23			
		Scheduled maintenance	12.5			
		Unscheduled maintenance	0	Availability	=AAT/TT	43.30%
		Setup and adjustment	2.5			
		Idle time	22.5			
		Loader waiting time	76.96			
Net Production Time (NPT)	64.8622	Propel time	0			
		Job condition loss	0	Performance	=NPT/AAT	59.94%
		Speed loss	43.35			
Valuable Production Time (VPT)		Quality loss	0.94	Quality		94.00%
OEE (%) =		24.40%				

4.5. Summary of Results

Table 6. *(Availability)*

Availability Estimated by OEE		
Truck Availability	Loader Availability	Benchmark Availability
60.67%	43.30%	90.00%

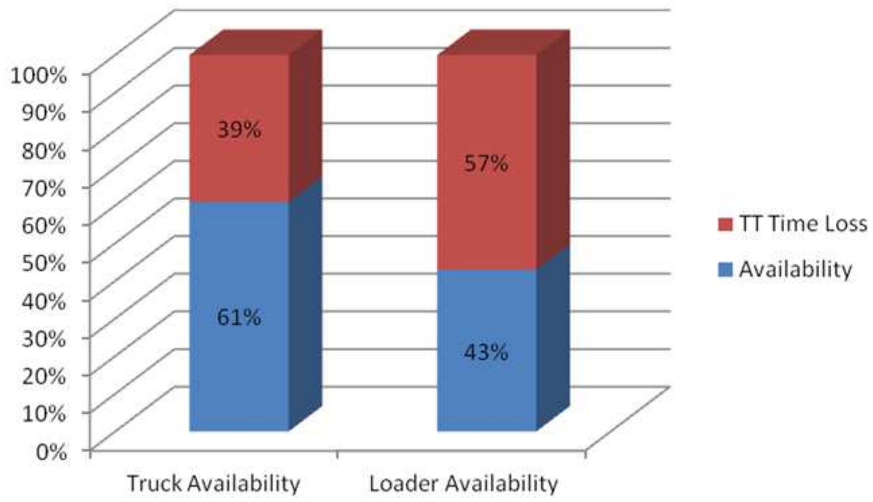

Figure 1. *(Availability)*

Table 7. *(Performance)*

Performance Estimated by OEE		
TruckPerformance	Loader Performance	Benchmark Performance
94.58%	59.94%	90.00%

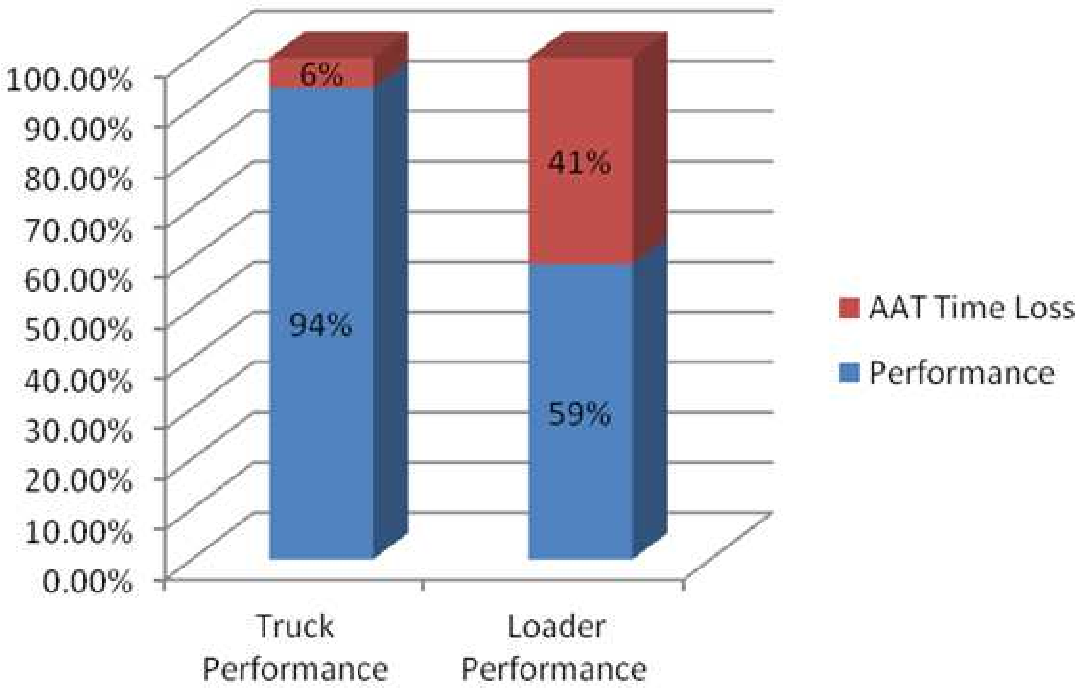

Figure 2. *(Performance)*

Table 8. *(Quality)*

Quality Estimated by OEE		
Truck Quality	Loader Quality	Benchmark Quality
110%	94.00%	95.00%

Figure 3. *(Quality)*

3.1. Availability

The OEE analysis has yielded both loader and truck availabilities below the benchmark value used. Under this heading, the meanings and underlying causes of losses in total available time for trucks and that in loaders will be discussed.

The truck availability is under the benchmark value by 39.33% of which the biggest contributors to actual available time loss for trucks are the loader waiting time followed by the non-scheduled time. It should be noted however that the non-scheduled time is calculated from annual scheduled maintenance hours and then distributed equally over twelve (12) months, so this equal distribution may not specifically reflect actual non-scheduled time for the equipment for a particular month, but just gives a general idea of the time dedicated to non-scheduled time in a year. The same applies to that of the loader. The loader waiting time for trucks however is a result of the time motion study and reflects the average amount of time a truck may spend waiting for the loader to load other trucks (time in queue at loading interface), level or muck the loading area. This waiting time makes up 37% of the time losses in total available time, and is mainly caused by queuing with the larger time loss share and highest frequency relative to the time spent waiting for the loader to finish leveling or mucking.

The loader availability is hindered mostly by truck waiting time (time loader spends waiting for trucks to load, which constitutes 54% of total time losses. This large constituent to loss time prompted a further investigation, whereby the researcher travelled cycles in the trucks to observe and discretely noted the below causes of time the loader spends waiting for trucks:

On various occasions the feed-rate of materials tipped into the plant front end was slower than the rate of service by the trucks, or the front end became unavailable for tipping, trucks found themselves with the bucket elevated at the front end, but may not move so as to keep the footwall condition free of spillage. This in turn caused other trucks to queue behind the truck at front end and extended the time the loader waits for trucks to serve at the loading site.

The match factor is the ratio of truck arrival times to loader service rates and can be used to determine the ideal number of trucks in the fleet. This ideal number of trucks however can be affected by the availability of trucks (e.g. some trucks dispatched elsewhere), which inadvertently results in the aforementioned "mismatch", and thus a larger time interval the loader waits between serving the current and next truck.

Daily maintenance checks such as tyre and general equipment condition checks are often performed at the tipping bin area. These checks are accounted for in planning and were observed to remain within the confines of their planned duration of 5 (five) minutes each. However, pulling a truck out and putting it back in a cycle averaging 18.96 minutes for intervals that are reserved to take up to 26% of that time not only increase the time interval the loader waits to serve that truck, but promotes queuing and bunching as well. Bunching is known to reduce a fleet's ability to meet its maximum capacity and can be due to small unpredictable delays (Burt et al., 2005), so the same can be said about refueling, bathroom breaks etc.

Other contributors to loss of total available time for trucks and loaders are idle time, scheduled maintenance time and set up and adjustment time (in order of decreasing time loss). These values are reflected in the plan and adhered to with minimal divergence by the operators as observed and noted during the study. The non-scheduled time is just as that of trucks, also with unscheduled times of 0 (zero) as the machines in scope have not broken down yet.

3.2. Performance

Truck performance during the day shift exceeded the benchmark by 4.58%. This reveals positive operator competence during loading and hauling material. Loading time loss was under 17 minutes per shift (±4% of actual available time) and a negative value was recorded for speed loss compared to benchmark cycle time derived from the haul curve, which indicates a “speed gain” of 12 (twelve) seconds per shift. This is mentioned to highlight that given ideal conditions (e.g. without queuing), the loading and hauling team is able to perform according to the plan.

Loader performance is low compared to the benchmark value (by 30.06%). This cause is identified as a speed loss and can be justified by the following statement:

The loader will control production if at least one extra truck is used whereas the trucks control production if fewer trucks are used [30] (Assakkaf, 2003).

During the study, one loader served a fleet with truck numbers varying from two to seven due to availability. The Match factor (17) for this cycle is calculated to be:

$$MF = \frac{N_T}{N_L} \times \frac{L_c}{T_c} \tag{20}$$

Where MF is the match factor, N_T is the number of truck, N_L is the number of loader, L_c is the loading cycle, and T_c is the truck cycle

$$N_T = \frac{N_L \times T_c}{L_c} \times MF \tag{21}$$

Where

MF = 1 for perfect match, N_L = 1, L_c = 3.2 min, and T_c = 18.96 min

So,

$$N_T = 18.96/3.2$$

N_T = 5.925 trucks

Therefore number of truck is 6 trucks

In noted cases where only two to five trucks were used, we can assume that the trucks controlled the production, and the loaders performance accommodated this by decreasing in value.

3.3. Quality

The quality metric simply represents the filling factor of the loader and that of the truck. The truck quality of 110% may at first glance seem like a favored value but in actual fact reflects machine abuse by overloading. Consider the following:

(i) The mine uses a payload representative of 40tons to represent a truck-full of heaped materials hauled by the Komatsu HD325-7 truck.

(ii) The heaped capacity of the truck is 24m³ (Komatsu, 2008).

(iii) The material hauled has a density of ±1.67 t/m³.

(iv) The rated payload of the truck is 32tons, and the maximum is 36.5tons (Komatsu, 2008).

(v) Fill factor (in this scenario) = Mass/Payload maximum = 1.10

The maximum amount (in tones) of material the truck is allowed to haul is 36.5 tons as per manufacturers’ recommendations. The measured exceeds this capacity by 3.5tons and thus points to machine abuse even though it yields a quality metric above the benchmark value. Overloading a truck abuses the tires, which are about 35% of a trucks operating cost (Assakkaf, 2003). Not only is replacing tires costly, but also consumes time as well, which will adversely affect machine availability, and in consequence OEE as well.

Loader bucket capacities come in defined sizes that correspond to the number of passes required to fill the truck. The bucket sizes are provided by the manufacturer. Having a 94% quality compared to a 95% benchmark can be considered an acceptable value.

3.4. OEE in Loading and Hauling

As in other operations, using the OEE rating in loading and hauling served no purpose other than a very high-level indicator of performance improvement or degradation. Through this, it effectively measured how close to expected production the loading and hauling team was, in which the difference indicated areas for improvement for which recommendations were provided. It however does not indicate the financial consequences that may result per factor.

OEE is associated with time and resources but is not suitable as a cost benefit indicator. This is evident in the results analysis section, where if we look at the indication of machine abuse derived from the quality factor, does not and cannot show any financial measures without further research. Keep in mind that equipment utilization also has significant influence on loading and hauling costs.

The definition of loss time is also open to debate. During some of the times the loader is recorded to be waiting for a truck to service, it engages in production aiding activities such as cleaning the loading area. For such cases, when the machine is utilized during “lost time”, provisions should be made to omit the time spent on such an activity from lost time. Especially for OEE analysis’s that span over lengthy periods as these will give more data and thus more representative averages of the durations of such activities.

4. Conclusion

In this research work an industrial implementation of the OEE measure as an improvement driver which has been analyzed. It has provided the Overall Equipment Efficiency (OEE) of loaders and rigid frame trucks at SCM and determined the OEE metrics that constitute to efficiency losses and identifying the consequent problem areas. From an availability perspective, it is recommended that queuing and bunching of trucks should be minimized.

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