Contents lists available at *Dergipark*

Journal of Scientific Reports-A

journal homepage: *https://dergipark.org.tr/tr/pub/jsr-a*

E-ISSN: 2687-6167 ***Number 56, March 2024***

RESEARCH ARTICLE

Receive Date: 19.02.2024 *Accepted Date: 18.03.2024*

Evaluation of overall equipment effectiveness (OEE) for mining equipment (shovel-truck): A case study Manisa-Soma (Turkey) open pit mine

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Abstract

Mining is a costly activity that requires huge investments and large equipment. Therefore, it is crucial to use mining equipment efficiently to maximize productivity. This requires the continuous analysis of equipment efficiency and taking action to reduce negative impacts. Accurately estimating equipment efficiency is essential to increase its effectiveness. One globally recognized and accepted measurement is Overall Equipment Effectiveness (OEE). In this study was conducted to calculate the OEE values of shovels and trucks, which are the primary equipment used in open pit mining. The study presented different loss times and quality values while calculating the OEE values of mining equipment. The OEE values of electric trucks and shovels were found to be consistent with actual work quantities in the Manisa-Soma Lignite open pit operation. This study is the first applied study of OEE analysis in Turkey.

Keywords: OEE; Equipment Utilization; Mining; Time Losses; open pit equipment

1. Introduction

The speed at which modernization and Industry 4.0 are spreading around the globe has raised the capacity of mining machines and equipment. This capacity growth has brought attention to the necessity of using the gear and equipment even more effectively, nevertheless. Analysing the overall productivity of the equipment utilized in mining operations is therefore considerably more important. As in other sectors of business, mining businesses now need to make sure that their machinery and equipment are used as efficiently as possible. Utilizing equipment at its optimal efficiency level is crucial and is contingent upon the operational parameters of the business. In the event that the operational efficiency falls to a level below that which is required, it is very important that quickly to one responds improving it. By checking efficiency of equipment and action just in time in order to correct, businesses can run their level of equipment with that which is required, lowers business production cost, and in investment cost at the same time reduces.

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Overall Equipment Efficiency, OEE, Analysis provides performance management of the equipment required for the mining operations. Since the method provides fast and accurate answers, many different businesses use this analysis method.

S. Nakajima has defined total Productive Maintenance (TPM) as having its positives and negatives. According to the author's comparison of TPM to OEE, the author states a point of simplicity and being user-friendly to the user [1]. Sharma et al. found that a relevant study of a whole range of manufacturing process equipment efficiency reflects competitiveness, hence would be ideal for measuring total equipment effectiveness and efficiency [2]. K. Yagi. To calculate their OEE in the industry, Jeong et al. used a different technique for loss prediction over the time production lines [3]. M. Braglia et al calculated the OEE of all equipment in the production line using a different method [4]. R. Oechsner et al proposed new approaches and calculation methods to determine overall plant efficiency instead of overall equipment efficiency [5]. J.A. Garza-Reyes et al investigated the correlation between system capacity and overall equipment efficiency (OEE) [6].

S. Elevli and his team applied theoretical OEE calculation methods and formulas to mining equipment in their study [7]. N.R. Sharma conducted a study on the relationship of OEE with the implementation of Preventative Maintenance systems for the reduction of equipment downtime, especially at the availability front of the equipment [8]. J.M. Akande et al. did a study on equipment optimization conducted on loaders and rigid frame trucks in a mining operation [9]. Conveyer and bucket-based backhoes efficiency study was done by M. Mohammadi et al. [10].

The idea of the study was to determine how efficient the electric trucks and shovels operating at the Manisa-Soma coal works. Data on shovels and trucks in Manisa-Soma (Turkey) coal mine for the years 2021 and 2022 were collected and analysed. Among the findings of this analysis was the determination of the state of equipment efficiency as well as suggestions on how overall equipment efficiency figures can be raised.

2. Methodology

OEE is an analytics tool that enables enterprises to make decisions with concerns to the already available equipment in the enterprise. After the 2000s, that kind of analysis was much favoured because it's logically simple and not too time-consuming. Following completion of the OEE assessment process, if the percentage OEE is found to be less than the targeted level, then some of the factors that need to be analysed include operator quality, down time of equipment, repair and installation times, lost time due to minor amount of equipment malfunction and problems which are caused due to the speed with which the equipment are operated. A business has the opportunity to become more efficient if it is able to identify and correct these problems.

OEE is one of the important techniques of progress control over and improvement in efficiency of equipment used in the mining operation. This method accounts for the losses incurred during the work process and is used to calculate real efficiency. Table 1 displays the six most prevalent major loss times. [11].

Table 1. Six Big Losses [11].

Factor	Six Big Loss Category	OEE Loss Category	OEE Factor
Mechanical	Equipment Failure	DowntimeLosses	**Availability (A)**
Human	Setup and Adjustment		
Operational	Idling and Minor Stoppages	Speed Losses	**Performance (P)**
Mechanical or Operational	Reduced Speed		

Mechanical	Reduced Yield	Defect Losses	**Quality(Q)**
Operational	**Quality Defects**		

Production line equipment availability is affected by any losses that occur during use, such as downtime and repair times. The availability can be calculated using the formula 1.

$$Availability\ (\%) = \frac{Net\ Available\ Hours - Downtime\ Losses}{Net\ Available\ Hours} * 100 \quad (1)$$

Net available hours =Total time-planned downtime

Equipment performance is affected by speed losses resulting from user error and operating conditions. Formula 2 can be used to calculate the speed loss.

$$Performance\ (\%) = \frac{Operating\ Times - Speed\ Losses}{Operating\ Times} * 100 \quad (2)$$

Operation Times: Net available hours-Downtime losses

"Quality" refers to a product's standard and includes the consideration of "product loss". The formula 3 is used to determine the amount of product loss.

$$Quality\ (\%) = \frac{Net\ Operating\ Times - Defect\ Losses}{Net\ Operating\ Times} * 100 \quad (3)$$

Net operation time = Operation time - Speed losses, Defect Losses: Operator defects

Once the Overall Equipment Effectiveness (OEE) has been analysed, it needs to be checked for compliance with industry standards. The acceptable average efficiency in the industry is typically around 85-90%. If the calculated total equipment efficiency value falls below the specified operating efficiency value, corrective measures are taken to increase system efficiency. It is important to base the calculated OEE value on accurate and realistic data, as using unrealistic data can lead to incorrect equipment efficiency readings. To calculate OEE, the actual total time, planned downtime, and unplanned downtime within this total time should be accurately calculated.

2.1. Calculating the Overall Equipment Effectiveness (OEE) for Mining Equipment

Mining operations are significantly distinct and more intricate than the manufacturing sector. As a result, both the expected and unexpected losses for mining equipment must be analysed based on their operating systems. However, collecting data on the planned time and losses for mining equipment is a more complex process. Table 2 illustrates the procedure for determining a truck's Overall Equipment Effectiveness (OEE). Due to differences in mining equipment, the collection of data can vary. However, the process is often challenging due to the following reasons:

- Mining activities involve several operations, such as drilling, blasting, excavation, loading and unloading. The efficiency of the equipment used in these operations is highly dependent on the efficiency of the previous operation. Therefore, to analyse the overall efficiency of the entire system, it is crucial to consider the efficiency of each operation.
- The productivity of mining operations is greatly impacted by the high equipment capacities used.
- The severe working conditions found in mining operations can have a negative effect on OEE efficiency, which lowers standard productivity figures.
- Elements in the working environment, like dust and lighting, have an impact on the efficiency of mining equipment. [12].
- The matching factor between trucks and shovels is a crucial consideration in open pit mining OEE (Overall

Equipment Effectiveness) calculations. For the truck and the bucket, the matching factor should ideally be 1. The truck will wait for the bucket to load it, increasing the loading time, if the matching factor is less than 1. Productivity will suffer if the matching factor is less than 1.

- In addition to the truck and shovel filling factor, the quality value calculation should consider the performance of operators operating the equipment.

Table 2. The methodology for determining a truck's Overall Equipment Effectiveness (OEE).

Loss Classification	Description
Non-Scheduled Time	1. Unplanned time for operation of the equipment. 2. Planned time for periodic maintenance of the truck.
Scheduled Maintenance Time	Time spent on breakdown.
Unscheduled Maintenance Time	Equipment preparation and setup time
Setup And Adjustment Time	Equipment operational but downtime due to other factors
Idle Time Without Operator	Time duration for which truck waits to get position to be loaded
Loading Time Loss	The time when the truck waits to be loaded.
Loss of working Conditions	Time loss due to management, supervision, climate, and job conditions
Speed Loss	Time loss due to the equipment that is operating under the standard speed
Quality Loss	1. Fill factor of loader 2. Loader operator efficiency

3. Overall Equipment Effectiveness Value Calculation

3.1. *Overall Equipment Effectiveness values for trucks*

Fig. 1. 630ES Electric Trucks.

The operation has ten Komatsu-630ES Electric trucks, each with a capacity of 170 short tons (Fig. 1). These trucks are primarily used for transporting excavated materials and were added to the system back in 1999. The distance between the open pit mine and the dump site is 4.7 km, and it takes approximately 19 minutes for the trucks to complete the tour. Tables 3 and 4 provide statistical data on truck usage in the business for the years 2021 and 2022. In this study, the OEE values for electric trucks in the field were determined for 2021 and 2022 to observe any changes over the years.

Table 3. Statistical Data for Trucks in 2021.

Model	*Truck Number*	*Programme (Hour)*	*Actual amount of work (Ton)*	*Failure total (Hour)*	*Loss of working conditions (weather opposition, etc.) (Hour)*
HAULPAK-KO/630 ES	548	5.535	345.982	2.364	862
HAULPAK-KO/630 ES	549	6.128	601.300	1.275	837
HAULPAK-KO/630 ES	550	5.633	381.500	2.488	551
HAULPAK-KO/630 ES	551	6.188	674.541	792	818
HAULPAK-KO/630 ES	552	6.435	808.192	404	929
HAULPAK-KO/630 ES	553	6.255	714.896	686	983

HAULPAK-KO/630 ES	554	6.293	638.491	558	970
HAULPAK-KO/630 ES	555	6.233	718.921	549	889
HAULPAK-KO/630 ES	556	6.285	728.721	800	712
HAULPAK-KO/630 ES	557	6.225	675.955	370	987

Table 4. Statistical data for Trucks in 2022.

Model	*Truck Number*	*Programme (Hour)*	*Actual amount of work (Ton)*	*Failure total (Hour)*	*Loss of working conditions (weather opposition, etc.) (Hour)*
HAULPAK-KO/630 ES	548	6.383	638.678	512	628
HAULPAK-KO/630 ES	549	6.720	775.580	236	728
HAULPAK-KO/630 ES	550	5.288	62.720	3.642	137
HAULPAK-KO/630 ES	551	6.383	627.313	572	714
HAULPAK-KO/630 ES	552	6.548	611.974	820	690
HAULPAK-KO/630 ES	553	5.970	388.972	2.483	167
HAULPAK-KO/630 ES	554	6.660	705.234	265	703
HAULPAK-KO/630 ES	555	6.503	641.916	552	676
HAULPAK-KO/630 ES	556	6.345	633.101	378	672
HAULPAK-KO/630 ES	557	6.473	702.972	639	511

Table 5 displays the time durations of the different parts of Truck No. 548. In Real-time OEE calculations, the total time determined by field authorities under actual working conditions was taken into account. The amount of work carried out by the truck was compared to the amount of work it was supposed to do under those working conditions. In calculating the work done, real data such as a truck capacity of 170 short tons (154 tons) and a truck tour time of 19 minutes were used.

Table 5. Time Lengths of the Elements of Truck No. 548/2021.

Item	**Description**	**Time (Hour)**
Total Duration	24 hours/day*30 days/month*12 months/year	**8640**
Scheduled Time (1): (Administrative Leave)	2 days/month*24 hours/day*12 months/year	576
Scheduled Time (2): (Meal and refreshment break)	1 hour/shift*3 Shifts/day*30 days/month* 12 months/year	1080
Scheduled Time (3): Time not intended for operation	60 days/year*24 hours/day	1440
Total scheduled time=1+2+3		**3096**
Planned Maintenance	0.1 day/month* 24 hours/day* 12 months	**28,8**
Unplanned Failure Stops		**2364**
Installation and Setup	0.4 hours/shift* 3 shifts/day* 24 hours/day* 12 Months	**432**
Idle Time	0.6 hours/shift* 3 shifts/day* 24 hours/day* 12 Months	**648**
Loading Waiting Time	0.1 hour/shift* 3 shifts/day* 24 hours/day* 12 Months	**108**
Loss of loading time	0.3 hours/shift* 3 shifts/day* 24 hours/day* 12 Months	**324**
Loss of working Conditions	Losses due to weather, etc.	**862**
Speed Loss	0.4 hours/shift* 3 shifts/day* 24 hours/day* 12 Months	**432**
Quality Loss	Filling Factor (87%)*Loader Operator Factor (95%) = 82.65	

Truck 548's Availability, Performance, Quality, and OEE values were calculated using the data in Table 6.

Net available hours =8640 – (3096+28,8) =5515,20
Downtime Loses = 2364+432+648+108 = 3552
Operation Times = 5515,20-(324+862+432) = 3897,20
Speed Losses = 324+862+432 = 1618

Availability = (5515,20-3552)/5515,20 =0,3559
Performance =(3897,20-1618)/3897,20 = 0,5848
Quality = 0,87*0,95= 0,8265

Table 6. The OEE Calculations of Truck No:548-2021.

	Calculation Based on Application Time	
Net available hours		5515,20
Availability		0,3559
Performance		0,5848
Quality		0,8265
OEE	***Availabitiy*Performance*Quality***	**0,1721**

Table 7. The calculation is based on the application time of 2021.

Truck Number	***Availability***	***Performance***	***Quality***	***OEE (%)***	***Actual Work Quantity (Ton)***	***Production Quantity (Tons) (OEE at 50% level)***
548	35,61	58,48	82,65	**17,21**	345.982	*: (%50*345.982)/%17,21 = 1.005.164*
549	59,76	64,81	82,65	**32,01**	601.300	939.152
550	34,82	69,84	82,65	**20,10**	381.500	949.028
551	67,65	65,38	82,65	**36,55**	674.541	922.714
552	75,44	64,86	82,65	**40,44**	808.192	999.239
553	69,98	61,38	82,65	**35,50**	714.896	1.006.926
554	72,13	61,97	82,65	**36,94**	638.491	864.149
555	72,27	64,39	82,65	**38,46**	718.921	934.666
556	68,26	69,39	82,65	**39,15**	728.721	930.676
557	75,13	61,45	82,65	**38,15**	675.955	885.823
				Total	**6.288.499**	**9.437.537**

Table 8. The calculation is based on the application time of 2022.

Truck Number	***Availability***	***Performance***	***Quality***	***OEE (%)***	***Actual Work Quantity (Ton)***	***Production Quantity (Tons) (OEE at 50% level)***
548	73,25	59,99	82,65	**36,32**	638.678	*879.224*
549	78,81	60,13	82,65	**39,17**	775.580	990.092
550	8,52	66,51	82,65	**4,69**	62.720	669.322
551	72,33	57,35	82,65	**34,29**	627.313	914.790
552	69,36	59,82	82,65	**34,29**	611.974	892.276
553	38,57	70,68	82,65	**22,53**	388.972	863.187
554	78,19	60,36	82,65	**39,01**	705.234	903.934
555	73,25	59,84	82,65	**36,23**	641.916	885.844
556	75,33	58,57	82,65	**36,47**	633.101	868.037
557	71,81	64,48	82,65	**38,27**	702.972	918.441
		Total			**5.788.460**	**8.785.148**

After analyzing the OEE values and actual work quantities of electric trucks operating in the field between 2021 and 2022, as shown in Table 7-8, we found that truck 548 had the lowest OEE value of 17.21% in 2021, and truck 550 had an OEE value of 4.69% in 2022. We observed that trucks with the lowest OEE value also recorded the lowest work quantities. For example, in 2021, truck 548 spent 2,364 hours in malfunction out of a planned work time of 5,515 hours. Similarly, in 2022, truck 550 had a planned work time of 5,280 hours, but its unplanned downtime was 3,642 hours.

It was observed that the trucks which had the highest OEE values also had the highest actual work quantities. In 2021, truck 552 recorded the highest OEE value of 40.44%, and in 2022, truck 549 recorded 39.17%. Additionally, it was noted that the trucks with the highest OEE value also produced the highest output when considering the actual work quantities. If the OEE value hits 50%, the total production of 6,288,499 tons in 2021 could potentially increase to 9,437,537 tons, resulting in a 66% increase.

Table 9. Illustrates the correlation between unplanned downtime and Overall Equipment Effectiveness (OEE).

2021					**2022**				
Truck Number	*Total Duration Time (Hour)*	*Unplanned Failure Stops (hour)*	*(Unplanned Failure Stops (hour)/(Net available hours)*100*	*OEE %*	*Truck Number*	*Total Duration (Hour)*	*Unplanned Failure Stops (hour)*	*(Unplanned Failure Stops (hour)/(Net available hours)*100*	*OEE %*
548	5515,2	2364	42,85	**17,21**	550	5280	3642	68,98	**4,69**
550	5640	2488	44,11	**20,1**	553	5976	2483	41,55	**22,53**
549	6120	1275	20,83	**32,01**	551	6360	572	8,99	**34,29**
553	6240	686	10,99	**35,5**	552	6552	820	12,51	**34,29**
551	6120	792	12,94	**36,55**	555	6504	552	8,48	**36,23**
554	6264	558	8,90	**36,94**	548	6355,2	512	8,06	**36,32**
557	6264	370	5,91	**38,15**	556	6348	378	5,95	**36,47**
555	6264	549	8,76	**38,46**	557	6480	639	9,85	**38,27**
556	6264	800	12,77	**39,15**	554	6660	265	3,97	**39,01**
552	6480	404	6,23	**40,44**	549	6720	236	3,51	**39,17**

Table 9 demonstrates that the Overall Equipment Effectiveness (OEE) values and unplanned downtime have an inverse relationship. By analyzing both the OEE and RAM (Reliability, Availability, and Maintainability) metrics together, the company can increase the OEE percentage. In order to improve the OEE values of the enterprise, it is necessary to carry out preventive maintenance and repair work on the trucks. It is also essential to minimize repair losses by conducting a maintainability analysis for each truck and following the types of failures and intervention times associated with those failures.

3.2. Overall Equipment Effectiveness Values of Shovel Working in Manisa-Soma Coal Mine

Fig. 2. Shovel.

Five shovels (Fig. 2.) actively used in the enterprise, which are quite old, were evaluated for their overall equipment effectiveness values using data from 2021 and 2022. Tables 10 and 11 provide statistical data on shovel usage in the business for the years 2021 and 2022.

The truck-shovel matching point value is much lower than 1, causing longer truck waiting times for shovels due to insufficient trucks.

Table 10. Statistical Data for Shovel-2021.

Model	*Shovel Number*	*Program (Hour)*	*Actual amount of work (Ton)*	*Failure total (Hour)*	*Loss of working conditions (weather opposition, etc.) (Hour)*
MARION/191M11	2	5910,0	1.776.600	793,50	980,50
MARION/191M-II	4	5407,5	954.800	2478,00	847,00
MARION/191M-II	5	5797,5	1.598.100	1008,50	1063,00
MARION/191M-	9	5527,5	544.600	767,50	740,50
MARION/191M11	16	5512,5	865.900	1563,50	719,00

Table 11. Statistical Data for Shovel-2022.

Model	*Shovel Number*	*Program (Hour)*	*Actual amount of work (Ton)*	*Failure total (Hour)*	*Loss of working conditions (weather opposition, etc.) (Hour)*
MARION/191M11	2	5400,00	532.000	2580,50	312,50
MARION/191M-II	4	6150,00	1.995.000	965,00	701,00
MARION/191M-II	5	6030,00	1.619.800	631,50	744,00
MARION/191M	9	5362,50	203.700	1604,50	609,50
MARION/191M11	16	5452,50	456.400	2365,50	378,50

Table 12 displays the time lengths for Shovel No. 2. In real-time OEE calculations, the total times determined by the field authorities under actual working conditions were taken into account. The amount of work that the shovel was expected to do according to all these working conditions was compared to the amount of work it actually did. Real data was used in the calculation of the amount of work done, which included the shovel's capacity of 19 Yd3 (14.50 m3) and 1.5 buckets per minute.

Table 12. Time Lengths of the Elements of Shovel No. 2 -2021.

Item	**Description**	**Time (Hour)**
Total Duration	24 hours/day*30 days/month*12 months/year	**8640**
Scheduled Time (1): (Administrative Leave)	*2 days/month*24 hours/day*12 months/year*	*576*
Scheduled Time (2): (Meal and refreshment break)	*1 hour/shift*3 Shifts/day*30 days/month* 12 Months/year*	*1080*
Scheduled Time (3): Time not intended for operation	*37.5 days/year*24 hours/day*	*900*
Total scheduled time=1+2+3		**2556**
Planned Maintenance	1 day/month* 24 hours/day* 12 months	**288**
Unplanned Failure Stops		**794**
Installation and Setup	0.5 hours/shift* 3 shifts/day* 24 hours/day* 12 Months	**540**
Idle Time	0.6 hours/shift* 3 shifts/day* 24 hours/day* 12 Months	**648**
Truck Waiting Time	0.1 hour/shift* 3 shifts/day* 24 hours/day* 12 Months	**108**
Loss of working Conditions	Losses due to weather, etc.	**981**
Speed Loss	0.4 hours/shift* 3 shifts/day* 24 hours/day* 12 Months	**864**
Moving Time	4 transports/month * 2hours/transport*12 Months	**96**
Quality Loss	Filling Factor (87%)*Loader Operator Factor (95%) = 82.65	

The Availability, Performance, Quality and OEE values of Shovel-2 are calculated as given in Table 13.

Net available hours =8640 – (2556+288) =5796
Downtime Loses = 794+540+648+108 = 2090
Operation Times = 5796-(981+864+96) = 3855
Speed Losses = 981+864+96= 1941

⟹

Availability = (5796-2090)/5796 =0,6394
Performance =(3855-1941)/3855 = 0,4964
Quality = 0,87*0,95= 0,8265

Table 13. OEE Calculations of Shovel No:2-2021.

Calculation based on Application Time	
Net available hours	5796,00

Availability	0,6394
Performance	0,4964
Quality	0,8265
OEE	**0,2623**

Table 14. Calculation based on Application Time-2021.

Shovel Number	***Availability***	***Performance***	***Quality***	***OEE %***	***Actual Work Quantity (Ton)***	***Production Quantity (Tons) (OEE at 50% level)***
2	63,95	49,64	82,65	**26,23**	1.776.600	3.384.000
4	31,33	51,02	82,65	**13,21**	954.800	3.613.929
5	59,31	44,44	82,65	**21,78**	1.598.100	3.668.733
9	61,79	54,03	82,65	**27,59**	544.600	986.952
16	47,05	54,88	82,65	**21,34**	865.900	2.028.819
		Total			**5.740.000**	**13.682.433**

Table 15. Calculation based on Application Time-2022.

Shovel Number	***Availability***	***Performance***	***Quality***	***OEE %***	***Actual Work Quantity (Ton)***	***Production Quantity (Tons) (OEE at 50% level)***
2	26,58	68,25	82,65	**14,99**	532.000	1.774.516
4	62,54	62,03	82,65	**32,07**	1.995.000	3.110.384
5	67,42	59,54	82,65	**33,18**	1.619.800	2.440.928
9	44,69	57,29	82,65	**21,16**	203.700	481.333
16	31,28	66,45	82,65	**17,88**	456.400	1.276.286
		Total			**4.806.900**	**9.083.447**

Upon analyzing Tables 14 and 15, it can be observed that shovel number 4 had the lowest OEE value of 13.21% in 2021, whereas shovel number 2 had an OEE value of 14.99% in 2022. It's worth noting that despite having the worst OEE value in 2021, shovel number 4 had the second-highest OEE value in 2022. The reason behind this is that shovel number 4 underwent an engine overhaul in 2021, which resulted in its low OEE value for that year. However, after the overhaul, shovel number 4's OEE value improved significantly, becoming the second-best in 2022. Therefore, it is recommended to conduct preventive-predictive maintenance operations for old-model shovels, especially after an engine overhaul.

Table 16. Relationship between unplanned downtime and OEE.

2021					**2022**				
Shovel Number	*Total Duration Time (Hour)*	*Unplanned Failure Stops (hour)*	*(Unplanned Failure Stops (hour)/(Net available hours)*100*	***OEE %***	*Shovel Number*	*Total Duration (Hour)*	*Unplanned Failure Stops (hour)*	*(Unplanned Failure Stops (hour)/(Net available hours)*100*	***OEE %***
4	5496	2478	45,09	**13,21**	2	5280	2581	48,87	**14,99**
16	5400	1564	28,95	**21,34**	16	5328	2366	44,40	**17,88**
5	5664	1009	17,81	**21,78**	9	5244	1605	30,60	**21,16**
2	5796	794	13,69	**26,23**	4	6036	965	15,99	**32,07**
9	5400	768	14,21	**27,59**	5	5916	632	10,67	**33,18**

Table 16 shows the relationship between Shovel OEE analysis and unplanned downtime. Similar to the truck analysis, there is an inverse proportion between the OEE value and unplanned downtime. To ensure maximum efficiency, the company should evaluate repairability analysis and OEE analysis together and take necessary

measures. Furthermore, it's important to evaluate the OEE of shovels with the truck-shovel matching factor. If the matching factor is below 1, the shovel may be waiting for truck loading due to the lack of trucks or the long distance to the dump site. In this case, the company must dispatch enough trucks or find solutions to reduce the distance to the dump site in order to maintain optimal performance.

$$\text{Match factor} = \frac{Number\ of\ truck * Total\ period\ duration\ of\ the\ shovel}{Number\ of\ Shovel * Truck\ tour\ time} = \frac{3 * 180\ second}{1 * 19\ minute * 60\ second} = 0{,}47$$

When analyzing the Shovel OEE, it is crucial to consider the truck-shovel compatibility factor within the enterprise. This factor is particularly important when analyzing the work quantities performed by shovels in 2021. It was observed that even though the OEE value was high, the work quantities were low. Upon analyzing the shovel-truck compatibility factor in the field, a compatibility factor of 0.47 was calculated. This was due to the fact that only 3 trucks were available for shovels, and the shovel tour time was 30 seconds while the truck tour time was 19 minutes. Additionally, each truck was filled with 6 shovels. A compatibility factor below 1 indicates that the shovel has to wait for the truck to load. Therefore, establishing a good truck dispatch system on-site and increasing the number of trucks can result in a proportional change in the actual volumes of work to the OEE values. In 2022, there is better alignment between actual throughput and OEE values.

4. Results

- Increasing the OEE values of the trucks will lead to more work performed due to the observed parallelism between the two factors.
- Due to the high total working time of trucks, the frequency of breakdowns increases. To prevent this, it is important to perform a reliability analysis of the trucks and apply preventive and predictive maintenance systems.
- When calculating OEE, shovel operator productivity is crucial for quality. Therefore, increasing loader personnel productivity increases OEE.
- The actual amount of work is not compatible with the OEE values of Shovels due to several reasons.
    1. The shovels have been used for a long time, resulting in a high total working time, which, in turn, increases their failure frequency. Therefore, it is important to perform a maintainability analysis along with the OEE (Overall Equipment Effectiveness) analysis. This helps to review the types and frequencies of failures, as well as the time taken for repairs.
    2. The shovel-truck compatibility factor is an important metric to consider. If the factor is less than 1, it means that the shovel is waiting for the truck to arrive. In such a scenario, the company should either increase the number of trucks assigned to the shovel or reduce the distance to the dump site to decrease the truck tour time. This will help the operations to run smoothly and efficiently.
- There is an inverse relationship between truck and shovel downtime and OEE values. Therefore, minimizing the downtime will increase the OEE value.
- Truck failure times must be reduced if an OEE of at least 50% is to be attained. Reducing the distance to the waste area will likewise raise the OEE value concurrently. The ideal shovel-truck matching for shovels is given by a matching factor of 1, and maintaining this value will raise the OEE. When arranging shovel-truck arrangements, it is crucial to have an adequate number of trucks scheduled for this reason. To achieve this, it is recommended to buy new trucks, minimize the period when trucks and shovels break down, and shorten the duration of truck tours. Production will rise if the OEE value is raised to 50%.

Acknowledgements

This study did not receive any specific funding or financial assistance from governmental, commercial, or non-profit organizations.

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