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Performance assessment of the coal crusher machine using the Overall Equipment Effectiveness (OEE) method

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ABSTRACT: *The coal milling process in the coal handling system unit begins with the coal crusher machining process. A coal crusher is an important machining unit in a power generation unit, it crushes coal into the appropriate size before burning it in the boiler. A common problem that often occurs and requires serious attention is the frequent stoppage of machine operations caused by the entry of foreign objects into the coal crusher. The analysis is done by seeing and identifying problems to determine the level of loss and prevention. This analysis is carried out by comparing the effect of the six big losses and the overall equipment effectiveness (OEE) value on the coal crusher machine. The value of availability rate, performance efficiency and rate of quality for the coal crusher show the fulfilment of the minimum value for each of these requirements so that it is safe to carry out production activities. The value of machine operational feasibility for Overall Equipment Effectiveness (OEE) and analysis of six big losses shows a value of 90% and a total downtime of 130.17 hours. Other values are shown for the period from September to January, respectively: Breakdown losses of 21 hours or 4.2%, setup and adjustment losses of 43 hours or 8.6%, idling and minor stoppages losses of 21 hours or 42%, Reduced speed losses of 2.05 hours or 0.41%, Rework Loss (RL) of 11 hours or 2.2% and Yield/scrap Loss of 32.12 or 6.4%.*

KEYWORDS: *coal crusher, coal handling system, overall equipment effectiveness (OEE), six big losses.*

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I. INTRODUCTION

Coal is one of the essential resources in an industry that requires energy. One of the industries that use coal as a source of energy is a steam power plant. In an industry that uses large numbers of coal with a certain size, it requires a coal crusher to change the shape of the coal into the desired shape. A coal crusher is a machine used to reduce the size of material such as coal, gravel or mountain rock[1][2]. Coal handling system in industry is the most important thing and the process consists of transportation from the coal stockpile, back stacking, transferring the coal to coal crusher and conveying it to the combustion system[3]. The coal handling system is a system that converts electrical energy into mechanical energy of displacement. In this system, tool efficiency values can be achieved in several stages such as engine performance efficiency, operating efficiency, machinery efficiency and technological efficiency of the system[4]. Crusher is a tool used to reduce size of particles used in industry, such as coal in power plants. The main component of the crusher is the use of very hard iron material that exceeds the size of the hardness material that wants to grind. The size of the material that is mashed is usually planned depending on material using. Following the crusher process, in some industries, the material will be sorted again so that it gets the size and shape that of material needed[5][6].

Efficient use of energy is one way to increase work productivity and achieves the environmentally friendly and sustainable performance of handling systems of power plants. Increasing the work efficiency of the system shows a decrease in energy use and it can increase awareness for the environment around the company[7][8]. In various mineral processing industries like coal, the use of stone crushers is very important and many types of stone crushers are available such as using electric power, thermal energy, and so on. Crusher using that is still commonly used today is mechanically driven crushers, due to considerations of effectiveness and efficiency of work[9]. The operation of crusher equipment to achieve high effectiveness values requires several factors such as the characteristics of the material to be crushed and the availability of mechanical power in maintaining the continuous operation of the crusher unit. In the aspect of the material that is crushed, the type of material such as having the appropriate size according to the capacity of the crusher, dry or moist, and whether it contains impurities such as plastic, latex and so on. All of these factors greatly affect the performance and effectiveness of the crusher unit[10].

To increase the productivity and efficiency of machines in a system, it is necessary to take multi-factor steps, such as verifying crusher productivity by sorting out and rearranging workshop functions to achieve high production values[9]. The company's activities in carrying out engine maintenance have an important role in the continuity of the company. Machine maintenances involve maintenance staff at a company to repair machines that have problems and perform the maintenance based on machine performance. all of these, machine maintenances will produce quality products based on capacity and operational efficiency called the overall equipment effectiveness (OEE)[11]. The utilization of the OEE method in maintenance uses several aspects to approach, such as tool performance and product quality. The ultimate goal of this method is to measure the efficiency of the company so that it can reduce losses due to impacts that hinder the production process. Maintenance management by managing the company's downtime can be very effective with the OEE method so that the company's efficiency can be increased[11]–[13].

II. MODELLING OF COAL HAULING SYSTEM

Storage and handling for the next coal requirement carried out as a form of action from the uncertainty of inventory and fuel transportation. Some things that are difficult to do when saving coal is a storage place or building barrier, poor quality and potential for fire.

II.1 Energy use on Belt Conveyor

The energy use calculation model on the conveyor belt provides an overview of the optimization of operating strategy control[14]. The energy analysis equation model given in equation (1) is in four-parameter groups, including θ_1 - θ_4, which can be further elaborated in the following equation[3]:

$$f_p(V,T) = \frac{1}{\eta_B}\left(\theta_1 V T^2 + \theta_2 V + \theta_3 \frac{T^2}{V} + \theta_4 T + \frac{V^2 T}{3.6}\right) \quad (1)$$

The relationship between the variables V and T respectively:

$$T = 3.6 Q_G V \quad (2)$$

The maximum QG value is determined by the characteristics of belt conveyor and the amount of material that was removed.

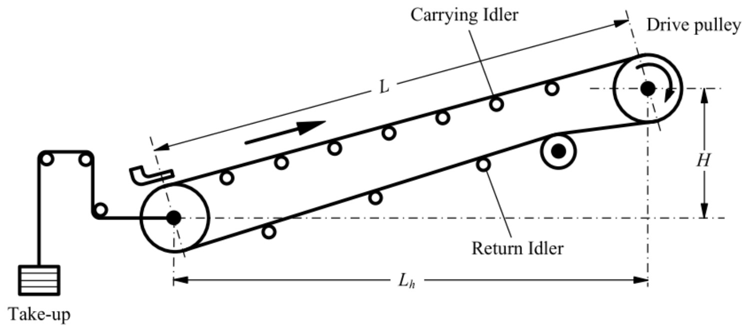

Fig. 1. Belt Conveyor System[14].

Energy consumption in the belt conveyor is determined by the energy consumption based on primary and secondary conditions. The primary condition of energy consumption is determined by the friction that occurs in the drive belt. The outside system has also affected the overall energy consumption and excluded from the special obstacles that occur in the system and then[14]:

$$F_H = f L_g [Q_{RO} + Q_{RU} + (2Q_B + Q_G) cos\delta] \quad (3)$$

Secondary energy consumption occurs in the outside movement of the system, namely inertial resistance that occurs in certain spaces of a belt conveyor system. Resistance occurs because of the friction between the conveyor belt-forming material and the outside base. According to the standard ISO 5048 and DIN 22101, the coefficient C is used to estimate the secondary energy value FN, which is called the coefficient C method, FN = (1-C) FH and the equation becomes[14]:

$$\begin{cases} C = 0.85 + 13.31 L^{-0.576}, & (10 \le L < 1840) \\ C = 1.025 & (1840 \le L) \end{cases} \quad (4)$$

$$F_U = F_H + F_N + \overbrace{F_{fr} + F_{sb} + F_c + F_p} + F_{st} \quad (5)$$

or:

$$F_U = C F_H + \overbrace{F_{fr} + F_{sb} + F_c + F_p} + F_{st} \quad (6)$$

With:

$$P_T = F_U V \quad (7)$$

II.2 Energy Use in Crusher

Energy of ring crusher is needed in coal hauling systems. The energy model usage is given in the equation. The energy transferred from system comes from the energy resulting on the rotation of the machinery in the crusher system. The equation is given in the following form[15]:

$$E = \frac{1}{2} R^2 \omega^2 \quad (8)$$

The total energy used by the system in the crusher model is used to through all elements multiplying with the values of E and TR and then adding all of the total energy which is required by the system, then:

$$P_m = \frac{ET_R}{3.6} + P_{m,0} \quad (9)$$

From the energy in the crusher conditions when not working load, there is an additional parameter λ from the above equation, then:

$$P_m = \frac{1}{\eta_c} \left(\frac{(R\pi)^2}{6480} n^2 T_R + \lambda n^3 \right) \quad (10)$$

The conveyor belt parameters are given in the following table 1 which states the conveyor belt comparison parameters for various reviews.

Table. 1. The conveyor belt parameters[14]

Parameter descripsion	Symbol	Value	Unit	Parameter descripsion	Symbol	Value	Unit
Transfer rate	T	2000	*t/h*	Centre-to-centre distance of the belt	L	313.25	*m*
Density of the material	ρ	900	Kg/m^3	The net change in elevation	H	9.98	*m*
Inclination angle	δ	1.825	^{0}	Width of the belt	B	1400	*mm*
Belt speed	V	3.15	*m/s*	Average spacing of the carrying idlers	a_0	1.2	*m*
Troughing angle	λ	35	^{0}	Average spacing of the return idlers	a_u	3	*m*
Forward tilling angle of idlers	ε	2	^{0}	Length of skirt boards outside feeder station	l_{sb}	4.5	*m*
Diameter of carrying idlers	Φ	133	*mm*	Diameter of return idlers	Φ	133	*mm*
Length of carrying idlers	L_{a0}	530	*mm*	Mass of the moving parts of each carrying idler	q_{r0}	6.3	*kg*
Length of return idlers	L_{au}	800	*mm*	Mass of the moving parts of each return idler	q_{ru}	11.64	*kg*
Unit mass of the belt	Q_B	18.73	*kg/m*	Unit mass of rotating parts of carrying idlers	Q_{Ro}	15.75	*kg/m*
Unit mass of the load	Q_G	176.37	*kg/m*	Unit of rotating part of return idlers	Q_{Ru}	7.76	*kg/m*
Surcharge angle	β	30	^{0}	Friction factor between belt and idlers	μ_0	0.3	*0.3-0.4*
Length for forward tilling idlers	l_r	313.25	*m*	Friction factor between material and belt	μ_1	0.6	*0.5-0.7*
Diameter of the pulley	D	0.8	*m*	Friction factor between material and skirt board	μ_2	0.6	*0.5-0.7*
Inclination coefficient	κ	1.0		Friction factor between belt and its cleaners	μ_3	0.6	
Interval of the skirt boards	b_1	0,85	*m*	Maximum sectional area	A	0.253	m^2
Thickness of the belt	d	0.01	*m*	Pressure exerted on belt by belt cleaner	P	100000	N/m^2
Friction factor	f	0.024		Coefficient of the troughing shape	C_e	0.45	
Coefficient of the scraping board	K_s	1500	*N/m*				

III. OVERALL EQUIPMENT EFFECTIVENESS (OEE)

OEE is a method used to measure the effectiveness of a unit of equipment in a company. Measurement of effectiveness is important because it helps a manager to see and determine the level of effectiveness from a unit of equipment. Table 2 shows the six components of losses that are calculated in a unit of equipment consisting of categories of equipment availability, performance and quality[16].

Table. 2. Six Big Losses[17]

Six Big Loss Category	OEE Loss Category	OEE Factor
Equipment Failure	Downtime Losses	Availability (A)
Setup and Adjustment		
Idling and Minor Stoppages	Speed Losses	Performance (P)
Reduced Speed		
Reduced Yield	Defect Losses	Quality (Q)
Quality Defects		

The relationship between OEE and machine maintenance is on performance and maintenance, which aims to maintain the productive quality and operational efficiency in the machining unit[18]. The strategy of implementing OEE in the machining process is further aimed at seeing responses from company management in seeing and assessing potential losses and obstacles in the production process, such as the potential for zero production, unwanted production failures and minimizing work hazard[19].

$$OEE = Availability\ x\ Performance\ x\ Quality \quad (11)$$

Equation 11 shows the calculation to achieve the value of the effectiveness of the equipment in achieving high performance. Then table 3 shows how to calculate based on the equation given above.

Table. 3. OEE Parameters[16]

Total Time				
Net Available Time				**Scheduled Downtime**
Operating Time			**Downtime Losses** $\rightarrow$	$A = \frac{Operating\ Time}{Net\ Available\ Time}$
Net Operating Time		**Speed Losses** $\rightarrow$	$P = \frac{Net\ Operating\ Time}{Operating\ Time}$	$\rightarrow\ P = \frac{Actual\ Output}{Target\ Output}$
Fully Productive Time	**Defect Losses**	$\rightarrow Q = \frac{Fully\ Productive\ Time}{Net\ Operating\ Time}$	$\rightarrow Q = \frac{Good\ Output}{Actual\ Output}$	

Equipment-loss data is used to calculate equipment operational efficiency which consists of time losses used to calculate the equipment's ability to work, then speed losses are used to measure equipment effectiveness and quality losses are used to compare the quality of the resulting production. All these calculations are given by the following equations[17]:

$$Availability = \frac{Net\ Available\ Time - Downtime\ Losses}{Net\ Available\ Time} x100\% \quad (12)$$

$$Performance = \frac{Operating\ Time - Speed\ Losses}{Operating\ Time} x100\% \quad (13)$$

$$Quality = \frac{Net\ Operating\ Time - Defect\ Losses}{Net\ Operating\ Time} x100\% \quad (14)$$

OEE management will increase the productivity of the equipment used. Equipment alertness in carrying out operations greatly determines the company productivity and minimizes losses that can occur[20]. Periodic maintenance is carried out to keep the productivity of the equipment in good condition and must be carried out with the right method, in addition for frequent maintenance in long-term conditions and the limited supply of basic materials also greatly affects the quality of production at the company, and it can affect the volume and quality of production[17].

IV. EXPERIMENTS

The implementation of maintenance management system in the interconnection system in a company is very important to increase work efficiency and effectiveness[21]. The Total Quality Management-TQM model has a maintenance goal, which is restoring the condition of the equipment to the required condition, so reducing the impact of decreasing work quality. According to the theory of maintenance costs, machinery requires 20-35 % of a company's total production and a maintenance strategy is needed to reduce this impact[22] and the use of correct maintenance methods focuses on preventing failures that may occur in a critical impact of production and in the implementation of maintenance strategies for continuous system improvement[23].

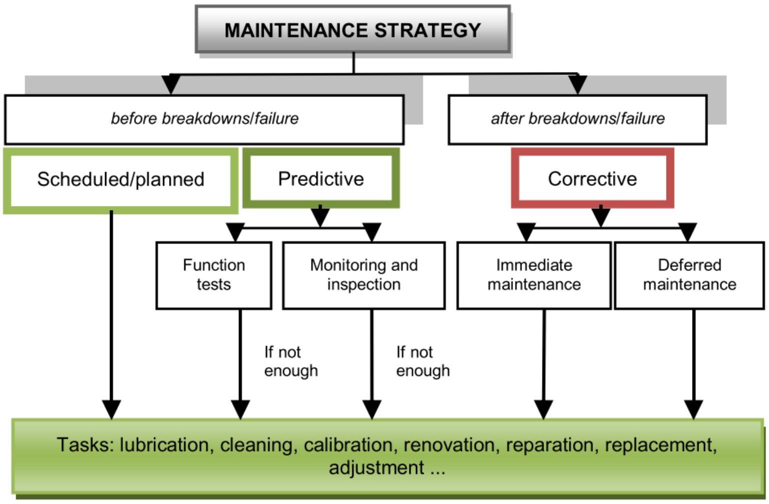

Fig. 2. Maintenance strategies and tasks[21]**.**

IV.1 Total Productive Maintenance Concept

The Total Productive Maintenance (TPM) concept provides an overall maintenance model for machine tools, which have the task to prevent equipment failures in operation[24]. TPM method will pay attention to the technical condition of the equipment and provide a guarantee much longer and more efficient and the main action is to check the condition of the machine in good condition and working properly[25].

Implementation of the TPM strategy is more emphasized on understanding the concept of prevention that is carried out to prevent failures and production defects and losses. Understanding in the application of this concept must also be understood by all employees in a company that aims to help management to achieve the so-called three zeros, zero accident, zero damage and zero downtime.

IV.2 Equipment effectiveness assessment

The overall effective analysis of the equipment is carried out to analyze three factors which include availability, machining capacity and work results and also the performance capabilities of each process have been determined[26]. Estimated analysis of the entire equipment has resulted in the OEE value in which the given equation consists of the comparison of the operating time (tr) and the normal time written on the implementation guide (tt).

$$A = \frac{t_r}{t_t} \quad (15)$$

Machine performance which shows the productivity of the work is calculated based on the productivity of the production in a company (p) multiplied by the time required in a production cycle (tc). And then the results are compared with the required operating hours (tr)[27].

$$P = \frac{p * t_c}{t_r} \quad (16)$$

Production-performance capacity can be decreased by non-dominant factors, such as minor damage to the machine or decreased performance function and also influenced by other non-technical factors, such as decrease in machine capability, excessive working time of employees, and many other factors. Those factors are measured by a good comparison of production results (pa), compared to the overall production (p), against the time required[27].

$$Q = \frac{p_a}{p} \quad (17)$$

The production-planning process which is not good results in waste and resulting losses for the company to repair non-conforming products, and other materials. Figure 3 shows the steps that need to be taken, such as controlling an effective and efficient production process and minimizing production damage, so it is necessary to adjust the total production time compared to the overall execution time and other losses that may occur.

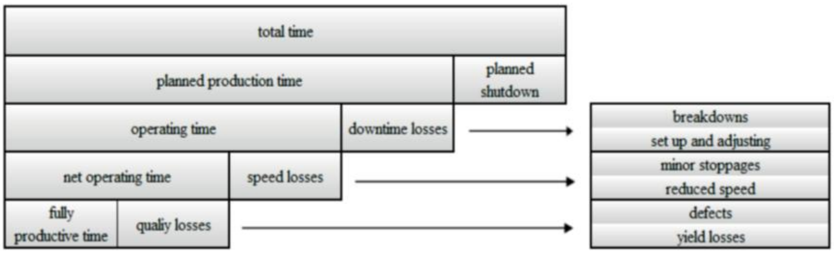

Fig. 3. Relationship between production time and losses[27].

IV.3 Research object using OEE method on Coal Handling System

The research object is taking data on the coal crusher machine in the coal handling system in the steam power plant unit, Nagan Raya, Aceh province. Data processing uses the Overall Equipment Effectiveness (OEE) method and all data will be processed further.

Fig. 4. Coal crusher unit on the coal handling system.

Table. 4. Coal crusher parameters on the coal handling system

No.	Technical Specification	
1.	Model	HS2400
2.	Output	300t/h
3.	Inlet coal granularity	< 70 mm
4.	Outlet coal granularity	< 25mm
5.	Type	Coiled Spring / Ring Hammer
6.	Motor	200 KW YKK400-8
7.	Coupling quality	350 kg
8.	Motor quality	2500 kg

V. RESULTS AND DISCUSSIONS

Machine operating time (downtime) is time used during the operation of the production unit reduced by the required maintenance time that occurs suddenly while the machine is operating. The operating time of the coal crusher unit is 13-14 hours per day which is divided based on work shifts and is reduced by the time for machine repairs that occur. The coal crusher downtime data is given in the range of September to January (5 months) respectively:

Table. 5. Coal crusher downtime data

Month	Total Downtime (Hours)	Coal crusher working hours (Hours)
September	7	13 x 30 = 343
October	3	13 x 31 = 403
November	4	14 x 30 = 434
December	4	13 x 31 = 403
January	3	13 x 31 = 403

Scheduled maintenance time (planned downtime) is given to provide certainty of machine operating time, which is used to carry out a whole series of activities starting from the production process, maintenance plans and follow-up plans. Time data for planning activities of coal crusher machines in the period from September to January are given:

Table. 6. Coal crusher-planed downtime data

Month	Total maintenance time (Hours)
September	10
October	11
November	6
December	9
January	7

One period of time to complete the entire production process that produces one type of product requires setting up time. Set-up time provides an estimation of the time required, from starting the machine to the end of the production process. For the coal crusher machine in the period from September to January, the following data are given:

Table. 7. Coal crusher set-up time data

Month	Total Set-Up Time (Hours)
September	9
October	8
November	13
December	7
January	6

Data on the overall performance of the coal crusher that produces the steam power plant unit are determined by three factors, i.e total available time which is the time availability by the machinery unit to produce total production which is calculated in tons/hour, secondly, the total good product which is the total production in good and in accordance with the expected criteria and the total reject product which is the total number of rejected production due to non-compliance with predetermined specifications.

Table. 8. Coal Crusher Production Time

Month	Time availability (Tons/Hour)	Good Product (Tons)	Reject product (Tons)
September	200 x 343 = 68600	198 x 343 = 67914	2 x 343 = 686
October	195 x 403 = 78585	193 x 403 = 77779	2 x 403 = 806
November	190 x 434 = 82460	189 x 434 = 82026	1 x 434 = 434
December	200 x 403 = 80600	197 x 403 = 79391	3 x 403 = 1209
January	189 x 403 = 76167	187 x 403 = 75361	2 x 403 = 806

V.1 Data processing results

The operating time of the coal crusher machine is given by the calculation of the Availability rate value during the operation of the unit. The table and graph below provide the evaluability of the coal crusher availability rate during the operational period from September to January:

Table. 9. Coal crusher Availability Rate

Month	Loading time (Hour)	Operational time (Hour)	Downtime	Availability Rate (%)
September	343	154	16	91.57
October	403	173	11	94.02
November	434	167	17	98.81
December	403	180	11	94.24
January	403	173	9	95.05

Table. 10. Coal Crusher Performance Efficiency

Month	Products (Ton)	Operational time (Hour)	Ideal cycle	Performance (%)
September	68600	174	200	78
October	78585	173	195	88
November	82460	167	190	93
December	80600	180	200	89
January	76167	173	189	83

Table. 11. Quality product rate value

Month	Products (Ton)	Reject (Ton)	Quality (%)
September	68600	686	99
October	78585	806	98.97
November	82460	434	99.4
December	80600	1209	98.5
January	76167	806	98.9

V.2 Overall Equipment Effectiveness (OEE) Calculation

The Overall Equipment Effectiveness (OEE) value is carried out after calculating the values for the availability, performance and product quality produced by the coal crusher unit in a power plant. It is important to calculate the OEE value and determine the effectiveness of the operational coal crusher. The following data provides OEE values for September to January:

Table. 12. Overall Equipment Effectiveness (OEE) Value

Month	Availability Rate	Performance Efficiency	Rate of Quality Product	OEE (%)
September	91	78	99	70.2
October	94	88	98.97	81.8
November	98	93	99.4	90.5
December	94	89	98.5	82.4
January	95	83	98.9	77.9

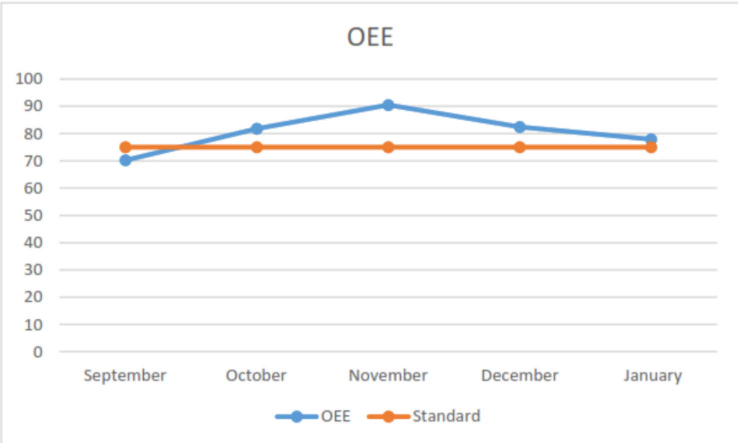

Fig. 5. The Overall Equipment Effectiveness (OEE) Coal Crusher Diagram.

V.3 The Overall Equipment Effectiveness (OEE) Six Big Losses Analysis

Calculation and Analysis from OEE show Six Big Losses in the production process of a coal crusher unit in a power generation system. The further analysis is carried out on the Six Big Losses so that follow-up planning will be carried out for improvement and optimization.

Table. 13. Six Big Losses-Coal Crusher Factor

Month	Breakdown Losses (%)	Setup and Adjustment Losses (%)	Idling and Minor Stoppages losses (%)	Reduced Speed losses (%)	Rework Loss (RL)	Yield/Scrap Loss
September	7	9	0.020	0.46	0	7.58
October	3	8	0.017	0.39	0	11.61
November	4	13	0.009	0.40	1	5.25
December	4	7	0.009	0.41	0.2	4.46
January	3	6	0.007	0.39	0	3.28
Total	21	43	0.062	2.05	1.2	32.12

Table. 14. Cumulative Percentage of Six Big Losses Coal Crusher

No	Six Big Losses	Total Time Losess (Hour)	Percentage (%)
1	Breakdown Losses	21	4.2
2	Setup and Adjustment Losses	43	8.6
3	Idling and Minor Stoppages losses	21	4.2
4	Reduced Speed losess	2.05	0.41
5	Rework Loss (RL)	11	2.2
6	Yield/Scrap Loss	32.12	6.4
	Total	130.17	

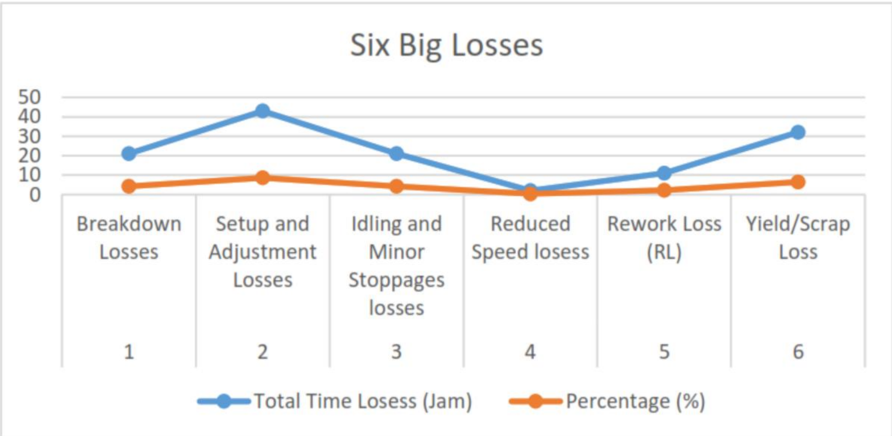

Fig. 6. Six Big Losses Coal crusher percentage chart.

From the analysis of Six Big Losses data, there is the highest percentage occurred in the setup and adjustment losses section at 43%, this happened because during the production process there was a sudden engine blackout, and then the smallest percentage value of Six Big Losses is 2% that occur in the reduced speed losses having little effect on the performance of machinery.

VI. CONCLUSION

Overall equipment effectiveness (OEE) data shows values for three components, namely Availability Rate, Performance Efficiency and Rate of Quality Product. The highest OEE value occurred in November is 90.5%, and the highest average value of the Rate of Quality Product is 99.4. The smallest OEE value occurred in September is 70.2%, occurred at the highest Rate of the Quality Product value of 99.

The data on the cumulative percentage of six big losses conclude that the highest production loss time occurs in setup and adjustment losses, which is 43 hours, with a ratio of 8.6 percent and the smallest production loss value is 2.05 hours on reduced speed losses or 0.41 percent.

All the provided data concludes that there is a loss of production in some parts of the process that caused production process to occur. This process loss occurs due to a sudden stop in machining problems caused by many factors or six big losses factors. And there are some insignificant reductions in machinery production capacity which have no impact on the production process.

REFERENCES

[1] G. Lodhi, “Operation and Maintenance of Crusher House for Coal Handling in Thermal Power Plant,” *Int. J. Mech. Eng. Rob. Res*, vol. 2, no. 4, 2013, [Online]. Available: www.ijmerr.com.

[2] E. Endarto, R. Juniah, and W. Herlina, “Evaluation of Concatenation Planning of Crushing Plant Production System Using Analytic Hierarchy Process (AHP) Method at PT Buana Eltra Coal Processing Unit, South Sumatra,” *Indones. J. Environ. Manag. Sustain.*, vol. 2, no. 1, pp. 1–6, 2018, doi: 10.26554/ijems.2018.2.1.1-6.

[3] S. Zhang and W. Mao, “Energy efficiency optimization of coal conveying systems with consideration of crushers,” *Energy Procedia*, 2017, [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1876610217307920.

[4] X. Xia and J. Zhang, “Operation efficiency optimisation modelling and application of model predictive control,” *IEEE/CAA J. Autom. Sin.*, vol. 2, no. 2, pp. 166–172, 2015, doi: 10.1109/JAS.2015.7081656.

[5] J. Wang, “Research on Structural Design of Coal Crusher House in Thermal Power Plant,” *J. Archit. Environ. Struct. Eng. Res.*, vol. 3, no. 2, pp. 14–17, 2020, doi: 10.30564/jaeser.v3i2.2103.

[6] V. Solovyova, D. Solovyov, and I. Stepanova, “Concretes with unique properties for special building structures,” *Mater. Sci. Forum*, vol. 945 MSF, pp. 64–69, 2018, doi: 10.4028/www.scientific.net/MSF.945.64.

[7] S. R. Patterson, E. Kozan, and P. Hyland, “International Journal of Production Research An integrated model of an open-pit coal mine: improving energy efficiency decisions An integrated model of an open-pit coal mine: improving energy efficiency decisions,” 2016, doi: 10.1080/00207543.2015.1117150.

[8] D. Laurence, “Establishing a sustainable mining operation: An overview,” *J. Clean. Prod.*, vol. 19, no. 2–3, pp. 278–284, 2011, doi: 10.1016/j.jclepro.2010.08.019.

[9] C. Mao and X. Mao, “Research on Productivity Detection Method of Gyratory Crusher based on Kinematic Characteristic Analysis,” vol. 4, no. 1, pp. 4–7, 2019.

[10] jumsar, H. Hasan, and Sakdillah, “(Evaluation of Crusher Productivity in Coal Processing Plant in PT . Bara,” vol. 8, no. 1, pp. 6–8, 2020, doi: 10.21275/27012001.

[11] S. Singh, K. Singh, V. Mahajan, and G. Singh, “Justificmation of Overall Equipent Effectiveness (OEE) in Indian Sugar mill industry for attaining core excellence,” *Int. J. Adv. Res. Innov.*, vol. 8, no. 1, pp. 34–36, 2020.

[12] R. S. Sen, G. Majumdar, and S. Nallusamy, “Enhancement of overall equipment effectiveness through implementation of total productive maintenance,” *Proc. Int. Conf. Ind. Eng. Oper. Manag.*, no. July, pp. 475–484, 2019.

[13] A. Kumar Gupta and R. K. Garg, “OEE Improvement by TPM Implementation: A Case Study,” *Int. J. IT, Eng. Appl. Sci. Res. Int. Res. J. Consort.*, vol. 1, no. 1, pp. 2319–4413, 2012.

[14] S. Zhang and X. Xia, “A new energy calculation model of belt conveyor,” *IEEE AFRICON Conf.*, no. September, pp. 1–6, 2009, doi: 10.1109/AFRCON.2009.5308257.

[15] S. Nikolov, “Modelling and simulation of particle breakage in impact crushers,” *Int. J. Miner. Process.*, vol. 74, pp. S219–S225, 2004, doi: 10.1016/j.minpro.2004.07.031.

[16] S. Elevli and B. Elevli, “Performance measurement of mining equipments by utilizing OEE,” *Acta Montan. Slovaca*, vol. 15, no. 2, pp. 95–101, 2010.

[17] H. M. Lazim, T. Ramayah, and N. Ahmad, “Total productive maintenance and performance : A Malaysian SME experience International Review of Business Research Papers Total Productive Maintenance And Performance : A Malaysian SME Experience,” no. June 2016, 2008.

[18] A. Ollila and M. Malmipuro, “Maintenance has a role in quality,” *TQM Mag.*, vol. 11, no. 1, pp. 17–21, Jan. 1999, doi: 10.1108/09544789910246589.

[19] K. Singh and S. Singh, “Eliminating Obstacles in TPM Implimentation In Sugarmill Industry,” vol. 6, no. 4, pp. 332–334, 2018.

[20] K. Shirose and N. P. M. Kyōkai., “TPM team guide,” p. 155, 1995.

[21] H. Pacaiova and J. Glatz, “Maintenance management system,” *MM Sci. J.*, vol. 2015, no. OCTOBER, pp. 665–669, 2015, doi: 10.17973/MMSJ.2015_10_201532.

[22] B. S. Dhillon, “Mining Equipment Reliability, Maintainability, and Safety,” 2008, doi: 10.1007/978-1-84800-288-3.

[23] H. Pacaiova, J. Glatz, and S. Kacvinsky, “Positive and negative aspect in application of maintenance management philosophy,” *J. Appl. Eng. Sci.*, vol. 10, no. 2, pp. 99–105, 2012, doi: 10.5937/jaes10-2131.

[24] “Nowoczesne metody w zarządzaniu przedsiębiorstwem - Zeszyty Naukowe. Organizacja i Zarządzanie / Politechnika Śląska - Numer z. 60 (2012) - BazEkon - Yadda.” http://bazekon.icm.edu.pl/bazekon/element/bwmeta1.element.ekon-element-000171412793 (accessed Mar. 04, 2022).

[25] E. Pawłowski, K. Pawłowski, and S. Trzcieliński, “Metody i narzędzia Lean Manufacturing : materiały dydaktyczne,” 2010.

[26] “OEE dla operatorów. Całkowita Efektywność Wyposażenia.” https://sklep.prodpublishing.com/katalog/oee-dla-operatorow-calkowita-efektywnosc-wyposazenia (accessed Mar. 09, 2022).

[27] “Wskaźnik całkowitej efektywności wyposażenia (Overall Equipment Effectiveness) jako miara skuteczności i narzędzie doskonalenia organizacji - Studia i Prace Kolegium Zarządzania i Finansów / Szkoła Główna Handlowa - Numer z. 134 (2013) - BazEkon - Yadda.” http://bazekon.icm.edu.pl/bazekon/element/bwmeta1.element.ekon-element-000171274853 (accessed Mar. 09, 2022).

Maidi Saputra, et. al. "Performance assessment of the coal crusher machine using the Overall Equipment Effectiveness (OEE) method.”*American Journal of Engineering Research (AJER)*, vol. 11(04), 2022, pp. 41-50.