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Technical analysis of fixed screen in coal extraction activities (case study: PT. MAL)

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Abstract:

The extraction of coal is one of the activities involved in mining operations, where drilling, blasting, milling, crushing, sizing, and screening of minerals are performed. At PT. MAL, Indonesia, this extraction activity involves in-pit processing, such as the sizing of coal using a fixed screen. This study aims to analyze the technical sectors regarding the use of fixed screens in coal production activities. This is carried out to reduce the production time and costs, as productivity is expected to increase and completely meet market demands. The challenges involved in the use of fixed screens influenced the availability value of coal. In this case, the use of availability (UA) and effective utilization (EU) values of the utilized excavator were insufficient. These conditions were due to the observation of many challenges in the coal extraction activities. The challenges also affected the performance and production of the excavator, where the solution emphasized the redesign of the fixed screen through the modification of several parameters, such as the angle of repose and screen capacity.

Keywords: extraction of coal, fixed screen, modification, sizing

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1. Introduction

Downstream coal products are essential in the mining industry and consistent with the use of the mineral resource in other related sectors. In the steam power plant (PLTU) industry, the use of this mineral is also related to the forecast benefits produced by coal extraction activities. The demand for electricity and energy consumption is found to continue increasing in both developed and developing countries [1]. China, the United States of America (USA), India, Germany, Russia and Japan consume 76 percent of world's coal consumption for energy [2]. Meanwhile, the countries of the Asia-Pacific region are the main consumers of primary energy in the world, where about 44.8% of world energy consumption or 5,921 million toe [3]. Similarly, the need for electricity in the industrial, household and service sectors continues to increase in developing countries, to support socio-economic development activities. This shows that the world electricity generation is expected to continuously increase by 21.6, 25.8, and 36.5 trillion kilowatt-hours (T-kWh) in 2012, 2020, and 2040, respectively [4].

Indonesia has abundant reserves of medium and low-quality coal, as well as presently ranks 9th with approximately 2.2% of the total global reserves, based on the BP Statistical Review of World Energy. About 60% of the country's total reserves contain cheaper (sub-bituminous) and low-quality coal, which has a content of less than 0.0255 MJ/kg. Besides being exported to the giant markets of developing countries such as China and India, medium and low-quality coal is also domestically utilized as fuels for power plants, whose demand is continuously increasing. Based on PLN's recent Electricity Supply Business Plan, the Indonesian coal demand for power generation was estimated to increase from 90 million tons to 150-160 million in 2028-2030 [5]. PT. Manggala Alam Lestari (PT. MAL) is one of the companies supplying coal for the power plants located in Musi Banyuasin Regency, South Sumatra, Indonesia. It also supplies coal to PLTU SUMSEL V, which is operated by PT. DSSP Power. The particle size of this mineral is very important for coal power plants, thus it is expected to meet the required specifications during extraction. In the process of coal production and preparation, it is very important to separate it into fractions for various applications by the screen tools [6,7,8,9].

Some of them also stated that the use of appropriate screens or jigs affected the recovery of mining outputs [10, 11, 12]. According to Lestari et al [13], the size of coal grains should not be fine for supply to coal-fired power plants, i.e., limited to < 3 mm. This was due to the effects of dust on the surrounding environment, which leads to the non-actualization of required specifications.

Additionally, PT. MAL is found to set the mineral's standard size at a maximum acceptable size of 20 cm, for supply to the DSSP Power. Besides the particle size, the quality of coal is also very important in power generation, using proximate and ultimate analyses [14]. Based on the proximate analysis, the quality specifications desired by PT. DSSP Power PLTU SUMSEL 5 are as follows, (1) Total Moisture, 45%, (2) Inherent Moisture, 15%, (3) Ash Content, 9% (ADB), (4) Volatile Matter, 41% (ADB), (5) Total Sulfur 0.4% (ADB), (6) Fixed Carbon, 35% (ADB), (7) HGI 74, and (8) Calorific Values, 14.22 and 21.75 MJ/Kg (AR and ADB). Meanwhile, the coal quality specifications according to the ultimate analysis are as follows, (1) Carbon (C), 56%, (2) Hydrogen (H), 4.25%, (3) Nitrogen (N), 0.90%, (4) Sulphur (S), 0.30%, and (5) Oxygen (O), 15.20% (PT. Manggala Alam Lestari's Archive, 2021).

Coal extraction is one of the activities involved in mining operations. At PT. MAL, the utilized extraction processes involve coal sizing, using a fixed screen. The functions of the fixed-screen tool show that the size of the coal to be crushed needs to be consistent with the required specifications for its easy destruction. During field application, two tools are often used, namely collection and loading excavators. In this case, coal is reportedly obtained by the collection excavator and transferred to the loading machine, which loads and crushes the mineral on a fixed screen, with the escaped residues dropping into the vessel dump truck. Using fixed screens, coal excavation activities have many productivity challenges, such as (1) The coal material stuck in between screens, (2) The screen removal when the front coal is exhausted, (3) The coal load fireplaces, etc. This leads to slower cycle

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times, compared to the extraction periods without a screen. Therefore, the réévaluations of these activities are needed for better effectiveness and efficiency, regarding the work performances and products obtained from the fixed screen.

The size reduction activity in coal processing often used crushing tools or comminution, whose standard products are supplied to coal-based power plants. Based on these processes, some previous reviews reported the use of the fixed or grizzly screen in andesite stone processing, after the crushing or comminution activity [15]. With most of them analyzing the use of the grizzly screen on andesite stone, for asphalt mixing plant needs [16], others emphasized the utilization of the fixed-screen tool in Croatia's limestone mining [17]. Irrespective of these results, the use of screen tools or sizing without a crusher is still very rarely carried out in the coal industry. Other previous studies also reported that coal processing was carried out for the stockpile port [18], evaluation of the crushing plant production series plan [19], and pit crushing application potential in Saint Petersburg, Russia [20]. Therefore, this study aims to examine the effectiveness of Fixed Screen Tools in PT. Manggala Alam Lestari (MAL), Indonesia, regarding the activities of coal extraction in the technical and economic sectors. The results obtained are expected to provide updates in the development of the mining science field, especially coal processing.

2. Literature review

2.1. Coal resources and reserves

Coal is one of the most abundant sources of energy in the world [21], as a global reserve estimation of approximately 1,074 billion tons was predicted in 2021 [22]. Due to its overall significance, several reviews were conducted on the sustainability of long-term supply. These included the following, (1) Economic Evaluation Regarding the Use of Indonesian Coal [23], (2) Low-Ranked Indonesian Coal Resources with commercially-efficient UBC Technology [24] and (3) Willingness of Indonesian Coal To Meet The 2050 Demand [25].

Besides future production analysis, more reports were also carried out on the peak manufacture of coal. This indicated that the production peak was expected between 2042 and 2062, at a maximum yield of 4.1-4.9 Gtoe/year [26]. Other studies also predicted the rapid increase of coal production by an average of 2.2% p.a from 2010 to 2030 [27]. The number and location of the world's coal beds are shown in Fig. 1.

Indonesia's coal reserves are the second-largest in South and Central Asia, specifically located on the islands of Kalimantan and Sumatra. This energy source is presently the main supply of electric fuel, with an allocation of 55.6% and it is also expected to achieve an electrification ratio of 98% [25]. Based on the Coal and Geothermal Mineral Resources Centre, Ministry of Energy and Mineral Resources [28], Indonesia's energy resources were estimated at approximately 110,069.91 million tons, mostly located in Sumatra and Kalimantan Islands (Fig.2). Measurable resources reached 41,369.38 million tons, where the potentially mined reserves are estimated at 17,903.92 million tons. In addition, the referenced resources are estimated at 34,350.38 million tons and predicted resources achieved 34,350.15 million tons.

Coal resources are mostly classified as lignite (58.7%), sub-bituminous (26.7%), bituminous (14.3%), and anthracite (0.3%). According to the classification of ASTM, the lignite and sub-bituminous grade "C" resources were categorized as Low-Rank Coal [24].

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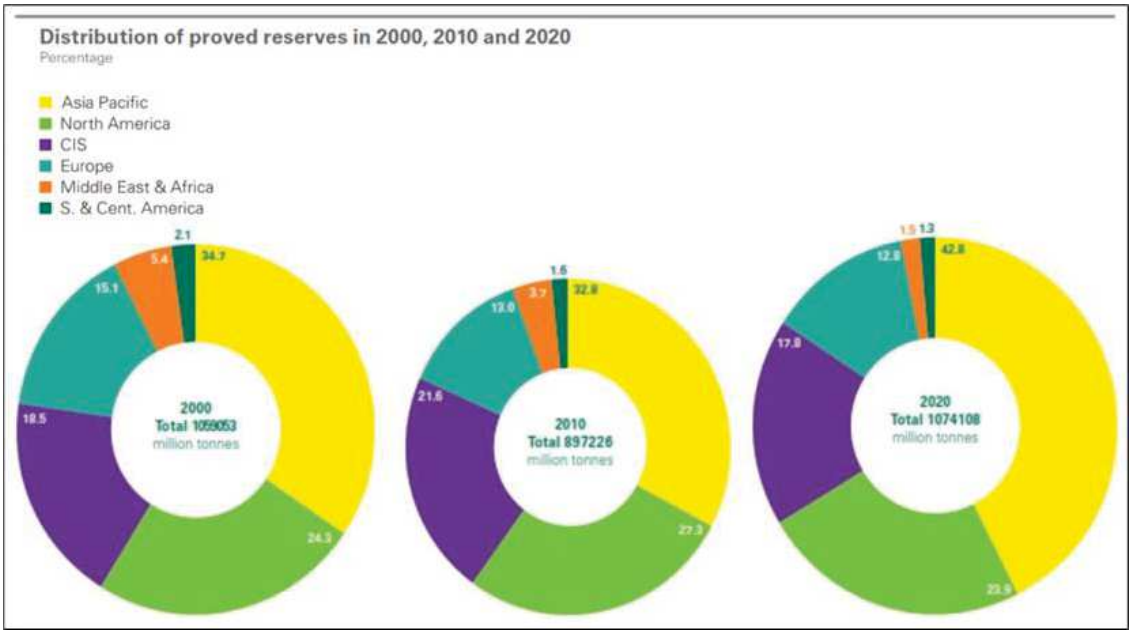

Fig. 1. World Coal Reserves

Kualitas	Target Eksplorasi	Total Inventori	Sumberdaya (Juta Ton)					Cadangan (Juta Ton)			
			Tereka	Tertunjuk	Terukur	Total	Total Terverifikasi	Terkira	Terbukti	Total	Total Terverifikasi
Kalori Rendah	417.17	11,252.41	14,961.91	11,979.49	10,402.32	37,343.72	29,703.20	7,523.85	5,401.22	12,925.07	10,869.81
Kalori Sedang	2.06	547.38	14,625.47	18,356.99	26,869.92	59,852.38	51,868.94	9,464.74	11,220.50	20,685.24	18,811.62
Kalori Tinggi	5,040.47	10,717.99	3,368.46	3,135.27	3,228.12	9,731.85	7,246.56	1,139.99	885.96	2,025.95	1,456.17
Kalori Sangat Tinggi	681.42	1,848.07	1,394.31	878.63	869.02	3,141.96	2,787.34	246.34	396.25	642.59	558.02
JUMLAH	6,141.12	24,365.84	34,350.15	34,350.38	41,369.38	110,069.91	91,606.04	18,374.92	17,903.92	36,278.85	31,695.63

Fig. 2. Distribution of Indonesian Coal Resources

The characteristics of coal resources are also shown in Fig. 3, where 8% of the components had high calorific profiles, with the rest mostly categorized as low and medium contents (low-rank coal). With the abundance of these low-ranked resources, the utilization of coal is promoted as fuel for steam power plants in Indonesia.

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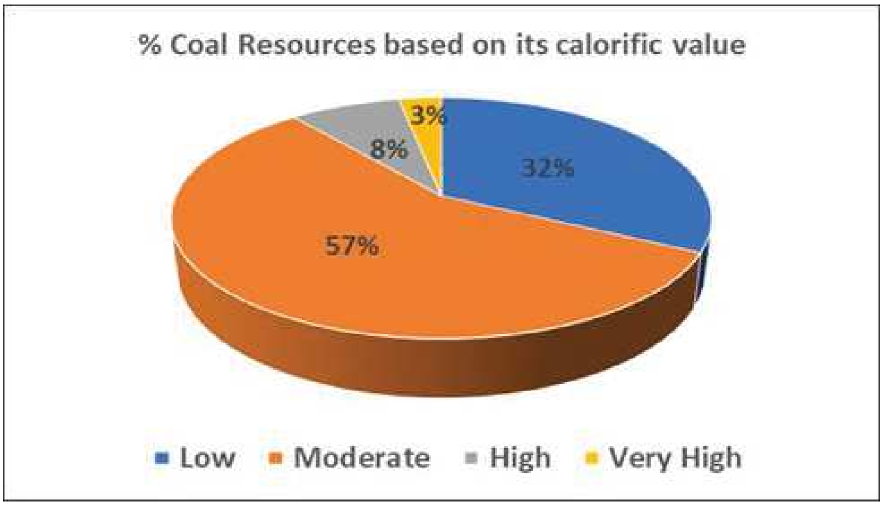

Fig. 3. Indonesian Coal Resources by calorific value

2.2. Coal mining

According to Law No. 3 of 2020 concerning the Amendments of Law No 4 of 2009, mining was partially or totally among the stages of the framework activity, management, and operation of coal. This included the general investigation, exploration, feasibility studies, construction, mining, processing/refining or development/utilization, transportation and sale, as well as post-mining activities [29].

2.3. Coal processing

2.3.1. Comminution

Comminution is the process of reducing specific average particle size to a smaller size, for the separation of impure particles from the existing method.

2.3.2. Sizing

Sizing or grain size uniformization is the process of levelling a sieve dimension according to the desired standards, for the derivation of homogeneous outputs. Based on Ogunmodimu et al [30], the following factors need to be considered in the selection of screen:

a. Methods of feed
   This is to obtain maximum capacity and achieve efficiency, i.e., the material rate should evenly flow over the entire screen surface at a low speed.
b. Angle of slope
   The addition of a suitable slope angle increases the material rate for greater efficiency and capacity, as well as a perfect separation process.
c. Screening surface
   Capacity and efficiency are higher when the screen surface is serially placed between one another, for the flat output of the material.
d. Direction of rotation
   An efficient rotating screen is higher when a rotation is carried out to disrupt the flow of the material rate and the direction of centrifugation.
e. Vibration amplitude and frequency
   The screen's vibration rates and the surface area affect the efficiency of the material. This indicated that higher vibrations and area led to greater efficiency.
f. Screen capacity

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Generally depends on the cross-sectional area or track length, load size, and feed properties, such as the specific gravity, water content, temperature, and the type of utilized mechanical screen.

2.4. Correction factors

In loading and digging productivity, the magnitude of the total correction factors includes operator skills, work efficiency, and machine availability [31].

2.4.1. Work efficiency

This is a comparison between productive and available working periods [32]. In this case, effective working time emphasizes the operator and the tools used to carry out production activities [33]. This shows that the available time is realistically unable to be used entirely for production (less than 100%), due to the challenges observed during the mechanical device's operation.

These operational activities include the state of the tool and the working field (mechanical and operating conditions), as well as its human traits as an operator [34]. In addition, the magnitude of the work efficiency value is strongly influenced by the operational condition of the equipment (Table 1).

Table 1. Work efficiency regarding the operational condition

Operating Conditions	Work Efficiency
Good	0.83
Normal – Medium	0.75
Not Good Enough	0.67
Bad	0.58

2.4.2. Machine availability

This indicates the condition and performa+nce of mechanical devices, considering the time lost during the operational period [35].

a. Mechanical Availability (MA)

Mechanical availability shows the readiness (available) of a tool from the time lost, due to instrumental damages or disruptions [34]. The equation used to calculate this factor is shown as follows:

$$MA = W/(W + R)\ x\ 100 \tag{1}$$

where:

MA – Mechanical willingness, %,
W – Working period, hours,
R – Repair period, hours.

The working period is often initiated when the operator mounts an available operational tool. This period is subsequently observed from the recording on the operator's time card or hour meter tool. It also includes delay time [34], which contains the following issues:

1) Loss of time when available to work,
2) Moving time,
3) Lubrication, gasoline filling, and tool maintenance periods,
4) Loss of time due to weather conditions,
5) Safety meeting time,
6) Others.

b. Physical availability (PA).

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Physical availability (Operational availability) shows the operational willingness of a tool, by eliminating the loss of time due to various causes [36]. The equation for calculating this factor is shown as follows:

$$PA = (W + S)/(W + R + S)\ x\ 100\ \% \tag{2}$$

where:
PA – Physical Willingness, %,
W – Working period, hours,
R – Repairs period, hours,
S – Standby period or loss of time when the tool is not operated, although is in good condition, hours.

c. Use of availability (UA)

This is the percentage of time used by a tool during operational performances [36]. It was also calculated by dividing the working periods by the sum of operational and standby hours (Eq. 3).

$$UA = W/(W + S)\ x\ 100\ \% \tag{3}$$

where:
W – Working period, hours,
S – Standby period, hours.

d. Effective utilization (EU)

This is the percentage figure of a tool's overall utilization [36], regarding the comparison of working and available periods (Eq. 4). It is also very similar to the utilization of availability, while only inconsistent with working to total periods. Therefore, the EU is the tool utilization in the time available for production activities [34].

$$EU = W/(W + R + S)\ x\ 100\ \% \tag{4}$$

where:
EU – Effective Use, %,
W – Working period, hours,
R – Repair period, hours,
S – Standby period, hours.

2.4.3. Bucket fill factor

The bucket fill factor is a comparison between the actual volume and the theoretical ability of a material. This shows that softer materials cause higher fill factors while forming a state of disrespect on the bucket. However, a hard material leads to many cavities and inadequate material contents. The value of this factor also emphasizes the natural nature of the evacuated material [37]. Based on material conditions, the bucket-fill factor values are determined, as shown in Table 2.

Table 2. Bucket-Fill Factor

Excavating Condition		Bucket Fill Factor
Easy	Excavating the natural ground of clayey, clay, or soft soil	1.1-1.2
Average	Excavating the natural ground of sandy and dry soil	1.0-1.1
Rather Difficult	Excavating the natural ground of sandy soil with gravel	0.8-0.9
Difficult	Loading blasted rock	0.7-0.8

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However, the current bucket fill factor value was searched by dividing the current bucket content and the theoretically heaped material (Eq. 5).

$$BF = \frac{Vessel\ Capacity}{Actual\ charging\ amount\ x\ Theoretical\ Heaped\ material} \tag{5}$$

2.4.4. Swell factor

The swell factor is a transformational process, regarding the addition and subtraction of the material volume from its original form [31]. This is divided into three states, namely Bank, Loose, and Compact Conditions. The value of this factor is also calculated by dividing the bank and loose volumes (Eq. 6).

$$SF = \frac{(Bank\ Volume)}{(Loose\ Volume)} \tag{6}$$

2.5. Productivity of excavator

The equation involved in this analysis is shown as follows,

$$\text{TP} = \frac{KB\ X\ BF\ \ X\ SF\ X\ 3600\ X\ FK}{CT} \tag{7}$$

where:
- TP – Estimated production, BCM/hour,
- KB – Bucket Capacity, m^3,
- BF – Bucket Factor,
- SF – Swell Factor,
- FK – Correction Factor, i.e., tool x work x operator efficiencies,
- CT – Cycle time, seconds.

2.6. Efficiency and calculation of loose screen

The amount of material passing at a specific screen size is often expressed in percent (%), as shown in the following equation.

$$\text{Eff}\ \ Screen = \frac{Product\ Weight}{Feed\ Weight}\ x\ 100\% \tag{8}$$

Using the material balance formula, the losses in a processing circuit were subsequently calculated [38].

$$Qin\ =\ Qout\ +\ Losses \tag{9}$$

where:
- Qin – Incoming Material, tons/hour,
- Qout – Material Out, tons/hour,
- Losses – Loss Factor, tons/hour.

3. Research methods

This experimental analysis was carried out by developing coal without a comminution process and redesigning the screening tool used in the extraction activities. Quantitative methods were also used to calculate the efficiency of a screen, through the challenges encountered in using a fixed-screen tool. Subsequently, these methods were used in comparing the costs of crushing and screen activities in the coal extraction. Irrespective of these conditions, the survey method was carried out to directly observe extraction processes in PT. Manggala Alam Lestari, Musi Banyuasin, South Sumatra, Indonesia.

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3.1. Data collection techniques

Data collection was carried out using two methods : primary and secondary. The primary data was obtained through the following methods:

(1) Direct observations in the coal mining field of PT Manggala Alam Lestari, Indonesia. The parameters obtained included : (a) the weight of coal entering the fixed screen as a feed, (b) the weight of coal escaping the filter, (c) the coal retained in the filter,
(2) Recording the time of digging, loading, and transporting,
(3) Conducting calculations to obtain efficiency, capacity, fixed screen productivity, and economic feasibility data,
(4) Field documentation,
(5) Conducting interviews with selected participants, to obtain data on tool production costs, life, and availability, as well as coal extraction process,
(6) Redesigning the fixed screen model efficient and effective for coal extraction,
(7) Other necessary related data.

Secondary data were also obtained through literature and instasional studies. Through the publication of national and international journals, the previous literature emphasized existing analyses, reviews, and other sources related to experimental problems. Meanwhile, the instasional studies were obtained through PT. Manggala Alam Lestari or other related agencies. In this case, the parameters obtained included :

(1) The map of the study location,
(2) Coal production,
(3) Tool feasibility,
(4) Fixed-screen tool specifications, and (5) Other data.

3.2. Data processing and analysis techniques

Data processing was carried out through the utilization of primary and secondary data, to determine the efficiency of screen work. This was subsequently conducted challenges of fixed screen utilization in coal extraction activities. The cost of crushing and screen activities of this mineral production were also compared. This should be conducted based on the obtained raw data, which need to be subsequently processed in deriving the work efficiency of fixed screen tools. They should also be used in redesigning an efficient and effective fixed screen model for coal extraction. In addition, data analysis was descriptively carried out using existing calculations, regarding the analysis of an efficient and effective screen model.

4. Results and discussion

Coal extraction is one of the activities in mining operations, where in-pit processing involved the sizing of this mineral using a fixed or grizzly screen (Figs. 4 & 5). The functions of the fixed screen tool show that the size of the coal to be crushed was consistent with the required specifications for easy destruction. During field application, two tools are often used, namely collection and loading excavators.

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Fig. 4. Coal Extraction with In-pit Processing

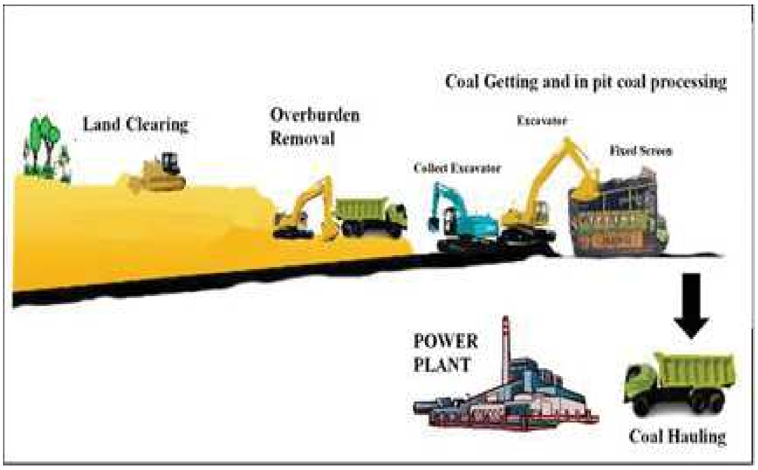

Fig. 5. Mining Process in PT. MAL

4.1. Availability analysis

The important factors, contained MA, PA, UA, and EU representing mechanical availability, physical availability, use of availability, and effective utilization production of the machine were analysed. In PT. MAL, the MA and PA values of the loading excavator were excellent, showing that the average mechanical and physical availability scores were 89 and 92%, respectively in 2021. Based on the MA value, the loading and unloading tools were adequately maintained and rarely damaged. In this case, such loading tools are relatively new or under two years old. For the PA value, non-mechanical resistance such as P2H, diesel lubrication and filling, rain, safety talk, moving unit, and overshift, did not greatly affect the performance of the loading and unloading tool.

However, the UA and EU values of these tools were inadequate in PT. MAL, with the average use of availability and effective utilization values being 67 and 62%, respectively in 2021, respectively. These were due to the encounter of several challenges in the coal extraction activities, including :
(1) The DT queues in the stockpile,
(2) The screen removal when the front coal was exhausted,
(3) The coal material stuck between the screens,
(4) The coal load fireplace,
(5) Awaiting the material feed from the coal collection excavators.
Additionally, the challenges ultimately affected the performance and production of loading and digging tools.

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4.2. Excavator productivity

The productivity of the excavator had a difference, which was observed between the screen and in the direct (in the vessel dump truck) coal loading activity. The following Table 3 shows a comparison of productivity and cycle time track length.

Table 3. Comparison of Productivity and Cycle Time

No.	Excavator	Productivity (Tons/h)		Cycle Time (s)	
		Screening	Direct Loading	Screening	Direct Loading
1.	Ex PC210 (TPE-04)	104.87	143.67	26.55	19.02
2.	Ex PC210 (TPE-05)	96.75	134.68	27.06	19.44
3.	Ex PC210 (TPE-11)	97.32	138.89	27.33	19.38
4.	Ex SK200 (TPE-16)	99.39	131.77	27.18	20.50

Based on Table 3, the cycle time of the excavator was slower during screen loading than the direct activity, leading to smaller excavator productivity. Furthermore, the productivity of loading and unloading tools was influenced by the EU and bucket fill factor. This showed that the working efficiency of the PC210 Excavator was insufficient at an average of 62%. Irrespective of this condition, the current bucket fill factor of the digging tool had a value of 1.0, indicating an easy collection of the excavated material. Therefore, cycle time is the main factor affecting the productivity of loading and unloading tools, as the screening process was slower than that of the direct activity due to several challenges. From these obstacles, the resistance of the coal stuck in between the screen and the mineral grinding above the fixed-screen tool was highly effective (Fig. 6). For productivity to be more optimal, engineering performances were importantly needed for the minimization of the material resistance stuck in between these screens. This confirmed that a fixed screen needs improvement and its redesign.

Fig. 6. Coal Stuck in the Sidelines of Fixed Screen

4.3. Fixed screen efficiency

When redesigning the fixed screen in PT. MAL, several parameters used as references were observed, namely the slope angle and the screen capacity, which emphasized the track length.

In this process, the utilized angles included 5°, 15°, 25°, 35°, and 45°, while the lengths were 80, 110, and 140 cm. From these parameters, a fixed screen with a scale of 1:10 was used according to the original size specification in PT. MAL. Experiments were also conducted to obtain the most optimal screen efficiency (Figs. 7 & 8).

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Fig. 7. Fixed Screen Scale 1:10

Fig. 8. Fixed Screen Trial Process

The following data (table 4) are the experimental results obtained by using the 1:10 scale fixed screen, 10 kg amount of feed and screen size at approximately 10x10 cm.

Table 4. The fixed screen experiments regarding the scale of 1:10

No.	Parameters		Feed Total Weight (kg)	Feed Weight Pass Screen (kg)	Screen Efficiency (%)	Flow Rate Time (s)
	Length (cm)	The angle of Slope (°)				
1.	80	5	10	7.63	76.3	2.98
		15	10	7.69	76.9	2.78
		25	10	7.86	78.6	2.76
		35	10	8.23	82.3	2.70
		45	10	8.71	87.1	2.82
2.	110	5	10	7.68	76.8	3.01
		15	10	7.79	77.9	2.84
		25	10	8.04	80,4	2.79
		35	10	8.34	83.4	2.84
		45	10	8.91	89.1	2.73
3.	140	5	10	7.77	77.7	3.06
		15	10	7.87	78.7	3.11
		25	10	8.08	80.8	2.81
		35	10	8.42	84.2	2.92
		45	10	9.13	91.3	2.56

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Based on Table 4, the most optimal fixed screen had the length, angle, efficiency, and flow time of 140 cm, 45°, 91.3%, and 2.56 s, respectively. However, the screen length needs to be adjusted to that of the dump truck during the field application, to prevent coal material from inappropriately dropping or hitting the roof of the vehicular vessel. From these descriptions, the most optimal fixed screen used in the field had the length, angle, efficiency, and flow time of 80 cm, 45°, 87.1%, and 2.82 s. This results was used to adjust the screen capacity of the dump truck.

5. Conclusions

1. The results obtained were recommended to PT Manggala Alam Lestari and other coal mining industries.
2. The MA and PA values of the coal excavator were approximately 89% and 92%, respectively. This showed that mechanical and non-mechanical resistances such as P2H, lubrication and solar contents, rain, safety talk, moving units, overshifts, etc, did not greatly affect the performance of the loading-digging tools.
3. The UA and EU values of the excavator were also 67% and 62%, respectively, indicating the occurrence of some challenges in coal extraction activities.
4. These coal activity challenges caused a slower cycle time for the excavator, leading to less productivity.
5. To overcome these challenges, the fixed screen should be redesigned by emphasizing the following parameters as references :

   (a) The repose angle,

   (b) The screen capacity.
6. Based on the experimental results, the most optimal fixed screen had the length, angle, efficiency, and flow-rate time of 140 cm, 45°, 91.3%, and 2.56 s, respectively.
7. To adjust toward the length of the dump truck, the most optimal fixed screen used in the field had the length, angle, efficiency, and flow-rate time of 80 cm, 45°, 87.1%, and 2.82 s, respectively.

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