Improvement of Overall Equipment Effectiveness Through Planned Equipment Maintenance: A Case Study

Asser Letsatsi Tau
Emmanuel Innocents Edoun
Charles Mbohwa
Anup Pradhan
University of Johannesburg, South Africa

Key words
Availability, bottleneck, classifier, OEE and reliability

Abstract
Maintenance of equipment in a manufacturing facility is of great importance to ensure availability, performance, and production of goods at the right quality level. Overall Equipment Effectiveness (OEE) is a good key performance indicator for monitoring and controlling the reliability of equipment within a production system. Classifier is one of the major equipment forming an integral part of a production line within a coal fly ash processing plant. The classifier had a capacity to produce 45 tons per hour of product, but its productivity had reduced to 33 tons per hour. Through bottleneck identification, it was noted that some of the components of the classifier had worn and tear, thus needs to be replaced. Planned maintenance of the classifier was carried out for a period of five days on shutdown. Data was collected over 31 days before the maintenance and 31 days after maintenance for availability, performance and quality of goods produced to quantify OEE before and after the maintenance. Although the classifier was producing less than its capacity, the goods produced were within the acceptable quality level, thus 100%. Post the maintenance, the production rate increased by 30.30%. The OEE improved by 21.76%, which ultimately improved the availability of products to customers. The Turn-Around-Time of trucks on the despatch line improved by 29.76%. A maintenance programme was recommended to have a system in place to be followed for maintainability of the equipment, thus, to have a sustained OEE.

Introduction
Background

To stay competitive in an ever-changing technological improvement on equipment of a manufacturing plant, most manufacturers strive to enhance the performance of their equipment for the purpose of increasing and maintaining its reliability and of the overall industrial plant in general. These help in ensuring better efficiency of equipment that forms part of a system that makes up the industrial plant to produce products to supply customers.

Mechanical equipment tends to underperform due to common reasons such as aging, worn components, lack of maintenance or continuous operator error. O'Connor and Kleyner (2012) indicated that the following could be the reasons why engineering products fail: the product design might be inherently incapable, product being in some way overstressed such that the stress being applied exceeds the strength, failures might be caused by variation, failures can be caused by wear-out, mechanisms of time dependency and errors such as specifications that are incorrect, for example, coding in software coding, designs or by assembly that is faulty and maintenance that is incorrect or inadequate.

In a coal fly ash processing plant, like other industrial plants, equipment exist which require good level of attention to maintain the equipment in thier efficient, operable state. A classifier is one of the equipment that is found in a coal fly ash processing plant. The function of a classifier in such a plant is to separate raw feed coal fly ash into fine material and tailings (rejects) material. The fine fly ash is considered as product at a targeted fineness level meanwhile the tailings are considered unwanted material. When such equipment produces fewer quantity of product than its design capacity and it is not available, such process parameters denote that the equipment's reliability has deteriorated. It is also important to also account for other process parameters of the concerned manufacturing plant.

Problem statement

The manufacturing plant experienced challenges with low production outputs of 33 tons per hour on average compared to the designed capacity of 45 tons an hour when using the classifier at the coal fly ash processing plant. This was further due to continuous unplanned downtime on the classifier, which affected the supply of product to market. The equipment's unavailability ultimately negatively affected the Overall Equipment Effectiveness as a measure of performance.

Objectives

Overall objective

The overall objective of the study was to improve the Overall Equipment Effectiveness (OEE) through equipment planned maintenance.

Sub-objectives

To identify the process bottleneck that led to the lower equipment performance.

To establish the current performance of equipment with respect to production output and OEE.

To conduct a planned maintenance on the equipment for the purpose of OEE performance improvement.

Literature review

Generally, the manufacturing industry is targeting production of goods of the right quality and quantity, and to deliver them at the right time to customers. To fulfil this, manufacturing plant should be operational efficiently and effectively. The manufacturers target to produce the goods at a profit, and this is achieved through the usage of a system of maintenance that is effective and assist with minimisation of downtime of machines because of stoppages that are unwarranted. Poor equipment performance, downtime and plant maintenance that is inefficient leads to reduction in profit, loss of opportunities in the market and production losses (Fore & Zuze, 2010). Fore & Zuze (2010) further indicated that low plant reliability and overtime cost can affect the manufacturing industry negatively based on its operational efficiency. Thus, an efficient and effective system for maintenance of equipment and plant in general is needed.Maintenance plays a vital role for the preservation of design life of an equipment and overall plant. The basic practices to improve equipment life through maintenance is conducted based on factors such as adjustments of loose belts, lubrication of parts and replacement of components that are faulty. Proper maintenance of equipment assists in equipment being capable to handle tolerances better, reduction in generation of scrap, improvement in the consistency and quality of product being produced (Jiménez et al., 2017). Thus, maintenance refers to the process of taking good housekeeping of machines and equipment for the purpose of achieving a maintained operable efficiency and useful life that is prolonged. Organisation takes necessary precautions during maintenance to replace, repair and maintain the components and equipment of the plant, which ultimately permits operation within limits that are satisfactory (Singh et al., 2020). Maintenance entails the routine and recurring process that is carried out to keep an equipment in its operating conditions that are normal to deliver expected performance (Tsang et al., 1999).

Improvement of performance of an equipment, operating procedures and processes of maintenances can be measured and analysed through implementation of Overall Equipment Maintenance (ATS International B.V, 2010).

OEE is a way in which monitoring and improvement of efficiency of manufacturing process can be carried out (Patel & Deshpande, 2016). It has been introduced in 1988 by Nakajima as a key performance indicator of Total Productive Maintenance (Ng Corrales et al., 2020). Since the development of this concept, it has been an accepted tool of management for measurement and evaluation of plant's floor productivity (Patel & Deshpande, 2016). OEE is the productivity ratio between real manufacturing and what could be manufactured ideally. Many companies use OEE as a critical tool, for example, when implementing lean manufacturing philosophies, or when implementing maintenance programs and for the purpose of monitoring actual equipment performance (Ng Corrales et al., 2020). Patel & Deshpande (2016) stated the metrics that measure OEE as availability, performance, and quality.

ATS International B.V (2010) and Hendri et al. (2019) defined and mathematically exprssed these factors of OEE as follows:

Availabilty refers to the percentage of time that are allocated to machine for a scheduled production in comparison to the amount of time that were actually spent in production. It is a factor that is calculated using the following equation:

Availability = $\frac{Operating\ time}{planned\ production\ time}$

Performance entails the comparison of the theoritical machine rate with the number of actual items produced on the machine during the operating time spent,calculated as follows:

Performance = $\frac{Total\ pieces}{Operating\ time \div Ideal\ run\ rate}$

Meanwhile, quality entails the percentage of items that passes the first inspection of quality post production and it is calculated as follows:

Quality = $\frac{Good\ pieces}{Total\ pieces}$

Thus, OEE take into account these factors and is caculated as expressed by the following equation defined by Vorne (2014) and Hendri et al. (2019):

OEE = Availability × Performance × Quality × 100

The initial OEE industry performance can be used as a benchmark for the purpose of comparing current OEE values of manufacturing system for the purpose of noting the need to improve, this is one of the quantitative performance metrics. OEE of 85% was suggested as an ideal value which is known as a world class value for measurement of components at availability rate of 90%, rate of performance of 95% and quality rate of quality rate of 99% (Cheh et al., 2016; Patel & Deshpande, 2016; Nakajima, 1988). Further research indicated that an OEE of greater than 50% is acceptable based on real performance rate, quality rate and availability of equipment. Typical manufacturing factors that affect OEE include breakdown (i.e., equipment failure), set-up and adjustment, idling and minor stoppages, reduction in speed, defects in quality and rework (Cheh et al., 2016).

ATS International B.V (2010) further indicated that some of the benefits that an enterprise can benefit from implemention of adequate system for tracking OEE include reduced downtime, reduced costs of repairs, maximised labour efficiencies, improved quality, maximsed productivity of personnel and increased capability of production.

Methodology

Process bottleneck identification

During the operation of the equipment (classifier), a high wear on the components, viz: rotor, vanes, buffer plates and seals were identified through visual inspection and resulted with low production rate of 33 tons per hour instead of a minimum of 40 tons per hour to a maximum of 45 tons per hour. This was further identified to be as a result of raw feed coal fly ash by-passing the system straight to the tailings side (rejects) of the classifier.

The results of actual production output, availability and quality were collected. OEE was calculted using the data which was initially collected over 31 days period thus indentifying that OEE was 51% instead of the targeted amount of ≥ 70%. The following formulars were used to calculate OEE:

OEE = (Availability × Performance × Quality) × 100
Where: Availability = (Operating time)/ (Planned production time)
Availability = (Actual equipment running time)/ (Planned production time)
Availability = (Actual equipment running time)/ (Planned production time)
Performance = (Actual equipment production run rate)/ (Ideal equipment run rate)
Quality = (Good pieces produced)/ (Total pieces produced)
Quality = (Good pieces produced Waste or rejects pieces)/ (Total pieces produced)

Data presented on Table 4 and Table 5 in the appendix was used to calculate availability and performance. The quality of goods produced was always 1 (or 100%), thus goods were always in specification. All these neccisitated the need for planned maintenance to improve the performance of the classifier.

Planned classifer equipment maintenance

Post the identification of the process bottleneck, a planned maintenance was conducted across the classification plant section of the coal fly ash processing plant. The maintenance entailed the replacment of the parts/components of the classifier that went through wear and tear.

Table 1 shows the components that were replaced and their function on the efficient operation of the classifier.

Component/Part	Function of the component on the classifier operation
Shaft classifer	Drive shaft of the rotor, connecting the rotor to drive gearbox
Taper lock, fenner	Taper lock bush for fitting and securing coupling to shaft
Coupling	Coupling flanges for fitting tyre coupling connecting shaft and gearbox
Tyre, fenaflex	Coupling that connects the gearbox and separator shaft
Plate, buffer, O-seperator	Hard wear component for reducing wear from ash inside separator
Seal, O-seperator	Seal between the rotor and separator body
Rotor, O-seperator	Rotor is the rotating part of the separator that disperses the material
Vane, O-seperator	Assist with air flow though the separator to separate material particals
Element, coupling	Connection between motor and gearbox
Fan, centrifugal	Induces a draft through the separator to remove fine ash particles through to the cyclone
Impeller fan, axial (helicoidal)	Hard surfaced fan blades for inducing draft though separator

Table 1: Classifier maintenance components

The maintenance was carried out over a five-day plant shutdown period. The following section explains in detail what has been achieved on each day of the maintenance, thus in order to improve the reliability of equipment.

Five-day kaizen event planned equipment maintenance.

Day one

The scope of the maintenance was discussed with everyone who was part of the project crew. Job hazard analysis was conducted for each activity that was executed. Log Out Tag Out Try Out (LOTOTO) safely procedure was followed. This was followed by isolating the classifier from the system by closing its raw coal fly ash feeding line, so it could be inspected while on a shutdown. The circulation fan was replaced as it contributed to the poor production output of the classifier system due to high wear and vibrations. Furthermore, the supporting structures and platforms were stripped to gain access for building scaffolds to remove the classifier cone.

Day two

The classifier was stripped to remove its internals to replace the critical parts that went through wear and tear. These involved removal of cones, rotor, buffer plates, vanes and seals and tiling inspection. Figure 1 shows some of these components during the striping of the classifier.

Figure 1: Classifier stripping

Day three

The installation of new vanes, rotors, seals, shaft, buffer plates and replacement of filter bags and assembling of the circulation fan were carried out. Figure 2 shows some of these assembling activities.

Figure 2: Classifier parts/components assembling.

Day four

Continuation of installation of the internal classifier components and tailings cone after some modifications were required for spare parts to fit. The separator was started, and the test ran without raw coal fly ash feed until satisfied with the running condition and no abnormalities were observed.

Day five

The classifier was run with raw coal fly ash feed, a blockage of the product cyclone was encountered due to a sealing cloth that came loose and blocked the outlet, causing the separator to trip, the cyclone was drained, and cloth membrane removed.

The classifier was restarted and feed opened, and material classified conformed to quality standards of product and increased production rate from 33 tons per hour to 43 tons per hour. Post the successfully planned maintenance, new data on the improved system was collected over 31 days. The after-maintenance key performance indicators on production output and OEE and Turn Around Time (TAT) (Gate in Gate Out and Yard in Gate Out) results were collected. The Gate in Gate Out (GIGO) and Yard in Gate Out (YIGO) data were collected using stopwatch and despatch software system using a truck for the time observations during the product despatch at the plant. The following formulas were used to calculate TAT:

TAT = (YIGO-GIGO)/2

Where: YIGO = Time truck gate out – Time truck gate in

GIGO = Time truck finish loading – Time truck arrival dispatch

Results and discussion

Production output, OEE and TAT results before equipment maintenance

Figure 3 graphically represents OEE as a function of time meanwhile Figure 4 indicates production rate as a function of time before classifier maintenance. The OEE and production rate before the equipment maintenance showed an inconsistent performance mainly because of the unavailability of the equipment due to unplanned downtimes. A peek OEE of 93% was achieved on day 12 when the production rate was 43.7 tons per hour. This is because downtimes were minimum and the total quantity produced during this day amounted to 1005.10 tons which further amounted to 31 number of trucks dispatched on average (refer to appendix, Table 4). Meanwhile, the lowest OEE of -6.00% was achieved during day 18 with production rate of 30.74 tons per hour as indicated on Figure 3, Figure 4, and Table 4 (appendix). This was further indicated by a total of downtime of 26 hours.

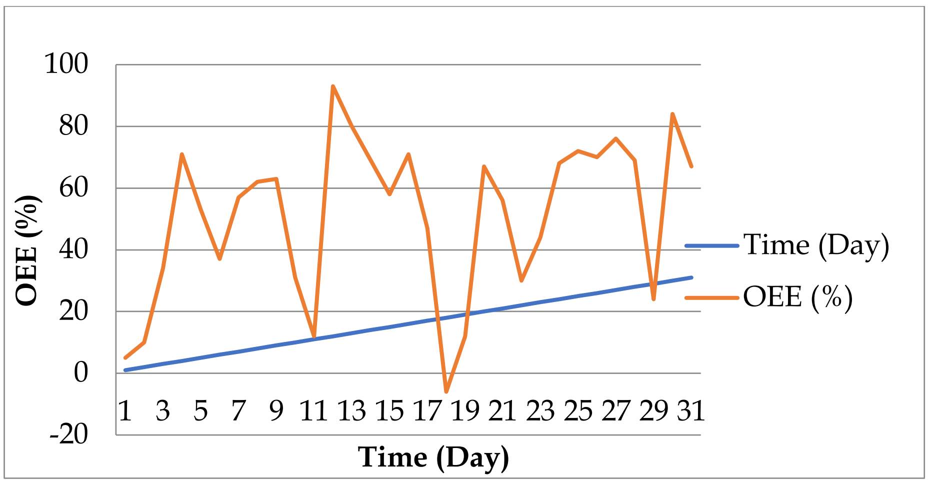

Figure 3: OEE versus time graph before classifier maintenance

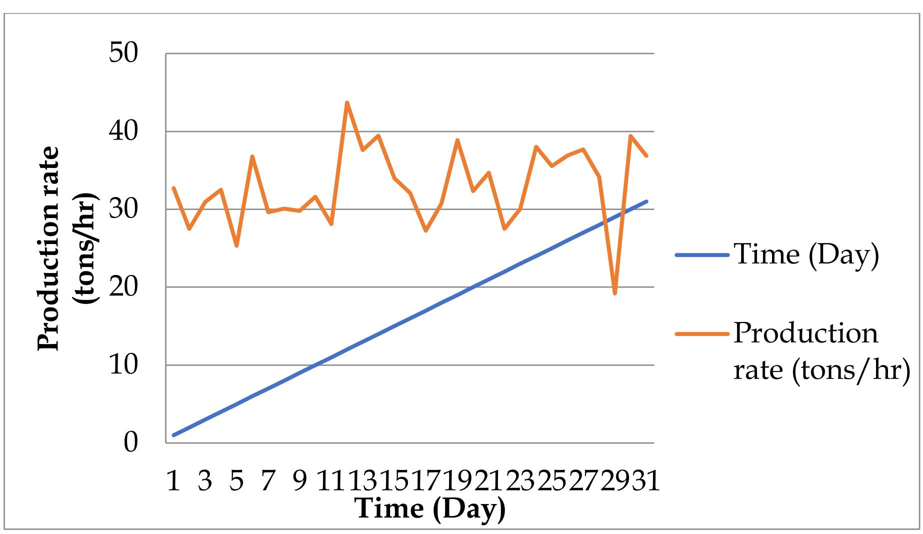

Figure 4: Production rate versus time before classifier maintenance

Figure 5 indicates the turnaround time of trucks before the maintenance being conducted. It can be noted that on day 12, the TAT was 106 minutes on average, meanwhile on day 18, the average TAT was 99 minutes as most trucks did arrive at plant due to assumed longer TAT.

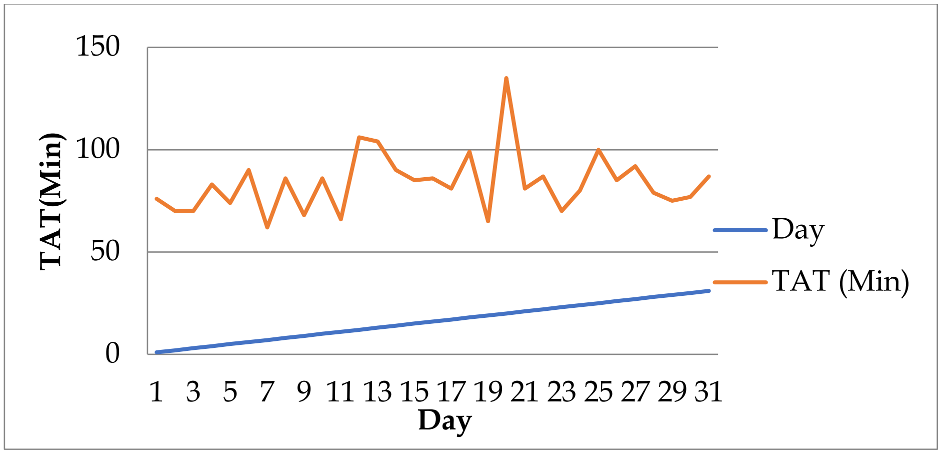

Figure 5: TAT before maintenance

This further cascaded into longer TAT of trucks while at the plant to load product for customers as the product output from the classifier directly affected daily product despatches.

Production output and OEE results after equipment maintenance.

Figure 6 indicates OEE as a function time after maintenance on classifier. It was noted that a maximum of 98% and a production rate of 44.20 tons per hour was achieved as indicated by Figure 7 on the same day. Furthermore, this indicated that TAT of trucks was improved to 53 minutes after maintenance as indicated by Figure 8.

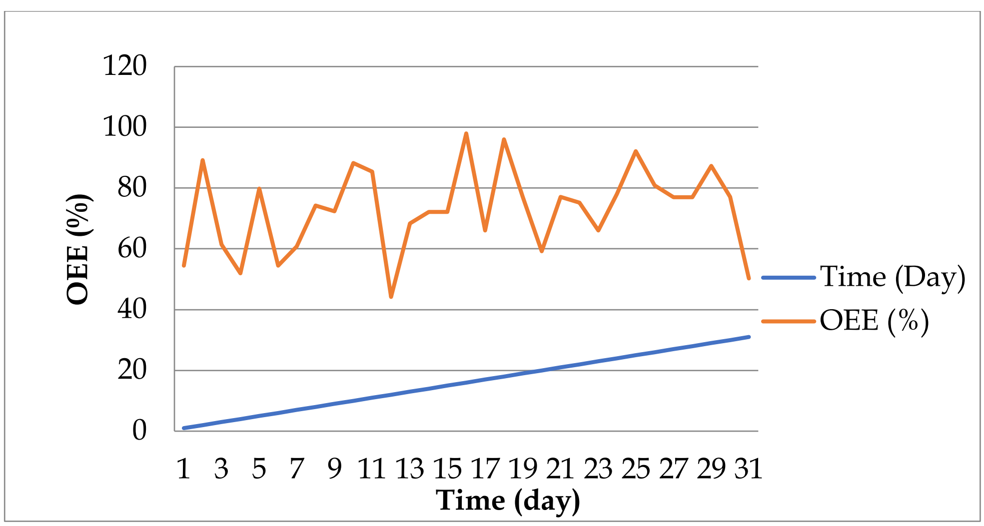

Figure 6: OEE versus time graph after classifier maintenance

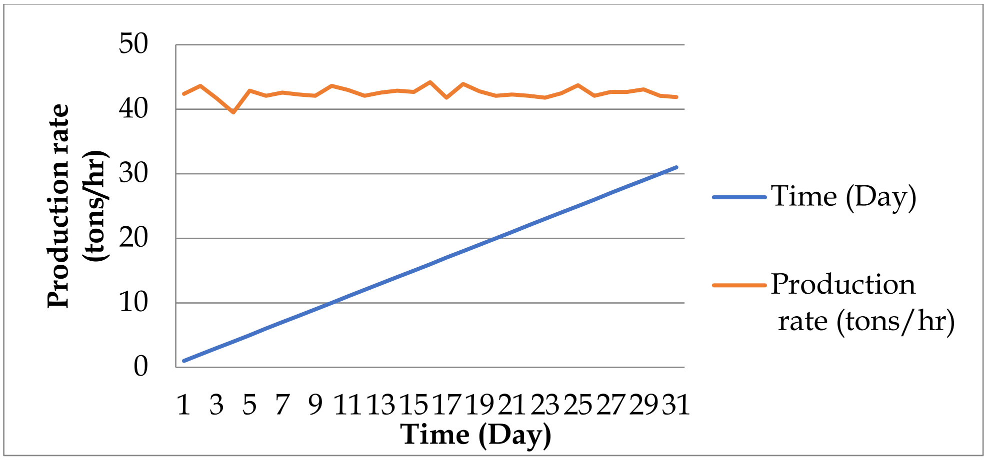

Figure 7: Production rate versus time after classifier after maintenance

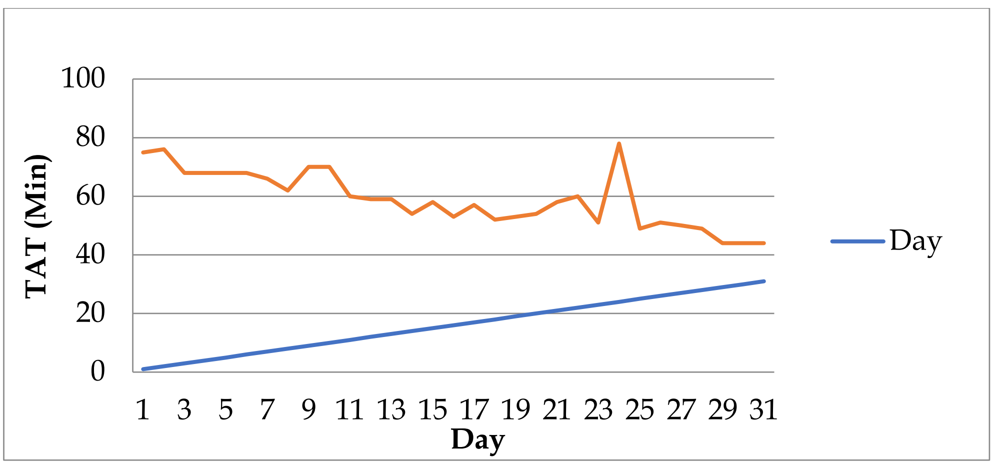

Figure 8: TAT after maintenance

Post the maintenance, the utilization of the equipment improved thus with production rate indicating consistent production output across the classifier, with average production of 42.51 tons/hr. The average OEE also showed consistent performance improvement, 73.02% was achieved on average. Meanwhile the Turn Around Time has improved from 84 minutes to 59 minutes on average.

Conclusion

It was evident that maintenance improves the Overall Equipment Effectiveness when other systems or process variables remain constant at efficient levels as noted in the study. After the maintenance activities, the utilization of the equipment improved production rate by 30.30%. The OEE improved by 21.76%, that is, from 51.17% to 72.93%. This further cascaded to improved product availability and improved product supply to customers. The TAT of trucks at the factory improved along the despatch line, ensuring timeous delivery of products to customers On-Time-In-Full (OTIF). TAT improved by 29.76% post equipment maintenance.

Recommendations

Post the planned maintenance, based on the definition of reliability engineering as defined by Vincent (2010), the basic concepts and fundamentals of reliability as intensively stated by Hashmy (2012) and, Rausand and Hoyland (2004), the reasons why product fails as indicated by O'Connor and Kleyner (2012) together with the consequences associated with products failures as stated by Kapur and Pecht (2014) also based on the governing principles and concepts of repairable and non-repairable items further indicated by O'Connor and Kleyner (2012) together with Jackson (2012), a maintanence programme was implemented in order to maintain the classifer as it affects the relaibility of the coal fly ash processing plant. The programme entailed routine daily visual inspection before any shift begins on the system components. Also, weekly inspection of classifier internals to determine wear, external inspection of V-belts and drive system coupling, gearbox and motors and replacement of spare part where required, were part of the maintenance program initiated.

Autonomous maintenence training was given to the general plant maintenance patrollers in order to maintain and standardize the task as a preventitive plan to avoid any classifer breakdown which can cause downtimes.

In this way, this will further keep the equipment maintained. Thus, standardization of work on the maintenance program was made with the set standards assisted to reduce variations of the operation of the classifier. Correction of any errors that might arise can be avoided by being proactive in the case of no standards governing the classifier utilisation. Improvement on safe operation of the equipment and the coal fly ash processing plant as no unsafe operation of the classifier was operated as the general plant maintenance patrollers were trained on monitoring and control of the classifier. Standardization was followed as defined by Košturiak et al. (2010) on the key functional benefits of using standardization.

Limitations and direction for future study

The findings of the study were only applicable to the case study and thus cannot be concluded on generalisation. However, the findings can be used as a benchmark on deployment of planned equipment maintenance to improve overall equipment effectiveness in a manufacturing facility. Future studies should consider the use of other lean tools to investigate continuous improvement in manufacturing companies.

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Appendix

Day	Actual Production Rate (tons/hr)	OEE (%)	TAT YIGO+GIGO Hr: min:sec
1	32.7	5	01:16:00
2	27.5	10	01:10:30
3	30.93	34	01:10:30

4	32.5	71	01:23:30
5	25.3	53	01:14:30
6	36.8	37	01:30:30
7	29.63	57	01:02:00
8	30.07	62	01:26:00
9	29.8	63	01:08:00
10	31.6	31	01:26:30
11	28.1	12	01:06:30
12	43.7	93	01:46:00
13	37.6	80	01:44:00
14	39.45	69	01:30:30
15	33.97	58	01:25:00
16	32.10	71	01:26:00
17	27.25	47	01:21:00
18	30.74	-6	01:39:00
19	38.87	12	01:05:00
20	32.33	67	01:35:30
21	34.7	56	01:21:30
22	27.5	30	01:27:30
23	30.05	44	01:10:30
24	38.01	68	01:20:30
25	35.55	72	01:40:00
26	36.9	70	01:25:30
27	37.7	76	01:32:00
38	34.16	69	01:19:00
29	19.2	24	01:15:00
30	39.43	84	01:17:30
31	36.85	67	01:27:00

Table 2: Results before classifier maintenance

Day	Actual Production Rate (tons/hr)	OEE (%)	TAT YIGO+GIGO Hr: min:sec
1	42.40	54.52	01:15:00
2	43.60	89.24	01:16:00
3	41.70	61.38	01:08:30
4	39.50	51.92	01:08:00
5	42.90	79.80	01:08:30
6	42.10	54.52	01:08:00
7	42.60	60.8	01:06:00
8	42.30	74.26	01:02:30
9	42.10	72.38	01:10:30
10	43.60	88.27	01:10:00
11	43.00	85.44	01:00:00
12	42.10	44.18	00:59:00
13	42.60	68.40	00:59:00
14	42.90	72.20	00:54:00
15	42.70	72.20	00:58:00
16	44.20	98.00	00:53:30
17	41.80	66.03	00:57:00
18	43.90	96.04	00:52:00
19	42.80	76.95	00:53:00
20	42.10	59.22	00:54:30
21	42.30	77.08	00:58:30
22	42.10	75.20	01:00:00

23	41.80	66.03	00:51:00
24	42.50	78.02	01:18:30
25	43.70	92.15	00:49:30
26	42.10	80.84	00:51:00
27	42.70	76.95	00:50:00
38	42.70	76.95	00:49:00
29	43.10	87.36	00:44:00
30	42.10	77.08	00:44:00
31	41.90	50.22	00:44:30

Table 3: Results after classifier maintenance

				Dispatches per hour			Unplanned downtime				Equipment Idle Time				Planned								
Day	Total Produced in Avaialable hours	Total Despatches in available hours of production	Total Waste	Road transport		Production Rate	Mant B/D	Maint Comp	Maint Leaks	Total	Balance & Setup	Product silo full	Raw Ash supplier	Total	Maintenance	Available Production	Standard Production	Total downtime	Equipment Actual Running	Availability	Performance	Quality	OEE
	Quantity producced (Tons)	No. of trucks	Tons	Product Quantity Tons	Total number of trucks	Tons/Hr	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	%	%	%	%
1	49.05	1.53	0	32.7	1.02	32.7	22	0	0	22	0.5	0	0	0.5	0	2	21.6	22.5	1.5	0.06	0.73	1.00	5
2	103.13	3.22	0	27.5	0.86	27.5	20.25	0	0	20.25	0	0	0	0	0	3.75	21.6	20.25	3.75	0.16	0.61	1.00	10
3	371.16	11.60	0	30.93	0.97	30.93	12	0	0	12	0	0	0	0	0	12	21.6	12	12	0.50	0.69	1.00	34
4	763.75	23.87	0	32.5	1.02	32.5	0	0	0.25	0.25	0.25	0	0	0.25	0	23.75	21.6	0.5	23.5	0.98	0.72	1.00	71
5	575.58	17.99	0	25.3	0.79	25.3	0	0.75	0	0.75	0.5	0	0	0.5	18.75	23.25	5.25	1.25	22.75	0.95	0.56	1.00	53
6	395.60	12.36	0	36.8	1.15	36.8	12	0.75	0	12.75	0.5	0	0	0.5	0	11.25	21.6	13.25	10.75	0.45	0.82	1.00	37
7	614.82	19.21	0	29.63	0.93	29.63	1	1.25	0	2.25	1	0	0	1	0	21.75	21.6	3.25	20.75	0.86	0.66	1.00	57
8	669.06	20.91	0	30.07	0.94	30.07	0.25	0	1	1.25	0.5	0	0	0.5	0	22.75	21.6	1.75	22.25	0.93	0.67	1.00	62
9	685.40	21.42	0	29.8	0.93	29.8	0.5	0	0	0.5	0.5	0	0	0.5	0	23.5	21.6	1	23	0.96	0.66	1.00	63
10	331.80	10.37	0	31.6	0.99	31.6	2.25	0.75	0	3	2	7	1.5	10.5	0	21	21.6	13.5	10.5	0.44	0.70	1.00	31
11	133.48	4.17	0	28.1	0.88	28.1	6.25	0	0.25	6.5	0.75	12	0	12.75	0	17.5	21.6	19.25	4.75	0.20	0.62	1.00	12
12	1005.10	31.41	0	43.7	1.37	43.7	1	0	0	1	0	0	0	0	0	23	21.6	1	23	0.96	0.97	1.00	93
13	864.80	27.03	0	37.6	1.18	37.6	0	0	0.75	0.75	0.25	0	0	0.25	0	23.25	21.6	1	23	0.96	0.84	1.00	80
14	749.55	23.42	0	39.45	1.23	39.45	0	1	0	1	0	0	4	4	0	23	21.6	5	19	0.79	0.88	1.00	69
15	628.45	19.64	0	33.97	1.06	33.97	0	3	0	3	1	1.5	0	2.5	0	21	21.6	5.5	18.5	0.77	0.75	1.00	58
16	770.40	24.08	0	32.1	1.00	32.1	0	0	0	0	0	0	0	0	0	24	21.6	0	24	1.00	0.71	1.00	71
17	510.94	15.97	0	27.25	0.85	27.25	5.25	0	0	5.25	0	0	0	0	0	18.75	21.6	5.25	18.75	0.78	0.61	1.00	47
18	-61.48	-1.92	0	30.74	0.96	30.74	1	2	0	3	2	0	21	23	0	21	21.6	26	-2	-0.08	0.68	1.00	-6
19	126.33	3.95	0	38.87	1.21	38.87	1.25	0	0	1.25	0.5	0	19	19.5	0	22.75	21.6	20.75	3.25	0.14	0.86	1.00	12
20	719.34	22.48	0	32.33	1.01	32.33	1.5	0.25	0	1.75	0	0	0	0	0	22.25	21.6	1.75	22.25	0.93	0.72	1.00	67
21	607.25	18.98	0	34.7	1.08	34.7	0	1	0	1	2	0	3.5	5.5	0	23	21.6	6.5	17.5	0.73	0.77	1.00	56
22	323.13	10.10	0	27.5	0.86	27.5	1.5	1.5		3	3		6.25	9.25	0	21	21.6	12.25	11.75	0.49	0.61	1.00	30
23	473.29	14.79	0	30.05	0.94	30.05	1.75	3	0	4.75	2.5	0	1	3.5	0	19.25	21.6	8.25	15.75	0.66	0.67	1.00	44
24	731.69	22.87	0	38.01	1.19	38.01	1.25	0.5	0	1.75	2	0	1	3	0	22.25	21.6	4.75	19.25	0.80	0.84	1.00	68
25	773.21	24.16	0	35.55	1.11	35.55	0	1	0.5	1.5	0.75	0	0	0.75	0	22.5	21.6	2.25	21.75	0.91	0.79	1.00	72
26	756.45	23.64	0	36.9	1.15	36.9	0	0.5	0	0.5	1.5	0	1.5	3	0	23.5	21.6	3.5	20.5	0.85	0.82	1.00	70
27	819.98	25.62	0	37.7	1.18	37.7	2	0.25	0	2.25	0	0	0	0	0	21.75	21.6	2.25	21.75	0.91	0.84	1.00	76
28	742.98	23.22	0	34.16	1.07	34.16	1.25	1	0	2.25	0	0	0	0	0	21.75	21.6	2.25	21.75	0.91	0.76	1.00	69
29	264.00	8.25	0	19.2	0.60	19.2	0		8.25	8.25	2			2	0	15.75	21.6	10.25	13.75	0.57	0.43	1.00	24
30	906.89	28.34	0	39.43	1.23	39.43				0	1			1	0	24	21.6	1	23	0.96	0.88	1.00	84
31	727.79	22.74	0	36.85	1.15	36.85	0	2.75	0	2.75	1.5	0	0	1.5	0	21.25	21.6	4.25	19.75	0.82	0.82	1.00	67
Totals	**17132.89**	**535.40**	**0**	**1020.99**	**31.91**	**32.94**	**94.25**	**21.25**	**11**	**126.50**	**26.50**	**20.50**	**58.75**	**105.75**	**18.75**	**617.50**	**653.25**	**232.25**	**511.75**	**0.69**	**0.73**	**1.00**	**51.17**

Table 4: Data collection before planned equipment maintenance.

				Dispatches per hour			Unplanned downtime				Equipment Idle Time				Planned							
Day	Total Produced in Avaialable hours	Total Despatches in available hours of production	Total Waste	Road transport		Production Rate	Mant B/D	Maint Comp	Maint Leaks	Total	Balance & Setup	Product silo full	Raw Ash supplier	Total	Maintenance	Available Production	Standard Production	Total downtime	Equipment Actual Running	Availability	Performance	Quality	OEE
	Quantity producced (Tons)	No. of trucks	Tons	Product Quantity Tons	Total number of trucks	Tons/Hr	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	%	%	%	%
1	593.60	18.55	0	42.4	1.33	42.4	1	5.5	0	6.5	3.5	0	0	3.5	0	17.5	21.6	10	14	0.58	0.94	1.00	54.96
2	959.20	29.98	0	43.6	1.36	43.6	0.5	0.5	0	1	1	0	0	1	0	23	21.6	2	22	0.92	0.97	1.00	88.81
3	656.78	20.52	0	41.7	1.30	41.7	4.5	3	0	7.5	0.75	0	0	0.75	0	16.5	21.6	8.25	15.75	0.66	0.93	1.00	60.81
4	562.88	17.59	0	39.5	1.23	39.5	2	4.75	0	6.75	3	0	0	3	0	17.25	21.6	9.75	14.25	0.59	0.88	1.00	52.12
5	868.73	27.15	0	42.9	1.34	42.9	1.75	0	0	1.75	2	0	0	2	0	22.25	21.6	3.75	20.25	0.84	0.95	1.00	80.44
6	589.40	18.42	0	42.1	1.32	42.1	5	1.25	3.75	10	0	0	0	0	0	14	21.6	10	14	0.58	0.94	1.00	54.57
7	649.65	20.30	0	42.6	1.33	42.6	1.25	7	0.5	8.75	0	0	0	0	0	15.25	21.6	8.75	15.25	0.64	0.95	1.00	60.15
8	803.70	25.12	0	42.3	1.32	42.3	0	3.5	0	3.5	1.5	0	0	1.5	0	20.5	21.6	5	19	0.79	0.94	1.00	74.42
9	778.85	24.34	0	42.1	1.32	42.1	2.25	0.75	0	3	2.5	0	0	2.5	0	21	21.6	5.5	18.5	0.77	0.94	1.00	72.12
10	948.30	29.63	0	43.6	1.36	43.6	0	1.75	0	1.75	0.5	0	0	0.5	0	22.25	21.6	2.25	21.75	0.91	0.97	1.00	87.81
11	913.75	28.55	0	43	1.34	43	1.5	0.75	0	2.25	0.5	0	0	0.5	0	21.75	21.6	2.75	21.25	0.89	0.96	1.00	84.61
12	473.63	14.80	0	42.1	1.32	42.1	7	3.75	0	10.75	2	0	0	2	0	13.25	21.6	12.75	11.25	0.47	0.94	1.00	43.85
13	734.85	22.96	0	42.6	1.33	42.6	0	4.75	0	4.75	2	0	0	2	0	19.25	21.6	6.75	17.25	0.72	0.95	1.00	68.04
14	782.93	24.47	0	42.9	1.34	42.9	1	4.75	0	5.75	0	0	0	0	6.5	18.25	17.5	5.75	18.25	0.76	0.95	1.00	72.49
15	779.28	24.35	0	42.7	1.33	42.7	0	5.75	0	5.75	0	0	0	0	0	18.25	21.6	5.75	18.25	0.76	0.95	1.00	72.16
16	1060.80	33.15	0	44.2	1.38	44.2	0	0	0	0	0	0	0	0	0	24	21.6	0	24	1.00	0.98	1.00	98.22
17	710.60	22.21	0	41.8	1.31	41.8	0	0	0	0	5	0	2	7	0	24	21.6	7	17	0.71	0.93	1.00	65.80
18	1031.65	32.24	0	43.9	1.37	43.9	0	0	0.5	0.5	0	0	0	0	0	23.5	21.6	0.5	23.5	0.98	0.98	1.00	95.52
19	834.60	26.08	0	42.8	1.34	42.8	4.5	0	0	4.5	0	0	0	0	0	19.5	21.6	4.5	19.5	0.81	0.95	1.00	77.28
20	631.50	19.73	0	42.1	1.32	42.1	5.5	0	0	5.5	2	0	1.5	3.5	2.5	18.5	21.5	9	15	0.63	0.94	1.00	58.47
21	835.43	26.11	0	42.3	1.32	42.3	1.75	0	0.5	2.25	2	0	0	2	0	21.75	21.6	4.25	19.75	0.82	0.94	1.00	77.35
22	810.43	25.33	0	42.1	1.32	42.1	3.25	0	1	4.25	0	0	0.5	0.5	0	19.75	21.6	4.75	19.25	0.80	0.94	1.00	75.04
23	710.60	22.21	0	41.8	1.31	41.8	3.25	2.75	0	6	1	0	0	1	0	18	21.6	7	17	0.71	0.93	1.00	65.80
24	850.00	26.56	0	42.5	1.33	42.5	2.5	0	0	2.5	1.5	0	0	1.5	0	21.5	21.6	4	20	0.83	0.94	1.00	78.70
25	994.18	31.07	0	43.7	1.37	43.7	1	0	0	1	0.25	0	0	0.25	0	23	21.6	1.25	22.75	0.95	0.97	1.00	92.05
26	873.58	27.30	0	42.1	1.32	42.1	0.5	0	1.75	2.25	1	0	0	1	0	21.75	21.6	3.25	20.75	0.86	0.94	1.00	80.89
27	832.65	26.02	0	42.7	1.33	42.7	3.5	0	0	3.5	1	0	0	1	0	20.5	21.6	4.5	19.5	0.81	0.95	1.00	77.10
28	832.65	26.02	0	42.7	1.33	42.7	0	2	0.5	2.5	2	0	0	2	0	21.5	21.6	4.5	19.5	0.81	0.95	1.00	77.10
29	937.43	29.29	0	43.1	1.35	43.1	0.5	0.75	0	1.25	0.5	0	0.5	1	0	22.75	21.6	2.25	21.75	0.91	0.96	1.00	86.80
30	831.48	25.98	0	42.1	1.32	42.1	1.5	2.75	0	4.25	0	0	0	0	0	19.75	21.6	4.25	19.75	0.82	0.94	1.00	76.99
31	544.70	17.02	0	41.9	1.31	41.9	6.5	2.5	0	9	2	0	0	2	0	15	21.6	11	13	0.54	0.93	1.00	50.44
Totals	24417.75	763.05	0	1317.9	41.18	42.51	62	58.5	8.5	129.00	37.50	0.00	4.5	42	9	615.00	665.40	171	573	0.77	0.94	1.00	72.93

Table 5: Data collection after planned equipment maintenance.