

Tactical Activities to Improve the Effectiveness of Concrete Batching Plant Based on Overall Equipment Effectiveness Analysis

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ABSTRACT

The growth of infrastructure projects has led to an increased demand for ready-mix concrete. A company that produces ready-mix concrete using a batching plant encountered difficulties in fulfilling customer orders due to the high rate of machine downtime. Overall equipment effectiveness (OEE) was employed to examine these issues at the tactical activities, where the root causes of losses that occur in the OEE components of availability, performance, and quality were addressed. The OEE analysis was extended to encompass maintenance effectiveness measures, as the anticipated solution to the problem was not the replacement of the machine, but rather an enhancement of its operational efficacy. The effectiveness of maintenance activities was measured using MTTF (mean time to failure), MTTR (mean time to repair), and MTBF (mean time between failure). A review of the OEE components revealed a necessity to reduce losses, as evidenced by the availability and performance rates. Although the performance rate has the lowest value, based on the frequent occurrence of failures to the availability component, the improvement process was carried out to overcome problems in the availability variable. The implementation of scheduled maintenance at the beginning of each month and the implementation of daily checks before and after the machine was used resulted in an increase in the OEE value from 56.62% to 71.15%. The incorporation of maintenance analysis into OEE has been shown to result in increased OEE values, as evidenced by a longer mean time between failures, a reduced time for process adjustments, and a decreased asset repair time.

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I. Introduction

A company that is based on orders requires a high level of effectiveness in the machines or equipment used. Machine ineffectiveness can cause the company to be unable to meet customer demand either due to delays in fulfilling orders or the number of products that do not meet the standards. The effectiveness of production equipment can be evaluated through its reliability and quality. One of the indicators to determine equipment effectiveness is overall equipment effectiveness (OEE), which consists of three components: availability, performance, and quality. The purpose of OEE is to assess individual machines or equipment without considering their relationships with other machines or the people involved in their operation [1]. Measurement of individual machines is originally defined by Nakajima [2]. However, over time, OEE has been proposed for broader applications, such as measuring process and company performance [3], [4]. The level of machine effectiveness is aligned with the achievement of company objectives [5]. Not only can OEE be used to measure effectiveness, but it can also be used to identify losses and analyze non-value added activities [6]. Improving machine effectiveness does not always require replacing machines with more



advanced ones; it can also be achieved by enhancing the maintenance system of the existing machines.

OEE can be implemented in various activities: operational, tactical, and strategic [7]. The application of OEE to tactical activities is to find the root cause of the low OEE value and then make improvements to solve the root cause of the problem. In this study, the application of OEE to tactical activities was carried out in a company engaged in the manufacture of ready-mix concrete on a large scale. With the increase in infrastructure development, there is an increase in the need for ready-mix concrete [8]. The main equipment used to process the ready-mix concrete is called concrete batching plant. The machine is used to mix concrete ingredients such as cement, gravel, sand, and water [9]. The manufacture of products that rely on an equipment requires a very high effectiveness of the equipment. The batching plant in this company experienced high downtime, resulting in delays in fulfilling customer orders.

The problem of high downtime in machinery can be closely related to maintenance factors [10]. In general, the criteria used to measure the effectiveness of machine maintenance are MTTR (mean time to repair), MTTF (mean time to failure), and MTBF (mean time between failure) [11]. The component of OEE that is related to these three maintenance effectiveness metrics is the availability [12], [13]. Therefore, the tactical activities of applying OEE to the concrete batching plant problems were extended to include machine maintenance metrics in the root cause analysis.

II. Material and Methods

The research was conducted using the following steps. First, some of the data needed to measure OEE were collected, which was extended to the measurement of equipment maintenance effectiveness. The effectiveness of concrete batching plants was measured using OEE where the OEE value is the product of the multiplication of the availability, performance, and quality as shown in Eq. (1).

$$OEE (\%) = Availability (\%) \times Quality (\%) \times Performance (\%) \dots \dots \dots (1)$$

1. Availability Rate

The availability rate also referred to as availability efficiency in machinery systems, was expanded by adding three measures of maintenance effectiveness: MTTF, MTTR, and MTBF. Inefficiencies in availability are categorized as losses, which are then viewed as waste. Waste must be reduced or eliminated to improve OEE. The formulas for availability, MTTF, MTTR, and MTBF are shown in Eq. (2), (3), (4), and (5) [12].

$$Availability (\%) = \frac{Actual\ Run\ Time}{Loading\ Time} \times 100 \dots \dots \dots (2)$$

$$MTTF = \frac{Actual\ Run\ Time}{Number\ of\ Repairable\ Asset\ Failures} \dots \dots \dots (3)$$

$$MTTR = \frac{Total\ Repair\ Time}{Number\ of\ Repairable\ Asset\ Failures} \dots \dots \dots (4)$$

$$MTBF = MTTF + MTTR \dots \dots \dots (5)$$

2. Performance Rate

The performance rate, also referred to as operational efficiency, is the ratio between actual product output and potential output. Inefficiencies in performance are categorized as losses that need to be reduced or eliminated to improve the OEE value. The calculation of the performance rate can be found in Eq. (6).

$$\text{Performance (\%)} = \frac{\text{Output} \times \text{Cycle time}}{\text{Actual Run time}} \times 100\% \dots\dots\dots(6)$$

3. Quality Rate

The measurement of quality efficiency can be found in Eq. (7). Inefficiencies in quality are classified as losses that must be reduced or eliminated to improve OEE.

$$\text{Quality (\%)} = \frac{\text{Total of Good Products} - \text{Total of Bad Products}}{\text{Total of Good Products}} \times 100\% \dots\dots\dots(7)$$

4. Analysis of OEE and the Effectiveness of Machine Maintenance

OEE value measurement was divided into several steps. The first step was to calculate the availability, performance, and quality values for each month. The calculation of availability used Eq. (2), incorporating machine maintenance effectiveness by calculating MTTF, MTTR, and MTBF, which were obtained using Eq. (3), (4), and (5). The performance was calculated based on Eq. (6), and the quality was calculated using Eq. (7).

All values for availability, performance, and quality were averaged to obtain a mean over several months. Once these values were obtained, the next step was to calculate the OEE using Eq. (1). The resulting OEE was then compared with the standard OEE and previous OEE studies to identify potential improvements. The global OEE standard is availability > 0.90, performance > 0.95, and quality > 0.99. These would result in an overall OEE > 0.84, which is considered world-class performance [14], [15].

5. Proposed and Implemented Improvements

The final section contains recommendations to address the problems encountered. After analyzing the root causes of the problems with the concrete batching plant, the next step was to propose solutions to resolve these problems.

The proposed improvements were implemented to assess the change in OEE. The implementation was conducted for one month, during which the production processes and machine conditions were monitored according to the proposed improvements. OEE was then recalculated using the same method previously described. This recalculation aimed to determine whether the implementation of the proposed improvements had a positive impact.

III. Results and Discussions

1. Availability Rate

The results of the availability calculation are presented in Table 1. It can be seen that the company had no scheduled downtime or maintenance time allocated for the concrete batching plant. Maintenance on the machines was only performed when they were broken down or completely inoperative. Additionally, during production activities, if the machines experienced abnormal functional disruptions, they had to be shut down in the middle of production to carry out repairs on the faults. From Table 1, it can be observed that machine

breakdowns occurred quite frequently, with an average of 6 breakdowns per month. The average time required to repair these breakdowns (MTTR) was approximately 107 minutes. Meanwhile, the average time between failures (MTTF) was 1956 minutes, which equated to around 32.6 hours or approximately every 4 days.

Table 1. Availability, MTTF, MTTR, and MTBF rate

No	Variable	June	July	August	Sept.	Oct.	Nov.	Dec.
1	Standard minute available (min.) ^a	12,480	6,720	9,600	7,680	14,400	14,400	14,880
2	Planned downtime (maintenance) (min.) ^b	0	0	0	0	0	0	0
3	Loading time (min.) ^{c = a - b}	12,480	6,720	9,600	7,680	14,400	14,400	14,880
4	Adjust process (min.) ^d	375	360	780	420	1,440	600	1,780
5	Waiting material (min.) ^e	0	0	0	0	0	0	0
6	Waiting operator (min.) ^f	520	280	400	320	600	600	620
7	Asset repair time (min.) ^g	720	240	360	480	480	720	720
8	Total lost time (min.) ^{h = d + e + f + g}	1,615	880	1,540	1,220	2,520	1,920	3,120
9	Actual run time (min.) ^{i = c - h}	10,865	5,840	8,060	6,460	11,880	12,480	11,760
10	Availability (%) ^{j = $\frac{i}{c} \times 100\%$}	87.05%	86.90%	83.95%	84.11%	82.5%	86.67%	79.03%
11	Number of repairable asset failures ^j	11	2	5	2	6	7	10
11	MTTF (min.) ^{k = i/j}	988	2,920	1,612	3,230	1,980	1,783	1,176
12	MTTR (min.) ^{l = g/j}	65	120	72	240	80	103	72
13	MTBF (min.) ^{m = k + l}	1,053	3,040	1,684	3,470	2,060	1,886	1,248

The average availability rate was 84.31%, which was lower than the rate for world-class performance, higher than 90%. However, this availability rate was still higher than the average availability rate from the study conducted as in [16], which was 78.9%. Efforts to improve availability could have included addressing the very high MTTR and MTTF.

2. Performance Rate

The performance data are presented in Table 2. The average performance rate was 67.22%, which was still lower than the world-class performance rate of more than 95%. This performance rate was nearly identical to that found in the study as in [16], which reported a value of 67.1%. This indicated that there were opportunities for improvement to enhance the performance rate.

3. Quality Rate

The quality data are presented in Table 3. Based on this data, it was concluded that the company had a high-quality percentage of 99.91%.

Table 2. Performance rate

Month	Actual Run Time (minutes) ^a	Good Products (m ³) ^b	Cycle Time (minutes) ^c	Performance [$\frac{b \times c}{a} \times 100\%$]
June	10,865	892.356	10	82.13%
July	5,840	239.000	10	40.92%
August	8,060	333.500	10	41.38%
September	6,460	223.500	10	34.60%
October	11,880	1,509.362	10	100.00%
November	12,480	2,275.895	10	100.00%
December	11,760	841.545	10	71.56%
Average				67.22%

Table 3. Quality rate

Month	Bad products (m ³)			Total of bad products (m ³) ^a	Products (m ³) ^b	%Quality [$\frac{b-a}{b} * 100\%$]
	Out of tolerance	Setting Part	Attribute failure			
June	0	1.644	0	1.644	894.0	99.81%
July	0	0	0	0	239.0	100.00%
August	0	0	0	0	333.5	100.00%
September	0	0	0	0	223.5	100.00%
October	0	2.138	0	2.138	1,511.5	99.85%
November	0	3.105	0	3.105	2,279.0	99.86%
December	0	1.455	0	1.455	843.0	99.82%
Average				1.192	903.4	99.91%

4. Overall Equipment Effectiveness

The OEE value of the concrete batching plant used by the company was as follows:

$$OEE (\%) = 84.31\% \times 67.22\% \times 99.91\% = 56.62\%$$

The OEE value was 56.623%, which could be classified as significantly below the target OEE for a world-class company, higher than 85%. However, this value could be categorized as a medium value for OEE [17]. This indicated a continued need for improvements to enhance machine effectiveness.

5. Root Cause Analysis

Concrete batching plant is mainly composed of mixing systems, material weighing systems, conveying systems, storage systems, and control systems. Table 4 shows data on the number of machine failures based on the losses category of each machine component using the failure data that has been obtained for seven months.

Based on the data presented in Table 4, it was identified that the majority of losses originated from availability losses, with a total of 24. The second-highest number of losses came from performance losses, totaling 16, followed by quality losses, which amounted to 3. The availability losses became the primary focus for follow-up actions due to its high

number of losses. Root cause analysis for each losses could determine appropriate strategies for resolving these problems [18]. Root cause analysis was conducted using a fishbone diagram to identify the cause of each losses. Essentially, the main objective of OEE analysis was to implement improvements based on the identification and reduction of specific losses [19].

Table 4. Number of machine failures based on losses

Losses	Components	Number of failures
Availability	Weighing system	1
	Mixing system	1
	Conveying system	14
	Storage system	2
	Control system	6
	Total	24
Performance	Weighing system	3
	Mixing system	2
	Conveying system	6
	Storage system	4
	Control system	1
	Total	16
Quality	Weighing system	3
	Total	3

Availability Losses

Availability losses disrupted the availability or reliability of the machines and several components. Table 4 showed that there were losses in each component of the batching plant (weighing system, mixing system, conveying system, storage system, and control system). The factors causing the majority of losses were found in the conveying system. In conveying system, there were compressors, cement conveying pipes, and buckets (Figure 1).



Fig. 1. Bucket

The compressor operated using a pneumatic system, making air pressure a critical factor for the driving machine. The problems that frequently occurred with the compressor included sudden shutdowns during operation due to improperly installed components and broken conductors. An indicator of compressor malfunction was excessive vibration in the machine. Pneumatic system failures in the conveying system usually occurred because air pressure dropped below operational levels. Additionally, the oil corona of the compressor experienced high friction forces due to high temperatures, which caused the lubricant temperature to rise.

Another source of losses occurred with the buckets, which became dirty due to residual material that had not been properly discharged. Additionally, the buckets did not always occupy the position where they were supposed to receive material from the conveyor, causing the material to fall and go to waste. This problem was often caused by the steel cables experiencing tension disturbances due to excessive friction on the bucket drive pulley. The heat generated caused the lubricant oil for the pulley to reach high temperatures, which slightly hindered lubrication and resulted in increased friction forces. Another constraint related to the machinery involved the pipes that were responsible for conveying the material. The most common damage to the pipes was found in the cement conveying pipes due to detached distributor valves.

The subsequent losses were observed in the mixing system, which comprised the mixer (Figure 2) as its primary component. Common problems with the mixer included residual material and the drive motor not functioning properly due to insufficient electrical current or inadequate power to operate the machine. In the storage system, the causes of availability losses were associated with the cement silos (Figure 3). Losses in silos are caused by operators such as silos being overloaded and silos not closing properly due to lack of supervision by operators.



Fig. 2. Mixer

The next losses were in the weighing system and control system. The primary causes of losses were attributed to environmental factors and methods. The environmental factors referred to included unstable electrical voltage, which led to failure in several parts, such as fires in the solenoid coil. The solenoid coil was a critical component in the weighing system, and it was expected that replacements would always be available in case of failure. Unstable

electrical voltage in the plant was usually caused by excessive power consumption or issues with electrical equipment such as switch terminals, sockets, fittings, and plugs. Additionally, the causes of system failures that occurred on the control panel were related to improper shutdown procedures for the concrete batching plant. Operators typically turned off the machine by pressing the emergency button on the indicator panel, and this mistake was made repeatedly, resulting in system breakdown. Besides panel system failures, fires in cables and electrical contactors also occurred due to unstable electrical voltage and high temperatures.



Fig. 3. Cement silos

Performance Losses

Performance losses reduced the machine's ability to produce products within the available time. Table 4 illustrates the number of losses in each component of the batching plant (weighing system, mixing system, conveying system, storage system, and control system).

In the conveying system, losses occurred in the conveyor. Failure of the conveyor was caused by several factors, such as belt failure, slipping, and carryback. Carryback, which referred to the return of material on the conveyor, happened due to the accumulation of debris on the belt. This debris could originate from residual material that had not been fully discharged or from dust in the surrounding environment. Another type of failure was known as slipping, which occurred due to excess or insufficient tension on the conveyor belt. The final type of failure involved the tearing of the conveyor belt, which was caused by roller failure. In addition to the conveyor, the water conveying pipes to the mixer also contributed to performance losses. The water pipes typically experienced disruptions due to debris, such as leaves, clogging the flow of water from the tank to the mixer.

Next, in the weighing system, the most crucial equipment was the hopper (Figure 4). Errors in the hopper could occur if it was not cleaned of residual material during the production process. In addition to residual material, inaccurate scales could also contribute to errors in weighing, resulting in defects in the final product. Scale inaccuracies were typically caused by the hopper's interface overheating, which led to imprecise measurements. Additionally, mixtures that were too wet occurred when the aggregate material measurements from the hopper and the water volume from the tank, as regulated by the flow meter, were not aligned. The standard tolerance for aggregate measurements was $\pm 0.5\%$, meaning that if the mixture was too wet, the measurement exceeded 0.5%.

The factors contributing to losses in the storage system were associated with the aggregate bin. Clogs in the bin valve were caused by a malfunctioning material bin actuator. The actuator was responsible for opening and closing the valve of the aggregate bin. Damage to the actuator rendered production rates ineffective. In addition to actuator issues, the low performance of the bin valve was attributed to the accumulation of residual material in the aggregate bin that had not been cleaned, as well as insufficient lubrication in the valve gear.



Fig. 4. Hopper

Additionally, there were problems with the bearings in the mixer, which produced a humming noise during operation. Errors in the bearings were caused by being too close to the bearing ring or occasionally breaking. Furthermore, the concrete produced in the mixer had a time limit for delivery to meet the quality standards. This condition required that the concrete be discharged immediately after mixing, leaving no waiting time in the mixer. Any waiting time would result in residual material and create a backlog.

Quality Losses

Quality losses were the least numerous. The errors that typically occurred were in the weighing system, which caused the cement mixture to become either too runny or too thick.

6. Proposed Improvements

After identifying the sources of the problems occurring in the batching plant, the next step was to propose improvements to address the issues. The improvement proposals were formulated according to the five components of the batching plant: weighing system, mixing system, conveying system, storage system, and control system.

Weighing system

In general, the solutions proposed for the weighing system included calibrating the hopper to ensure accurate measurement. Calibration could be performed at least once a month. In addition to calibration, several components in the weighing section were found to be failed due to dirt or burning. The unstable electrical voltage caused some components in the hopper to burn out quickly, highlighting the need to check the electrical voltage before operating the system. Routine cleaning of each component was also necessary to prevent failure caused by dirt accumulation in the machine.

Mixing system

In the mixing system, the proposed solutions to minimize failure included conducting routine cleaning and having readily available spare parts when the mixer's drive motor failed to operate. Additionally, regular cleaning of the mixer was essential. The cleaning process involved introducing a solvent solution into the mixer, after which the drive motor would be activated to remove residual concrete from the pan mixer. Disposal of the cleaning solution

had to be carried out according to established procedures to prevent environmental contamination. Furthermore, the operators were required to remain vigilant and disciplined in inspecting the mixer components, as the quality of the concrete was determined during the mixing process. In addition to maintaining the cleanliness of the pan mixer and drive motor, two key factors needed attention to prevent failure to the components in the mixing system: the capacity of the pan and the mixing speed had to align with the existing standards. The capacity of the mixer was 5 m³, and the mixing speed was set at 14-20 revolutions per minute.

Conveying system

In the conveying system, the critical components that required primary focus included the compressor (in the cement conveying area), conveyor, bucket, and several parts such as pipes, as these components frequently experienced failure. The proposed improvements included proper maintenance and servicing procedures for the machine. These suggested solutions aimed to reduce the frequency of malfunctions.

There was a need for the workers to understand how to analyze compressor failures. The signs of compressor malfunction included the machine shutting down, excessive vibrations, and overheating to the point of producing a burning smell. Repairs to the compressor could be conducted in two ways: when the machine exhibited the signs of failure and through pre-operation inspections.

The following were solutions to address the issues with the compressor. A compressor failure could be attributed to several factors, such as air pressure not reaching operational capacity. The solution involved checking the state of the compressed air and refilling it as necessary. Excessive vibrations in the compressor occurred due to certain spare parts not being properly installed. The remedy was to ensure that these spare parts were correctly fitted. Additionally, excessive compressed air within the compressor necessitated adjustments to the air conditions inside the unit. Loud noises from the compressor were typically caused by issues with the solenoid. Therefore, it was essential to inspect the solenoid valve.

Common failures that occurred in the conveyor included damage to the belt, slippage, and carryback. The following solutions were proposed to address these issues. Failures in the rollers and lagging pulleys caused damage to the conveyor belt and slippage. The quality of the rollers and lagging pulleys significantly influenced these problems. Limited budgets for spare parts forced the company to pay more attention to maintenance processes to reduce the percentage of conveyor failures. Maintaining the cleanliness of the conveyor belt was crucial to prevent carryback. Installing cleaners on the conveyor belt could minimize carryback occurrences. However, financial constraints made this installation unfeasible, leading to the recommendation of routine cleaning of the conveyor belt instead.

The issues that frequently arose with the bucket included dirt accumulation and unstable tension in the steel cable. The unstable tension was caused by insufficient lubrication in the pulley, which necessitated regular inspections to ensure that the pulley was in good working condition. Additionally, a routine cleaning schedule for the interior of the bucket was required.

Storage system

In the storage system, the proposed improvements included regularly checking the storage equipment, specifically the bin and silos. Extra attention was required during the

loading of materials into the bin and silos to prevent errors such as overloading and improper sealing. The discipline of the workers was essential in this regard.

Control system

The monitor panel functioned to control all the components within the batching plant. This system was operated through a computer connected to a system panel. System failures occurred because operators infrequently shut down the machines according to the established procedures. In addition to ensuring that the shutdown procedures were followed step by step, it was essential to ensure that the monitor panel was in good condition and reflected the actual state of the equipment. For instance, the 'low pressure' indicator light in the pneumatic system should turn off once the compressor was activated and the air pressure within the compressor stabilized. The 'bottom position' indicator light illuminated when the bucket was in the lowest position, and the 'empty' indicator light also turned on to confirm that the bucket was indeed empty.

To support the examination of the batching plant's condition, it was recommended to establish a routine maintenance schedule for the machines, as well as a checklist for inspection before and after operating the equipment. A checklist was created to assist operators in monitoring the readiness of the machines. This batching plant inspection checklist needed to be completed daily before the machines were operated.

Routine inspections were proposed as a corrective measure. Before operating the batching plant, it was expected that the assigned workers would examine all the components listed in the created checklist to avoid uncertainties during the production process and to reduce the percentage of machinery failures. The time allocated for daily checks was the operators' waiting time. During this period, it was anticipated that the operators would be more effective in utilizing the available time.

In addition to daily inspections, the implementation of a monthly maintenance system was also proposed with the same objective. Every month, maintenance would be conducted for approximately 100 minutes on all machine conditions, particularly focusing on the weighing system and the control system. Calibration would be performed on the weighing system, while repairs and updates would be carried out on the control system. The proposed improvements also required discipline from the operators to ensure they regularly checked the machine conditions.

7. Implementation of Proposed Improvements

The implementation of the proposed solutions was conducted over a period of one month. The implementation involved performing daily checks based on the list that had been created. The time allocated for conducting the daily checks was utilized during the operator's waiting time (20 minutes). Additionally, a monthly maintenance schedule was established at the beginning of each month to carry out a thorough inspection, particularly focusing on the weighing system (calibration).

Based on the data presented in Table 5, the results of availability rate after implementing the measures were recorded at 93.4%. The daily checks, conducted according to the proposed checklist, utilized the operators' waiting time, thereby avoiding additional working hours and enhancing job efficiency. Furthermore, the availability rate improved, increasing from 84.31% to 93.4%.

In addition to the availability rate calculations within the OEE framework, an analysis was also conducted on maintenance performance metrics, including MTTF, MTTR, and

MTBF. Prior to implementation, the average monthly MTTF and MTTR values were 1956 minutes and 107 minutes, respectively. The implementation of the proposed improvements enhanced the MTTF and MTTR values to 4890 minutes and 60 minutes, respectively. A high MTTF value indicated a favorable condition, meaning that the time between the first failure and subsequent failures occurred over an extended period. Conversely, a lower MTTR value signified better performance, as it indicated that the required repair time was short.

Table 5. Availability and maintenance rate after implementation

No	Variable	
1	Standard minutes available (minutes) ^a	10,560
2	Planned downtime (maintenance) (minutes) ^b	100
3	Loading time (minutes) ^{c = a - b}	10,460
4	Adjust process (minutes) ^d	120
5	Waiting material (minutes) ^e	0
6	Waiting operator (minutes) ^f	440
7	Asset repair time (minutes) ^g	120
8	Total lost time (minutes) ^{h = d + e + f + g}	680
9	Actual run time (minutes) ^{i = c - h}	9,780
10	Availability (%) [$\frac{i}{c} \times 100\%$]	93.4
11	Number of repairable asset failures ^j	2
11	MTTF (minutes) ^{k = i/j}	4,890
12	MTTR (minutes) ^{l = g/j}	60
13	MTBF (minutes) ^{m = k + l}	4,950

Based on the calculations of the performance rate presented in Table 6, it was observed that the performance rate improved, increasing from 67.22% to 76.18%.

Table 6. Performance rate after implementation

Actual Run Time (minutes) ^a	9,780
Total of Good Products (m ³) ^b	745
Cycle Time (minutes) ^c	10
% Performance ^{(b x c)/a}	76.18

Based on the quality rate in Table 7, it can be seen that there was no defects in the products, resulting in a quality percentage of 100% and zero defects. Additionally, the quality rate improved after the implementation of the proposed improvements, increasing from 99.91% to 100%.

The quality of the company's products was not a significant issue. The simplicity of the process for repairing defective products was the primary reason for the consistently high quality of the company's products. For instance, if the concrete mix was too watery, the appropriate action was to add more material to ensure the mix conformed to the established standards. The main problem laid in the operational costs, which necessitated rework and additional material if discrepancies in the cement measurements occurred. The continuous increase in operational costs could be detrimental to the company.

The OEE value of the concrete batching plant after the implementation of the proposed improvement was as follows:

$$OEE (\%) = 93.4\% \times 76.18\% \times 100\% = 71.15\%$$

The OEE value after implementation was 71.15%. This indicated an improvement in the OEE value following the implementation, rising from an initial 56.62% to 71.15%. This OEE value changed the company's OEE category from medium to high-value [17]. Therefore, it could be stated that the daily checks conducted on the machine contributed to a reduction in the percentage of losses. The reduction in losses occurred because the machine's condition was consistently monitored both before and after use, in addition to adhering to other procedures in operating the machinery. This showed that maintenance greatly affects the OEE value [20].

Table 7. Quality rate after implementation

Out of tolerance ^a	0
Setting Part ^b	0
Attribut failure ^c	0
Total of Bad Products (m ³) ^{d = a+b+c}	0
Total Product (m ³) ^e	745
% Quality ^{(e-d)/e}	100

In addition, there is also an influence among OEE variables. Although problem-solving was largely emphasized through improving losses in availability, the process of solving the problem also affects the value of other variables because the three variables are interrelated [21], [22]. An increase in the availability rate impacted the performance rate, as both were related to the actual run time. If the actual run time was low, it would affect the production quantity, leading to a decrease in the performance rate.

Likewise, the performance variable is related to the quality variable. Both variables are related because they are influenced by good products. If the amount of good products is limited due to a small actual run time, then the quality percentage will also decrease. However, the OEE in the company showed a performance rate that was less than satisfactory while maintaining a high-quality rate. This situation arose because the process of rectifying defective products that did not meet standards was relatively straightforward. An incorrect concrete mixture simply required the addition of materials to readjust it to meet the company's standard product specifications. The rectification process inevitably added to the working time, and this increase in working time impacted both availability and performance rates.

The implementation process, which primarily focused on the incorporation of machine maintenance activities, could be regarded as a cost-effective approach. Scheduled machine maintenance at the beginning of the month was carried out for 100 minutes, adjusted to the production schedule, and did not result in additional costs. The daily check, which lasted for 20 minutes, used of the operator's waiting time, thereby reducing non-value added activities.

IV. Conclusions

The tactical activities conducted on the concrete batching plant, utilizing an expanded OEE analysis combined with maintenance activities, demonstrated an increase in machine effectiveness from 56.62% to 71.15%. The improvement process involved analyzing the

root causes of losses in the availability, performance, and quality variables. Although the performance rate was the lowest, the highest occurrence of failures was found in availability; therefore, the analysis of maintenance metrics was employed to support the root cause analysis for availability. Planned downtime for maintenance, which previously did not exist, was scheduled at the beginning of each month for 100 minutes. To improve maintenance effectiveness, daily inspection activities were carried out on machines before and after use by utilizing operator waiting time. It was evident that the implementation of machine maintenance procedures inevitably resulted in a certain degree of machine downtime. However, this was counterbalanced by the enhanced average time between failures, the reduced time required for process adjustments, and the decreased asset repair time, which collectively contributed to an increase in the actual run time. An increase in actual run time was associated with an increase in both the availability rate and the performance rate, as both of these variables utilize actual run time as a basis for measurement. The increase in performance rate can be maintained because the other influencing factor, that was good products, was also increasing, where the amount of good products also affected the increase in quality rate. The implementation of OEE improvements was only carried out for one month so there is a possibility that the OEE value will be lower when the implementation of these improvements is carried out for several months. Further research could be conducted at the level of strategic activities, where strategic policies such as the replacement of the machine using an investment feasibility analysis could be evaluated.

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