Plant Maintenance Modelling Through Availability Analysis In Raw Mill of Cement Production

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Abstract. Maintenance activities are a particular concern at PT XYZ, which is the largest cement producer in Eastern Indonesia. PT XYZ has five main factories located in Pangkep, South Sulawesi, units 1, 2, 3, 4, and 5. In 2019, PT XYZ's five clinker production only reached 2,445,515 tons or 93.64% of the target. The details, raw meal production was not achieved, namely 4,041,377 tons or 96.54% of the target set by the company due to the unplanned shutdowns. This research tries to control the breakdowns of raw mill machine by evaluating the availability and day of operation (calendar day). The availability analysis method used is the discrete system simulation approach because the discrete system simulation can accommodate random behavior and dependence between variables. In the existing condition, system availability is 72.83% and calendar day is 239 days. These two parameters are still less than the target. To overcome this problem, experimentation was carried out with 3 scenarios. The best simulation results shows that the preventive maintenance activities changes the value of TTF (Time to Failure), TTR (Time to Repair), and reduces the duration of overhaul activities. This can increase the availability to 83.04% and calendar day to 255 days.

1. Introduction

Maintenance is all actions needed to maintain the condition of the equipment or return it to a certain condition [1]. According to [2], maintenance is an activity to maintain factory facilities, by adjustments or replacements needed in order to create a satisfactory production operational state, according to what has been planned.

Maintenance activities are a particular concern at PT XYZ, which is the largest cement producer in Eastern Indonesia. PT XYZ has five main factories located in Pangkep Regency, South Sulawesi, namely unit 1, 2, 3, 4, and 5. In 2019, PT XYZ unit 5 clinker production only reached 2,445,515 tons or 93.64% of the target. Raw meal production was 4,041,377 tons or 96.54% of the target. The total kiln operating days for one year were 310 days or only 97.18% of the target of 319 days. The Raw mill's total operating days did not reach its target in 2019, which is only 245 days or 90.07% of the target of 272 days. Unplanned shutdowns were affected by the unplanned shutdowns in the kiln and raw mill operating days. The breakdown factor can be controlled by evaluating availability to increase availability and day of operation (calendar day).

One indicator of inadequate production can be seen from the data on the kiln and raw mill operating days in the image below:

The total kiln operating days for one year were 310 days or only 97.18% of the target of 319 days.
This target is set based on normal production capacity. Similar to kiln operating days, raw mill operating days did not reach the target in 2019, which is only 245 days or 90.07% of the target of 272 days.

Unplanned shutdowns are affected by the unplanned shutdown in the kiln and raw mill operating days, with details of the frequency of events in the Figure 1 and Figure 2 below:

![Figure 1. Unplanned kiln machine breakdown](image1)

![Figure 2. Unplanned raw mill machine breakdown](image2)

The factors that caused this unplanned breakdown were instrument disturbances, electrical disturbances, power problems, operation problems, and mechanical problems.

In this study, the authors focused on the raw mill sub-system because this sub-system is an important part of a cement factory known as "the heart of the plant". This sub-system requires more handling than other sub-systems [1].

The problem of availability in a production system is a complex system, which is a system that has uncertainty in one or more of its variables and has interdependence among variables [2].

Reliability, availability, and maintainability (RAM) analysis is a tool for evaluating the performance of a tool at different stages of planning [3]. RAM analysis can address operational and security issues to identify system elements where corrective action can be taken. Several key performance indicators can be generated from this RAM analysis, namely availability, MTTF, and MTTR [4]. Availability is the probability of a system operating according to its function when it wants to be used. Mean time to failure is the average time between failure events in a system. Meanwhile, the mean time to repair is the average time needed to repair a system that is experiencing a breakdown or damage [5]. Availability analysis is used to determine the critical sub-systems that exist in the cement production process so that equipment production capacity utilization can be increased [1]. This analysis can also be used as a guide for developing maintenance strategies and increasing maintenance effectiveness [6].
2. Problem Description
The case study is based on a cement company in Indonesia. In general, the cement manufacturing process starts with the limestone mining process as the main material and some of the supporting materials and correction materials are crushed or crushed to the appropriate size. The results of the crushing are then milled in the milling and drying of the raw materials or called raw meal. The result of the mill is called raw meal and is accommodated in the blending silo. With the right composition, raw meal will be transported to the preheater for preheating and kiln is the main equipment of the cement production process which functions as a means of burning feed material (raw meal) into clinker with an operating temperature of up to 1500 °C. Kiln unit 5 has a capacity of 9,000 tons per day which produces clinker to be used as the main raw material for cement. The clinker that has been produced is immediately transported to the clinker storage. Then, with the right composition, clinker is added with gypsum and a third material to be grounded and processed into cement in a cement mill [7].

The simulations carried out in this study started from the raw materials in the form of limestone, clay, iron sand, and silica sand in the form of entities from the warehouse stored in the raw mill feed bin, which was then transported to the raw mill for the grinding process to produce raw meal products which are then transported via the belt bucket elevator to the raw meal silo.

| No | Sub-system       | Equipment Name     | Equipment Code |
|----|------------------|--------------------|----------------|
| 1  | Raw mill Feed    | Limestone Bin      | 531BI01        |
| 2  |                  | Silicastone Bin    | 531BI02        |
| 3  |                  | Iron Sand Bin      | 531BI03        |
| 4  |                  | Clay Bin           | 531BI04        |
| 5  | Raw mill Feed    | Limestone Feeder   | 531WF01        |
| 6  |                  | Silicastone Feeder | 531WF02        |
| 7  |                  | Iron Sand Feeder   | 531WF03        |
| 8  |                  | Clay Feeder        | 531WF04        |
| 9  | Raw mill Feed    | Belt Transport     | 531BC02        |
| 10 | Transport        | Belt Transport     | 531BC03        |
| 11 |                  | Belt Transport     | 531BC04        |
| 12 |                  | Rotary Feeder      | 532RF01        |
| 13 | Raw mill         | Vertical Mill      | 532RM01        |
| 14 |                  | Separator          | 532SR01        |
| 15 |                  | Cyclone            | 532CY01        |
| 16 |                  | Rotary Air Lock    | 532RF03        |
| 17 |                  | Air Slide          | 532AS01        |
| 18 | Raw Meal         | Air Slide          | 532AS02        |
| 19 | Transport        | Diverter Gate      | 532DG04        |
| 20 |                  | Bucket Elevator    | 532BE02        |
| 21 | Raw Meal Silo    | Silo               | 532SI01        |

In detail, there are 21 types of equipments in five sub-systems of the raw mill that will be modeled in this study. In the raw mill feed unit, there are eight types of equipments, the raw mill feed transport unit has three types of equipments, the raw mill unit has five types of equipments, the raw meal transport unit has four types of equipments, and the raw meal silo unit has one equipment. Table 1 describes all equipments in each sub-system.

Key performance indicators to be measured in this study are availability and day of
operation/calendar day. The availability generated from the simulation model is the accumulated availability of the sub-systems. Therefore, to calculate system availability can be done with the following equation [8]:

\[ A = (A1) (A2) (A3) (A4) (A5) \]  

Where:

- \( A \) = System availability
- \( A1 \) = Availability of Raw Mill Feed Sub-System
- \( A2 \) = Raw mill Feed Transport Sub-System Availability
- \( A3 \) = Availability of Raw Mill Sub-System
- \( A4 \) = Availability of Raw Meal Transport Sub-System
- \( A5 \) = Availability of Raw Meal Silo Sub-System

While the calendar day is the time used by the system to produce products by a predetermined plan.

3. Model Development

This study used the flow diagram and reliability block diagram to model the system quantitatively.

3.1. Reliability Block Diagram

Reliability Block Diagram is a graphical representation of a component in a system and how the relationship between these components is [9]. All units in raw mill system are connected in a series system. If one unit fails, the whole system cannot operate. Figure 3 describes the reliability block diagram of all equipments in raw mill system.

3.2. Flow Diagram

Flow diagrams are used to model the system logic, which represents the failure logic and production process. Figure 4 describes the flow diagram of failure logic, as follows. (1) Generate time between failures of the components, which is found from the fitting distribution of raw data. (2) Update machine status, when the breakdown occurred, the machine status is set to be zero. With this status, the authors can identify and calculate machine availability. (3) Repairment process, at this stage, delay in the repair process is carried out. The repair process time is determined based on the results of distribution fittings that have been done previously. (4) Update the machine status, at this stage, the machine status is updated again to 1, which means the machine can operate properly.

In modelling the production system, the authors apply the black box system, so that the simulated production process is only based on units and does not model each sub-unit in the factory. The authors model the production system by considering the combination of failures during the production process.
After the conceptual model is generated, the next step is generating the simulation model [8]. The simulation model provides the random number generation that will be used to represent the MTTR, MTTF, and production delay. There are two important stages in the simulation model, verification and validation [10]. The purpose of model verification is to avoid simulation error, while the model validation is to ensure that the simulation model truly represents the real system. The input system of the simulation model is generated by random value; thus, the output system will be random. Therefore, several replications are required to represent the real system.

4. Results and Discussion
The simulation is conducted in two steps; the first is to evaluate the performance of the existing condition. Based on the existing simulation result, the scenarios are developed to improve system performance. Each experiment is conducted in 13 replications.

4.1. Existing Condition
In the existing condition, the company implements the preventive maintenance policy that affects this simulation result. In this study, the authors analyzed availability and calendar day as performance criteria. After the simulation, existing calendar day and system availability are obtained.

Based on Table 2, it can be seen that the average system availability is 0.7283 and the calendar day average is 239 days. The next step is evaluating system availability in each unit to find out which unit has the lowest availability. The whole system is connected in a series configuration. In line with this, the system availability is calculated by multiplying each of unit availability.

The next step is determining which equipment contributes to the low availability. Table 3. Describe the availability of all equipment starting from the lowest to the highest. In this study, the modeling decision is by evaluating each of the equipment availability and from the discussion with Raw Mill Maintenance Manager. Spare part availability means the availability of each spare part whenever required during the corresponding machine failure.

4.2. Scenario Development
In this Scenario 1, the authors perform simulation by optimizing plant maintenance activities that affect the TTF (Time to Failure) and TTR (Time to Repair) Raw Mill system equipment values. Based on simulation results (Table 2) and interviews with PT XYZ's Raw Mill Maintenance Manager. The
selected equipments are Equipment 532RM01 (Vertical Raw mill), Equipment 531WF04 (Clay Weigh Feeder), and Equipment 532BE02 (Belt Bucket Elevator). The selection of these three equipment is based on the disturbance data obtained from the work unit. These three pieces of equipment have a higher TTF rate than other equipments. These three equipment are also critical parts in the raw mill system, which are very important in the system and also require a longer procurement time than other equipments.

Table 2. Existing condition performance summary

| Replications | System availability | Calendar Day (days) |
|--------------|---------------------|---------------------|
| 1            | 0,8131              | 248                 |
| 2            | 0,7211              | 237                 |
| 3            | 0,7092              | 227                 |
| 4            | 0,7654              | 250                 |
| 5            | 0,6815              | 242                 |
| 6            | 0,7757              | 240                 |
| 7            | 0,7187              | 229                 |
| 8            | 0,7394              | 258                 |
| 9            | 0,5955              | 215                 |
| 10           | 0,7447              | 246                 |
| 11           | 0,7923              | 243                 |
| 12           | 0,7781              | 248                 |
| 13           | 0,6335              | 220                 |
| Average      | 0,7283              | 239                 |

Table 3. Existing condition of equipment availability

| No | Equipment   | Availability average | No | Equipment   | Availability average |
|----|-------------|----------------------|----|-------------|----------------------|
| 1  | 531BI01     | 0,8965               | 12 | 532RF01     | 0,9036               |
| 2  | 531BI02     | 0,8737               | 13 | 532RM01     | 0,8907               |
| 3  | 531BI03     | 0,8766               | 14 | 532SR01     | 0,8673               |
| 4  | 531BI04     | 0,8957               | 15 | 532CY01     | 0,8839               |
| 5  | 531WF01     | 0,9970               | 16 | 532RF03     | 0,8865               |
| 6  | 531WF02     | 0,9994               | 17 | 532AS01     | 0,9991               |
| 7  | 531WF03     | 0,9995               | 18 | 532AS02     | 0,9989               |
| 8  | 531WF04     | 0,9946               | 19 | 532DG04     | 0,8983               |
| 9  | 531BC02     | 0,9968               | 20 | 532BE02     | 0,8938               |
| 10 | 531BC03     | 0,9988               | 21 | 532SI01     | 0,8849               |
| 11 | 531BC04     | 0,9986               |

In the TTF (Time to Failure) optimization scenario, the following steps are carried out:

- Replacement of spare parts by considering the rate of equipment wear based on the spare part manual and best practice.
- Optimization of Preventive Maintenance activities that are integrated with spare part planning in the SAP Plant Maintenance Module system.
- Use of original and quality spare parts.
- Implementation of TPM (Total Productive Maintenance).
In the TTR (Time to Repair) optimization scenario the following steps are carried out:

- Added overtime hours and resources in the event of a breakdown,
- Improved work procedures through sharing internal knowledge and external training to similar industries or expert teams,
- Modernization of work equipment to speed up repair work.

In the Scenario 2, the authors perform a simulation by optimizing the overhaul implementation. Based on the interview results with PT XYZ's Raw Mill Maintenance Manager, optimization can be carried out in Plant Maintenance/Preventive Maintenance activities, namely, by entering activities in the overhaul activity into the daily, weekly, or monthly Preventive Maintenance activities, so that a reduction in the duration of the overhaul can be reduced. Initially 19 days (456 hours) to 12 days (288 hours).

### Table 4. Scenario development experiment summary

| Replication | Availability | Calendar Day |
|-------------|--------------|--------------|
|             | Existing     | Scenario 1 | Scenario 2 | Scenario 3 | Existing | Scenario 1 | Scenario 2 | Scenario 3 |
| 1           | 0.7          | 0.8082     | 0.8827  | 0.878    | 245      | 247        | 262        | 261        |
| 2           | 0.7          | 0.7746     | 0.7894  | 0.8396   | 245      | 239        | 251        | 253        |
| 3           | 0.7          | 0.7876     | 0.757   | 0.8536   | 245      | 249        | 235        | 262        |
| 4           | 0.7          | 0.7106     | 0.8424  | 0.7824   | 245      | 238        | 266        | 253        |
| 5           | 0.7          | 0.6201     | 0.7596  | 0.6899   | 245      | 225        | 250        | 241        |
| 6           | 0.7          | 0.8347     | 0.8431  | 0.9023   | 245      | 253        | 253        | 267        |
| 7           | 0.7          | 0.7475     | 0.7757  | 0.8084   | 245      | 240        | 240        | 252        |
| 8           | 0.7          | 0.8313     | 0.8164  | 0.8984   | 245      | 257        | 267        | 272        |
| 9           | 0.7          | 0.7275     | 0.6646  | 0.7941   | 245      | 226        | 229        | 239        |
| 10          | 0.7          | 0.7585     | 0.8139  | 0.8361   | 245      | 256        | 259        | 265        |
| 11          | 0.7          | 0.7447     | 0.86    | 0.812    | 245      | 230        | 256        | 243        |
| 12          | 0.7          | 0.8226     | 0.8473  | 0.8904   | 245      | 250        | 262        | 263        |
| 13          | 0.7          | 0.7335     | 0.7086  | 0.8097   | 245      | 226        | 236        | 242        |
| Average     | 0.7          | 0.7616     | 0.797   | 0.8304   | 245      | 241        | 252        | 255        |

### Table 5. Hypothesis testing result summary

| Student's t Hypothesis | Availability | Calendar Day |
|------------------------|--------------|--------------|
|                        | Scenario 3   | Scenario 3   | Scenario 3   | Scenario 3   |
| Mean                   | 0.830376923  | 0.7          | 254,8462     | 245          |
| Variance               | 0.003410644  | 0            | 121,9744     | 0            |
| Observations           | 13           | 13           | 13           | 13           |
| Pooled Variance        | 0.001705322  | 60,98718     |              |              |
| Hypothesized Mean Difference | 0           | 0            |              |              |
| Df                     | 24           | 24           |              |              |
| t Stat                 | 8.049228095  | 3,21443      |              |              |
| P(T<=t) one-tail        | 1.42E-08     | 0.001854     |              |              |
| t Critical one-tail    | 1.71088208   | 1.710882     |              |              |
| P(T<=t) two-tail       | 2.83E-08     | 0.003709     |              |              |
| t Critical two-tail    | 2.063898562  | 2.063899     |              |              |
In the Scenario 3, the authors perform a simulation by combining Scenarios 1 and 2. The results of these 3 scenarios can be seen in the Table 4. The Table 5 describes the hypothesis testing result summary which concludes that the result is significant. Scenario 3 provides better availability and calendar day values than other scenarios compared to the existing and target systems. Likewise, for calendar day values, the value of Scenario 3 is better than other scenarios, and the existing system. However, this scenario has not provided a calendar day value as targeted. The system availability value in the simulation Scenario 3 is better and has significant value 0.8304. Likewise, the resulting calendar day value provides a better and significant value 255 days.

5. Conclusion
Based on the existing conditions at PT XYZ, the average system availability is 72.83% and the average calendar day is 239 days. These two performance indicators have not yet reached the target, namely the availability of 75% and the calendar day of 272 days.

Based on the experiments, the recommended scenario is Scenario 3 because it provides the best availability and calendar day values than other scenarios. The availability is 83.04% and the calendar day is 255 days.

The further research can be done by optimizing all existing equipments in the raw mill system and conducting a financial feasibility analysis on the selected scenario.

6. References
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