Failure Mode and Effect Analysis (FMEA) Applications to Identify Iron Sand Reject and Losses in Cement Industry: A Case Study

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Abstract. One of the main raw materials required in the manufacture of cement is iron sand. Data from the Procurement Department on XYZ Company shows that the number of defective iron sand (reject) fluctuates every month. Iron sand is an important raw material in the cement production process, so that the amount of iron sand reject and losses got financial and non-financial impact. This study aims to determine the most dominant activity as the cause of rejection and losses of iron sands and suggest improvements that can be made by using the approach of FMEA (Failure Mode and Effect Analysis). Data collection techniques in this study was using the method of observation, interviews, and focus group discussion (FGD) as well as the assessment of the experts to identify it. Results from this study is there are four points of the most dominant cause of the defect of iron sand (mining activities, acceptance, examination and delivery). Recommendation for overcoming these problem is presented (vendor improvement).

1. Introduction
The main objective of the company is getting profit by reducing or even eliminating the waste. So that the process of improvement (continuous improvement) must be done to improve the quality of the product. Not only the number of failed products to be reduced, but also customer satisfaction will be increased so as to win the market. One of the raw materials that focused in the fulfillment of quality is the quality of the iron sand raw material. The role and function of iron sand as one of the key raw material in the cement manufacturing industry makes the fulfillment of the quality and quantity of iron sand as a requirement that must be met. Procurement Department’s data from XYZ company shows the amount of iron sand reject and losses were fluctuating every month. Iron sand is also very important for the cement manufacturing process compared with other raw materials so that the presence of iron sand reject and losses would impact on financial and non-financial. Although the factors that lead to low productivity of the manufacturing industry quite a lot, but the quality and quantity of raw materials had the largest percentage compared to other factors. It is in line with the statement that the quality will always directly proportional to productivity [7]. Company utilizing limestone, silica sand, clay, iron sand as the main raw material of cement production before the addition of gypsum and trass.
Company gets iron sand from supplier in Cilacap. The use of iron sand a day is 250-400 tons, and if counted in months, the use of iron sand per month can reach 10000-15000 ton. Therefore, iron sand is the main ingredient that is very important in the cement manufacturing process. Based on this background, we conducted research aiming to identify the dominant cause of failure in achieving quality and quantity of iron sand by using FMEA method (Failure Mode and Effect Analysis). FMEA is one of the most powerful methods available for measuring the reliability of products or process. It provides an easy tool to determine which risk has the greatest concern and therefore an action is needed to prevent a problem before it arises and can considerably decrease the loss to the industry in terms of both money and time [1, 12]. It is the correct method to identify the cause of the problem and prevent the recurrence of the problem in a system such as previous research in Semen Padang Company [9] and in Ceramic Tiles Manufacturing Plant [17]. Other research discusses about Pareto Analysis and FMEA to identify the failures stemming from forklift break, pilling, machine failure and wet wedge mark in XYZ business firm [5]. The final output of this study was able to determine the most dominant activity as the cause of rejection and losses of iron sand. Then, propose improvement suggestions to reduce iron sand reject and losses in XYZ company.

2. Literature Review

2.1. Quality
In everyday life, we often hear people talk about quality issues. Quality is a prime concern for any organization. A quality product must fulfill the customer need and meet the specification [16]. The concept of quality itself is often regarded as a measure of the relative goodness of products and services consisting of design quality and quality compliance. The design quality is a function of product specifications, while the quality of conformity is a measure of how much a product meets the requirements or specifications of a predetermined quality. However, this aspect is not the only aspect of quality. TQM (Total Quality Management) is a much broader concept that not only emphasizes the aspects of the results but also the human qualities and the quality of the process [4].

2.2. Quality Control
To be able to always maintain good quality consistently, required an activity called quality control. It defines quality control in general as a system that is used to preserve or maintain the desired level of quality in a product or service [2]. Quality control also has an idea of the use of techniques and activities in order to achieve, maintain, and improve the quality of a product or service. Quality control can be divided into two [11]: 1) On-line Quality Control is a quality control during the production process is running, such as diagnosing and adjustment process, process control, and inspection results of the process, 2) Off-line Quality Control. It is the efforts that aim to optimize the design of products and processes as business support of On-Line Quality Control. Off-Line Quality Control is done before and after the process. According to [6], quality control consists of three aspects, known as the trilogy concept of quality, namely Quality Planning, Quality Control, and Quality Improvement.

2.3. FMEA
FMEA is a structured procedure to identify and prevent as much as possible modes of failure (failure mode). FMEA is used to identify the sources and root causes of quality problems [2]. A failure mode is what is included in the defect / failure in design, conditions beyond the limits established specifications, or changes in the product that causes disruption of the function of the product. FMEA can be done by [10]:

a. Identifying and evaluating the potential failure of a product and its effects.
b. Identify actions that could eliminate or reduce the chance of potential failure occurs.
c. Recording process (document the process)

The purpose can be achieved by the company with the implementation of FMEA:

a. To identify the mode of failure and the severity of the effect
b. To identify critical characteristics and significant characteristic

c. To sort order potential design and deficiency process

d. To help focus engineer in reducing attention to the products and processes,

e. and help to prevent problems

2.4. Implementation Steps using FMEA [3]
The basic steps in the process of Failure Mode and Effect Analysis (FMEA):
1. Identify the functions of the business process being studied.
2. Identify potential failure modes in the business process being studied.
3. Identifying potential effects of failure on the business process being studied
4. Identify the causes of the failure of the business process being studied.
5. Identify modes of detection on the business process being studied.
6. Determine the rating of the severity, occurrence, detection and Risk Priority Number (RPN) on business processes that are being studied.
7. Proposed improvements.

Measurement of the value of severity, occurrence and detection are as follows [8, 13]:

a. Severity value

Severity is the first step to analyse risks, which calculates how much impact or intensity of incident affect the final outcome of the process because a failure mode in one activity can lead to a failure mode in another activities. The impact on the rating scale ranging from 1 to 10 in the table 1. These numbers will conduct an expert to prioritize the failure modes. A severity rating of 1 means there is no danger or no effect on the quality. Otherwise, a severity rating of 9 or 10 is made for those effects that could cause bad effect or injury to the user. If it is happened, the actions to eliminate the failure mode such as change the design are considered.

| Classification   | Scale | Example                                                                 |
|------------------|-------|-------------------------------------------------------------------------|
| No result/ none  | 1     | No effect on the quality                                                |
| Very minor       | 2     | Iron sand quality characteristics is not disturbed                      |
| Minor            | 3     | Consequently little to the quality of iron sand                         |
| Very low         | 4     | Iron sand quality small impaired                                        |
| Low              | 5     | Failure resulted in some dissatisfaction on the quality of iron sand     |
| Moderate         | 6     | Failure cause inconvenience                                             |
| High             | 7     | Iron sand quality unsatisfactory                                        |
| Very high        | 8     | Iron sand quality is very unsatisfactory                                |
| Hazardous with   | 9     | Potential cause bad effect on iron sand                                 |
| Hazardous without| 10    | Failure mode effect is fatal to the quality of iron sand                |

b. Occurrence value

If predetermined rating on the severity, the next step is to determine the rating of the value of occurrence. Occurrence is a possibility that the cause of the failure will occur and result in the failure during the period of business processes running. Determining the value of occurrence can be seen by the table 2. If the occurrence is high that means more than 4 or more than 1 when the severity rating is 9 or 10, the actions needed. This step is also means the detailed development section of the FMEA process. The occurrence rating 1 means no failure. Then, the occurrence rating from 2 to 10 shows elevated level of the occurrence of failure.
Table 2. Occurrence ratings

| Classification   | Scale | Criteria                                      |
|------------------|-------|-----------------------------------------------|
| Never            | 1     | History showed no failure                     |
| Rarely           | 2     | Possible failure is very rare                  |
| Very little      | 3     | The possibility of failure is very little      |
| Bit of all       | 4     | Iron sand quality suffered minor annoyances   |
| Low              | 5     | Some of the possible failure                   |
| Medium           | 6     | The possibility of failure occurs              |
| Quite high       | 7     | The possibility of failure is high enough      |
| High             | 8     | The high number of failures                    |
| Very high        | 9     | The extremely high number of the possibility of failures |
| Almost certainly | 10    | Failure is almost certainly                    |

c. Detection Value
Having obtained the value of occurrence, it is time to determine the value of detection. Detection function for preventing potential business processes are being researched and reduce the failure level on business process. Rate determination detection can be seen in the table below.

Table 3. Detection ratings

| Classification   | Scale | Criteria                                      |
|------------------|-------|-----------------------------------------------|
| Almost certainly | 1     | Controls definitely detect                    |
| Very High        | 2     | Control almost detect                         |
| High             | 3     | Controls possessed greater chances to detect  |
| Mod. High        | 4     | Controls may detect high enough               |
| Moderate         | 5     | Controls may detect moderate                  |
| Low              | 6     | Controls may detect low                       |
| Very low         | 7     | Controls possessed very low opportunities to detect |
| Remote           | 8     | Control possessed very little opportunities to detect |
| Very remote      | 9     | Controls may not detect                       |
| Impossible       | 10    | Controls certainly not detect                 |

After getting the value of severity, occurrence, and detection, it will obtain the value of Risk Priority Number (RPN), by multiplying the value of severity, occurrence and detection (RPN = S x O x D). Then, do the sorting based on the value of Risk Priority Number (RPN) highest to the lowest. After that, the activities that have great value Risk Priority Number (RPN) and has an important role in a business process activities studied, performed the proposed improvements to reduce the failure rate of the business processes.

2.5. Analysis of Variance (ANOVA)

According [15] analysis of variance (ANOVA) is a method to describe the total diversity of data into components that measure the various sources of diversity. In application, ANOVA was used to test an average of more than two samples of whether there are differences in average significant / not between the groups. It is can be classified into several criteria [18], as follows:
- Classification in one direction (One-Way ANOVA)
  One way ANOVA classification is based on the observation ANOVA criteria or the factors that cause variation.
Classification in two directions (Two-Way ANOVA)
Two-way ANOVA classification is based on the observation of two factors that cause variation.
Classification in many directions (MANOVA)
Multi-way ANOVA is based on observations of many criteria.

3. Methodology
The final output of this study was able to determine the most dominant activity as the cause of rejection and losses of iron sand. Research stage are as follow to solve this problem (figure 1). Data collection methods that used in this research are observation, interview and group discussion forum. Observations carried out to observe the process of iron sand supply chain activities, orderings business process in the company and the needs of quality iron sand that must be met by supplier’s specifications iron sand quality. Its specification obtained from Quality Control Department. Following up with interviews were conducted to identify the cause of the failure to reject and loses in iron sand as well as to get an assessment of the four respondents who have been determined. Then, group discussion forum used to determine whether the results of expert assessment of the dominant cause occurs reject and quantity of iron sand loses no element subjectivities.

![Figure 1. Research stage](image)

4. Result and Discussion

4.1. The Benefits of Iron Sand
At XYZ Company, iron sand is used as a corrective raw material. Iron sand that content of Fe₂O₃, SiO₂, MgO and concrete 80-100 mesh size has the potential to be used as a substitute for cement in the production of high-performance concrete. Iron sand has a tendency to heat up in direct sunlight, causing the temperature high enough to cause minor burns. According to the results of research [14] demonstrate the benefits and usefulness of iron sands are:
1. The use of iron sand is 80% of the total weight of the sand provides maximum compressive strength between the levels of iron sand is 42.65 MPa and compressive strength can increase by 28.41% compared normal concrete.
2. The use of iron ore by 80% of the total weight of the sand increases tensile strength divided by 4.84% compared to normal concrete. In this iron sand increases the compressive strength and tensile strength divided by 80%, this is possible because in addition to the nature of the filler is also the chemical properties of iron sand containing SiO₂ so as to help the performance of cement as a binder.
3. Iron sand forming the colour of cement

4.2. Identification of the Ordering Business Process for Iron Sand
In the figure 2 can be seen a description of activities undertaken in the ordering supply chain to the use of iron sand. Some of the activities carried out by the company and suppliers. Through a number of these activities can be identified type of failure or potential failure modes that can occur. The description of the types of failures and possible causes other potential failure of the supply chain ordering iron sand that is on the next point.
The Ordering Business Process of Iron Sand

| Planning & control | Procurement | Vendor | Inventory management | Quality control |
|--------------------|-------------|--------|----------------------|-----------------|
| Purchase Requestion| Purchase Order | Items in (a letter of introduction of goods) | Acceptance/Scales IN/OUT | Sampling & Recap per LOT |
|                    |             |        | Unloading process    | Testing of samples |
| Reject             |             |        | No                   | According to specifications |
| Reject Material Information |        |        | Correction Tonnage | Yes |
|                     |             |        | Good Receipt         | Correction Tonnage & lab test result accompanying |
| Print GR           |             |        | Iron sand is stored & ready to use | |
|                    |             |        | Reject Material Information | |
|                    |             |        | Spending Process     | The process of updating the document |

**Figure 2.** Identification of the Ordering Business Process for Iron Sand
### 4.3. Identification of failure modes

Here is the identification mode failure of iron sand reject and losses.

**Table 4. Identification of Potential Failures**

| Activity                  | Potential Failure Mode | Symbol | Causes                                      | Effect                                      | Control                                                                 |
|---------------------------|------------------------|--------|---------------------------------------------|---------------------------------------------|-------------------------------------------------------------------------|
| Mining                    | unfavorable quality map | A1     | human error                                 | reduced iron sand quality because one determines the location of mining iron sand which has the highest Fe content. | data accuracy                                                          |
|                           | iron sand contaminated soil | A2     | mining techniques less than perfect and unfavorable separation systems (magnetic separator) | reduction in the tonnage of iron sand and low of Fe content in iron sand | determine the specifications, iron sand sampling test, the effectiveness of the penalty clause of the purchase contract iron sand to suppliers |
| Shipping                  | iron sand splattered on the streets | A3     | damaged roads, the rear cover truck is less than perfect | reduced iron sand tonnage | perform a physical examination on a truck used to send iron sand covered with tarpaulins |
|                           | iron sand becomes wet | A4     | rainy weather/humid during the delivery process | affect the tonnage of iron sand when weighed | delay the fulfillment of supplies determine the standard of the minimum number of trucks will be used, delivery deadline |
|                           | truck number is not optimal | A5     | for the inability of suppliers to provide truck | delay the fulfillment of supplies | determine the standard of the minimum number of trucks will be used, delivery deadline |
|                           | Wrong unloading site instruction | A6     | human error                                 | double handling/cost incurred is high | to establish coordination with the unloading iron sand workers and the inventory workers |
| Acceptance                | sample test results iron sand from the supplier and the actual iron sand in a test by the company as a whole is not equal | A7     | fraud by supplier that carries a good sample but actual his iron sand that was sent has a low Fe quality | receiving iron sand with a lower quality and made losses to financial | quality checks iron sand before unloading iron sand into the truck |
| Checking                  | take a sample error | A8     | lack of tools and knowledge about the correct sampling | misidentified quality iron sand | modification tools that can represent the whole population sample of iron sand and do training workers who has the integrity to sampling activities |
| Storage                   | bad drainage stockpile | A9     | flow of water does not drain | the water content in iron sand increased/stagnant water and difficult to dry | drainage maintenance periodically for stockpile |
|                           | limited storage area | A10    | storage techniques (pileup) iron sand less precise | companies into limited capacity | engineering storage (pileup) improved |
|                           | sloppy in the process of loading/unloading/storage | A11    | lack of knowledge of handling iron sand | not optimal warehouse | storage techniques (pileup) improved |
|                           | iron sand spilled when loading | A12    | over carrying capacity | the road becomes dirty, splattered iron sand | loading techniques improved |
From the identification of the failure modes of the next process is weighting conducted by the expert. In this study researchers determine the four experts who come from Procurement Department at XYZ Company. Fourth experts will assess the severity, occurrence and detection on failure mode that has been made above. Then, the experts will assess the Risk Priority Number (RPN). It is calculated value to determine the cause of the most dominant in the high issues the iron sand reject and losses.

4.4. Risk Priority Number (RPN) calculations

Risk Priority Number (RPN) value assessment carried out by interview and group decision forum. The results of the assessment based on the table above can be seen the results of 12 different types of Risk Priority Number (RPN) value and potential failure of the most dominant can be seen in Table 5.

| No | Activities           | Failure Mode                                                                 | RPN  |
|----|----------------------|------------------------------------------------------------------------------|------|
| 1  | Mining               | quality map poor                                                             | 284.5|
| 2  | Acceptance           | iron sand contaminated soil                                                  | 221.8|
| 3  | Acceptance           | sample test results iron sand from suppliers and actual iron sand in a test by the company as a whole does not equal | 205  |
| 4  | Examination          | mistake taking samples                                                       | 200.5|
| 5  | Delivery             | iron sand getting wet                                                         | 197  |

4.5. ANOVA

ANOVA is a statistical technique that is applied to compare the average of two samples or more. ANOVA analysis was performed to compare the value of the RPN of 12 failure modes. To prove whether the average RPN twelve failure modes are different, then the test hypothesis is:
● $H_0 = \text{RPN}_1 = \text{RPN}_2 = \text{RPN}_3 = \text{RPN}_4$

● $H_1 = \text{average value of RPN different for at least two failure modes}$

One-way ANOVA uses SPSS software performed in this research. In this statistical test some assumptions must be met, namely:

a. Samples derived from a group of independent
b. Data each failure mode normally distributed
c. Among the groups should be homogeneous Variants

The test output results of statistical tests One Way ANOVA using SPSS software in figure 4.

| Failure Mode | Sum of Squares | df | Mean Square | F    | Sig. |
|--------------|----------------|----|-------------|------|------|
| Between Groups | 68085,167 | 3  | 22695,656  | 3,573 | .021 |
| Within Groups  | 279613,500 | 44 | 6352,680   |       |      |
| Total         | 347598,667 | 47 |             |       |      |

**Figure 4. ANOVA Output**

After the fourth variant proved similarly, new ANOVA test done to test whether the four samples had an average the same or different. ANOVA test showed the value or significance probability is 0.021. This means significance = 0.021 <0.05 then $H_0$ is rejected. Can be deduced by using ANOVA showed that there was no value Risk Priority Number (RPN) of twelve identified failure modes of equal value, so that the predominant failure mode for the failure of iron sand reject and quantity losses in XYZ can be directly determined by that failure mode with Risk Priority Number (RPN) average value.

5. Conclusions and Recommendations

The activities were dominant as a cause of rejection and quantity losses of iron sand in XYZ company is on mining activities, the quality map is not good, and iron sand contaminated soil, then test results of samples of iron sand from suppliers and iron sand actually tested by the company as a whole is not the same, the activity of examination / inspection, such as errors in sampling and at the time of delivery, namely iron into the wet sand. Proposed improvements to reduce this failure rate is company need to re-review of the contract clause with the vendor. A review of the contract clause can be done by increasing the penalty sanctions in violation of the contract clause and accelerate the due date making status iron sand reject.

Based on the conclusion, recommendations are given by the author. Firstly, for company, the advice that can be given is to assess the scale of priorities vendor based on the consistency of the quality of iron sand, the fastest time of reservation and within the nearby mine. As well as upgrading the effectiveness of sanctions penalties for vendors who violate the rules of a contractual agreement. Company also need to provide training for workers in charge of the sampling. For further research, the advice given to the development of the research is to determine the fundamental causes of failure and the risk of failure suggested for using house of risk to quantify how big a risk that will result from failure. Another recommendation is by using quality methods such as Fault Tree Analysis (FTA) and the methods of other qualities associated with finding the fundamental causes of product failure. In analysing the causes of the failure of the product to the next process is to continue the improvements that have been proposed to expand research on the value engineering analysis, which is an advanced technique in analysing the causes of product failure.

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