Analysis and Design of Precast Concrete Product Quality Improvement at PT. XYZ using the DMAIC and FMEA Method

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Abstract

PT. XYZ is a manufacturing company that produces concrete. One type of product produced is precast concrete with a make-to-stock production system. During this production process the company experienced problems such as product defects. There is a final product that does not meet the specifications that have been set. The purpose of this study is to identify the most dominant level of damage, analyze the factors causing the damage, and provide suggestions for improvement to improve product quality. This study uses the DMAIC (Define, Measure, Analyze, Improve, and Control) method and the FMEA (Failure Mode Effect Analysis) method. Based on the identification results, the most dominant defect is void defects, which are 60 units out of a total of 162 defects. FMEA results show that the largest component with an RPN value of 280 is caused by human factors. Recommendations for suggested improvement to the company is to apply the maximum workload calculation to reduce operator fatigue.

Keywords
Concrete, Product Defects, DMAIC, FMEA

1. Introduction

The current era of globalization creates intense competition in the manufacturing and service industries. The dynamic business environment creates conditions for companies to be able to adapt to the demands of existing changes and always make continuous improvements to the company's business model (Felita, 2016). Business is an organization that provides goods or services that aim to earn profits (Sholichah & Sutopo, 2020).The business model is a representation of management's thoughts and actions that can help the business (Djap, 2016). Meanwhile, with the times that continue to develop, there is no perfect business system, companies must always evaluate business systems to be able to compete and continue to exist in the industrial world.

PT. XYZ is a company engaged in the bonded and non-bonded industrial area (Export Processing Zone) located in the Jakarta area. PT. XYZ formed a subsidiary strategic business unit which is a company that produces ready mix concrete and precast concrete. This subsidiary is the sole supplier for tenants who build factories in the PT. XYZ. The increasing growth in the construction sector also provides opportunities for external sales such as local

governments by being directly involved in city development & maintenance projects, building construction for private companies or state-owned companies, contractors & developers, and to individual consumers.
Companies in their business activities are required to always improve services to consumers which are a source of income for the company. In these activities the company uses several ways, one of which is by producing quality products. The existence of market competition in which many companies offer similar products triggers companies to continue to improve the quality of the products they produce in order to retain customers (Rahman & Perdana, 2021). With increasing competition, company will further improve the quality of its management in order to survive in the competition (Nugraha et al., 2020).Therefore, every trade business in Indonesia must secure and prepare quality goods (Sakinah et al., 2021). Based on the results of observations and interviews, it is known that PT. XYZ experienced several problems in running its business. From the existing business processes in the company, problems were found in the precast concrete production flow. Defect and reject final products were found that did not pass quality control such as shrinkage cracks in concrete, voids in concrete, and several other types of defects according to SNI 03-4433-1997.

According to the description of the company's condition, problems were found in the system that had been running so that improvements needed to be made so that the problems that occurred could be overcome. In this study, business and production processes were improved using the DMAIC (Define-Measure-Analyze-Improve-Control) and FMEA (Failure Mode Effect Analysis) methods. DMAIC is a quality improvement method that directly solves problems related to product quality to the main cause (Asnan & Fahma, 2019). The DMAIC method is a complete approach to quality control and improvement because it starts with identifying problems to controlling and making suggestions for improvement (Nasution & Sodikin, 2018). Improvements are made using the FMEA method which is used to find out or observe whether a failure can be analyzed or measured so that it can be anticipated, mitigated or prevented, either the failure rate or the negative effects that arise as an output factor (Rahman & Perdana, 2021). The FMEA method is used with the results of getting the factors that most influence the failure or disability with the aim of getting which factors require further treatment. The ranking factor analysis leads into an insight of the possible causes of problems (Puteri et al., 2016).

2. Literature Review

Urban development in the field of construction is currently experiencing very rapid progress such as the construction of buildings, housing complexes, urban infrastructure such as bridges, dams and so on. Concrete is one of the options of choice as a structural material in building construction. Concrete has advantages compared to other materials, including being easy to form, having good strength, easily available raw materials, durable, resistant to air, not decaying (Pane et al., 2015)

Concrete is a mixture consisting of coarse aggregate, fine aggregate, portland cement or other hydraulic cement, and or additional additive solutions that form a solid mass (SNI 03-2834-1993). The ratio of these mixtures produces concrete with certain characteristics, such as workability, durability, strength, and hardening time (McCormac, 2005).
Precast Concrete is a method of using concrete in which the components are mechanized printing at the factory by giving hardening time and obtaining the desired strength before being installed at the project site (shown in Figure 1 & 2). In order to get an economic advantage, precast concrete will only be produced with repeated forms in large quantities (Batubara, 2012).
Types of damage to precast concrete generally have the same characteristics as in situ concrete. Types of defects in concrete include voids & honeycomb and cracks. A common cause of damage to precast concrete is during the delivery process to the project site (Pratiwi et al., 2021).

• Void & Honeycomb
This type of damage is characterized by the presence of relatively deep and wide holes, known as voids or honeycomb. This defect is formed when compaction using a vibrator is not optimal so that the concrete fails to fill the area inside the formwork. This happens because the concrete is broken in areas where the reinforcement is rarely too tight so that the mortar cannot fill the voids between the coarse aggregates (Isneini, 2009).

• Cracked Concrete
This type of damage is characterized by the presence of relatively long and narrow lines. Cracks can be divided into two types, namely structural and non-structural. Construction cracks occur due to design errors or loads that exceed capacity. Non-structural cracks occur due to internally induced stresses in building materials (Pratiwi et al., 2021).

Figure 1. Precast concrete finish product in PT. XYZ

Figure 2. Precast concrete finish product in PT. XYZ

3. Methods

DMAIC is an acronym for Define, Measure, Analyze, Improve, & Control. This method is a systematic and continuous methodology used by professional companies to solve problems, improve product quality, and reduce defects or waste in a company (Patel et al., 2012). DMAIC is method that highlight five-phased methodological framework that guides in conducting the improvement project (Fajrianto et al., 2020). Process improvement include reducing occurrence defects so that defects can be minimized as much as possible (Heryadi & Sutopo, 2018).

• Define (Identify Problem)
The first stage is to identify problems faced by the company, such as mapping the activity process to understand and minimize problems. The formulation of project success parameters is carried out by considering the scope of work, the level of problem-solving according to the desired target, the availability of equipment for implementing personnel, time, and cost. Next, Define the Critical to Quality (CTQ) of the production. CTQ is a predetermined quality with the customer's specific requirements. There needs to be an understanding of the internal company in terms of defects in the production process by determining the quality characteristics of the CTQ.

• Measure
After knowing the number of defects, the calculation of the amount of deviation that occurs is compared with the quality standard that has been set using Defects Per Million Opportunities (DPMO).

$$\text{DPMO} = \frac{defect}{unit \times opportunity} \times 10^6 \quad (1)$$

The DPMO value is used to generate the sigma value. The sigma value is a benchmark used to determine quality or performance ratings (Gasperz, 2013).The basis for calculating the sigma level is calculated using the help of Microsoft Excel software (Rahman & Perdana, 2021) based on the following formula:

$$\text{Sigma } (\sigma) = NORMSINV\left(\frac{10^6 - DPMO}{10^6} + 1{,}5\right) \quad (2)$$

Control chart is a tool used to visualize the variations that occur in the production flow. Control charts are made to determine whether the process is under control and monitor variations continuously. The following formula is used to make a P-Chart (Rahman & Perdana, 2021):
Mean $\bar{p}$ (CL) can be calculated as follows:

$$\bar{p} = \frac{\Sigma \, np}{\Sigma \, n} \quad (3)$$

Upper Class Limit (UCL) can be calculated as follows:

$$\text{UCL} = \bar{p} + 3\sqrt{\frac{\bar{p}\,(1-\bar{p})}{n}} \quad (4)$$

Lower Class Limit (LCL) can be calculated as follows:

$$\text{LCL} = \bar{p} - 3\sqrt{\frac{\bar{p}\,(1-\bar{p})}{n}} \quad (5)$$

• Analyze
This step is carried out by looking for an analysis of why deviations occur and looking for reasons that can result in defects or damaged products. The analysis is carried out using quality tools or tools such as Pareto diagrams and cause-and-effect diagrams.

• Improve
At this stage the FMEA (Failure Mode Effect Analysis) method is used. FMEA is made based on a cause-and-effect diagram reference, then identification and estimation of damage or defects are carried out. Identification is work based on the value of the RPN (Risk Priority Number). RPN is the value of the assessment used to determine priority based on the failure that occurs, the number is obtained from the multiplication of Severity (S) × Occurrence (O) × Detection (D). Severity is the seriousness of the impact of a damage on the entire existing system. Occurrence is the level of frequency of occurrence of damage. Detection is the probability that a malfunction can be found.

• Control
In the last stage the results of quality improvement are documented and become a consideration for companies to evaluate existing systems, successful best practices in improving processes are standardized and used as work guidelines.

4. Data Collection

This research is quantitative research. Methods of data collection is done by direct observation, interviews with company employees, and literature review. Data collection is done by taking the number of units produced each month, the number of defective units each month, and the types of defects that occur shows in table 1.

Table 1. Production Recapitulation at XYZ Company

Period	Total Product (Unit)	Total Product Defect (Unit)
Jan-20	64	4
Feb-20	22	5
Mar-20	19	3
Apr-20	33	7
Mei-20	89	12
Jun-20	89	25
Agu-20	40	12
Okt-20	12	8
Des-20	13	3
Jan-21	84	16
Feb-21	27	5
Mar-21	10	1
Apr-21	81	23
Mei-21	60	19
Jun-21	168	19
Total	811	162

5. Results and Discussion

This section contains the data that has been obtained and explains how to process the data so that the expected research objectives are obtained. then in the discussion section, it contains a description of the analysis and interpretation of the results of data collection and processing that has been carried out.

5.1 Numerical Results

The numerical results that are processed in solving problem in PT. XYZ are in the form of calculating Critical To Quality (CTQ) in table 2, Defect Per Million Opportunities (DPMO), and Sigma Value (σ) as shown in table 3.

Table 2. Critical To Quality (CTQ) Potential Product

No.	Type of Defect	Total (Unit)
1	Voids & honeycomb	60
2	Outer surface damage	41
3	Cracks concrete	37
4	Broken concrete	24
Total Defect		162

Table 3. Recapitulation Of Calculations For DPMO And Sigma Values

Period	Total Production Actual (Unit)	Total Production Defect (Unit)	CTQ	DPMO	σ
Jan-20	64	4	4	15625	3,65387
Feb-20	22	5	4	56818	3,08206
Mar-20	19	3	4	39474	3,25683
Apr-20	33	7	4	53030	3,11616
Mei-20	89	12	4	33708	3,32889
Jun-20	89	25	4	70225	2,97412
Agu-20	40	12	4	75000	2,93953
Okt-20	12	2	4	41667	3,23166
Des-20	13	3	4	57692	3,07444
Jan-21	84	16	4	47619	3,16839
Feb-21	27	5	4	46296	3,18188
Mar-21	10	1	4	25000	3,45996
Apr-21	81	23	4	70988	2,96847
Mei-21	60	19	4	79167	2,9107
Jun-21	168	19	4	28274	3,40679
Total	811	156	4	48089	3,16367

Total sigma value is still below the target because a good sigma value is if the sigma value is close to 6 (Gasperz, 2013), this is because there are still many defective products found so that the DPMO value is still high which causes the sigma value to be small. Next, make a control chart calculation, this is to monitor process variations continuously. The map depicts the parts that were rejected because they did not meet the desired specifications, the calculation can be seen in table 4.

Table 4. Calculations value of CL, P, LCL and UCL

No.	Periode	n	p	P	P bar	CL	UCL	LCL
1	Jan-20	64	4	0,0625	0,230822	0,230822	0,595729	-0,13409
2	Feb-20	22	5	0,227273	0,230822	0,230822	0,595729	-0,13409
3	Mar-20	19	3	0,157895	0,230822	0,230822	0,595729	-0,13409
4	Apr-20	33	7	0,212121	0,230822	0,230822	0,595729	-0,13409

5	Mei-20	89	12	0,134831	0,230822	0,230822	0,595729	-0,13409
6	Jun-20	89	25	0,280899	0,230822	0,230822	0,595729	-0,13409
7	Agu-20	40	12	0,3	0,230822	0,230822	0,595729	-0,13409
8	Okt-20	12	8	0,666667	0,230822	0,230822	0,595729	-0,13409
9	Des-20	13	3	0,230769	0,230822	0,230822	0,595729	-0,13409
10	Jan-21	84	16	0,190476	0,230822	0,230822	0,595729	-0,13409
11	Feb-21	27	5	0,185185	0,230822	0,230822	0,595729	-0,13409
12	Mar-21	10	1	0,1	0,230822	0,230822	0,595729	-0,13409
13	Apr-21	81	23	0,283951	0,230822	0,230822	0,595729	-0,13409
14	Mei-21	60	19	0,316667	0,230822	0,230822	0,595729	-0,13409
15	Jun-21	168	19	0,113095	0,230822	0,230822	0,595729	-0,13409
Total		811	162	3,462329	-	-	-	-

Table 4. Calculations Type of Defect

Type of Defect	Total (Unit)	Cumulative (Unit)	Percentage of Defect	% Cumulative
Voids & honeycomb	60	60	0,370370	0,3703704
Outer surface damage	41	101	0,253086	0,6234568
Cracks concrete	37	138	0,228395	0,8518519
Broken concrete	24	162	0,148148	1
Total	162		1	

Based on the calculations that have been made in the table above, a Pareto diagram can be formed in Figure 4.

5.2 Graphical Results

The figure 3 shows that P is mostly located between LCL and UCL. This shows that the process capability is able to meet the expected tolerance limit specifications. But there is still a need for system improvement because there is still one period above UCL.

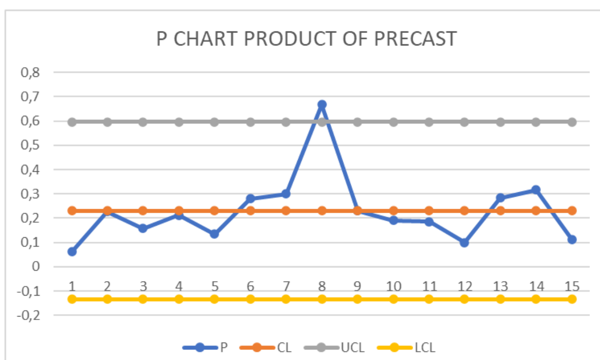

Figure 3. P-Chart

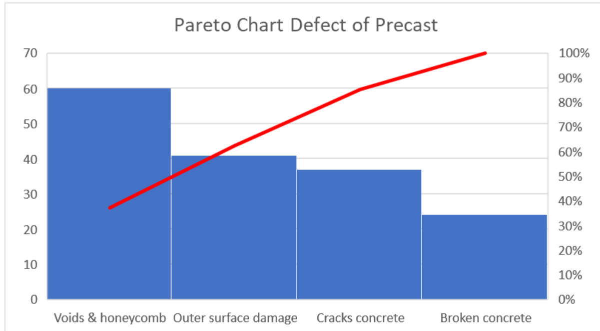

Figure 4. Pareto Chart

From the results of the Pareto diagram, it can be seen that the highest level of defects in precast concrete products is voids & honeycomb also outer surface damage (scratches). In the next stage, an analysis of the causes is carried out with the help of cause-effect diagram tools

5.3 Proposed Improvements

A at the analysis stage, a breakdown of the causes that became the root causes of the problem for the two most problems in this case was carried out it shown on Figure 5 and Figure 6.

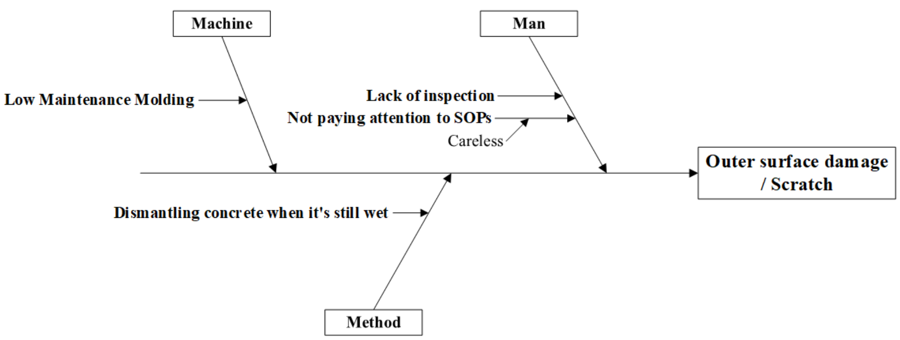

Figure 5. Cause-Effect Diagram of Scratch Defect

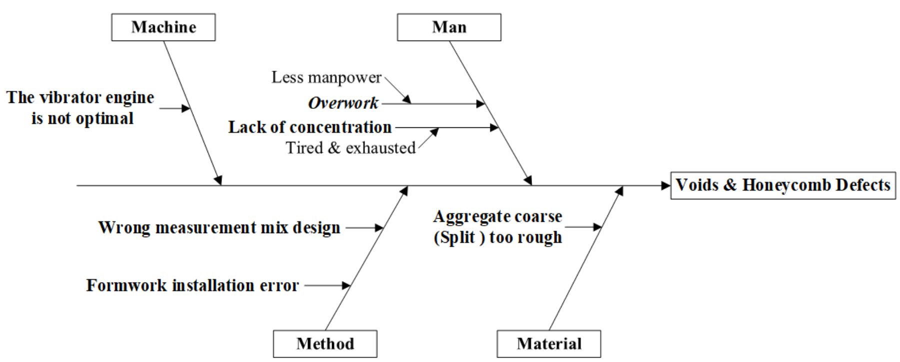

Figure 6. Cause-Effect Diagram of Voids & Honeycomb Defect

At the improve stage, suggestions will be given that can reduce failures in the production process. At this stage, the FMEA tools are used, where the calculation of the RPN value is carried out after determining the severity, occurrence, & detection that have been identified from the results of brainstorming with competent parties in the company, the calculations shown in table 5.

Table 5. Calculations of FMEA

Type of Defects	Potential Failure Mode	Potential Effect(s) of Failure	S	O	D	RPN	Ranking
Outer surface damage / Scratch	Less stringent inspection	Defective products will pass inspection	4	4	4	64	8
	Not Paying Attention to SOPs	Skipping one of the work steps can cause product defects	4	5	6	120	5
	Low Maintenance Molding	Precast concrete will not be precise with the initial production plan	6	3	5	90	7
	Dismantling concrete when it's still wet	The final concrete product has a scratch	5	5	6	150	4
Voids & Honeycomb Defects	Overwork	Work accident	6	4	8	192	3
	Lack of concentration	production flow error	5	7	8	280	1
	Aggregate coarse (Split) too rough	Material does not meet specifications	5	2	6	60	9
	The vibrator engine is not optimal	Compaction process is not optimal	8	4	7	224	2
	Wrong measurement mix design	Concrete quality is not achieved as desired	6	2	3	36	10
	Formwork installation error	Concrete cannot fill cavities/pores when cast	7	3	5	105	6

Based on the RPN calculation in the table above, it is found that the potential failure mode with the highest RPN value is that the operator lacks concentration at work, which is the human aspect with the RPN value. This value is the most critical failure mode and is used as the first priority so that immediate corrective action is needed.

6. Conclusion

The factors that cause product defects are the human aspect (operator), based on the results of calculations using FMEA tools, the highest RPN results are the operator lacks concentration. The most dominant type of defect based on the Pareto diagram is voids, which is 60 units with a percentage value of 37.03% of the total defects, which is 162 units. Based on the results of the analysis, proposals that can help reduce production defects are required to calculate the workload of each operator to reduce fatigue.

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Biography

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