

Analysis of Defects in U-Ditch Concrete Using DMAIC Method and RCA Method

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ABSTRACT

Objective: This study aims to analyze the causes of defects and minimize their occurrence in PT XYZ, a concrete company producing U Ditch concrete, which has a defect standard of 0.1%. The percentage of defects from January to November 2023 exceeded this standard. **Method:** The methods used in this study are DMAIC (Define, Measure, Analyze, Improve, Control) and RCA (Root Cause Analysis). DMAIC is employed to define the level of defect control, while RCA is applied to analyze the root causes of the defects. **Result:** The results indicate that the highest causes of defects are related to the worker factor, which includes frequent human errors; the material factor, where materials do not meet standards; the machine factor, with inadequate calibration; and the production environment factor, which is still carried out in an open space. The DPMO (Defects Per Million Opportunities) value of PT XYZ is 46,557, meaning there is a possibility of 46,557 defective products per one million products produced. **Novelty:** The study highlights the importance of a comprehensive analysis using DMAIC and RCA to address the root causes of defects in production processes, which can help the company achieve quality standards and minimize product defects.

INTRODUCTION

PT XYZ is a company that manufactures concrete. The concrete production capacity is expected to increase and significantly increase the need for raw materials. PT XYZ also produces various types of concrete products such as ready-mix concrete, precast concrete, masonry concrete, crushed concrete, and was established in 1991 based on notarial deed Suyati Subadi, SH No. 18/1991 and its amendment deed [1].

This company is a manufacturing company that produces various types of lightweight concrete such as lightweight bricks, lightweight brick panels, and mortar. Compared to other products, lightweight bricks are the main product with the highest production volume. Therefore, when making precast concrete or u-ditch concrete, it is more likely to experience major product defects. Defects that commonly occur during the manufacture of precast concrete or u-ditch concrete include breakage, cracking, uneven cutting, and imprecise dimensions. These lightweight concrete beams cause the most product defects, and the average defect percentage exceeds the concrete tolerance set by the company. The total production of u-ditch concrete from January to November 2023 reached 10,937 units. The problem at PT XYZ is the high number of product defects in the production process, which is suspected to be due to a lack of attention to quality control. Quality control in the production process is important to minimize the risk of defects [2]. Production in January was 1,010 units, February 1,033 units, March 998 units, April 1,180 units, May 1200 units, June 1227 units, July 1109 units, August 1272 units,

September 1309 units, October 1223 units, and November 1150 units. The standard given to the company for product defects is 0.1% of monthly production. In January, the defect rate was 0.6%, in February it was 0.2%, in March it was 0.3%, in April it was 0.2%, in May it was 0.3%, June had a defect rate of 0.4%, July had a defect rate of 0.5%, August had a defect rate of 0.4%, September had a defect rate of 0.7%, October had a defect rate of 0.5%, and November had a defect rate of 0.6%. Meanwhile, the application of the RCA method can be targeted to minimize defective products. We conducted research to analyze the extent of defects in precast concrete or u-ditch concrete using the define, measure, analyze, improve, and control (DMAIC) method and the Root Cause Analysis (RCA) method to clarify the scope and causes of product defects and provide recommendations for improvement [3].

DMAIC is a comprehensive approach to implementing quality control and improvement, starting with identifying problems, implementing controls, and making recommendations for improvement [4]. DMAIC is also a method of measurement that includes sigma values consisting of define, measure, analyze, improve, and control [5]. DMAIC also analyzes the quality desired by customers. DMAIC also aims to reduce defects to improve product quality by providing suggestions for improvement [6].

RCA (Root Cause Analysis) is a system developed to maintain production quality standards at minimum cost and to help achieve company efficiency in factories [7]. The root cause analysis (RCA) method is also a structured investigation that aims to identify the root cause of a problem by identifying the actual cause of a problem that occurred in an event. The goal is to create and implement solutions that can prevent the problem from recurring. Root cause analysis can be used to identify the cause of a problem. Therefore, companies can minimize product defects, especially in the precast concrete manufacturing process. This is designed to address these issues. Based on the results of this study, it is hoped that the number of defective products in each output can be reduced, enabling companies to introduce the DMAIC method and the RCA method for product defects in their production processes [8]. Root cause analysis is a very useful tool for finding the root cause of an incident that has occurred.

RCA (Root Cause Analysis) is also a new additional tool to the DMAIC method that aims to achieve this goal, which is to simplify complex problems by identifying the contradictions inherent in the problem and the relationship between contradictions. RCA can also be used as an independent tool. In this study, RCA can also describe the main issues presented in the form of a tree diagram, cause and effect, by following several rules in its creation [8]. RCA (Root Cause Analysis) is also a process of identifying the root causes of accidents, problems, concerns, or non-conformities that occur [4]. RCA (Root Cause Analysis) is used to improve the capabilities of a system so that it can increase the availability factor of the system [9].

Previous research supported this study by designing prefabricated U-shaped ditches with a corrugated system on the walls, thereby reducing the weight of U-shaped ditches such as U-Ditch or ordinary precast ditches [10]. It was found that this could be reduced. Test results showed that the use of cardboard reduced the strength of the U-

shaped ditch, but it could be reinforced again using the DMAIC and RCA methods. It was found that locally prefabricated Ugroove products did not meet strength requirements. Therefore, a design and scope for U-Ditch in accordance with SNI 1725: 2016 was proposed. This resulted in a U-groove design that meets the SNI 1725: 2016 standard and improves the capacity and efficiency of the U-groove. It was found that the deflection of local precast U-groove concrete components obtained from testing was lower than that of standard Japanese precast U-groove concrete components. The manufacture of prefabricated V-groove formwork began with the selection of materials used, assembly, and completion [6].

Research Objectives: (1) To determine the cause of the highest defect rate in U-Ditch or precast concrete experienced by PT XYZ, (2) To determine the DPMO value in the U-Ditch or precast concrete manufacturing process.

RESEARCH METHOD

Time and Place of Research

This research was conducted at PT XYZ, located at Tambak Oso, Jl. H. Anwar Hamzah Blok F02-F03, Kp. Baru, Tambakoso, Kec. Waru, Sidoarjo, East Java. This research was conducted over a period of 6 months, from October 2023 to March 2024.

Data Collection

In this study, two types of data were used, namely primary data and secondary data. The primary data needed for information related to the issues in this study were observations made by observing every action carried out in a production section. From these observations, the objects that were the focus of the research were identified to obtain the necessary information. This included production data and the types of defects that occurred in each product. Through observation of the product defects, the aim was to identify the factors that caused the defects in the products. Next, interviews were conducted with two operators and three production supervisors to analyze the causes of the defects. The sources in the interview process were those directly involved in the issues that would be the focus of experts in their fields. The interviews were conducted by presenting a number of questions, and the information obtained from the interviews was recorded as relevant data. The interview data included information about production and the types of defects that occurred from the beginning of the production process to the finished product. After that, there was secondary data needed in a study for a general review of the company, the production volume, the number of production defects, the data on the number of production defects, and the data on the types of product defects obtained from a company.

Research Process

The following are the stages of research as shown in Figure 1 below.

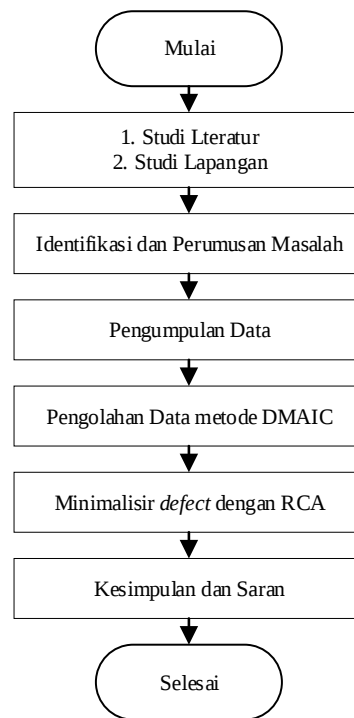


Figure 1. Research Flow Chart.

In this study, two types of methods were used, namely qualitative and quantitative. The qualitative method was carried out through field observations by observing the activities carried out by the production department. Next, the observation data was recorded and the research objects were identified for the collection of production data and the types of product defects in the results were recorded as part of the data collection. Meanwhile, the quantitative method used the DMAIC method with RCA.

A. DMAIC

DMAIC is called a strategy because it focuses on improving customer satisfaction, and it is called a discipline because it follows a formal model, namely Define, Measure, Analyze, Improve, Control [11]. The following are the steps used by the DMAIC method:

a. Define

The define stage begins with identifying the problem to be solved based on a Pareto chart. The defect found in the side frame is a defect caused by corrosion of the material. In the define stage, customer needs are identified. At this stage, cause and effect diagrams and Pareto charts are commonly used statistical tools [12].

b. Measure

The measure stage involves using an np control chart to identify deviations in defect data. This np control chart can assist in controlling production quality and provide information for making quality improvements [12].

The defect proportion is calculated using the following formula:

$$p = \frac{\text{Number of nonconforming products (defects)}}{\text{Total number}} \quad (1)$$

Source: [8]

The *upper control limit (UCL)* is calculated using the following formula.

$$UCL = P + 3 \sqrt{\frac{P(1-P)}{n}} \quad (2)$$

Source: [8]

The *control limit (CL)* is calculated using the following formula.

$$CL = \frac{\Sigma Defect}{\Sigma Total\ production} \quad (3)$$

Source: [13]

The *lower control limit (LCL)* is calculated using the following formula.

$$LCL = P - 3 \sqrt{\frac{P(1-P)}{n}} \quad (4)$$

Source: [8]

The measure stage also uses DPMO and sigma calculations. The following are the formulas used. Defects per Unit (DPU) is calculated using the following formula.

$$DPU = \frac{Amount\ of\ Defect}{Amount\ of\ Unit} \quad (5)$$

Source: [14]

Defects per Opportunities (DPO) are calculated using the following formula.

$$DPO = \frac{DPU}{CTQ} \quad (6)$$

Source: [14]

Defects per Million Opportunities (DPMO) are calculated using the following formula.

$$DPMO = DPO \times 10^6 \quad (7)$$

Source: [14]

Sigma calculation uses the following formula.

$$\text{Sigma level} = \text{Normsinv} \left(1 - \frac{DPMO}{1000000} \right) + 1,5 \quad (8)$$

Source: [8]

c. Analyze

The Analyze stage is where the cause or causes of the problem are sought and determined. This analysis is where the root cause phase, i.e., the defined problem or root cause analysis, is carried out based on data analysis [12].

d. Improve

The Improve stage is where the process is improved and the causes of failure are eliminated based on the results of the analysis phase [12]. This stage is integrated with the RCA method to minimize defects. In sigma analysis, RCA is an important element in identifying factors that hinder the achievement of quality levels [13]. RCA is a tool used to find the root cause of a problem from risks or incidents that occur in a company [15].

e. Control

The Control stage is the monitoring phase of performance and ensures that the main problems that caused the failure do not recur [12]. The purpose of this final step is to control every movement of activities in order to obtain maximum results and reduce time, inconvenience, and unnecessary costs [9].

RESULTS AND DISCUSSION

Results

A. Define Stage

The define stage is a risk analysis that is used as the basis for prioritizing improvements (critical to quality) in the company. There are four CTQs in the company, namely breakage, cracking, uncut areas, and imprecise dimensions. Breakage defects increase production time and decrease productivity due to the need for rework in concrete manufacturing. Cracking defects have an impact on increasing production costs for concrete structure repairs and concrete rework. Uncut areas cause additional production time for rework in cutting uncut areas. Imprecise dimensions cause a decrease in concrete functionality and also cause extra time for rework. The percentage standard set by the company is 0.1%, but from January to November 2023, the defect percentage exceeded the company standard.

Defects in the U-ditch concrete production process occur during the finishing process. Data on defects that occurred in the company from January to November 2023 can be seen in Table 1.

Table 1. Critical to Quality

Month	Total production (pcs)	Total production defects (pcs)				Total number of defects	% defects (company standard 0,1%)
		Broken	Cracked	Uncut area	Imprecise dimensions		
JAN	1010	0	4	0	2	6	0,6%
FEB	1033	0	2	0	0	2	0,2%
MAR	998	0	0	1	2	3	0,3%
APR	1180	0	2	0	0	2	0,2%
MEI	1200	0	1	1	1	3	0,3%
JUN	1227	1	2	0	2	5	0,4%
JULI	1109	1	2	0	3	6	0,5%
AGS	1272	1	2	0	2	5	0,4%
SEP	1309	2	3	1	3	9	0,7%
OKT	1223	0	1	1	4	6	0,5%
NOV	1150	1	3	2	1	7	0,6%

B. Measure Stage

The Measure stage involves measuring and evaluating product defects using histograms, P control charts, and sigma calculations to determine the DPMO level.

1. Histogram

The total defects for each category can be seen in Figure 1 below.

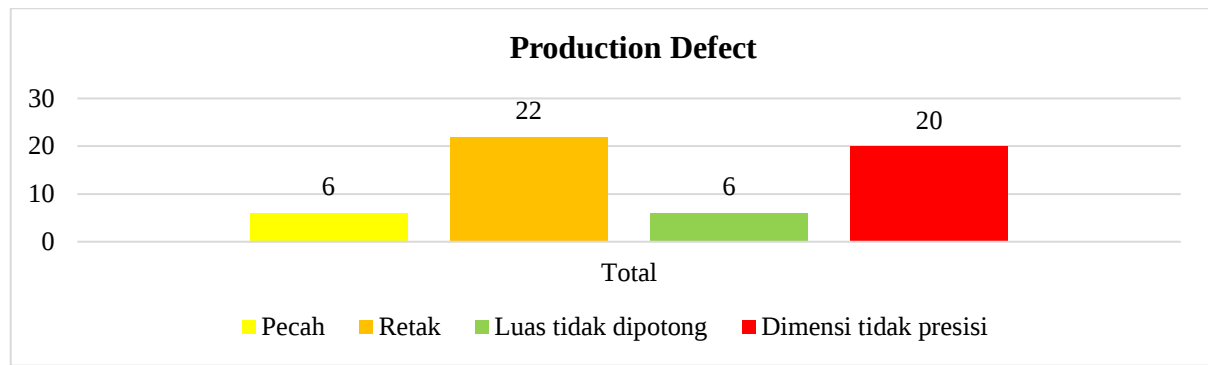


Figure 1. Production Defect Histogram.

Based on Figure 1, the most common defect was cracking, with 22 pieces over 11 months, and the least common defect was uncut and broken pieces, with 6 pieces.

2. P Control Chart

The P control chart is used to determine whether defects are within control limits or outside control limits (extreme data). The calculation of the P control chart can be seen in Table 2.

Tabel 2. Calculation of UCL, CL, and LCL.

Month	Total production (pcs)	Total number of defects	P	UCL	CL	LCL
JAN	1010	6	0,00594	0,01319	0,004248135	-0,00131
FEB	1033	2	0,00194	0,00604	0,004248135	-0,00217
MAR	998	3	0,00301	0,00820	0,004248135	-0,00219
APR	1180	2	0,00169	0,00529	0,004248135	-0,00190
MEI	1200	3	0,00250	0,00682	0,004248135	-0,00182
JUN	1227	5	0,00408	0,00953	0,004248135	-0,00138
JULI	1109	6	0,00541	0,01202	0,004248135	-0,00120
AGS	1272	5	0,00393	0,00920	0,004248135	-0,00133
SEP	1309	9	0,00687	0,01372	0,004248135	0,00002
OKT	1223	6	0,00491	0,01090	0,004248135	-0,00109
NOV	1150	7	0,00608	0,01296	0,004248135	-0,00079
Total	12711	54	0,00425	0,00598	0,004248	0,00252

Based on Table 2, the highest total defect rate occurred in September with 9 pieces and a proportion of 0.0068. The impact was that the control chart showed BKA and BKB that were significantly different from other months. The P control chart for PT XYZ during the 11-month period can be seen in Figure 2.

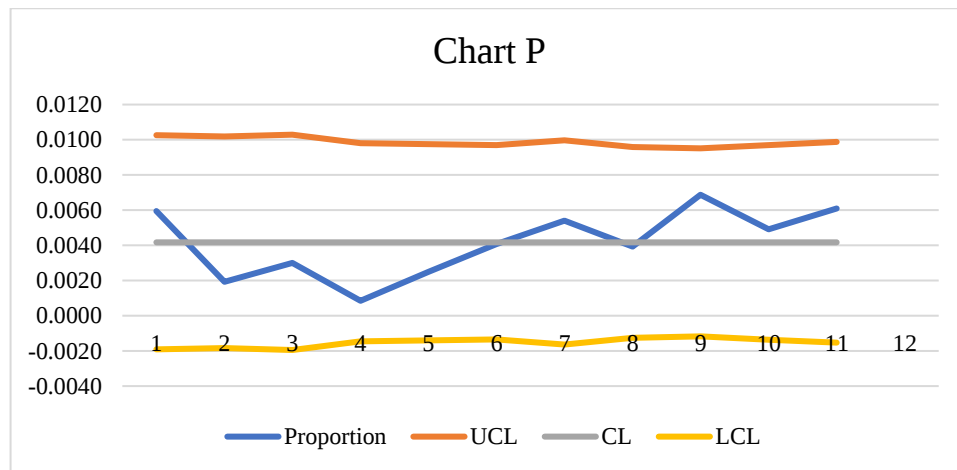


Figure 2. Control Chart P.

Based on Figure 2, there is no extreme data or data that exceeds the upper control limit and lower control limit. However, the high percentage of defects occurring at PT XYZ means that defect control is still necessary.

3. Calculating DPMO and Sigma values

The next step is to calculate the DPMO and sigma to determine the level of production quality based on the number of defects that occur. This is to analyze the achievement of zero defects at PT XYZ. An example of the DPMO calculation for January is as follows.

$$\begin{aligned}\text{January DPMO} &= \text{January DPMO} \times 10^6 \\ &= 0,02376 \times 10^6 \\ &= 23755,79047\end{aligned}$$

The DPMO and Sigma calculations can be seen in Table 3.

Tabel 3. DPMO and Sigma Calculations.

Month	Total production (pcs)	Number of defects	DPU	CTQ	DPO	DPMO	Sigma
JAN	1010	6	0,00594	4	0,02376	23755,79047	3
FEB	1033	2	0,00194	4	0,00774	7742,484951	4
MAR	998	3	0,00301	4	0,01202	12024,0481	4
APR	1180	2	0,00169	4	0,00678	6779,661017	4
MEI	1200	3	0,00250	4	0,01000	10000	4
JUN	1227	5	0,00408	4	0,01631	16306,56339	4
JULI	1109	6	0,00541	4	0,02164	21641,11812	4
AGS	1272	5	0,00393	4	0,01573	15725,61939	4
SEP	1309	9	0,00687	4	0,02750	27496,23836	3
OKT	1223	6	0,00491	4	0,01963	19625,6409	4
NOV	1150	7	0,00608	4	0,02434	24338,3024	3

Based on Table 3, The average sigma value is 4, which means that the company needs more control so that PT XYZ can achieve zero defects. In January, September, and November, the sigma value was 3, which means that it is very unlikely for PT XYZ to

achieve zero defects, so the company needs to improve the quality of its concrete production.

C. Analyze Step

The analyze stage is the stage for analyzing the causes of defects based on the highest number of defects. At this stage, Pareto charts and fishbone diagrams are used. The cumulative percentage of defects can be seen in Table 4.

Table 4. Cumulative disability percentage.

Type of defect	Number of defects	Cumulative frequency	Percentage	Cumulative
Cracks	22	22	41%	41%
Dimensions not precise	20	42	37%	78%
Broken	6	48	11%	89%
Area not cut	6	54	11%	100%

The total number of defects during the 11 months from January to November 2023 was 54 pieces. The cumulative Pareto chart of defects can be seen in Figure 3.

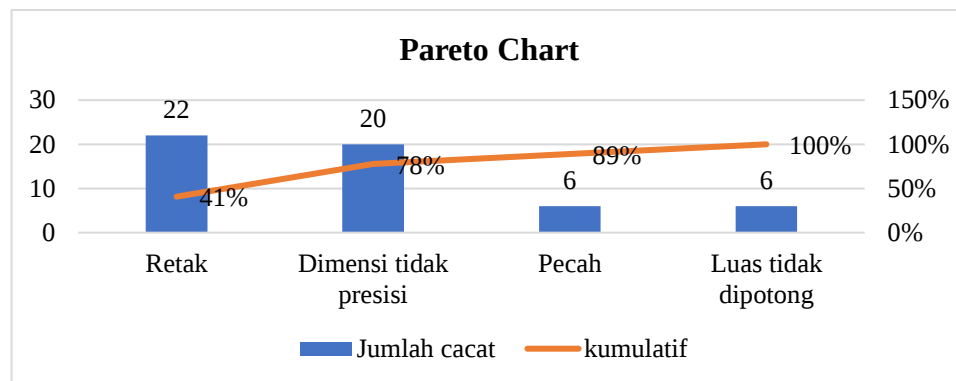


Figure 3. Cumulative defect Pareto chart.

Based on Figure 3, the highest defect percentage was found in cracks, at 41% with a total of 22 defective items. Cracks were prioritized for improvement in order to reduce the defect percentage. Crack defects were analyzed using a fishbone diagram based on the 5M + 1E factors.

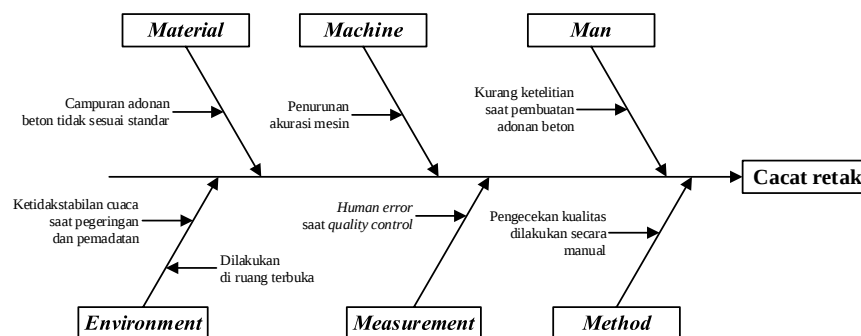


Figure 4. Fishbone diagram of cracks.

D. Improve Stage

The improvement stage is carried out to improve production quality based on the defect type with the highest percentage. Cracking is the defect type with the highest percentage at PT XYZ, so an improvement plan is carried out to improve production quality in order to minimize the number of this type of defect. This stage uses the RCA method with a 5W+1H table, which can be seen in Table 5.

Table 5. Improve by method 5W+1H.

		<i>Why</i>	<i>What</i>	<i>Where</i>	<i>When</i>	<i>Who</i>	<i>How</i>
Dominant factor	Dominant cause	Why it needs to be fixed	What is the plan to fix it?	Where will the repairs be carried out?	When will the repairs be carried out?	Who will carry out the repair?	How will the repairs be carried out?
<i>Man</i>	Lack of precision when mixing	To enable more accurate mixing	Supervision	Production area	June 2024 (After monthly audit)	Operators, production supervisors	Increase supervision during mixture production
<i>Machine</i>	Decreased machine accuracy	To ensure that the U Ditch concrete mix complies with the specified requirements	Improvement	Machines in the production area	June 2024 (After monthly audit)	Operators, production supervisors	Create a routine machine calibration schedule
<i>Material</i>	Concrete mixture does not meet standards (damp)	To ensure that the mix quality complies with standards	Supervision	Production area	June 2024 (After monthly audit)	Production supervisor	Ensure that raw materials for mixing comply with company standards
<i>Method</i>	Quality checks are performed manually	To minimize manual checks	Supervision	Production area	June 2024 (After monthly audit)	Operator, production supervisor	Test materials before mixing for large-scale production
<i>Measurement</i>	Human error during quality control	To eliminate human error	Supervision	Production area	June 2024 (After monthly audit)	Production supervisor, QC	Improve accuracy during quality control
<i>Environment</i>	Open production space, unstable weather during drying and compaction	To eliminate risks caused by the environment	Improvement	Production area	June 2024 (After monthly audit)	Production supervisor	Ensure a stable environment despite changing weather conditions by providing a special drying room

E. Control Step

The control stage is a stage that focuses on implementing controls based on the proposed improvements. Proposed improvements are based on the 5M+1E factors and focus on the types of defects with the highest percentages. At this stage, it is expected that controls can continue to be implemented on an ongoing basis so that defects can be minimized. Proposed improvements can be seen in Table 6.

Table 6. Proposed improvements.

Factor	Cause	Proposed improvements
<i>Man</i>	Lack of precision during mixing	Improve supervision and accuracy when mixing concrete.
<i>Machine</i>	Decreased machine accuracy	Create a regular machine calibration schedule and schedule maintenance before each use.
<i>Material</i>	Concrete mixture does not meet standards (damp)	Ensure that raw materials meet company standards, are dry, and are measured accurately according to the company's established standards.
<i>Method</i>	Quality checks are performed manually	Ensuring that the checksheet is filled in according to field conditions and conducting concrete mix trials
<i>Measurement</i>	Human error during quality control	Improving accuracy during quality control, with inspections carried out periodically
<i>Environment</i>	Open production space, unstable weather conditions during drying and compaction	Ensuring a stable environment even when the weather changes, with a special room for compaction and drying

Discussion

Based on data from January to November 2023, the percentage of defects that occurred exceeded the set standard, with the highest percentage of defects in September at 0.7%. Data processing results using the integration of the DMAIC and RCA methods showed that the company's defect proportion was 0.0042 or 0.4%. The type of defect with the highest percentage was cracks, numbering 322 pieces or 41% of the total defects during 11 months of production. The risk that caused cracks was the human factor, namely the lack of precision of the production operator when making the concrete mixture. Based on the machine factor, the defect occurred due to a decrease in machine accuracy. In terms of material factors, cracks were caused by concrete mixes that did not meet standards. This was also influenced by environmental factors, namely unstable weather during concrete drying and compaction, as well as compaction and drying being carried out in open spaces. Based on measurement factors, there were human errors when checking concrete quality. The final risk that caused cracks based on method factors was manual quality checks.

The lowest sigma value in January, September, and November was 3, which means that the company needs to improve production quality in order to achieve zero defects [15]. To achieve a proportion of 0% and a sigma value of 6, production quality control needs to be improved after the monthly audit so that zero defects can be realized. Furthermore, the stage of improving production quality uses the RCA 5W+1H tool method. Based on the analysis using the 5W+1H tools, it was found that in order to produce accurate concrete mixtures, supervision and precision during the mixing process must be improved. In order for the concrete to be in accordance with the set up, it is

necessary to schedule machine calibration. To ensure that the quality of the mixture meets the standards, it is necessary to ensure that the quality of the raw materials meets the standards set by the company. Quality control yang masih manual menyebabkan munculnya akibat human error, oleh karena itu perlunya peningkatan ketelitian saat checking. On the other hand, it is also necessary to ensure a stable environment even when the weather changes so that causes related to the environment can be minimized

CONCLUSION

Fundamental Finding : The cause of defects in PT XYZ's U-Ditch concrete is prioritized based on cracks, which account for 41% of the defects. These cracks are analyzed using the 5M+1E factors, with human error in manual quality checks, inadequate machine capabilities, and external drying and compaction processes identified as key contributors. The DPMO value during the period from January to November 2023 was 46,557.5653, indicating a defect probability of 46,557 defective products per million, with a sigma value of 3. **Implication :** The findings imply that PT XYZ's defect control level is not optimal, which has significant implications for the company's quality assurance and overall production efficiency. Immediate improvements are necessary to reduce defects and enhance product quality to align with industry standards. **Limitation :** The study's limitation lies in its focus on the analysis of cracks, with the potential for other contributing factors to defects not being fully explored. Additionally, the reliance on manual checks and external conditions for drying and compaction were not examined in more depth. **Future Research :** Future research should focus on automating the quality control process to reduce human error, improving machine calibration, and investigating more controlled environments for the drying and compaction stages. Studies could also explore alternative methods for reducing defects to achieve a higher sigma value and optimize the production process.

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