Six Sigma-DMAIC (Define, Measure, Analyze, Improve, And Control) Analysis in Reducing Building Structural Defects (Case Study: Emirates Indonesia Cardiology Hospital Project)

Risti Mustika Hati[1], Putri Anggi Permata Suwandi[1], Agung Kristiawan[1]

Faculty of Engineering and Informatics, PGRI University Semarang, East Sidodadi Road Number 24 Semarang, Central Java 50232, Indonesia

ristimustika08@gmail.com

Abstract. Construction projects often face challenges in maintaining quality, one of which is structural defects that can affect the quality and safety of the building. This study aims to analyze the level of defects in column, beam, and slab structures using the Six Sigma DMAIC method and provide solutions to improve these defects. The study was conducted on the Emirates Indonesia Cardiology Hospital Building Construction Project in Surakarta. The method used is a quantitative descriptive approach with the stages of Define, Measure, Analyze, Improve, and Control. Data were obtained through field observations, interviews, documentation, and secondary project data. The analysis results show that the average sigma level value is above 3, with the highest level in the column structure reaching 4.3 sigma for the type of concrete flow defect. The main causes of defects come from human factors, work methods, materials, and supervision. Improvement solutions are formulated using a fishbone diagram analysis approach and the assistance of NVIVO software for qualitative data analysis. This study shows that the Six Sigma DMAIC method is effective in identifying and reducing defects in concrete structure work and can be used as a quality control strategy in construction projects.

Keywords: Six Sigma, DMAIC, Structural Defects, Construction Quality, NVIVO

1. Introduction

The rapid increase in human needs is driving development across various sectors, particularly the construction industry, which plays a crucial role in regional development in Indonesia. This development is occurring evenly alongside economic growth and urbanization, as evidenced by the numerous construction projects, from small to large [1]. However, the construction industry faces a common challenge: construction defects not only cause financial losses but also threaten the safety and reputation of companies. Consequently, building defects need to be prevented or repaired to allow buildings to perform at an optimal level. In buildings where defects have not been repaired, the building's function and the satisfaction levels, safety and health of the users will be affected.[2]

Budget, schedule, and quality are critical parameters in construction projects. Project success is measured by timeliness, cost, and joint achievement of plans. Quality is a key indicator of project success, therefore, an effective management system is essential at both the company and project levels.

A defect is an imperfection in the results or during the construction process that results in a decrease in quality, function, or safety, but remains within tolerance limits, meaning it does not endanger the construction as a whole [3]. ISO 15686-1:2011 stated that "Defect" is defined as a fault, or deviation from the intended level of performance of a 35 building or its parts [4]

This study applies the Six Sigma DMAIC method to analyze and reduce defects in construction structure work because defect handling in the project is still inefficient. The project being studied is the Emirates Indonesia Cardiology Hospital Building in Surakarta, with a focus on the beam, column, and plate structures that have many defects. Previous handling only used the PDCA method, so this study aims to provide evaluation material and find more effective repair solutions.

The construction project for the Emirates Cardiology Hospital – Indonesia, located in Jebres, Surakarta, Central Java, is a grant from the United Arab Emirates Government to help reduce the death rate from heart disease in Indonesia. The hospital is built on a 17,000 m² plot of land with a building area of 8,750 m², consisting of three floors and one roof and has 100 beds. The project is being carried out by PT Adhi Persada Gedung as the main contractor, with PT Virama Karya as the management consultant and PT Penta Architecture as the planning consultant. The project implementation will last for 304 calendar days, starting on November 1, 2023, and is planned for completion in August 2024.

2. Methods

The research was conducted on the construction project of the Emirates Indonesia Cardiology Hospital in Surakarta. The research method used was descriptive quantitative with a Six Sigma DMAIC approach.

A. Data Collection and Variabels

The data collected consisted of primary and secondary data. Primary data consisted of direct field observations, interviews with the quality control team, defect documentation photos, and regular daily inspections. Secondary data consisted of shop drawings and defect data. The independent variable in this study, construction defects, influenced the results of the dependent variable, which is the variable influenced by the presence of the independent variable or the sigma value.

B. Data Processing

1. Six Sigma DMAIC Analysis

   This study analyzes the sigma value of defects in the construction of the Emirates Indonesia Cardiology Hospital building using the Six Sigma method. This method measures the level of defects per unit (DPU) to assess the quality of output received by customers. Its implementation follows the DMAIC (Define, Measure, Analyze, Improve, Control) stages, which are used to measure the effectiveness of Six Sigma implementation and encourage continuous improvement towards Six Sigma quality targets.

   a. *Define*

      The Define stage in Six Sigma aims to identify critical issues by determining Critical to Quality (CTQ) criteria based on customer needs and establishing objectives. In this study, the define stage involved direct field inspections to identify defects in the concrete structures of columns, beams, and slabs.

   b. *Measure*

      The Measure phase follows the Define phase, collecting data and measuring performance to provide a baseline overview of the project. This phase involves calculating the number of defects to determine the percentage and determine the sigma value.

   c. *Analyze*

      The Analyze stage is the third step in Six Sigma to identify the causes of failures and improve quality. The causes of dominant defects are analyzed using a fishbone diagram to find the root cause of the defective work.

d. *Improve*
After measurements and analysis, the next step is improvement. In the process or output improvement phase, to resolve problems or address product defects, improvements are made to all sources of potential defects in the work, based on the results of the Fishbone Diagram analysis.

e. *Control*
The Control phase is the final stage of Six Sigma, focusing on monitoring and evaluating the process to ensure desired results are achieved. After this phase, the DMAIC cycle is repeated to correct deficiencies until the defect rate approaches zero.

2. Data Processing Of Defect Repair Methods Using NVIVO Software

3. Results and Discussion

The data collected in Chapter 3 will be used to process the data in Chapter 4. The data required is structural defect data related to column, beam and plate work in the construction of the Emirates Indonesia Cardiology Hospital project.

3.1 Define

The first thing to do is to identify the type of defect in the concrete structure work of columns, beams and plates to determine the CTQ.

Table 3.1 Summary Data on the Number of Defects

NO	Jenis Cacat	Jumlah Cacat		
		Kolom	Balok	Plat
1	Sisa Bekisting	18	10	8
2	Leleran Beton	25	2	2
3	Ketidaksesuaian Dimensi	23	15	0
4	Sisa Besi Tierod	5	4	0
5	Spalling Sudut Beton	6	4	0
6	Ketidakseragaman Warna Beton	1	0	0
7	Keropos Beton	2	1	0
8	Celah pada Pertemuan Balok	1	0	0
9	Permukaan Berlubang	2	0	0
10	Bekas karat	0	0	4
11	Bekas sambungan	0	0	7
	TOTAL	83	36	21

Source: Researcher, 2025

After that, the CTQ value can be determined from the identification data above.

Table 3.2 Critical To Quality

Type of Work	Quality Driver	CTQ	Number of Defects
Coloumn	Neatness of concrete surface, casting quality, formwork installation, and correct concrete pouring method	Concrete Leaching	25
Beam	Accuracy and precision of dimensions in formwork installation, formwork	Dimensional Mismatch	15

	stability and rigidity, control of work implementation according to work drawings, and use of precise and calibrated measuring tools.		
Slab	Cleanliness of casting results, correct formwork dismantling procedures, supervision during	Remaining Formwork	8

Source: Researcher, 2025

3.2 Measure

Table 3.3 Calculation Of DPMO Value And Sigma Value Of Column Work

NO	Jenis Cacat	Jumlah Cacat	DPU	CTQ	DPO	DPMO	SIGMA
1	Sisa Bekisting	18	0.273	26	0.010	2464	4.3
2	Leleran Beton	25	0.379	26	0.015	3422	4.2
3	Ketidaksesuaian Dimensi	23	0.348	26	0.013	3148	4.2
4	Sisa Besi Tierod	5	0.076	26	0.003	684	4.7
5	Spalling Sudut Beton	6	0.091	26	0.003	821	4.6
6	Ketidakseragaman Warna Beton	1	0.015	26	0.001	137	5.1
7	Keropos Beton	2	0.030	26	0.001	274	5.0
8	Cold Joint	1	0.015	26	0.001	137	5.1
9	Permukaan Berlubang	2	0.030	26	0.001	274	5.0
10	Bekas karat	0	0.000	26	0.000	0	0.0
11	Bekas sambungan	0	0.000	26	0.000	0	0.0
TOTAL		83	1.258	286	0.048	11361	42.3
Rata - Rata		7.5	0.114	26	0.004	1033	3.8

Resource: Researcher, 2025

Table 3.4 Calculation Of DPMO Value And Sigma Value Of Beam Work

NO	Jenis Cacat	Jumlah Cacat	DPU	CTQ	DPO	DPMO	SIGMA
1	Sisa Bekisting	10	0.313	15	0.021	1063	4.6
2	Leleran Beton	2	0.063	15	0.004	213	5.0
3	Ketidaksesuaian Dimensi	15	0.469	15	0.031	1595	4.4
4	Sisa Besi Tierod	4	0.125	15	0.008	425	4.8
5	Spalling Sudut Beton	4	0.125	15	0.008	425	4.8
6	Ketidakseragaman Warna Beton	0	0.000	15	0.000	0	0.0
7	Keropos Beton	1	0.031	15	0.002	106	5.2
8	Cold Joint	0	0.000	15	0.000	0	0.0
9	Permukaan Berlubang	0	0.000	15	0.000	0	0.0
10	Bekas karat	0	0.000	15	0.000	0	0.0
11	Bekas sambungan	0	0.000	15	0.000	0	0.0
TOTAL		36	1.125	165	0.075	3828	28.9
RATA -RATA		3.3	0.102	15	0.007	348	2.6

Resource: Researcher,2025

Table 3.5 Calculation Of DPMO Value And Sigma Value Of Slab Work

NO	Jenis Cacat	Jumlah Cacat	DPU	CTQ	DPO	DPMO	SIGMA
1	Sisa Bekisting	8	0.5	8	0.063	250000	2.2
2	Leleran Beton	2	0.125	8	0.016	62500	3.0
3	Ketidaksesuaian Dimensi	0	0	8	0.000	0	0.0
4	Sisa Besi Tierod	0	0	8	0.000	0	0.0
5	Spalling Sudut Beton	0	0	8	0.000	0	0.0
6	Ketidakseragaman Warna Beton	0	0	8	0.000	0	0.0
7	Keropos Beton	0	0	8	0.000	0	0.0
8	Cold Joint	0	0	8	0.000	0	0.0
9	Permukaan Berlubang	0	0	8	0.000	0	0.0
10	Bekas karat	4	0.250	8	0.031	125000	2.7
11	Bekas sambungan	7	0.438	8	0.055	218750	2.3
TOTAL		21	1.313	88	0.164	656250	10.1
RATA - RATA		1.9	0.119	8	0.015	59659	0.9

Resource: Researcher,2025

To produce the above value, use the calculation method as below:

DPU = (Number of defective products) / (Number of products examined)
DPO = DPU / CTQ
DPMO = (Number of defects) / (Number of units × CTQ) × 1,000,000
Sigma = NORMSINV ((1,000,000 − DPMO) / 1,000,000) + 1.5

3.3 Analyze

Before creating a fishbone diagram, a calculation is made of the cumulative percentage of the number of defects that have been categorized based on their type, then sorted according to the level of damage and presented in a Pareto diagram.

Table 3.6 Pareto diagram calculation

NO	Jenis Cacat	Jumlah Cacat			Jumlah	Persentase	Persentase Kumulatif
		Kolom	Balok	Plat			
1	Ketidaksesuaian Dimensi	23	15	0	38	27.14	27.14
2	Sisa Bekisting	18	10	8	36	25.71	52.86
3	Leleran Beton	25	2	2	29	20.71	73.57
4	Spalling Sudut Beton	6	4	0	10	7.14	80.71
5	Sisa Besi Tierod	5	4	0	9	6.43	87.14
6	Bekas sambungan	0	0	7	7	5.00	92.14
7	Keropos Beton	2	1	0	3	2.14	94.29
8	Bekas karat	0	0	4	4	2.86	97.14
9	Permukaan Berlubang	2	0	0	2	1.43	98.57
10	Cold Joint	1	0	0	1	0.71	99.29
11	Ketidakseragaman Warna Beton	1	0	0	1	0.71	100.00
TOTAL					140		

Resource: Researcher, 2025

Percentage % = ((Number of defects of a certain type)/(Total of all defects))×100

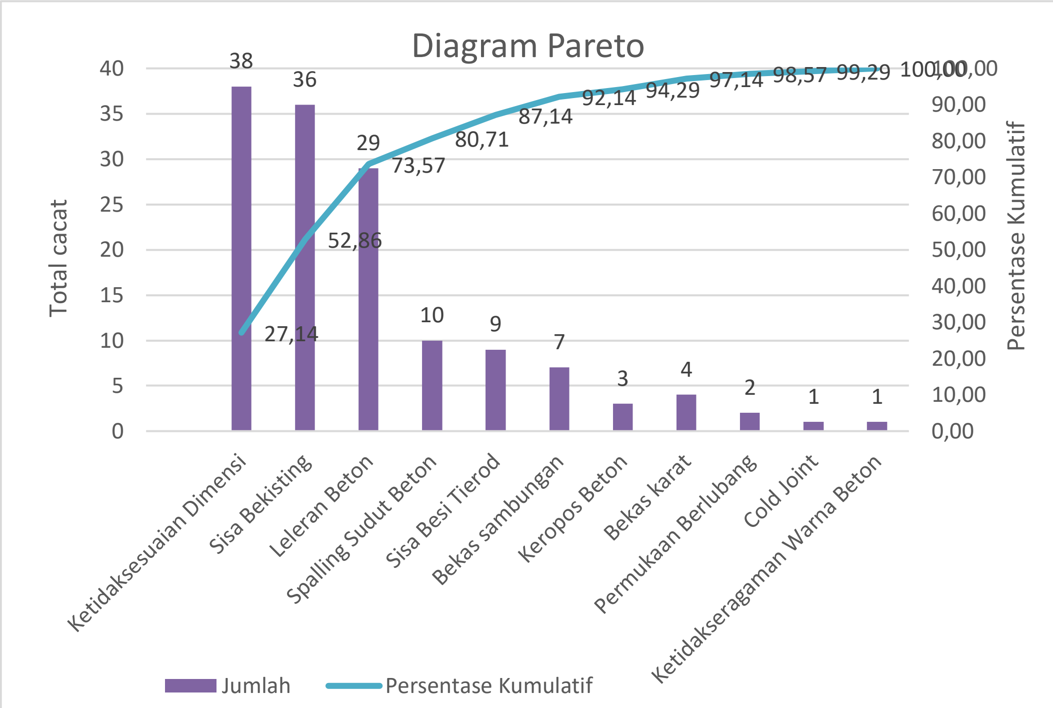

Figure 3.1 Pareto Diagram
Source: Researcher, 2025

After identifying the dominant defect, it will then be analyzed using a fishbone diagram.

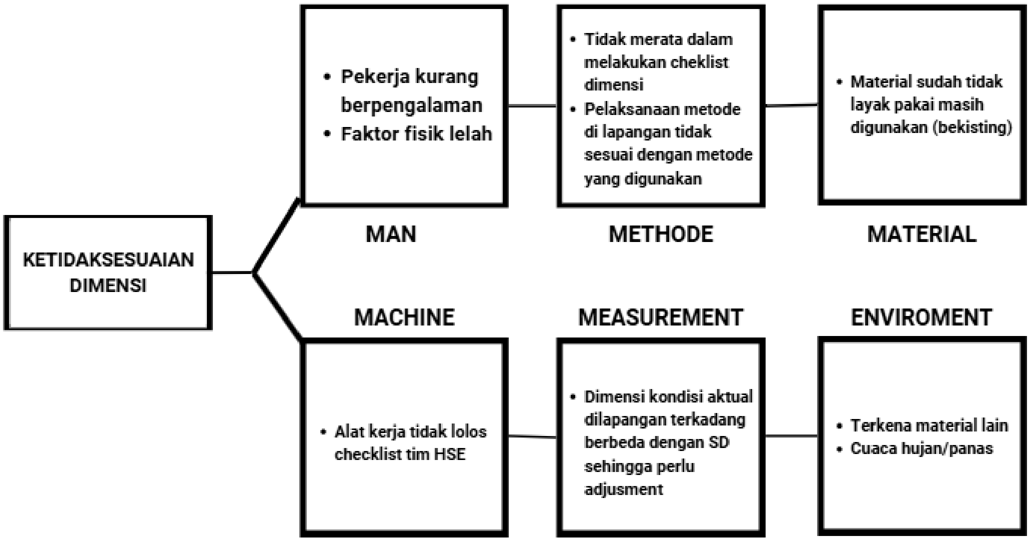

Figure 3.2 Fishbone Diagram
Source: Researcher, 2025

3.4 Improve

The Improve phase was carried out to correct the dominant flaw in the project, namely dimensional mismatches. Repairs included chipping the mismatched areas, followed by patching the concrete according to shop drawings using Fosroc Combextra, with a spray of Calbond prior to application.

No.	Lokasi	Jenis Cacat	Dokumentasi Cacat	Setelah Perbaikan	Status
1	Lantai 1 As 12/B	Spalling beton			Close
2	Lantai Dasar As 12/B	Ketidaksesuain Dimensi kepala kolom			Closed
3	Lantai 1 As 7/G	Kepala kolom keropos			Closed
4	Lantai 1 As 11-12/A-B	Sisa Bekisting dan dimensi tidak sesuai			Closed
5	Lantai 3 As 1-2/C-D	Leleran beton			Open

Figure 3.2 Defects After Repair
Source: Researcher, 2025

3.5 Control

The Control phase ensures that improvements made remain consistent and are applied to subsequent projects. There are top ten most effective strategies of minimizing the defect in building construction project are improve workmanship quality, all parties take responsibilities, frequent progress meeting, select the good quality of the materials, use modern construction method such as IBS, improve ability to read and understand drawings, compliance with specifications, do proper inspection, improve quality control and improve oversight in inspection [5]. Even after the project has been handed over, quality control can be carried out through the preparation of a Control Plan as a preventive quality standard, containing CTQs, control parameters, PIC assignments and periodic documentation, as well as corrective actions if there are any non-conformities. With a Control Plan, the quality of column, beam, and slab work is expected to be maintained and similar defects can be minimized in future projects.

4. Conclusion

A. Conclusion

Based on the results of research and analysis conducted using the Six Sigma DMAIC method on structural defects in columns, beams, and slabs in the Emirates Indonesia Cardiology Hospital construction project, it can be concluded that:

1.) The Six Sigma analysis yielded sigma values for the column structure ranging from 4.2–5.1, with an average of 3.8. The beam structure ranged from 4.4–5.2, with an average of 2.6. The slab structure had the lowest sigma value, at 2.2–3.0, with an average of 0.9. This indicates that the quality of the work is quite good, but has not yet reached World Class Quality standards (≥6 Sigma). The dominant type of defect in the column, beam, and slab structures was dimensional mismatch, with the highest cumulative percentage of 26.57% according to the Pareto diagram analysis.

B. Suggestion

The following suggestions from the research on the Emirates Indonesia Cardiology Hospital building construction project for improvement and for future researchers are as follows:

1.) The application of the Six Sigma method to defect management in a company is highly recommended so that quality control is not only reactive (repairing defects), but also proactive in preventing defects through structured process monitoring. Furthermore, the application of the Six Sigma method is not only for defect identification but also as a quality control tool throughout the project.

Acknowledgements

This section expresses its gratitude to those who have a role in conducting research activities, for example the laboratory where the research is conducted. The role of donors or those supporting research is briefly mentioned. Lecturers who are writers do not need to be listed here.

References

[1] Jaya Santoso, K., Kurniawan Hartono, Y., & Andi. (2014). *Inspeksi Proses Pelaksanaan Dan Cacat Pada Dinding Panel Pracetak Suatu Proyek Apartemen*. 2–6.

[2] Tarekegn Gurmu, A., Shooshtarian, S., & Mahmood, M. N. (2022). Critical evaluation of building defects research: A scientometric analysis. Journal of Performance of Constructed Facilities, 36(3), 03122001.

[3] Nyoman, N. I., & Pradnyani, T. (2024). *SKRIPSI ANALISIS CACAT KONSTRUKSI DENGAN METODE SIX SIGMA PADA PEKERJAAN STRUKTUR BANGUNAN (Studi Kasus : Proyek Icon Bali)*.

[4] ISO 15686-1:2011 Buildings and constructed assets — Service life planning- Part 1: General principles and framework

[5] Hasan, M. I. M., Abd Razak, N. N., Endut, I. R., Samah, S. A. A., Ridzuan, A. R. M., & Saaidin, S. (2016). Minimizing defects in building construction project. Jurnal Teknologi (Sciences & Engineering), 78(5-2).