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IMPROVING THE QUALITY OF WORK ON CULVERT UNDERPASS BOX STRUCTURES USING THE LEAN SIX SIGMA METHOD

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Abstract

Underpass is an infrastructure built by the government below the ground level to alleviate traffic congestion in large cities. The box culvert system serves as the construction for underpasses. The selection of this system has a significant impact on quality as it will affect the quality of work. The BSD underpass project on the Serpong - Balaraja toll road (Interchance Legok Area STA 9+800) needs to improve its quality because the results of the work do not meet the required standards. The aim of this research is to determine the most influential factors in the quality of underpasses and the implementation of lean six sigma. The research utilizes the Relative Importance Index (RII) method and the Lean Six Sigma method. From the research results, it was found that the most influential factor is ensuring that every incoming material meets the desired quality standards in the quality control variable. In addition, the analysis using Lean Six Sigma in Box Culvert work resulted in a DPMO value of 6058 per one million or equivalent to 4.133 sigma with a yield of 99.39%, thus requiring evaluation through the the DMAIC method Define – Measure – Analyze – Improvement – Control) to reduce defects and improve quality.

Keywords: Box Culvert, Lean Six Sigma, RII, Quality, Defect

Introduction

Underpass is an infrastructure built by the government underground to alleviate traffic congestion in big cities. The construction of the underpass requires precise engineering. The box culvert system is used in underpass projects (Pasaribu, 2018). The underpass has large dimensions in its implementation because it serves as a traffic flow for vehicles, so the construction method used is in situ concrete which is the direct on-site concrete work. (Madilla et al, 2019)

High mistake in the casting process, errors in formwork removal, incorrect formwork installation are part of the causes of damage occurring during on situ casting (Andry et al, 2019). The larger a project is, the more complex its mechanisms, which means there are more problems to be faced. If not handled properly, these various issues will result in delays in project completion, deviation from quality standards, increased financing, wastage of resources, unhealthy competition among stakeholders, and failure to achieve desired goals and objectives (Dipohusodo, 2019).

The implementation of Lean Six Sigma using the DMAIC principle focuses more on improvement. The Lean Six Sigma method evaluates a defect by investigating the causes, effects, and suggestions for improvements on what must be done to prevent the recurrence of these defects. This can streamline the costs incurred from rework due to job quality not meeting the target.

Research Methodology

The construction project chosen as the research subject is the underpass project on the (Interchance Legok Area STA 9+800) in the work of box culvert underpass 12.075x5.3 m2 cell with a height of 2m embank.

Figure 1. Layout Project

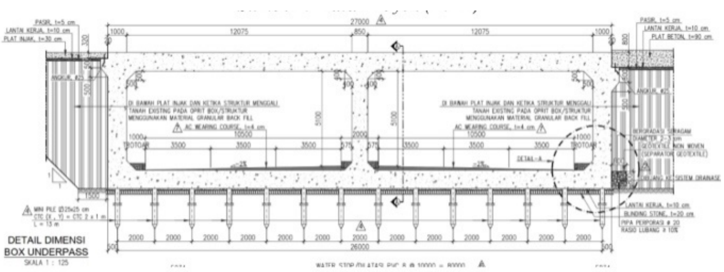

Figure 2. Cross Section

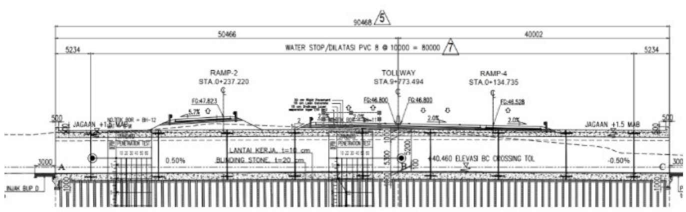

Figure 3. Longitudinal Section

In the construction of the box culvert underpass, with dimensions of 27m wide and 90.5m long, consisting of three parts including the bottom plate, box wall, and top plate.
This study utilizes the lean six sigma method to evaluate defects by investigating causes, effects, and corrective actions to prevent recurring errors in ongoing construction projects, reducing costs from rework without compromising quality (Hussain et al., 2019).
Additionally, the Relative Importance Index (RII) method is utilized to determine the most influential factors through a ranking system based on respondent weights assigned after completing a questionnaire, operated using Microsoft Excel. The formula for ranking with the RII method can be seen in the equation below (Ongkowijoyo et al., 2021).

$$RII\ (\%) = \frac{6(n_6) + 5(n_5) + 4(n_4) + 3(n_3) + 2(n_2) + n_1}{W \times (n_6 + n_5 + n_4 + n_3 + n_2 + n_1)}$$

With RII = Relative Importance Index, n6 = Total number of respondents who filled out scale 6, n5 = Total number of respondents who filled out scale 5, n4 = Total number of respondents who filled out scale 4, n3 = Total number of respondents who filled out scale 3, n2 = Total number of respondents who filled out scale 2, n1 = Total number of respondents who filled out scale 1, W = The largest Likert scale used. The RII value can also determine the range of importance levels as shown in the following table.

Table 1. RII Importance Level

RII Value Range	Importance Level
0.8 ≤ RII ≤ 1	*High* (H)
0.6 ≤ RII ≤ 0.8	*High-Medium* (H-M)
0.4 ≤ RII ≤ 0.6	*Medium* (M)
0.2 ≤ RII ≤ 0.4	*Medium-Low* (M-L)
0 ≤ RII ≤ 0.2	*Low* (L)

Research Results and Discussion

In obtaining this data, researchers conducted offline and online questionnaire surveys by distributing printed questionnaires to relevant parties or respondents whose positions are related to the substance.

The number of respondents was determined based on the definition by Hair et al. (2019) that the sample size as respondents should be adjusted to the number of question indicators used in the questionnaire, assuming n x 5 observed variables (indicators) up to n x 10 observed variables (indicators). With a total of 50 indicators, the minimum research sample is 50 x 5 = 250 respondents, and the maximum sample is 50 x 10 = 500 respondents. This can be seen in Table 2. The distribution of questionnaires is as follows.

Table 2. Distribution of Questionnaires

Description	Amount
Minimum Respondents	250
Distribution of Questionnaire	310
Questionnaire Return	302
Presentation Return	97.42%

In addition, there is a questionnaire related to the working experience data of the respondents. Therefore, it can be said that the respondents already have sufficient knowledge in the field of construction, especially in the construction of underpass.

Table 3. Responden Work Experience

Responden Work Experience	Frequency	Percent
< 1 Year	15	4.97%
1 - 2 Year	20	6.62%
2 - 5 Year	89	29.47%
> 5 Year	178	58.94%
Amount	302	100%

This study utilizes the Likert scale. The Likert scale is used to measure Quality Planning Variable (X1), Quality Assurance (X2), Quality Control (X3), Quality Improvement (X4), and Quality Performance (Y).

Table 4. Weighing of Scores and Assessment Categories

Category	Score
Strongly disagree	1
Disagree	2
Slightly disagree	3
Agree	4
Strongly agree	5
Strongly disagree	6

The variables used in the study are as follows:

Table 5. Variable

VARIABEL		SUB VARIABEL		SOURCE
X1	Quality Planning	X1.1	Identify quality problems	Latief, Y and Puji Utami R (2009)
		X1.2	Set quality goals	Latief, Y and Puji Utami R (2009)
		X1.3	Determining quality standards	Latief, Y and Puji Utami R (2009)
		X1.4	Follow standards and regulations	Latief, Y and Puji Utami R (2009)
		X1.5	Create quality targets	Latief, Y and Puji Utami R (2009)
		X1.6	Create a project management plan	Latief, Y and Puji Utami R (2009)

		X1.7	Creating SOP	Latief, Y and Puji Utami R (2009)
		X1.8	Create Inovation	Latief, Y and Puji Utami R (2009)
		X1.9	Create special the product	Latief, Y and Puji Utami R (2009)
		X1.10	Analyze and identify	Latief, Y and Puji Utami R (2009)
		X1.11	Establish a consultation /discussion forum	Latief, Y and Puji Utami R (2009)
		X1.12	Communicate plans	Latief, Y and Puji Utami R (2009)
		X1.13	Identify Project CTQ	Latief, Y and Puji Utami R (2009)
		X1.14	Implement preventive measures	Latief, Y and Puji Utami R (2009)
		X1.15	Implement defect fixes	Latief, Y and Puji Utami R (2009)
X2	Quality Assurance	X2.1	Accept proposed changes	Indah Suci (2023)
		X2.2	Implement quality changes	Indah Suci (2023)
		X2.3	Procedure adjustments	Indah Suci (2023)
		X2.4	Identify defects	Indah Suci (2023)
		X2.5	Always innovate in recommendations	Indah Suci (2023)
		X2.6	Has good control flow	Indah Suci (2023)
X3	Quality Control	X3.1	Material suitability	Putri Elsari R (2021)
		X3.2	Monitor repairs	Putri Elsari R (2021)
		X3.3	Job inspection	Putri Elsari R (2021)
		X3.4	Review work progress	Putri Elsari R (2021)
		X3.5	Delivering results	Putri Elsari R (2021)
		X3.6	Analyze improvements	Putri Elsari R (2021)
		X3.7	Controlling and monitoring work	Putri Elsari R (2021)
		X3.8	Identifying problems	Putri Elsari R (2021)
		X3.9	Determining strategy	Putri Elsari R (2021)

		X3.10	Comparing results	Putri Elsari R (2021)
		X3.11	Defining a valid and reliable system.	Putri Elsari R (2021)
		X3.12	Interpreting performance differences	Putri Elsari R (2021)
		X3.13	Final inspection	Putri Elsari R (2021)

VARIABEL		SUB VARIABEL		SOURCE
X4	Quality Improvement	X4.1	Determine the control object	Indah Suci (2023)
		X4.2	Determine the units to be measured	Indah Suci (2023)
		X4.3	Determining performance	Indah Suci (2023)
		X4.4	Developing ideas	Indah Suci (2023)
		X4.5	Create opportunities and opportunities	Indah Suci (2023)
		X4.6	Reviewing knowledge management	Indah Suci (2023)
		X4.7	Implement and standardize	Indah Suci (2023)
		X4.8	Establish feasibility	Indah Suci (2023)
		X4.9	Determine the final goal	Indah Suci (2023)
		X4.10	Document results	Indah Suci (2023)
		X4.11	Organize quality improvement steps	Indah Suci (2023)
		X4.12	Implementing quality improvement	Indah Suci (2023)
		X4.13	Continuous Quality Improvement Program	Indah Suci (2023)
Y1	Quality performance	Y1.1	Quality management system assessment	LPJKN "Penerapan Keahlian dalam Quality Manajemen" Kode Unit : kon. mpk. 06. 005. 01
		Y1.2	Assessment of work results	LPJKN "Penerapan Keahlian dalam Quality Manajemen" Kode Unit : kon. mpk. 06. 005. 01
		Y1.3	Improved quality management	LPJKN "Penerapan Keahlian dalam Quality Manajemen" Kode Unit : kon. mpk. 06. 005. 01

Validity Test

Validity testing refers to the indicators that have been grouped into various variables. Validity testing is done for each item, in order to link the score of each item with the total score. The results for each indicator can be considered valid if the calculated value r is greater than the table value r. The results of the validity test are presented in Table 6 below.

Table 6. Validity Test

No	Variable	Indicator	$r$count	$r$tabel	Result
1	Quality Planning	X1.1	0.823	0.133	Valid
		X1.2	0.735	0.133	Valid
		X1.3	0.700	0.133	Valid
		X1.4	0.827	0.133	Valid
		X1.5	0.678	0.133	Valid
		X1.6	0.727	0.133	Valid
		X1.7	0.824	0.133	Valid
		X1.8	0.666	0.133	Valid
		X1.9	0.697	0.133	Valid
		X1.10	0.769	0.133	Valid
		X1.11	0.719	0.133	Valid
		X1.12	0.758	0.133	Valid
		X1.13	0.806	0.133	Valid
		X1.14	0.691	0.133	Valid
		X1.15	0.725	0.133	Valid
No	**Variable**	**Indicator**	**$r$count**	**$r$tabel**	**Result**
2	Quality Assurance	X2.1	0.827	0.133	Valid
		X2.2	0.737	0.133	Valid
		X2.3	0.733	0.133	Valid
		X2.4	0.773	0.133	Valid
		X2.5	0.782	0.133	Valid
		X2.6	0.828	0.133	Valid
3	Quality Control	X3.1	0.840	0.133	Valid

		X3.2	0.864	0.133	Valid
		X3.3	0.781	0.133	Valid
		X3.4	0.796	0.133	Valid
		X3.5	0.786	0.133	Valid
		X3.6	0.825	0.133	Valid
		X3.7	0.847	0.133	Valid
		X3.8	0.814	0.133	Valid
		X3.9	0.813	0.133	Valid
		X3.10	0.836	0.133	Valid
		X3.11	0.726	0.133	Valid
		X3.12	0.760	0.133	Valid
		X3.13	0.766	0.133	Valid
4	Quality Improvement	X4.1	0.891	0.133	Valid
		X4.2	0.932	0.133	Valid
		X4.3	0.897	0.133	Valid
		X4.4	0.833	0.133	Valid
		X4.5	0.906	0.133	Valid
		X4.6	0.912	0.133	Valid
		X4.7	0.866	0.133	Valid
		X4.8	0.886	0.133	Valid
		X4.9	0.855	0.133	Valid
		X4.10	0.831	0.133	Valid
		X4.11	0.891	0.133	Valid
		X4.12	0.901	0.133	Valid
		X4.13	0.674	0.133	Valid
5	Quality Performance	Y1.1	0.953	0.133	Valid
		Y1.2	0.963	0.133	Valid
		Y1.3	0.943	0.133	Valid

Reliability Test

Reliability testing is conducted using internal consistency testing. According to V. Wiratna Sujarweni (2016):

- If Cronbach's Alpha value > 0.60, then it is reliable or consistent
- Cronbach's Alpha value < 0.60, then it is not reliable or consistent

The results of the validity test are presented in the following table.

Table 7. Reability Test

No		Variable	Cronbach's Alpha	Criteria	Result
1	X1	Quality Planning	0.942	0.6	Reliable
2	X2	Quality Assurance	0.778	0.6	Reliable
3	X3	Quality Control	0.944	0.6	Reliable
4	X4	Quality Improvement	0.962	0.6	Reliable
5	Y1	Quality Performance	0.678	0,.6	Reliable

Relative Importance Index (RII)

Based on the data feasibility test, namely validity and reliability tests, 50 indicators on 5 variables can be used, then the indicators on each variable are ranked using the RII method. With the ranking results in table 8.

Table 8. Variable Rating RII

VARIABLE		SUB VARIABLE		RESULT		LEVEL OF IMPORTANCE
				RII	RANK	
X1	Quality Planning	X1.1	Identify quality problems	0.776	3	*High-Medium (H-M)*
		X1.2	Set quality goals	0.774	5	*High-Medium (H-M)*
		X1.3	Determining quality standards	0.735	14	*High-Medium (H-M)*
		X1.4	Follow standards and regulations	0.775	4	*High-Medium (H-M)*
		X1.5	Create quality targets	0.785	2	*High-Medium (H-M)*

		X1.6	Create a project management plan	0.737	13	*High-Medium (H-M)*
		X1.7	Creating SOP	0.757	8	*High-Medium (H-M)*
		X1.8	Create Inovation	0.751	11	*High-Medium (H-M)*
		X1.9	Create special the product	0.752	10	*High-Medium (H-M)*
		X1.10	Analyze and identify	0.732	15	*High-Medium (H-M)*
		X1.11	Establish a consultation /discussion forum	0.739	12	*High-Medium (H-M)*
		X1.12	Communicate plans	0.769	7	*High-Medium (H-M)*
		X1.13	Identify Project CTQ	0.772	6	*High-Medium (H-M)*
		X1.14	Implement preventive measures	0,755	9	*High-Medium (H-M)*
		X1.15	Implement defect fixes	0.808	1	*High (H)*
X2	Quality Assurance	X2.1	Accept proposed changes	0.776	1	*High-Medium (H-M)*
		X2.2	Implement quality changes	0.774	2	*High-Medium (H-M)*
		X2.3	Procedure adjustments	0.735	6	*High-Medium (H-M)*
		X2.4	Identify defects	0.773	3	*High-Medium (H-M)*
		X2.5	Always innovate in recommendations	0.761	4	*High-Medium (H-M)*
		X2.6	Has good control flow	0.760	5	*High-Medium*

						(H-M)

VARIABLE		SUB VARIABLE		RESULT		LEVEL OF IMPORTANCE
				RII	RANK	
X3	Quality Control	X3.1	Material suitability	0.838	1	*High (H)*
		X3.2	Monitor repairs	0.814	6	*High (H)*
		X3.3	Job inspection	0.785	12	*High-Medium (H-M)*
		X3.4	Review work progress	0.769	13	*High-Medium (H-M)*
		X3.5	Delivering results	0.807	8	*High (H)*
		X3.6	Analyze improvements	0.816	5	*High (H)*
		X3.7	Controlling and monitoring work	0.811	7	*High (H)*
		X3.8	Identifying problems	0.825	3	*High (H)*
		X3.9	Determining strategy	0.801	9	*High (H)*
		X3.10	Comparing results	0.832	2	*High (H)*
		X3.11	Defining a valid and reliable system.	0.797	10	*High-Medium (H-M)*
		X3.12	Interpreting performance differences	0.785	11	*High-Medium (H-M)*
		X3.13	Final inspection	0.824	4	*High (H)*
X4	Quality Improvement	X4.1	Determine the control object	0.816	6	*High (H)*
		X4.2	Determine the units to be measured	0.821	3	*High (H)*
		X4.3	Determining performance	0.811	7	*High (H)*
		X4.4	Developing ideas	0.796	12	*High-Medium*

VARIABLE		SUB VARIABLE		RESULT		LEVEL OF IMPORTANCE
				RII	RANK	
						(H-M)
		X4.5	Create opportunities and opportunities	0.828	2	*High (H)*
		X4.6	Reviewing knowledge management	0.821	4	*High (H)*
		X4.7	Implement and standardize	0.804	8	*High (H)*
		X4.8	Establish feasibility	0.799	9	*High-Medium (H-M)*
		X4.9	Determine the final goal	0.797	10	*High-Medium (H-M)*
		X4.10	Document results	0.797	11	*High-Medium (H-M)*
		X4.11	Organize quality improvement steps	0.830	1	*High (H)*
		X4.12	Implementing quality improvement	0.817	5	*High (H)*
		X4.13	Continuous Quality Improvement Program	0,804	8	*High (H)*
Y1	Quality Performance	Y1.1	Quality management system assessment	0.829	1	*High (H)*
		Y1.2	Assessment of work results	0.811	3	*High (H)*
		Y1.3	Improved quality management	0.821	2	*High (H)*

Based on the ranking results, the first rank of each variable is shown in the following Table 9.

Table 9. Variable Rating RII (Result)

VARIABLE		SUB VARIABLE		RESULT		LEVEL OF IMPORTANCE
				RII	RANK	
X1	Quality Planning	X1.15	Implement defect fixes	0.808	1	*High (H)*
X2	Quality assurance	X2.1	Accept proposed changes	0.776	1	*High-Medium (H-M)*
X3	Quality control	X3.1	Material suitability	0.838	1	*High (H)*
X4	Quality improvement	X4.11	Organize quality improvement steps	0.830	1	*High (H)*
Y1	Quality performance	Y1.1	Quality management system assessment	0.829	1	*High (H)*

Application of *Lean Six Sigma*

This research utilizes the Lean Six Sigma method and will be integrated into the Lean and DMAIC methodology (Define, Measure, Analyze, Improve, and Control). To determine the total value of work defects and the total potential for defects in each job check (Defects per million opportunities). Through the checklist conducted with the owner, findings were discovered on work items that did not meet the quality target, along with the defect results documented in the Non-Conformance Report (NCR) table in the check performed in the following table 10.

Table 10. Sigma Value

No	Area	Work Item	Total Production	Total Damage	%	DPU	DPMO	Sigma Value
1	Box Bottom Plate	Porous Concrete	4	1	2.17%	0.010000	10000	3.826
		Concrete Cracks	4	1	2.17%	0.010000	10000	3.826
		Honeycomb	4	1	2.17%	0.010000	10000	3.826
		Uneven Concrete	4	1	2.17%	0.010000	10000	3.826
		Plin Concrete	4	2	4.35%	0.020000	20000	3.554
2	Box Wall	Porous Concrete	2	4	8.70%	0.003419	3419	4.205
		Concrete Cracks	2	5	10.87%	0.004274	4274	4.130
		Honeycomb	2	2	4.35%	0.001709	1709	4.427
		Uneven Concrete	2	5	10.87%	0.004274	4274	4.130
		Plin Concrete	2	10	21.74%	0.008547	8547	3.885
3	Box Top Plate	Porous Concrete	0	3	6.52%	0.001852	1852	4.402
		Concrete Cracks	0	2	4.35%	0.001235	1235	4.527
		Honeycomb	0	1	2.17%	0.000617	617	4.731
		Uneven Concrete	0	2	4.35%	0.001235	1235	4.527
		Plin Concrete	0	6	13.04%	0.003704	3704	4.178
		Result		46	100%			

Average	0.006058	6058	4.133

From the sigma data shown in the calculation results for defects generated from the construction of box culvert structures with a DPMO value of 6058 equivalent to sigma 4.133 and a yield of 99.39%, it is concluded that the construction of an underpass project for box culvert structures has a high likelihood of defects, which can impact the completion target of the project. Therefore, in this case, the author utilizes the lean six sigma method for box culvert structure work (bottom plate of the box, box wall, top plate of the box) where the quality improvement stages are implemented through DMAIC evaluation.

Define

This stage is for identifying the product, the owner's desires for the best outcome of the product from each task, and determining the issues present in the construction of the underpass project for box culvert work. The processes include:

1. Selecting the project for research, which is the underpass construction project for box culvert work.
2. Choosing the work to be studied, which consists of the box culvert structure work including the bottom plate of the box, box wall, and top plate of the box.
3. Identifying the owner's desires to understand the quality standard of the work in order to achieve optimal results.
4. Developing project character to explain a project covering issues, objectives, benefits, constraints, assumptions, project member scope, and the project plan.
5. Creating a SIPOC table (Supplier, input, process, output, and customer) for each task.

Measure

Using a Pareto chart makes it easier for us to focus on factors in improving the frequently occurring work defects effectively.

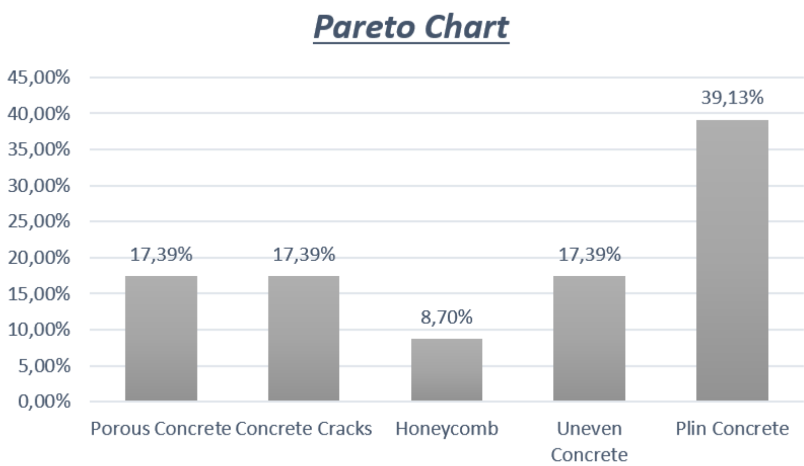

Figure 4. Pareto Chart

Analyze

The presentation in this analysis phase involves using a fishbone diagram or Ishikawa diagram for each defect to make it easier to understand.

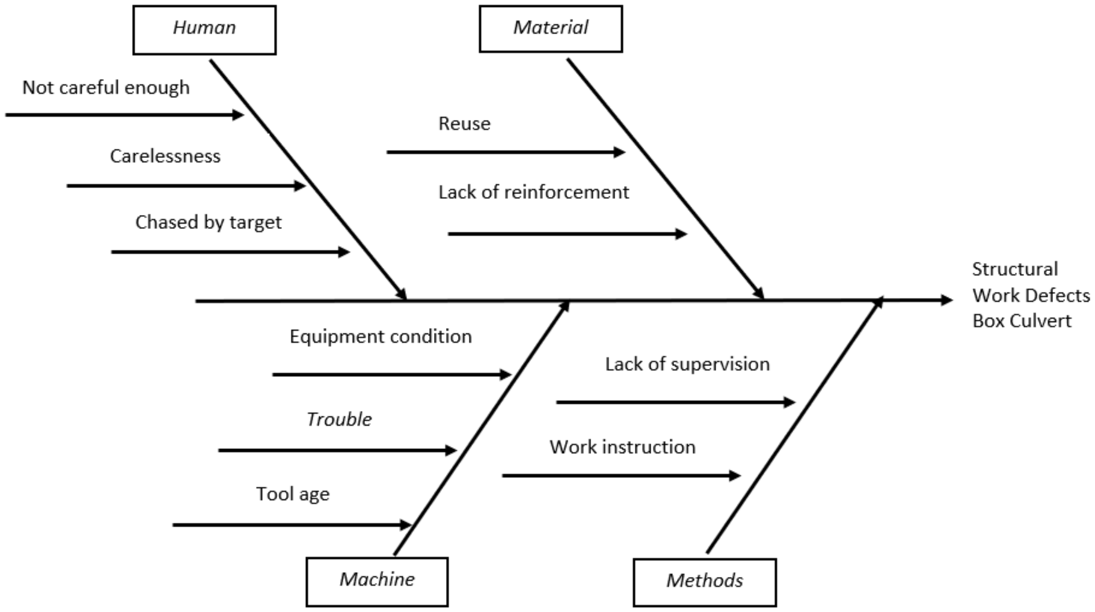

Figure 5. *Fishbone*

Improvement

At this stage, proposals will be presented (brainstorming), with the hope that these proposals can provide input to the project team on what can be done to make the work better, by implementing PDCA (Plan Do, Check, Action). Therefore, defects in the work process can be reduced. Here are recommendations.

Table 11. Recommendation to reduce *defect*

No	*Defect*	Repair
1	Porous Concrete	*Grouting*
2	Concrete Cracks	Injrksi
3	Honeycomb	*Grouting*
4	Uneven Concrete	*Patching*
5	Plin Concrete	*Patching*

Control

To check preventive measures for repair work, a checklist can be used as a control plan.

Research Implications

Regarding theoretical implications of the following research:

1. The Lean Six Sigma (LSS) method can be used in improving the quality of underpass construction, as evidenced by testing that all variables received from LSS have a positive impact on enhancing underpass structure work.
2. In the case study of underpass construction, there is a defect in the concrete plinth that needs to be evaluated and improved in quality to enhance the underpass.

Moreover, practical implications of this research are as follows:

1. Practical implications of this research, especially for infrastructure contractors, particularly in underpass construction work of box culvert structures, need to emphasize attention to Quality

Planning, Quality Assurance, Quality Control, and Quality Improvement activities. Additionally, paying attention to Quality Performance carried out before, during, and after work.
2. Furthermore, contractors are highly recommended to focus on Quality Planning, Quality Assurance, Quality Control, and Quality Improvement activities to check compliance with construction plans to produce good quality, while also paying attention to defects, especially the plinth in the concrete, at every step to ensure the results meet the requirements.

Conclusion

Based on the analysis conducted, the following conclusions can be drawn:
1. Based on the questionnaire survey results analyzed using RII for validation and reliability, the factors with the highest impact on each variable are as follows:
   a. Quality Planning (X1), implementing efforts to improve defects (RII=0.808).
   b. Quality Assurance (X2), accepting change proposals from stakeholders (RII=0.776).
   c. Quality Control (X3), ensuring that incoming materials meet the desired specifications (RII=0.838).
   d. Quality Improvement (X4), managing quality improvement steps (RII=0.830).
   e. Quality Performance (Y1), assessing quality management systems for continuous improvement (RII=0.829).
2. The application of Lean Six Sigma in this study follows the D-M-A-I-C (Define, Measure, Analyze, Improve, Control) principles:
   a. In the Define stage, identifying work areas experiencing defects.
   b. In the Measure stage, demonstrating the DPMO calculation results for a case study of a construction project underpass with a structure box culvert having 6058 defects per million or equivalent to sigma 4.133 sigma with a yield of 99.39%.
   c. In the Analyze stage, identifying that the causes of defects are human, material, machine, and method-related.
   d. In the Improve stage, carrying out improvement in grouting, injection, and patching.
   e. In the Control stage, using a checklist as a control plan.
3. As in conclusion (1), it is evident that all variables are influenced by the application of Lean Six Sigma, namely Quality Planning, Quality Assurance, Quality Control, Quality Improvement, Quality Performance contributing to the enhancement of construction quality underpass.

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