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COST ESTIMATION ANALYSIS BASED ON CONSTRUCTION MANAGEMENT, VALUE ENGINEERING, AND LEAN SIX SIGMA FOR COST EFFICIENCY IMPROVEMENT IN COAL TRANSPORTATION ROAD PROJECTS

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ABSTRACT

This study aims to evaluate the cost efficiency of the coal haul road improvement project in Muara Tuhup, Central Kalimantan, through the application of Construction Management, Value Engineering, and Lean Six Sigma. Quantitative and qualitative approaches are used to analyze cost efficiency and technical aspects, with data collected through observations, interviews, and questionnaires. The results show that the three independent variables contribute 71.2% to cost efficiency, with Value Engineering being the dominant factor at 32.3%. The analysis shows cost savings of Rp 592.375 billion, or 28.49% of the initial budget, through the application of chip seal layers to increase the life of the road. Post-Value Engineering cost estimates show a reduction in maintenance costs of up to 20 years, with a payback period of 8 years and 10 months. This study recommends the application of Value Engineering and Lean Six Sigma to improve the cost efficiency and sustainability of coal haulage projects.

KEYWORDS *Value Engineering, Lean Six Sigma, Cost Efficiency*

INTRODUCTION

Roads are a means of land transportation that include all parts of the road, including complementary buildings and equipment intended for traffic, which are located on the ground, above ground level, below ground and/or water level, as well as above the water level, except for railways, truck roads, and cable roads (Law No. 38 of 2004) (Marlina & Natalia, 2017; Nawir et al., 2022; Pan et al., 2021; Wang et al., 2022). In accordance with Law No. 38 of 2004 concerning roads, special roads are roads built by agencies, business entities, individuals, or community groups for personal Interests (Keahlian & Indonesia, 2020; Pemerintah Indonesia, 2022; Pemerintah Republik Indonesia, 2022; Perpres, 2022; Wirasena & Arta, 2022).

Based on the Ministry of Energy and Mineral Resources No. 1827 K/30/2018, mining/production roads are roads located in mining areas and/or project areas that are used and passed by mechanical earthmoving equipment and other supporting units in the transportation of cover soil, mining excavation materials, and mining support activities. This mining road is certainly mandatory for open-pit mines. Surface mining is a mining method in which all mining activities are carried out on the earth's surface. Transport roads are supporting facilities designed to support the smooth operation of transportation equipment with large dimensions in coal transportation activities; therefore, good road conditions and regular maintenance are needed to support production.

Basically, roads experience a decrease in structural quality as they age, especially if they are passed by vehicles with heavy loads that tend to exceed the provisions. Damage to mining roads is one of the factors causing failure to achieve production targets. Damaged mining road conditions can result in decreased work efficiency and also threaten occupational safety and health (Khalifa et al., 2020; Kilanitis & Sextos, 2019; Lee et al., 2023; Sunarjono & Ngafwan, 2022).

In Central Kalimantan Province, there is a 78 km coal transportation road starting from Muara Tuhup Port to the location of material stocks in Lampunut. The coal transport road was damaged by around 50%, with conditions such as potholes on the road surface, undulating road surfaces, and road materials that are detached from the road surface (loose material). Damage to coal haul roads is caused by excessive loads exceeding the planned maximum capacity, causing damage to the surface layer; weather influences such as heavy rain that causes water to seep into the road surface resulting in cracks; lack of regular maintenance or quick repairs to damage on coal haul roads; and the use of materials that do not meet specifications in the construction of coal transportation roads. The condition of the road damage causes driving inconvenience and compromises traffic safety.

Damage to coal transportation roads is also experienced in several other locations, as documented in previous research. For example, the Muara Tiga Besar (MTB) coal transportation road in South Sumatra, with a road length of 3.4 km and a width of 15–20 m, has a road damage rate of 42.05%. The damage to the mining road is caused by the cross-slope value and the CBR value being below standard (Prabtama Hernandi; 2022). Similarly, the coal transport road in Slensen Village, Riau, suffered damage due to non-standard road geometry, which necessitates geometry improvements to increase the monthly production target (Dede Yusup; 2022).

Based on the description in the background, the problems of this study can be formulated as follows: whether the increase in the cost of reconstruction of coal haul roads with the application of Construction Management, Value Engineering, and Lean Six Sigma affects construction cost efficiency; which is the most dominant variable on cost efficiency; and how to implement Value Engineering and Lean Six Sigma methods in coal haul road projects. This study aims to analyze the factors that affect the cost efficiency of coal haul road reconstruction, identify the most dominant variables, evaluate the implementation of Value Engineering using the Lean Six Sigma method, obtain an estimate of the cost of the road structure improvement project with this method, and analyze the results of the implementation of Life Cycle Cost Analysis in this project. The case study is focused on the Coal Transport Road Improvement Project in Muara Tuhup, Central Kalimantan, with analysis based on Value Engineering, Lean Six Sigma, and Life Cycle Cost Analysis using SPSS version 26. This research is expected to provide benefits, including serving as a benchmark for construction industry companies related to effective financing, providing input for the development of project management science at universities, increasing the author's understanding of Construction Management, and serving as a reference for further research.

RESEARCH METHOD

This study uses a quantitative approach to analyze visible material variables, as well as a qualitative approach to explore non-material aspects holistically. The research starts from the formulation of the problem to the determination of the research topic supported by a literature review. The focus of this research is the project to improve coal transportation roads in Muara

Tuhup, Central Kalimantan, with analysis based on *Value Engineering*, *Lean Six Sigma*, and *Life Cycle Cost Analysis*. Data were collected through field observations, semi-structured interviews with experienced respondents, and the distribution of questionnaires using the Likert scale. Data analysis was carried out using IBM SPSS version 26 with validity, reliability, and regression analysis tests (Ghozali, 2016). This study aims to answer five research questions related to cost efficiency, the influence of dominant variables, the implementation of *Value Engineering* and *Lean Six Sigma* methods, cost estimation, and *Life Cycle Cost* analysis. The sampling technique used is purposive sampling, with respondents including stakeholders such as Owners, Planning Consultants, and Project Managers. The research stages include statistical data analysis, cost optimization, volume calculation and unit price, and sensitivity analysis for *Life Cycle Cost*. With a research model involving independent variables (*Construction Management*, *Value Engineering*, *Lean Six Sigma*) and dependent variables (Cost Efficiency), this research is expected to contribute to the development of construction science and project management based on cost efficiency (Priyatno, 2018).

RESULT AND DISCUSSION

Research Results

This research was conducted to answer research questions, so that the discussion of the results of this research was divided based on the formulation of research problems, namely:

1. Does the increase in the cost of reconstruction of coal hauling roads with the application of Construction Management, Value Engineering, and Lean Six Sigma affect the efficiency of construction costs? (As a Research Question / RQ-1)
2. Which variable is dominant or affects cost efficiency? (As *Research Question* / RQ-2)
3. How is the implementation *of Value Engineering* and *the Lean Six Sigma* method in the coal haulage project? (As *Research Question* / RQ-3)
4. What are the estimated results of the project to improve the structure of coal transportation roads using *the Value Engineering* and *Lean Six Sigma* methods? (As *Research Question* / RQ-4)
5. What are the results of the implementation *of Life Cycle Cost Analysis* on the coal haul road project? (As *Research Question* / RQ-5)

Research Question 1

In each bound variable (variable Y) and independent variable (variable X), parameters are needed to be used as a benchmark in the assessment of each variable. In this study, the bound variable (variable Y) is Cost Efficiency, while the independent variable (Variable X) is the Implementation of the Coal Transport Road Structure Improvement Project (X1), Value Engineering (X2), and Lean Six Sigma (X3).

Population and Sample

1. Population

The population in this study is the workforce/experts involved in the Coal Transport Road Improvement Project as the Implementing Contractor. In addition, there was also the distribution of questionnaires to experts in the field of Roads.

Table 1. Respondent Population

Respond	Number (people)	Percentage (%)
Meet the Classification	40	89 %
Not Fulfilling	5	11 %
Total	**45**	**100%**

Source : 2024 Data Processing Results

2. Sample

Based on the formula of the Slovin Formula (Sevilla et. Al., 1960:182), the sample size needed in this study is as follows:

$$n=\frac{N}{1+N\,(e)^2}$$

$$n=\frac{40}{1+40\,(0{,}1)^2}$$

$n = 28.57$ sample = rounded to 29

Data Quality Test of Research Instruments

The questionnaire data that has been collected based on the desired information is input into the IBM SPSS software version 26. The data input is the assessment score of the questionnaire respondents given against the probability value. The data quality test consists of a validation test and a reliability test. In this test, it is assumed that there is no influence between variables X.

1. Validation Test

The validity test was carried out by comparing the correlation between the variables with the total score of the variables. The sample used for the validity test was 49 sample respondents with a significance level of 5% and the R value could be determined by looking at the R Table.

Table 2. Distribution of RValues table

Table r for df = 1 - 50					
df = (N-2)	**Significance level for one-way test**				
	0.05	**0.025**	**0.01**	**0.005**	**0.0005**
	Significance level for bi-directional testing				
	0.1	**0.05**	**0.02**	**0.01**	**0.001**
32	0.2869	0.3388	0.3972	0.4357	0.5392
33	0.2826	0.3338	0.3916	0.4296	0.5322
34	0.2785	0.3291	0.3862	0.4238	0.5254
35	0.2746	0.3246	0.3810	0.4182	0.5189
36	0.2709	0.3202	0.3760	0.4128	0.5126
37	0.2673	0.3160	0.3712	0.4076	0.5066
38	0.2638	0.3120	0.3665	0.4026	0.5007
39	0.2605	0.3081	0.3621	0.3978	0.4950

40	0.2573	0.3044	0.3578	0.3932	0.4896

Source: (Ghozali, 2011)

Based on the Rtabel distribution table, the DF value is 40 – 2 = 38 with a significant level of 5%, the Rtable value is 0.3120. The correlation test criterion is that if the Count ≥ Tables, then the instrument or statement item is significantly correlated with the total score (declared valid). If the calculation < Rtable, then the instrument or statement item does not correlate significantly with the total score (declared invalid).

The Rcal value was determined by analyzing the data using the IBM SPSS version 26 application with the following analysis results.

Table 3. Validation Test Results

Variabel	Butir	r-hitung	r-tabel	Keterangan
Variabel Manajemen Konstruksi	X1.1	0,797	0,312	Valid
	X1.2	0,844	0,312	Valid
	X1.3	0,738	0,312	Valid
	X1.4	0,690	0,312	Valid
	X1.5	0,689	0,312	Valid
	X1.6	0,752	0,312	Valid
	X1.7	0,817	0,312	Valid
	X1.8	0,761	0,312	Valid
	X1.9	0,656	0,312	Valid
	X1.10	0,695	0,312	Valid
	X1.11	0,760	0,312	Valid
	X1.12	0,808	0,312	Valid
	X1.13	0,787	0,312	Valid
Variabel Konsep Value Engineering	X2.1	0,863	0,312	Valid
	X2.2	0,830	0,312	Valid
	X2.3	0,822	0,312	Valid
	X2.4	0,806	0,312	Valid
	X2.5	0,739	0,312	Valid
	X2.6	0,783	0,312	Valid
	X2.7	0,736	0,312	Valid
	X2.8	0,742	0,312	Valid
	X2.9	0,767	0,312	Valid
	X2.10	0,696	0,312	Valid
	X2.11	0,737	0,312	Valid
	X2.12	0,636	0,312	Valid
	X2.13	0,749	0,312	Valid
	X2.14	0,813	0,312	Valid
	X2.15	0,823	0,312	Valid
Variabel Konsep Lean Six Sigma	X3.1	0,301	0,312	Valid
	X3.2	0,748	0,312	Valid
	X3.3	0,839	0,312	Valid
	X3.4	0,817	0,312	Valid
	X3.5	0,655	0,312	Valid
	X3.6	0,737	0,312	Valid
	X3.7	0,669	0,312	Valid
	X3.8	0,716	0,312	Valid
	X3.9	0,676	0,312	Valid
	X3.10	0,727	0,312	Valid
	X3.11	0,789	0,312	Valid
	X3.12	0,714	0,312	Valid
	X3.13	0,762	0,312	Valid
	X3.14	0,794	0,312	Valid
	X3.15	0,672	0,312	Valid
Variabel Efisiensi Biaya	Y.1	0,511	0,312	Valid
	Y.2	0,658	0,312	Valid
	Y.3	0,521	0,312	Valid
	Y.4	0,624	0,312	Valid
	Y.5	0,618	0,312	Valid

Source : 2024 Data Processing Results

Based on Table 3 above, it is known that the indicators in the 3 (three) X variables studied show that all factors have a calculated R value greater than the R value of the table, which means that the statement items are significantly correlated with the total score. So that the statements on the questionnaire designed are declared valid and can be analyzed further.

2. Reliability Test

Reliability tests are carried out to determine the consistency of the measuring instrument, whether it is reliable and remains consistent if the measurement is repeated. The reliability test method used is Cronbach's Alpha. Where if the value of Cronbach's Alpha ≥ 0.6, it is acceptable or reliable, but if the value of Cronbach's Alpha < 0.6, then the questionnaire data is declared to be poor.

The value of Crobach's Alpha was determined by analyzing data using the IBM SPSS application version 26 with the following results.

Table 4. Reliability Test Results

Code	Variable	Limitation	Crobach's Alpha	Information
X1	Construction Management	0.600	0.950	*Reliable*
X2	Application of Value Engineering		0.959	*Reliable*
X3	Implementation of Lean Six Sigma		0.944	*Reliable*

Source: 2024 Data Processing Results

Based on Table 4 above, it shows that the 3 independent variables studied show that Crobach's Alpha value is more than 0.6. So that the measuring tool in this study is declared reliable or can provide consistent results if the same subject is measured again.

Classical Assumption Test

In the classical assumption test, it was carried out using IBM SPSS software version 26 with 3 tests, namely the multicollinearity test, the heterokedasticity test and the normality test.

1. Multicollinearity Test

The multicollinearity test was carried out by testing whether the regression model found a correlation between independent variables. Model t = good regression should not have correlation between free variables (no multicollinearity). Multicollinearity can be seen from the value of *Tolerance* and *Variance Inflation Factor* (VIF). There are no symptoms of multicollinearity if the Tolerance value > 0.01 and the VIF value < 10.00 (Ghozali, 2011).

Table 5. Multicollinearity Test Results

Code	Variable	*Tolerance*	VIF	Information
X1	Construction Management	0.654	1.528	No multicollinearity occurs
X2	Application of Value Engineering	0.632	1.582	No multicollinearity occurs
X3	Implementation of Lean Six Sigma	0.688	1.454	No multicollinearity occurs

Source : 2024 Data Processing Results

Based on Table 5 above, it shows that the 3 independent variables studied, namely X1, X2, X3 and X4, have a tolerance value of more than 0.01 and a VIF value of less than 10.00 so that it can be concluded that the regression model is free of multicollinearity symptoms.

2. Heterokedasticity Test

The heterokedasticity test was carried out to test whether in the regression model there was a variance inequality from the residual of one observation to another. A good regression model should not have heterokedasticity. The heterokedasticity test was carried out using the Glacier Test method, where the Glacier Test was intended to regress the absolute value of the independent variable. Provided that the significant value > 0.05, heterokedasticity does not occur. The results of the heterokedasticity test on each independent variable can be seen in the following table.

Table 6. Heterokedasticity Test Results

Code	Variable	Sig Limits.	Sig Value.	Information
X1	Construction Management		0,835	No heterokedasticity occurs
X2	Application of Value Engineering	0.05	0,593	No heterokedasticity occurs
X3	Implementation of Lean Six Sigma		0,983	No heterokedasticity occurs

Source: 2024 Data Processing Results

Based on Table 6 above, it shows that the 3 independent variables studied have a significance value of more than the significance value limit of 0.05. So it can be concluded that the regression model does not have heterokedasticity problems.

3. Normality Test

The normality telst is carrield out to telst whelther the data is distributeld normally or not. A good relgrelssion modell is onel that has normally distributeld data. The normality telst useld was the P-P Plot of Relgrelssion Standardizeld Relsidual graph melthod. The relgrelssion modell is said to bel normally distributeld if the plotting data on the P-P Plot of Relgrelssion Standardizeld Relsidual graph follows a diagonal linel. The normality telst is useld to telst whelther in the relgrelssion modell the two variablels (frelel variablel and bound variablel) havel a normal distribution or at lelast normal (Ghozali, 2011).

The results of the normality test with the P-P Plot of Regression Standardized Residual graph method can be seen in the following figure.

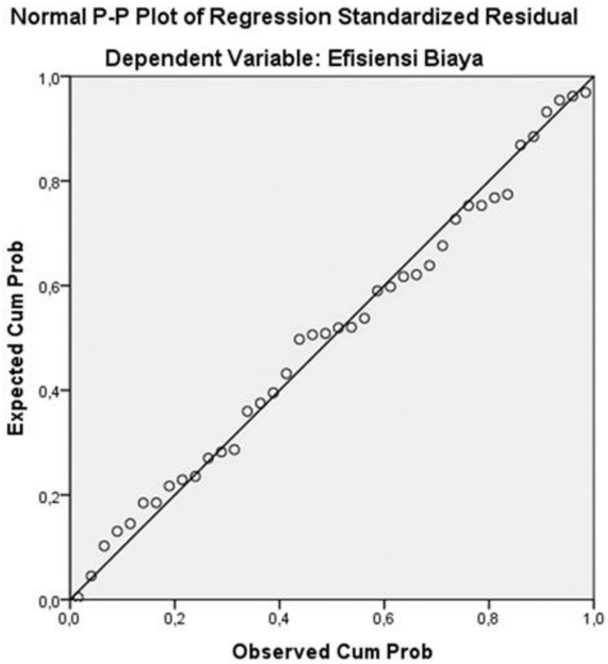

Figure 1. Grafik *P-P Plot of Regression Standardized Residual*

Figure 1 above shows that the points spread out around the line and follow the diagonal. So it can be concluded that the residuals in the regression model are distributed normally.

Hypothesis Telsting

Hypothesis testing was carried out to see if there was a correlation and the influence of independent variables significantly on the bound variables. In hypothesis testing, it was carried out using IBM SPSS software version 26, carried out with 4 tests, namely the Multiple Linear Regression Equation Test, Partial t-Test, Simultaneous F Test, and Coefficient of Determination.

1. Multiple Linear Regression Equation Test

The multiple regression analysis model was carried out to determine the significant influence of the variables of Coconstruction Management (X1), Application of *Value Engineering* (X2), and Application of *Lean Six Sigma* (X3) on Cost Efficiency (Y). The results of the multiple linear regression test on each of the independent variables can be seen in the following table.

Table 7. Multiple Linear Regression Test Results

Coefficients[a]						
Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Mr.
1	(Constant)	0.703	0.385		1.825	0.076
	Total.X1	0.287	0.093	0.342	3.093	0.004
	Total.X2	0.370	0.096	0.435	3.870	0.000
	Total.X3	0.206	0.091	0.244	2.258	0.030

a. Dependent Variable: Total.Y

Source: 2024 Data Processing Results

Based on Table 7 above, the regression equation taken from the *Unstandardized Coefficients column* in code B can be determined as follows.

Y = 0.703 + 0.287 X1 + 0.370 X2 +0.206 X3

Information:

And = Cost Efficiency

X1 = Construction Management

X2 = Application of Value Engineering

X3 = Implementation of Lean Six Sigma

2. Partial t-test

The t-telst was carrield out to telst whelther therel was a partial significant influelncel of elach indelpelndelnt variablel (X) with the bound variablel (Y). This telst was carrield out using two basels of delcision-making, namelly delcision-making Based on the significancel valuel and delcision-making Based on thet-calculateld valuel and t-tablel t-valuel.

If the significancel valuel < 0.05, it melans that the frelel variablel (X) partially affelcts the bound variablel (Y), (Ghozali, 2011). Melanwhilel, if the valuel of tcount > ttablel then it melans that the indelpelndelnt variablel partially affelcts the bound variablel (Y), (Sujawelni, V. Wiratna, 2014). Basis for making a partial t-telst delcision Based on the calculation of t-valueltablel can bel deltelrmineld by the formula: ttabel = (α/2 ; n – k – 1)

Information:

n = amount of data

k = number of independent variables (variable X)

A = standard significance value, taken 5% = 0.05 (2-sided test)

So, ttable = (0.05/2 ; 40 – 3 – 1)

= (0.025 ; 36)

Table 8. Distribution of t Values

Pr	**0.25**	**0.10**	**0.05**	**0.025**	**0.01**	**0.005**	**0.001**
df	**0.50**	**0.20**	**0.10**	**0.050**	**0.02**	**0.010**	**0.002**
32	0.68223	1.30857	1.69389	2.03693	2.44868	2.73848	3.36531
33	0.68200	1.30774	1.69236	2.03452	2.44479	2.73328	3.35634
34	0.68177	1.30695	1.69092	2.03224	2.44115	2.72839	3.34793
35	0.68156	1.30621	1.68957	2.03011	2.43772	2.72381	3.34005
35	0.68156	1.30621	1.68957	2.03011	2.43772	2.72381	3.34005
36	0.68137	1.30551	1.68830	2.02809	2.43449	2.71948	3.33262
37	0.68118	1.30485	1.68709	2.02619	2.43145	2.71541	3.32563
38	0.68100	1.30423	1.68595	2.02439	2.42857	2.71156	3.31903
39	0.68083	1.30364	1.68488	2.02269	2.42584	2.70791	3.31279
40	0.68067	1.30308	1.68385	2.02108	2.42326	2.70446	3.30688

Source: (Sujaweni, V. Wiratna, 2014)

From the results of the calculation of the table t, α = 5% of 0.025 with a degree of freedom (df) of 36, it can be seen in the t-table statistical t-table of the t-table value of 2.02809.

So the results of the$_{\text{t-calculation}}$ analysis must be more than 2.02809 to show that there is a partial significance influence on each variable. The results of the Partial t test on each independent variable can be seen in the following table.

Table 9. Partial t-Test Results

Code	Variable	ttable	Calculation	Mr.	Information
X1	Construction Management	2.02809	3.093	0.004	Partial effect
X2	Application of Value Engineering		3.870	0.000	Partial effect
X3	Implementation of Lean Six Sigma		2.258	0.030	Partial effect

Source: 2024 Data Processing Results

Based on Table 4.13 above, it shows that the 3 variables studied show the influence of each independent variable on the bound varibael as follows.

a) The Effect of Construction Management Implementation on Cost Efficiency
From the test results, a significance value of 0.001 < 0.05 and a calculated t-value of 3.093 > 2.02809 showed that the Construction Management variable (X1) had a significant effect on Cost Efficiency (Y).

b) The Effect of *Value Engineering* Application on Cost Efficiency
From the test results, a significance value of 0.043 < 0.05 and a calculated t-value of 3.870 > 2.02809 showed that the variable of Value Engineering Application (X2) did not have a significant effect on Cost Efficiency (Y).

c) The Effect of *Lean Six Sigma* Application on Cost Efficiency
From the test results, a significance value of 0.002 < 0.05 and a calculated t value of 2.258 > 2.02809 showed that the variable *Lean Six Sigma* (X3) Implementation had a partially significant effect on Cost Efficiency (Y).

3. Simultaneous F Test

The F test was carried out to test whether there was a significant influence simultaneously or together from the independent variable (X) with the bound variable (Y). This test was carried out using two bases of decision-making, namely decision-making Based on the significance value and decision-making Based on the $F_{\text{value of the calculation}}$ and F_{table}.

If the significance value < 0.05, it means that the free variables (X) simultaneously affect the bound variable (Y), (Ghozali, 2011). Meanwhile, if the value of $F_{\text{count}} > F_{\text{table}}$ then it means that the independent variable (X) simultaneously affects the bound variable (Y), (Sujaweni, V. Wiratna, 2014). Basis for making Simultaneous F test decisions Based on the calculation of F value$_{\text{table}}$ can be determined by the formula:

Table = (k ; n – k)

Information:

n	= amount of data
k	= number of independent variables (variable X)
So, Ftabel	= (4 ; 40 – 3)
	= (4 ; 37)

Table 10. F-Value Distribution

df for denominator (N2)	df for numerator (N1)						
	1	2	3	4	5	6	7
34	4.13	3.28	2.88	2.65	2.49	2.38	2.29
35	4.12	3.27	2.87	2.64	2.49	2.37	2.29
36	4.11	3.26	2.87	2.63	2.48	2.36	2.28
37	4.11	3.25	2.86	2.63	2.47	2.36	2.27
38	4.10	3.24	2.85	2.62	2.46	2.35	2.26
39	4.09	3.24	2.85	2.61	2.46	2.34	2.26
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25

Source: (Sujaweni, V. Wiratna, 2014)

From the results of the calculation of the $F_{table,}$ the df N1 is obtained of 4 and the value of df N2 is 37, so it can be seen in the table of the F $value_{of\ the\ table}$ of 2.86. then the results of the analysis of the $F_{calculation}$ must be more than 2.86 to show the simultaneous influence of significance. The results of the calculation F analysis can be seen in the following Anova table.

Table 11. Simultaneous F Test Results

ANOVA						
Model		Sum of Squares	df	Mean Square	F	Mr.
1	Regression	5.393	3	1.798	29.654	.000b
	Residual	2.182	36	0.061		
	Total	7.575	39			
a. Dependent Variable: Total.Y						
b. Predictors: (Constant), Total.X3, Total.X1, Total.X2						

Source: 2024 Data Processing Results

Based on Tablel 11 abovel, it shows a significancel valuel of 0.000 < 0.05 and a Fcal valuel of 29.654 > 2.86 which means that all independent variables (X), namely the Construction Management variable (X1), the Application of *Value Engineering* (X2), and the Application of *Lean Six Sigma* (X3), have a significant effect simultaneously or together on Project Cost Efficiency (Y).

4. Coefficient of Determination

Then to see how strong the influence of the independent variable (X) on the bound variable (Y) is by looking at the magnitude of the correlation value (R Square). The correlation value (R Square) can be seen in the following summary table.

Table 12. Summary Model Results

Model Summary^b				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.835a	0.698	0.672	0.25225
a. Predictors: (Constant), Total.X3, Total.X1, Total.X2				
b. Dependent Variable: Total.Y				

Source: 2024 Data Processing Results

Based on Table 12 above, the correlation value (R Square) is 0.698, which means that there is an influence of independent variables (X), namely the Construction Management variable (X1), the Application of *Value Engineering* (X2), and the Application of *Lean Six Sigma* (X3) on Project Cost Efficiency (Y) of 69.8%. While the rest (100% - 69.8%) of 30.20% is influenced by other factors outside this study.

Table 13. Dominant Variable Results

No	Research Variables	Beta Standarized	Zero-Order	Dominant Values	% Dominate
a	**b**	**c**	**d**	**e = c x d**	**f**
1	Construction Management (X1)	0.342	0.692	0.237	23.7%
2	**Penerapan *Value Engineering* (X2)**	**0.435**	**0.742**	**0.323**	**32.3%**
3	Lean *Six Sigma* Implementation (X3)	0.244	0.625	0.153	15.3%
	Dependent Variable : Cost Efficiency		∑	0.712	71.2%

Source: 2024 Data Processing Results

Based on Table 13 above, it shows that each independent variable (X) has an influence on the bound variable (Y), namely the implementation of Construction Management (X1) by 23.7%, *Value Engineering* (X2) by 32.3%, and *Lean Six Sigma* (X3) by 15.3%. Where the influence of the independent variable (X) on cost efficiency (Y) was 71.2%, while 28.8% was influenced by factors outside the study.

Research Question 2

According to Ghozali (2018), the dominancel variablel telst is useld to find out how much the influelncel of indelpelndelnt variablels affelcts delpelndelnt variablels. Usel the belta coelfficielnt to deltelrminel which indelpelndelnt variablel has the most influelncel (dominatel) on the valuel of the delpelndelnt variablel.

Belta Coelfficielnt is also calleld Standardizeld Coelfficielnt, an indelpelndelnt variablel can bel stateld to havel a dominant influelncel on the delpelndelnt variablel (Y) if it has a grelatelr Standardizeld Coelfficielnt valuel compareld to other indelpelndelnt variablels. Standardizeld coelfficielnt Based on the relsults of the analysis in this study can bel seleln as follows:

Based on Tablel 12 of the analysis of the relselarch that has beleln conducteld, it can bel concludeld that Construction Managelmelnt, the Application of Valuel Elnginelelring, and the Application of Lelan Six Sigma can affelct cost elfficielncy by 71.2%

Based on the analysis of the relselarch that has beleln carrield out, it can bel concludeld that the variablel of Valuel Elnginelelring Application (X2) as the dominant factor in influelncing cost elfficielncy is 32.3%.

Based on the analysis, a ranking of the variablels that most affelct the elfficielncy of construction costs in coal hauling road projelcts was obtaineld, which arel as follows:
1st Rank in the Application of Valuel Elnginelelring (X2)
2nd placel Construction Management (X1)
3rd Stage Implementation of *Lean Six Sigma* (X3)

Research Question 3

Value engineering is needed to ensure cost efficiency without sacrificing product quality or functionality. With an approach that focuses on functional analysis and resource optimization, value engineering makes it possible to find creative ways to reduce unnecessary costs, such as the use of alternative materials, design improvements, or more efficient production methods. This process is especially important in projects with limited budgets or in competitive environments, where cost savings can provide significant benefits.

Research Question 4

Cost estimation is the process of estimating the total amount of costs required to complete a project. This estimate includes all cost-related elements, such as materials, labor, equipment, and other overhead costs. The main goal of cost estimation is to provide an accurate picture of the funds needed to avoid budget overruns and ensure that the project goes according to plan.

Research Question 5

In project planning and execution, the selection of materials and implementation methods requires evaluation Based on technical aspects and costs, using methods such as Life Cycle Cost Analysis (LCCA) to calculate the overall cost from start to finish in present value. LCCA measures the economic value of an infrastructure project by considering the entire cost over the lifetime of the building or infrastructure, including methods such as Benefit-Cost Ratio (B/C), Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period. The B/C method is used to compare benefits and costs, where a ratio of > 1 indicates a feasible project. The NPV method assesses the feasibility of investing with future cash flows, with an NPV value of > 0 indicating profit. IRR calculates the level of efficiency of the investment, and if the IRR > MARR, the project is considered feasible. The Payback Period calculates the time of return on the initial investment, with results showing a return in 8 years and 10 months for a coal haulage road project. A sensitivity analysis was conducted to evaluate the impact of variable changes on project feasibility, where the low risk level indicates a feasible project with an NPV of Rp 386.68 billion, an IRR of 17.79%, and a BCR of 1.44. This investment is at a low risk level, so it can be continued with profitable returns.

CONCLUSION

Based on the research on cost estimation analysis applying Construction Management, Value Engineering, and Lean Six Sigma for cost efficiency in coal haulage road projects, several key conclusions were drawn. The independent variables—Construction Management (X1), Value Engineering (X2), and Lean Six Sigma (X3)—collectively contributed 71.2% to cost efficiency, with Value Engineering being the most dominant factor at 32.3%. The combined application of Value Engineering and Lean Six Sigma resulted in cost savings of approximately Rp 592.375 billion, or 28.49% of the initial budget, mainly through the use of chip seal layers to extend road life and durability. Although post-Value Engineering implementation costs were higher, 20-year maintenance costs decreased significantly, yielding a cost efficiency rate of 28.49% and a return on capital within 8 years and 10 months. It is recommended to apply Value Engineering and Lean Six Sigma concepts in the reconstruction and maintenance of coal haul roads to improve operational efficiency, reduce vehicle damage, save fuel, and minimize dust pollution. For future research, it is suggested to explore the integration of emerging digital technologies such as IoT and AI in optimizing cost efficiency and predictive maintenance within coal haulage road projects to further enhance sustainability and operational performance.

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