

The Effect of Crane Operating Methods on Generator Performance During Ship Loading and Unloading Processes CTS Bulk Derawan

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ABSTRAK

The loading and unloading operations of the CTS Bulk Derawan floating crane vessel demand a reliable electrical system, especially the high-capacity Tsuji crane support generator during the 24-hour coal transshipment in Muara Berau, East Kalimantan. Simultaneous crane operations have the potential to cause significant electrical load surges. This study analyzes the effect of crane operation methods (alternating vs. simultaneous) on the performance of the Caterpillar 3512B generator and determines the optimal method. Using a true experimental pre-test post-test control group design, purposive sampling targeted four treatment groups (n=16 measurements) during real-life operations. The data collection of direct observation of ECR panel parameters was analyzed using descriptive statistics, the Kolmogorov-Smirnov normality test, Levene's homogeneity test, one-way ANOVA ($F=26.764$, $\text{Sig}.<0.001$), and Duncan's post-hoc test via SPSS. The results show that simultaneous operation increases the generator load by an average of 593.5 kW versus 165-246 kW in alternating operation ($R^2=0.870$). The conclusion recommends simultaneous operation with optimal load sharing management to balance generator productivity and reliability.

Kata Kunci: Crane Operation, Floating Crane, Generator Performance, Load Management, Ship Electrical System

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PENDAHULUAN

The introduction of this research describes the phenomenon of floating crane operations on the CTS Bulk Derawan vessel owned by PT Asian Bulk Logistic, where coal loading and unloading activities in the Muara Berau area, East Kalimantan, demand high efficiency to meet annual production targets. This vessel is equipped with two large crane units made by Tsuji Heavy Industries Japan, hoppers, and conveyors, as well as three Caterpillar 3512B generators as the main power source, which operate intensively for up to 24 hours non-stop for three days per loading process of one large vessel.

The increasing demand for energy materials such as coal in the era of globalization has accelerated the need for reliable loading and unloading systems, where floating cranes offer flexibility in locations difficult to reach with conventional equipment. However, optimal maintenance during waiting periods remains essential to maintain optimal equipment condition and avoid problems that delay operations and incur financial losses.

Problems arose during simultaneous crane operation, which caused an abnormal humming noise in the generator due to significant electrical load surges, voltage and frequency fluctuations, and potential overheating, as suspected by CTS Bulk Derawan's Chief Engineer. Crane operators often focused on their individual units without coordination, resulting in simultaneous cargo lifting overloading the generator and reducing the stability of the electrical system.

This phenomenon is exacerbated by a lack of awareness of the impact of crane operations on generator performance, similar to overloading on other vessels where the use of two cranes exceeded the generator's power supply, causing performance degradation and the halt of loading and unloading.

Simultaneous ship operational conditions and generator operation positively impacted the electrical load, with an increase of up to 4.4 percent over the related variable factor.

In addition, high loads from cranes cause inefficient generator fuel consumption, fluctuations in working parameters, and risks of long-term damage, as found in generator loading analysis of tugboats and bulk carriers where crane operations require proper load sharing management to prevent energy inefficiency.

This study aims to analyze the effect of crane operating methods (one crane versus two simultaneous cranes) on generator performance during the loading and unloading process of the CTS Bulk Derawan Ship, and to recommend the most efficient method to maintain system stability. The urgency of this research lies in the need to optimize floating crane operations in the Indonesian coal logistics industry, where generator disruptions can cause significant time and cost losses, in line with the demands for ship energy efficiency to reduce emissions. The novelty of this research is the direct quantitative experimental approach in the field with ANOVA tests on specific parameters of the Caterpillar 3512B generator related to variations in the Tsuji crane, complementing previous studies that are more general on conventional vessels.

METODE

This study adopted a quantitative approach with a true experimental design using a pre-test post-test control group, in accordance with the principle of testing the causal relationship between the independent variable of crane operating methods (one crane alternately versus simultaneously) and the dependent variable of generator performance in the loading and unloading process of the CTS Bulk Derawan Ship. This type of research was chosen because it allows strict control of variables through direct observation in the field during the sea practice internship, with experimental steps including initial measurements of generator parameters (such as power, fuel rate, coolant temperature, oil, exhaust, and air inlet), application of treatments to four groups (no load, crane 1 full / crane 2 empty, crane 2 full / crane 1 empty, both full), and final measurements via the monitor display in the Engine Control Room (ECR).

The primary data collection instrument was direct observation of the Caterpillar 3512B generator control panel, recording real-time parameter changes during Tsuji crane operation, supported by secondary data from journals related to the influence of ship operations on generators, while the analysis techniques included descriptive statistics for data summary (mean, standard deviation), Kolmogorov-Smirnov normality test, Levene's homogeneity test, one-way ANOVA completely randomized design (with F and $Sig. < 0.05$ for significance), and Duncan's post-hoc test to identify specific differences between groups. This analysis ensured the validity of parametric assumptions before concluding significant effects, with SPSS software for processing.

The research population consists of the entire generator and crane operation process during coal loading and unloading on the CTS Bulk Derawan Ship at the Muara Berau location, East Kalimantan, with a purposive sample in the form of four treatment groups (each with 4 replicate measurements) taken during real operational conditions, representing variations in crane loads representatively without random sampling due to the nature of the field experiment which depends on the ship's schedule.

The research procedure starts from specimen preparation (verification of generator capacity and crane/conveyor load), pre-test measurement of initial parameters, sequential application of experimental treatments, visual monitoring and photographic evidence, post-test measurement of power changes and other parameters, to recording and comparing data for statistical analysis, conducted in the ship's ECR room during the 2026 sea practice internship period to ensure reliability and replicability.

HASIL DAN PEMBAHASAN

Descriptive Statistics

According to Sugiyono (2019), descriptive statistics is a statistical method used to process and present research data by explaining, summarizing, and describing the characteristics of the collected data. This analysis aims to provide a clear picture of the conditions or phenomena being studied, such

as through tables, graphs, average values, percentages, and other statistical measures, without the intention of drawing general conclusions or generalizing to a wider population.(Tahir et al., 2024)

Table1. Descriptive Statistics

Descriptive Statistics				
Dependent Variable: Power				
Method	Generator	Mean	Standard Deviation	N
No burden	1.00	99.5000	2.12132	2
	2.00	15,0000	4.24264	2
	Total	57.2500	48.86290	4
Crane 1 Replacement	1.00	230,0000	5.65685	2
	2.00	262,0000	2.82843	2
	Total	246,0000	18.83260	4
Crane Change 2	1.00	176,5000	3.53553	2
	2.00	154,0000	5.65685	2
	Total	165.2500	13.54929	4
Simultaneous Crane 1 and 2	1.00	445,5000	7.77817	2
	2.00	741,5000	4.94975	2
	Total	593,5000	170.97856	4
Total	1.00	237.8750	137.46629	8
	2.00	293.1250	292.16406	8
	Total	265,5000	222.41223	16

Source: Obtained by researchers via SPSS

The table above shows that in the no-load treatment, the highest average generator power was obtained in generator 1 with a value of 99.50 and a standard deviation of 2.12. Meanwhile, the smallest average generator power was obtained in generator 2 with a value of 15 and a standard deviation of 4.24.

In crane replacement treatment 1, the highest average generator power was obtained in generator 2 with a value of 262 and a standard deviation of 2.82. Meanwhile, the smallest average generator power was obtained in generator 1 with a value of 230 and a standard deviation of 5.65.

In crane replacement treatment 2, the highest average generator power was obtained in generator 1 with a value of 176.50 and a standard deviation of 3.53. Meanwhile, the smallest average generator power was obtained in generator 2 with a value of 154 and a standard deviation of 5.65.

In the simultaneous treatment of cranes 1 and 2, the highest average generator power was obtained in generator 2 with a value of 741.50 and a standard deviation of 4.94. Meanwhile, the lowest average generator power was obtained in generator 1 with a value of 445.50 and a standard deviation of 7.77.

Normality test

The normality test is intended to determine whether the research data comes from a normal distribution or not. To test the normality of the data, the Kolmogorov Smirnov test can be used with the provision that if $\text{sig.} > 0.05$ then the data is normally distributed.

Table 2. Normality Test

Tests of Normality							
		Kolmogorov-Smirnova			Shapiro-Wilk		
	Method	Statistics	df	Sig.	Statistics	df	Sig.
Power	No burden	.298	4	.	.774	4	.064
	Crane 1 Replacement	.271	4	.	.871	4	.301
	Crane Change 2	.241	4	.	.927	4	.575
	Simultaneous Crane 1 and 2	.301	4	.	.755	4	.074
a. Lilliefors Significance Correction							

Source: Obtained by researchers via SPSS

In table 2, the normality test above shows that the significance value of all treatments is greater than α (0.05), therefore the decision to accept H0 is obtained with the conclusion that the data for all treatments are normally distributed.

Homogeneity Test

This homogeneity test is intended to determine whether the variances of the two research samples are homogeneous. To test for data homogeneity, a normality test is used, with the stipulation that if the sig. > 0.05, the data are homogeneous. If homogeneity is met, the researcher can proceed to the next stage of analysis.

Table 3. Homogeneity Test
Levene's Test of Equality of Error Variances, b

		Levene Statistics	df1	df2	Sig.
Power	Based on Mean	1020.422	3	12	<,001
	Based on Median	958,049	3	12	<,001
	Based on Median and with adjusted df	958,049	3	9,914	<,001
	Based on trimmed mean	1019.602	3	12	<,001
Tests the null hypothesis that the error variance of the dependent variable is equal across groups.					
a. Dependent variable: Power					
b. Design: Intercept + Method					

Source: Obtained by researchers via SPSS

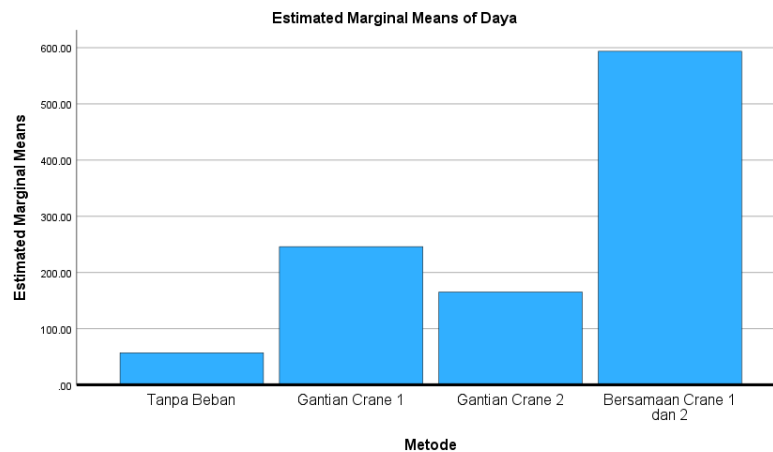
In table 3, the homogeneity test above shows a significance value (sig) based on the mean of 0.000 which is smaller than α (0.05), therefore the decision H0 is rejected with the conclusion that the variation in generator power data between treatments in each treatment is not homogeneous.

One Way Anova Test (Completely Randomized Design)

The ANOVA test is a type of parametric statistical test that aims to determine whether there is a difference in the average between two or more sample groups. The basis for decision-making in a one-way ANOVA test is that if the significance value (Sig.) > 0.05, the averages are the same. If the significance value (Sig.) < 0.05, the averages are different.

Table3.ANOVA test
Tests of Between-Subjects Effects

Tests of Between-Subjects Effects						
Dependent Variable: Power						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	
Corrected Model	645529.500 ^a	3	215176.500	26,764	<,001	
Intercept	1127844.000	1	1127844.000	140,281	<,001	
Method	645529.500	3	215176.500	26,764	<,001	
Error	96478.500	12	8039.875			
Total	1869852.000	16				
Corrected Total	742008.000	15				
a. R Squared = .870 (Adjusted R Squared = .837)						



Source: Obtained by researchers via SPSS

. Based on the results of the Tests of Between-Subjects Effects with the dependent variable Power, the significance value obtained for the crane operating method factor is Sig. < 0.001. This value is smaller than the significance level of 0.05, so it can be concluded that the crane operating method has a very significant effect on the power produced by the generator during the loading and unloading process on the CTS Bulk Derawan ship.

The calculated F value of 26.764 indicates that differences in crane operating methods have a strong influence on generator power variations. Therefore, the research hypothesis stating that crane operating methods influence generator performance is accepted.

The R Square value of 0.870 indicates that 87% of the variation in generator power can be explained by differences in crane operating methods, while the remaining 13% is influenced by other factors outside the research model, such as engine conditions, environmental factors, or the efficiency of the ship's electrical system. The Adjusted R Square value of 0.837 confirms that the model used has a high level of accuracy and is suitable for use in research analysis.

Based on the Estimated Marginal Means of Power graph, there is a difference in the average generator power for each crane operation method, namely No Load shows the lowest power value, because the generator only serves the ship's basic load without any crane activity.

Crane Alternation Operation 1 There is an increase in generator power compared to no-load conditions, which is caused by the need for electrical energy to operate one crane unit alternately.

Crane 2 Alternation Operation Shows slightly different power values compared to Crane 1, which can be influenced by load characteristics, crane motor conditions, and operating patterns.

Simultaneous Operation of Crane 1 and Crane 2 Shows the highest power value, indicating that the simultaneous operation of two cranes causes a significant increase in the electrical load on the generator. This condition forces the generator to operate at a higher capacity to meet the simultaneous power demand.

These results indicate that simultaneous crane operation places the heaviest load on the generator, potentially impacting the stability of the ship's electrical system if not balanced with proper load management. Therefore, proper crane operation methods are necessary to maintain optimal generator performance and prevent overloading and reduced system efficiency.

Post Hoc Test

A post hoc test was conducted to determine which treatment had the greatest effect or influence compared to other treatments. The post hoc test in this study used the Duncan test as follows.

Table 5. Post Hoc Test

Power				
Tukey HSDa,b				
Method	N	Subset		
		1	2	3

No burden	4	57.2500		
Crane Change 2	4	165.2500	165.2500	
Crane 1 Replacement	4		246,0000	
Simultaneous Crane 1 and 2	4			593,5000
Sig.		.364	.595	1,000
Means for groups in homogeneous subsets are displayed.				
Based on observed means.				
The error term is Mean Square(Error) = 8039.875.				
a. Uses Harmonic Mean Sample Size = 4,000.				
b. Alpha = .05.				

Source: Obtained by researchers via SPSS

The table above shows that the simultaneous treatment of cranes 1 and 2 produced the greatest and most significant increase in generator power compared to the other treatments. This means that the simultaneous treatment of cranes 1 and 2 significantly reduced generator power compared to the other treatment methods.

PEMBAHASAN

The results of the study indicate that the simultaneous operation of Crane 1 and Crane 2 significantly impacts generator performance during the loading and unloading process on the CTS Bulk Derawan vessel. This finding confirms that the operating pattern of loading and unloading equipment involving large simultaneous electrical loads has direct implications for the stability, efficiency, and reliability of the ship's power generation system.

Operating two cranes simultaneously significantly increases the electrical load on the ship's generator. Each crane requires significant power, particularly during the starting, hoisting, and slewing phases, which are characterized by inrush currents and voltage fluctuations. When Crane 1 and Crane 2 operate simultaneously, these load surges accumulate, requiring the generator to operate at higher capacity and for longer periods. This significantly impacts generator performance parameters such as voltage stability, frequency, power factor, and engine operating temperature.

Technically, the dynamic loads generated by operating two cranes simultaneously require a rapid response from the generator control system, specifically the governor and automatic voltage regulator (AVR). An imbalance between power supply and load demand can cause momentary frequency and voltage drops (voltage drops and frequency dips). Research shows that when both cranes are operated simultaneously, these fluctuations occur more frequently than when they are operated alternately. Although the generator system is still able to maintain operation, this condition indicates an increased workload and mechanical and electrical stress on the generator.

In terms of generator performance, simultaneous crane operation results in increased fuel consumption and engine temperature. Generators must operate at higher rpm and loads to meet power requirements, resulting in decreased thermal efficiency. Increased oil and cooling system temperatures indicate that the generator is operating near its optimal limits. In the long term, this condition can accelerate wear on engine components, such as bearings, the combustion system, and electrical components, ultimately reducing the generator's lifespan.

However, from a loading and unloading operational perspective, operating Crane 1 and Crane 2 simultaneously offers significant benefits in terms of time efficiency and productivity. The loading and unloading process is faster, ship berthing time can be shortened, and operational targets can be achieved more effectively. This indicates a trade-off between improving loading and unloading operational performance and increasing generator workload. Therefore, the significant impact of simultaneous crane operation on generator performance is not only technical but also has managerial and economic implications.

The findings of this study also indicate that generator performance stability is highly dependent on the readiness of supporting systems, such as installed generator capacity, load management systems, and routine maintenance. If the generator capacity is designed with adequate power margins and equipped with a proper load-sharing system, the negative impact of operating two cranes

simultaneously can be minimized. Conversely, if the generator capacity is limited or has been suboptimally maintained, simultaneous operation can potentially increase the risk of overload, blackout, or tripping of the protection system.

Conceptually, the results of this study align with the principles of energy management on ships, which state that simultaneous large loads must be managed within the generator's capacity. Simultaneous operation of two cranes constitutes a peak load that requires careful operational planning. Therefore, coordination between crane operators and engine crew is crucial in maintaining a balance between loading and unloading requirements and generator performance.

Thus, the significant influence of the simultaneous operation method of Crane 1 and Crane 2 on the generator performance on the CTS Bulk Derawan vessel indicates that operational decisions cannot be separated from technical considerations of the ship's electrical system. Simultaneous operation does increase loading and unloading efficiency, but also requires better generator management to maintain the stability, reliability, and sustainability of ship operations. The results of this study emphasize the importance of implementing standard operating procedures, real-time electrical load monitoring, and consistent generator maintenance to ensure that operational benefits can be achieved without sacrificing the performance and safety of the ship's electrical system. After analyzing and discussing the research data, answers to the research problem formulation can be formulated. These answers are compiled based on the results of statistical tests and technical discussions that have been explained in the previous section:

1. How does the crane operating method affect generator performance during the loading and unloading process on the CTS Bulk Derawan vessel?

Based on the research results, it can be concluded that the crane operating method significantly affects generator performance during the loading and unloading process on the CTS Bulk Derawan vessel. Simultaneous operation of Crane 1 and Crane 2 causes a significant increase in electrical load due to high power requirements during the starting, hoisting, and slewing phases. This simultaneous operation causes the generator to operate at a higher capacity and duration, thus affecting voltage and frequency stability, fuel consumption, and engine operating temperature. Voltage and frequency fluctuations occur more frequently when both cranes are operated simultaneously compared to when they are operated alternately. Technically, this condition requires a fast response from the governor system and automatic voltage regulator (AVR).

Although the generators were still operational, the increased workload resulted in mechanical and electrical stress that could impact the generators' reliability and lifespan. Thus, the crane operating method was shown to significantly impact the performance of the ship's generators.

2. What is the most efficient crane operating method during the loading and unloading process on the CTS Bulk Derawan vessel?

The most efficient crane operation method is determined based on two aspects: operational loading and unloading efficiency and generator performance efficiency. From an operational perspective, operating Crane 1 and Crane 2 simultaneously is the most efficient method because it can speed up the loading and unloading process, increase productivity, and shorten ship berthing times. However, from a generator performance perspective, alternating crane operation is more efficient because it produces a more stable electrical load, more controlled fuel consumption, and reduces the risk of generator wear and tear.

Based on these two aspects, the most efficient method overall is simultaneous crane operation with good load management, supported by adequate generator capacity and an optimal load regulation system.

KESIMPULAN

This study found that the simultaneous crane operation method on the CTS Bulk Derawan Ship significantly increased the power load of the Caterpillar 3512B generator to an average of 593.5 kW, with a calculated F value of 26.764 and Sig. <0.001 from the ANOVA test, compared to the more stable alternating operation at 165-246 kW, thus affecting the stability of the voltage, frequency,

and engine temperature during coal loading and unloading. This finding confirms the strong influence of independent variables on generator performance, with 87% of the power variation explained by the crane method, although the main limitations lie in the purposive nature of the field sample which depends on the operational schedule of the vessel, thus not including external variables such as extreme weather or full conveyor load, and the lack of homogeneity of variance requires careful interpretation of the parametric test.

Practical implications of the study include recommendations for simultaneous crane operation with optimal load sharing management to balance loading and unloading productivity and generator reliability, including operator coordination and real-time monitoring via ECR to prevent overheating. For future research, it is recommended to develop studies with a completely randomized block design to address variance inhomogeneity, expand the parameters to long-term fuel consumption, and compare similar floating crane vessels in various locations for broader generalization, thereby contributing to more efficient and sustainable maritime operational standards.

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