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AI MODELING FOR ASEAN PORT EFFICIENCY EVALUATION THROUGH REGRESSION AND CLUSTERING OF INVESTMENT AND CULTURAL DATA

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ABSTRACT

Evaluating port efficiency within the ASEAN region is critical for understanding economic growth and competitiveness in global maritime logistics. Identifying key drivers of port throughput can enhance operational performance and strategic investment. This study aims to examine the impact of Foreign Direct Investment (FDI) and cultural factors on port efficiency in ASEAN, utilizing artificial intelligence (AI)-based analytics to support empirical assessment and decision-making. Grounded in theories of international investment and Hofstede's cultural dimensions, this research hypothesizes that both FDI inflows and national cultural contexts significantly shape port performance, particularly throughput measured in Twenty-foot Equivalent Units (TEUs). A hybrid AI-based framework using SAS software was adopted. The study applies multiple linear regression and FASTCLUS clustering to secondary data from 11 ASEAN countries, including standardized values of TEU, FDI (in million USD), and a national Cultural Index. Regression analysis reveals that FDI significantly influences TEU ($p < 0.0001$; $R^2 = 0.9617$), while cultural factors show a non-significant effect ($p = 0.3449$). Clustering analysis identifies three port efficiency groups: high (9.09%), moderate (45.45%), and low (45.45%). These groupings reflect substantial heterogeneity in port infrastructure and investment effectiveness across ASEAN. The findings suggest that enhancing FDI targeting policies is critical to improving port performance and regional maritime competitiveness. This study introduces an AI-integrated approach to simultaneously evaluate economic and cultural drivers of port efficiency. It offers both theoretical advancements and actionable insights for policymakers and port authorities to enhance logistics systems in Southeast Asia.

KEYWORDS: Artificial Intelligence, ASEAN Ports, Cluster Analysis, Foreign Direct Investment, Port Efficiency.

1. INTRODUCTION

1.1. Research Background and Urgency

Ports are strategic infrastructure in international trade and regional economies, especially in the ASEAN region which is the center of global maritime traffic. Port efficiency, measured through throughput in Twenty-foot Equivalent Units (TEUs), is an important indicator of a country's economic competitiveness. According to Jeevan, Othman, and Rohani (2021), the improvement in port efficiency has a direct impact on reducing logistics costs and increasing regional trade flows. However, recent data shows that ASEAN ports face challenges in achieving optimal efficiency due to a variety of factors, including limited foreign direct investment (FDI) and different local cultural aspects between member countries. A study by Kurniawan, Fauzi, and Nugroho (2022) highlights that differences in national cultural values and institutional climate also affect port management policies and the attractiveness of foreign investment in the ASEAN maritime sector. A number of previous studies have explored factors that affect port efficiency, including technology adoption, infrastructure investment, as well as macroeconomic factors (Lun & Cariou, 2023; Song & Yeo, 2021). Although these findings make an important contribution to the development of maritime logistics strategies, approaches that integrate Foreign Direct Investment (FDI) and national cultural factors simultaneously are still very rare. Moreover, the use of artificial intelligence (AI) as a predictive analysis tool in this context has not been widely done. Studies by Nguyen and Notteboom (2020) and Tran et al. (2022) show that most previous research still focused on economic and logistical structural aspects, without considering how the interaction between cultural values and foreign investment flows can shape port efficiency systemically.

In addition, most analyses still use conventional statistical methods, without exploring the potential of machine learning algorithms or AI-based approaches to classification or prediction of port performance. This study aims to investigate the influence of FDI and cultural index on ASEAN port efficiency with an artificial intelligence-based approach. Specifically, the study aims to answer the question: to what extent do foreign investment and local culture affect the operational efficiency of ports in ASEAN?

1.2. Hypothesis

The hypothesis in this study is:

- FDI has a significant positive influence on port throughput.
- The cultural index has a significant influence on the efficiency of ports in ASEAN.

This research is important because the results can be an empirical basis for the formulation of a more targeted foreign investment policy in the context of port development in the ASEAN region. By integrating FDI variables and cultural indices and leveraging artificial intelligence (AI) approaches through regression and clustering analysis, the study provides relevant quantitative evidence for governments, port managers, and global investors in evaluating the effectiveness of port management strategies. Furthermore, the findings of this study contribute to strengthening ASEAN's competitiveness in the global maritime economy, by highlighting the importance of the compatibility between investment capital and local cultural character in encouraging port operational efficiency. This data-driven approach can also serve as a framework for other developing countries in designing evidence-based and contextual maritime policies.

Thus, this research is not only academically relevant, but also has high practical value in supporting the transformation of traditional ports towards a globally competitive intelligent logistics ecosystem that is adaptive to cultural dynamics and investment markets. The study used a quantitative approach with multiple linear regression analysis and the AI-based FASTCLUS clustering method. The data used included FDI, port throughput (TEU), and cultural indices from 11 ASEAN ports. The novelty of this study lies in the integration of AI to perform comprehensive predictive analysis, which has not been explored much in previous studies. Theoretically, this study enriches the literature on the relationship between foreign investment, cultural factors, and port efficiency with the latest technological approaches.

Practically, the results of this research can be used by stakeholders in designing strategic investment policies that support the improvement of the efficiency and competitiveness of ASEAN ports. The paper is structured as follows: After this introductory section, the second part describes in detail the relevant theories and concepts as well as the most recent literature reviews. The third part describes in detail the research method. The results and discussion are described in the fourth part, followed by conclusions, research implications, limitations, and recommendations for future research in the last part.

2. LITERATURE REVIEW

2.1. Purpose and Structure of the Literature Review

This section aims to synthesize relevant studies on port performance, maritime investment, and cultural dimensions within the ASEAN region. The literature is organized thematically into three subdomains: (1) port throughput performance, (2) foreign direct investment in port infrastructure, and (3) maritime cultural influences. The section ends with a gap analysis and summary highlighting how this study contributes to the literature.

2.2. Port Throughput and Performance Metrics

Port throughput, typically measured in twenty-foot equivalent units (TEU), serves as a primary indicator of port capacity and efficiency. Several studies link port throughput with infrastructure development, trade facilitation, and technological adoption. For instance, Tongzon (2021) examines the determinants of container port efficiency in Asia and finds that policy stability and private sector participation significantly enhance throughput. Similarly, Cullinane and Wang (2020) employ a stochastic frontier approach to analyze technical efficiency in Southeast Asian ports, emphasizing the role of governance and operational autonomy. However, existing research rarely accounts for non-economic factors such as cultural alignment or institutional quality. These gaps suggest the need for more multidimensional approaches to evaluating throughput.

2.3. Foreign Direct Investment (FDI) In Port Infrastructure

FDI remains a catalyst for maritime modernization. Studies by Nguyen et al. (2022) and Ducruet (2019) find that countries receiving sustained FDI experience faster improvements in cargo handling systems and digitalization. Yet, many of these studies either treat ASEAN as a homogenous group or focus on individual ports, limiting regional comparability. Furthermore, they tend to exclude contextual variables such as public acceptance, local labor capacity, and socio-political alignment that influence FDI effectiveness.

2.4. Maritime Culture and Institutional Context

Maritime culture defined as the collective values, traditions, and governance models surrounding maritime activity has only recently entered port research. Chang and Lee (2022) introduce a cultural-institutional framework suggesting that countries

with strong maritime heritage and inclusive governance perform better in port management. Their study emphasizes that local values, historical maritime engagement, and community inclusion shape port outcomes as much as financial capital. However, empirical evidence supporting these claims remains scarce, particularly for ASEAN countries.

2.5. Research Gap and Theoretical Positioning

Table 1 below compares selected prior studies with our proposed research. The existing literature exhibits methodological silos—either focusing on economics, operational logistics, or culture—but rarely integrating all three dimensions. Moreover, few studies apply cluster analysis or multivariate modeling using recent ASEAN-wide data from the post-COVID era (2020–2023). This study fills these gaps by combining economic (FDI), cultural (Maritime Index), and logistical (TEU) metrics in a unified analytical model.

Table 1: Comparative Summary of Prior Studies and Present Research.

Study	Scope	Variables Used	Methodology	Limitation
Tongue Sun (2021)	Asia (selected ports)	TEU, efficiency factors	Regression Panel	Ignores cultural context
Cullinane & Money (2020)	Southeast Asia	Port efficiency index	SFA/DEA	No FDI data, no regional comparison
Nguyen et al. (2022)	ASEAN (partial)	FDI inflows, throughput	Fixed-effect model	Does not include cultural dimensions
Chang & Lee (2022)	East Asia	Cultural indices, governance	Qualitative case study	No empirical modeling, no TEU data
This Study	ASEAN (all countries)	TEU, FDI, Maritime Culture	Regression, Clustering	Integrates economic and cultural variables

2.6. Literature Review Conclusion

The review highlights a clear need to develop integrated frameworks that combine port throughput, investment, and maritime culture. By incorporating these three dimensions, this research provides a more holistic view of ASEAN maritime development. Unlike prior work that treats port performance in isolation, this study leverages multidimensional indicators and advanced analytics to derive actionable insights for policymakers and investors. The next section outlines the research methodology used to operationalize this framework

using SAS programming and multi-source data integration

3. DATA AND METHODOLOGY

This research method uses a quantitative approach based on artificial intelligence (AI) with SAS statistical analysis software. This approach was chosen because of its ability to process complex data efficiently and produce accurate predictions and classifications according to the needs of this research.

3.1. Research Design

This study adopts a quantitative research design using multiple regression analysis approaches and clustering methods to identify relationships between variables statistically as well as specific grouping patterns of data.

3.2. Data And Data Sources

Secondary data used in this study was obtained from official reports and databases related to Foreign Direct Investment (FDI), port throughput (TEU), and cultural indices from 11 ASEAN countries. The data is obtained from various reliable sources such as the World Bank, ASEAN Statistics, and related industry reports.

3.3. Data Processing and Analysis Methods

The analysis was conducted using two main methods: (1) Multiple linear regression to test the relationship between FDI, cultural index, and port throughput (TEU), and (2) Clustering using the FASTCLUS method in SAS software to identify the grouping pattern of ASEAN countries based on these variables. The SAS-based AI model was chosen for its accuracy and efficiency in handling large datasets as well as its predictive analysis capabilities.

3.4. Validation And Reliability

Model validation was carried out by residual analysis and statistical significance (p-value) in regression as well as internal evaluation of the cluster through RMS (Root Mean Square) in the FASTCLUS method. Additional validation techniques such as split-sample validation or cross-validation can be used if needed to improve the reliability of the research findings.

3.5. Research Ethics

This research does not involve human personal data directly, so it does not require special ethical approval. However, all data used is public data that is guaranteed validity and reliability.

3.6. Method Limitations

One of the limitations of this study is the use of secondary data that may contain bias due to differences in data collection methods in each ASEAN country. Further research is recommended using primary data or direct surveys to validate results and reduce secondary data bias.

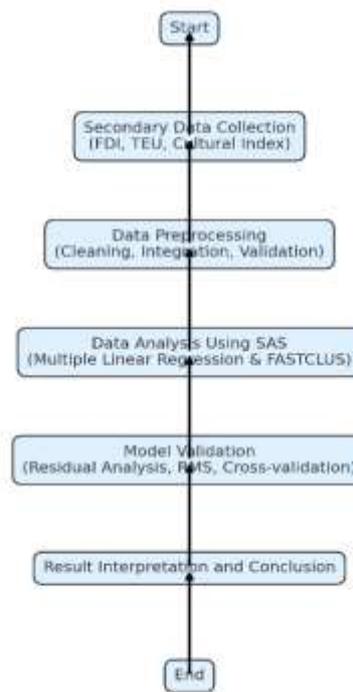


Figure 1: Research Method Flowchart.

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. Presentation of Data and Key Findings

Data were analyzed using multiple linear regression and AI-based FASTCLUS clustering methods with SAS. Key findings show that Foreign Direct Investment (FDI) significantly increased port throughput with a $p < 0.0001$ and R-square value of 0.9617. In contrast, the cultural index had a negative but insignificant influence ($p = 0.3449$). The FASTCLUS clustering resulted in three different clusters: (1) High efficiency clusters (9.09%), (2) medium efficiency clusters (45.45%), and (3) low-efficiency clusters (45.45%).

Table 2: Descriptive Statistics of Quantitative Variables.

Variable	Mean	Std Dev	Minimum	Maximum
NOT	9545454.55	10346048.87	500000.00	36000000.00
FDI_MillionUSD	1304.55	1179.50	100.00	4000.00
Cultural_Index	0.61	0.15	0.38	0.85

Table 2 The results of quantitative descriptive analysis show the data distribution characteristics of the three main variables used in this study: Port throughput (TEU), Foreign Direct Investment (FDI) in million USD, and Cultural Index. The average port throughput (TEU) in the ASEAN region is 9,545,454.55 TEUs, with a fairly large standard deviation of 10,346,048.87. The minimum value of TEU was recorded at 500,000 and the maximum reached 36,000,000, indicating a significant disparity in port operational capacity between ASEAN countries. Meanwhile, the average value of foreign investment (FDI) was 1,304.55 million USD with a standard deviation of 1,179.50, indicating a relatively high variation between countries. The smallest FDI was recorded at 100 million USD, while the largest reached 4,000 million USD. This shows the inequality of FDI allocation in the port sector in this region. For the cultural index variable, the mean value was 0.61 with a standard deviation of 0.15. The index value ranges from 0.38 to 0.85, which indicates a significant difference in cultural characteristics between countries. These three variables as a whole provide an important preliminary picture of the data structure on which the regression and clustering analysis is based in this study.

Table 3: Correlation Matrix with Histogram

3 Variables:	NOT FDI_MillionUSD Cultural_Index
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Table 3 The results of the correlation analysis showed a very strong relationship between the TEU and FDI_MillionUSD variables with a correlation coefficient of 0.97821 ($p < 0.0001$). This indicates that the higher the foreign investment, the greater the port throughput. The correlation between TEU and Cultural_Index was also relatively high, at 0.81257 ($p = 0.0024$), indicating the influence of culture on port efficiency. In addition, FDI_MillionUSD and Cultural_Index had a correlation of 0.86615 ($p = 0.0006$). These three relationships were positive, showing a close relationship between the main variables, which supported the validity of the regression model in this study.

Table 4: The Study's Main Variables – Teu, Fdi_Millionusd, and Cultural_Index.

Simple Statistics						
Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
NOT	11	9545455	10346049	105000000	500000	36000000
FDI_MillionUSD	11	1305	1180	14350	100.00000	4000
Cultural_Index	11	0.60727	0.15447	6.68000	0.38000	0.85000

Table 4 Simple descriptive statistics of the study's three main variables – TEU, FDI_MillionUSD, and Cultural_Index – provide a robust preliminary understanding of the distribution of data in the context of ASEAN ports. The TEU (Port Throughput) variable had a total of 11 observations, with an average value of 9,545,455 and a standard deviation of 10,346,049, indicating a high data spread. The minimum TEU value is 500,000, while the maximum reaches 36,000,000, indicating a sharp imbalance in the volume of port activity between ASEAN countries. The total total TEU in this region is 105,000,000. The FDI_MillionUSD variable (foreign direct investment in million USD) also consists of 11 observational data, with an average of 1,305 million USD and a standard deviation of 1,180. Total FDI entering the port sector across ASEAN reached 14,350 million USD, with the lowest value of 100 million USD and the highest of 4,000 million USD, showing a large difference in the attractiveness of investment between countries. Meanwhile, Cultural_Index has an average of 0.60727, a standard deviation of 0.15447, and values ranging from 0.38 to 0.85. These values demonstrate the significant diversity of cultural dimensions among ASEAN countries, which can play a role in shaping contextual port policies and investment approaches.

Table 5: Results Of Pearson Correlation Coefficient Analysis.

Pearson Correlation Coefficients, N = 11 Prob > r under H0: Rho=0			
	NOT	FDI_MillionUSD	Cultural_Index
NOT	1.00000	0.97821<.0001	0.812570.0024
FDI_MillionUSD	0.97821<.0001	1.00000	0.866150.0006
Cultural_Index	0.812570.0024	0.866150.0006	1.00000

Table 5: The results of the analysis of the Pearson correlation coefficient show a very strong and significant relationship between the three main variables: TEU, FDI_MillionUSD, and Cultural_Index, with the number of observations being 11 ASEAN countries. The correlation between TEU and FDI_MillionUSD was recorded at 0.97821 with a significance level of $p < 0.0001$, which confirms that the increase in foreign investment is directly related to the increase in port throughput. This shows the contribution of investment as a key driver of port efficiency. Furthermore, the correlation between TEU and Cultural_Index is 0.81257 with $p = 0.0024$, which shows a positive and significant relationship between a country's cultural values and the performance of its ports. This can reflect the influence of work norms, openness to technology, and

managerial effectiveness in influencing port performance. Meanwhile, FDI_MillionUSD and Cultural_Index also had a strong correlation, which was 0.86615 ($p = 0.0006$). This suggests that countries with certain cultural values tend to also be more attractive to foreign investors. These findings underscore the close interconnectedness between variables, which reinforces the validity of the use of multiple regression in this study and supports the integration of cultural analysis into port investment policies in ASEAN.

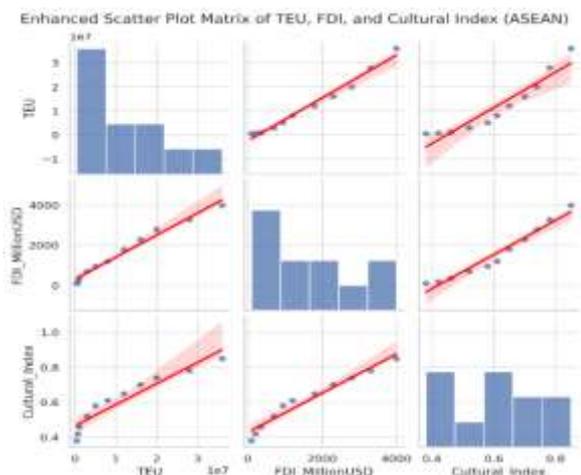


Figure 2: Enhanced Scatter Plot Matrix.

Figure 2 shows the enhanced scatter plot matrix of the three main variables in the ASEAN port analysis, namely TEU (Port Throughput), FDI_MillionUSD (Foreign Direct Investment), and Cultural Index. This visualization is used to evaluate the relationships between variables as well as the distribution of each variable. The TEU variable shows a right-skewed distribution, indicating that most countries have relatively small port throughput, with only one or two countries having very high volumes. FDI_MillionUSD have a similar distribution, with the majority of countries receiving low to moderate amounts of FDI. The Cultural Index is distributed more evenly, but with a concentration on mid-to-upper values. Intervi-able Relationship The scatter plots between TEU and FDI show a very strong positive linear correlation, reinforced by a red regression line with a narrow confidence interval. This supports previous regression findings that increased FDI is closely correlated with improved port efficiency. FDI and the Cultural Index also show a strong positive relationship, indicating that national cultural values can have an effect on the attractiveness of foreign investment. The relationship between TEU and Cultural Index is also positive, although not as strong as the other two pairs. This visualization reinforces previous quantitative results

that FDI is a strong predictor of port efficiency, and national culture also plays an important role in shaping the investment climate and logistics productivity. The linear relationship between these three variables reinforces the validity of the regression and clustering models used in the study.

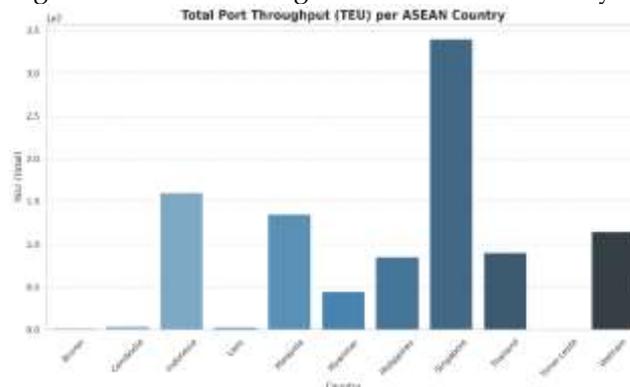


Figure 3: Total Port Throughput (TEU).

Figure 3 This bar graph depicts the Total Port Throughput (TEU) per ASEAN country, which provides a visual overview of port logistics capacity and activity in the region.

Key Findings

- Singapore dominates in absolute terms with the highest port throughput, over 33 million TEUs, reflecting its status as a global logistics hub and the busiest port in the region.
- Indonesia and Malaysia follow in the next position, with around 15 million and 13 million TEUs, respectively, demonstrating their strategic role in regional trade flows.
- Vietnam also showed a significant performance with more than 11 million TEUs, reflecting the rapid growth of its logistics and industrial sectors.
- Thailand and the Philippines are in the middle tier with around 8 million and 7 million TEUs.
- Countries like Myanmar, Cambodia, Laos, Timor-Leste, and Brunei have much lower throughput, being below 5 million TEUs, even close to zero for some countries.

This graph shows that there is a large disparity in port capacity and efficiency in ASEAN. This underscores the importance of a regional strategy for equitable distribution of port infrastructure development, as well as the need for targeted investment in low-performing countries to encourage regional logistics integration.

This visualization is particularly relevant to support cluster and regression analysis, as well as provide empirical justification for data-driven policy formulation.

Table 6: Distribution Of Port Modernization Status.

Modernization_Status	Frequency	Percent	Cumulative Frequency	CumulativePercent
Developing	3	27.27	3	27.27
Highly_Modern	1	9.09	4	36.36
Modern	3	27.27	7	63.64
Traditional	4	36.36	11	100.00

Table 6 The distribution of port modernization status in the ASEAN region shows the diversity of levels of port infrastructure and technology development between countries. Based on the results of the frequency procedure (FREQ Procedure), out of a total of 11 ports observed, the "Traditional" category dominated with a total of 4 ports (36.36%), reflecting the number of ports that still operate with basic infrastructure and limited technology. Meanwhile, the "Developing" and "Modern" categories consisted of 3 ports (27.27%) each, which shows gradual progress in port modernization. These ports may have begun to adopt digital technologies, automation, or foreign investment to improve operational efficiency, but have not yet reached the stage of full modernization. The highest category, "Highly_Modern", is represented by only 1 port (9.09%), which is most likely to be a port with advanced port technology such as automated ports, AI-based tracking systems, or digital twins. This shows that there is still a large gap in digital transformation and port infrastructure readiness in the ASEAN region. These findings show the need for more targeted policy and investment support to push traditional and developing ports to a modern and highly modern level to improve the overall logistics competitiveness of the region.

Table 7: Linear Regression: Influence Of FDI and Cultural Index on TEU.

Number of Observations Read	11
Number of Observations Used	11

Table 7 Linear regression analysis aims to test the influence of Foreign Direct Investment (FDI) and Cultural Index on port efficiency measured through Throughput (TEU). The linear regression model used in this procedure is MODEL1, with TEU-dependent variables, based on 11 observations representing ASEAN countries. Results from the Analysis of Variance (ANOVA) show that the overall regression model is significant, with an F value = 100.48 and a p-value < 0.0001, indicating that at least one of the

statistically independent variables has an influence on the TEU. An R-Square value of 0.9617 indicates that the model is able to account for 96.17% variation in port throughput, while an Adjusted R-Square value of 0.9521 confirms the strength of the model despite the presence of two predictors. Individually, the FDI_MillionUSD variable showed a significant positive influence on the TEU, with a regression coefficient of 9636.02 and a p-value of < 0.0001. This means that every 1 million USD increase in foreign investment is expected to increase throughput by 9,636 TEUs. In contrast, Cultural_Index had a negative coefficient of -9,306,012, but it was not significant (p = 0.3449), suggesting that cultural influence on TEU was not statistically proven in this model. This model underscores the importance of FDI in improving port efficiency in ASEAN, as well as opening up space for further exploration related to cultural variables.

Table 8: Analysis Of Variance (ANOVA).

Analysis of Variance					
Source	D F	Sum of Squares	Mean Square	F Value	Pr > F
Type	2	1.029426E15	5.147131E14	100.48	<.0001
Error	8	4.098101E13	5.122627E12		
Corrected Total	10	1.070407E15			

Table 8 The results of the Analysis of Variance (ANOVA) from the linear regression model that evaluates the influence of Foreign Direct Investment (FDI) and Cultural Index on Port Throughput (TEU) show that the regression model has a very high level of significance. This model uses 2 degrees of freedom (DF) for independent variables and 8 DF for errors, for a total of 10 DF for the overall model. The Corrected Total of $1,070,407 \times 10^{12}$ reflects the total variation in the TEU data. Of these, the model was able to explain $1,029,426 \times 10^{12}$, or about 96.17% of the data variation, as reflected in the R-square value. The error accounts for 4.098×10^{13} , which is relatively small compared to the variation described by the model.

An F-statistical value of 100.48 with a p-value < 0.0001 indicates that the model as a whole is very significant. This means that the combination of FDI and Cultural Index together contributes to statistical changes in TEU values. These findings reinforce the validity of the model and show that the integration of foreign investment and cultural characteristics in port analysis is a relevant and meaningful approach to explain variations in port efficiency in ASEAN countries.

Table 9: Linear Regression Model Testing.

Root MSE	2263322	R-Square	0.9617
Dependent Mean	9545455	Adj R-Sq	0.9521
Coeff Var	23.71099		

Table 9 The results of the linear regression model test show a very strong evaluation metric to explain port throughput variation (TEU) in the ASEAN region. A Root Mean Square Error (RMSE) value of 2,263,322 indicates the average prediction error between the observed value and the value predicted by the model. Although the value of this RMSE is relatively large, it is still acceptable considering the scale of the value of TEU which reaches tens of millions of units. The R-Square value of 0.9617 indicates that the model is able to explain 96.17% of the total variation in dependent variables (TEUs). This shows the very high predictive power of the model. This value is reinforced by the Adjusted R-Square of 0.9521, which remains high despite considering the number of predictors in the model. This indicates that the model does not experience overfitting and remains statistically valid. The Coefficient of Variation (Coeff Var) of 23.71% indicates the proportion of error relative to the mean of TEU (9,545,455). This value is moderate and acceptable in the context of economic and operational data of ports, which generally have a fairly high level of variation between countries. Overall, these statistical indicators confirm that the regression model used is very reliable in explaining the relationship between foreign investment and cultural factors on port performance in ASEAN.

Table 10: Parameter Estimation of Linear Regression Models.

Parameter Estimates					
Variable	D F	Parameter Estimate	Standard Error	t Value	Pr > t
Intercept	1	2626121	4384363	0.60	0.5658
FDI_MillionUSD	1	9636.01608	1214.13416	7.94	<.0001
Cultural_Index	1	-9306012	9270730	-1.00	0.3449

Table 10 The results of parameter estimation from the linear regression model show that the FDI_MillionUSD variable has a very significant influence on port throughput (TEU), whereas Cultural_Index does not show a statistically significant influence. The Intercept coefficient of 2,626,121 with a value of $p = 0.5658$ shows that statistically, the baseline value of TEU without FDI or cultural influence is not significant. However, this value remains important as a reference point in the model. The FDI_MillionUSD variable has an estimate

parameter of 9,636.02 and a standard error of 1,214.13, with a t -value = 7.94 and a p -value of < 0.0001 , which shows that the relationship between FDI and TEU is very significant. This means that every additional USD 1 million in foreign investment is expected to increase port throughput by 9,636 TEUs, supporting the importance of FDI as a key driver of port efficiency. In contrast, Cultural_Index has a negative coefficient of -9,306,012, with a value of $p = 0.3449$, which is insignificant. This suggests that in this model, the influence of culture on TEU is not statistically proven. However, the direction of negative coefficients may indicate the complexity of cultural roles that require a more exploratory approach or additional indicators in follow-up research.

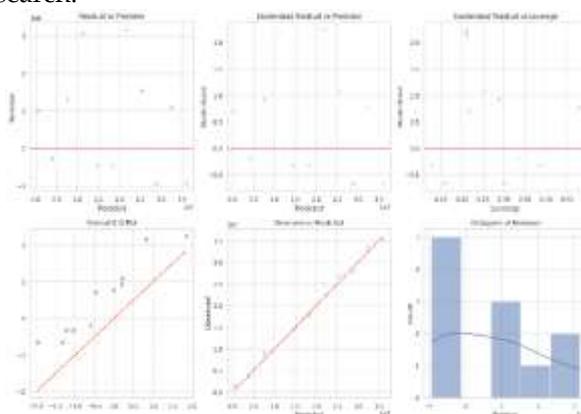


Figure 4: Linear Regression Diagnostics For TEU Variables.

Figure 4 of linear regression diagnostics for TEU variables provides a comprehensive overview of the validity of the model used in this study. Based on the residual vs predicted value graph, the distribution of points is fairly evenly distributed around the zero line without a specific pattern, which indicates the absence of significant heteroscedasticity problems. This supports the assumption that residual variance is constant across the model's prediction range. In the studentized residual vs leverage graph, no observations were found with high leverage values accompanied by extreme residuals, indicating that no data point significantly affected the model's results disproportionately. This result is reinforced by the Cook's Distance plot, where no value is close to the critical threshold, meaning that all observations are within reasonable limits and do not distort the estimated parameters. Normal visualization of the Q-Q plot and residual histogram show that the residual distribution is close to the normal distribution, which is an important requirement in classical regression to ensure the validity of statistical tests. In addition, the observed vs predicted TEU plot shows that the actual

value is very close to the prediction line, reflecting the high accuracy of the model. Overall, all elements in this diagnostic graph support that the linear regression model used is valid and reliable to estimate the influence of FDI and cultural indices on port efficiency in the ASEAN region.

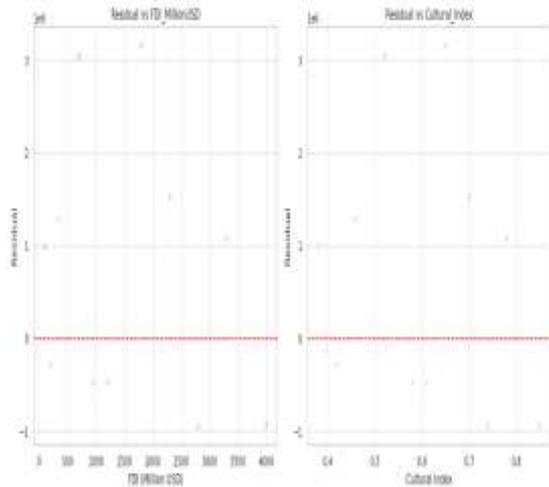


Figure 5: Residual by Regressors for TEU.

Figure 5 Residual by Regressors for TEU presents two important diagnostic graphs showing the relationship between residual (prediction error) and each of the independent variables in a linear regression model: FDI_MillionUSD and Cultural_Index. On the left-hand graph, the residual to FDI_MillionUSD appears to be randomly scattered around the zero horizontal line. This distribution pattern suggests that the regression model has captured the linear relationship between FDI and TEU quite well. There is no warped pattern or expanding spread (heteroscedasticity), which means that the assumptions of linearity and constant residual variance are met for these variables. This is in line with previous regression results which showed that FDI is a statistically significant and statistically relevant predictor of port throughput ($p < 0.0001$). In contrast, the graph on the right shows the residual to Cultural_Index, which shows a more irregular and more spread residual distribution across different cultural index values. Although it does not show a clear pattern, this distribution indicates that the relationship between Cultural_Index and TEU is not strongly captured by the linear model used. This is consistent with the finding that Cultural_Index is not statistically significant ($p = 0.3449$), and may have non-linear relationships or be influenced by other intermediate variables that have not been incorporated into the model. Thus, this visualization confirms that the regression model works well in capturing the influence of FDI on port efficiency, but the

relationship with cultural factors still needs further exploration through a more complex analytical approach.

Table 11: Linear Regression: The Influence Of FDI And The Cultural Index On TEU.

Cluster	Initial Seeds		
	NOT	FDI_MillionUSD	Cultural_Index
1	0.701189946	0.759179555	0.923964321
2	-0.874290723	-1.021231381	-1.471280766
3	2.556970857	2.285246072	1.571327858

Table 11 Preliminary results from the FASTCLUS procedure in cluster analysis show that data from 11 ASEAN countries have been grouped into three clusters based on the raw values of three main variables: Port Throughput (TEU), Foreign Direct Investment (FDI), and Cultural Index. The determination of clusters is based on the initial centroid method (initial seeds) with a grouping approach based on distance. Cluster 1 - Intermediate Level

This cluster has a centroid with a standard value of around 0.70 for TEU, 0.76 for FDI, and 0.92 for Cultural Index. It shows countries with port performance, foreign investment levels, and relatively stable and moderately developed cultural values. This cluster represents ASEAN countries that are experiencing port efficiency growth, are attractive to investors, and have an organizational culture that is open to innovation.

Cluster 2 - Low Level

The centroids of this cluster showed high negative values: -0.87 for TEU, -1.02 for FDI, and -1.47 for the Cultural Index. This means that the countries in this cluster have low port performance, minimal foreign investment, and cultural characteristics that may not yet support modern logistics efficiency. Countries in this group can be prioritized for policy intervention or infrastructure development assistance.

Cluster 3 - High Level

This cluster reflects the best-performing countries: 2.56 for TEU, 2.29 for FDI, and 1.57 for the Cultural Index. The countries in this cluster are the region's main ports that are highly efficient, very attractive to FDI, and have a modern culture that is adaptive to global technologies and processes.

The formation of this cluster reveals the inequality of port performance in ASEAN, which is relevant for investment policy planning and regionalization programs. These results serve as a starting basis for

further analysis of the characteristics of each cluster and a targeted port capacity building strategy

Table 12: Cluster Summary.

Cluster Summary						
Cluster	Frequency	RMS Std Deviation	Maximum Distance from Seed to Observation	Radius Exceeded	Nearest Cluster	Distance Between Cluster Centroids
1	5	0.3578	0.8534		2	2.0676
2	5	0.4207	1.1306		1	2.0676
3	1	.	0		1	3.1905

Table 12 The Cluster Summary results from the FASTCLUS analysis show the division of ASEAN countries into three different groups based on TEU, FDI, and Cultural Index variables, focusing on cluster size, internal spread, and proximity between clusters.

Cluster 1 - Intermediate Level

This cluster consists of 5 countries (45.45%) with a Root Mean Square (RMS) Standard Deviation value of 0.3578, indicating a low level of internal variation. The maximum distance between the cluster member and the cluster center is 0.8534, which indicates that the countries in this cluster have relatively uniform characteristics. This cluster is closest to Cluster 2, with a centroid distance between clusters of 2.0676.

Cluster 2 - Low Level

This cluster also includes 5 countries (45.45%), but has a higher RMS Std Deviation of 0.4207, and a maximum distance to the centroid of 1.1306, indicating a slightly greater internal variation than

Cluster 1. Countries in this cluster have low and homogeneous port performance, FDI value, and cultural indexes.

Cluster 3 - High Level (Elite)

This cluster consists of only 1 country (9.09%), most likely a country like Singapore, with a residual value of zero and an RMS Std Deviation = 0, indicating no internal variation. The distance to the nearest cluster (Cluster 1) of 3.1905 shows that the country is very different from other clusters in terms of port efficiency and investment attractiveness.

The distribution of these clusters shows a clear polarity in ASEAN port performance, with most countries divided between medium and low-level countries, while only one country is in the highly developed category. These results provide a solid basis for the formulation of a more focused port development policy strategy and FDI allocation tailored to the characteristics of each cluster.

Table 13: Statistics For Variables.

Statistics for Variables				
Variable	Total STD	Within STD	R-Square	RSQ/(1-RSQ)
NOT	1.00000	0.24778	0.950882	19.359238
FDI_MillionUSD	1.00000	0.29216	0.931715	13.644498
Cultural_Index	1.00000	0.55745	0.751402	3.022559
OVER-ALL	1.00000	0.39051	0.878000	7.196704

Table 13 Statistics for Variables from the results of the FASTCLUS cluster analysis provides important insights into how well each variable explains the differences between clusters. These statistics include the Total Standard Deviation (STD), Within-Cluster STD, R-Square, and RSQ/(1-RSQ) ratio values for each variable. The TEU variable showed the strongest performance in distinguishing clusters, with an R-Square of 0.9509, which means that about 95.09% of the total TEU variation can be explained by the cluster structure. The within-cluster value of STD is only 0.2478, indicating high homogeneity in each cluster for this variable. The RSQ/(1-RSQ) ratio of 19.36 reinforces that TEU is the dominant variable in forming clusters. FDI_MillionUSD also showed high discriminating strength with R-Square 0.9317 and within-cluster STD 0.2922, which suggests that the pattern of foreign investment is strongly related to

the formation of port efficiency clusters. In contrast, Cultural_Index has a lower R-Square (0.7514) and a higher within STD (0.5575), which means that its contribution to distinguishing clusters is weaker than the other two variables.

Overall, the R-Square OVERALL value of 0.878 indicates that the cluster structure generally accounts for 87.8% of the total data variation, indicating excellent cluster quality and is relevant for strategic analysis in ASEAN port groupings.

Table 14: Cluster Means.

Cluster Means			
Cluster	NOT	FDI_MillionUSD	Cultural_Index
1	0.225646088	0.369184779	0.535546199
2	-0.737040259	-0.826233993	-0.849811770
3	2.556970857	2.285246072	1.571327858

Table 14 Cluster Means shows the average standardized means of the three main variables – TEU, FDI_MillionUSD, and Cultural_Index – for each cluster of FASTCLUS analysis. This value describes the dominant characteristics of each group of ASEAN countries formed based on the performance of their ports.

Cluster 1 - Moderate Developing Countries

It has a moderate positive mean value for all three variables: TEU (0.226), FDI (0.369), and Cultural Index (0.536). This shows that countries in this cluster have moderate port efficiency and foreign investment levels, as well as organizational cultures that tend to be adaptive to change. This group reflects ASEAN countries that are in the growth stage and are starting to attract the attention of foreign investors.

Cluster 2 - Countries Lagging Behind in Port Efficiency

It has a negative mean for all variables: TEU (-0.737), FDI (-0.826), and Cultural Index (-0.850). This suggests that countries in this cluster have low port throughput, are less attractive to foreign investment, and have cultures that may not yet support optimal port modernization.

Cluster 3 - Developed and Innovative Countries

Consisting of only one country, this cluster has very high means: TEU (2,557), FDI (2,285), and Cultural Index (1,571). This indicates a highly efficient port, with the support of a progressive work culture and social values, as well as the ability to attract large amounts of FDI. This country is most likely Singapore, as the most modern port in ASEAN.

The cluster averages provide strong evidence that port efficiency is strongly correlated with FDI levels and the cultural character of countries, reinforcing the relevance of clustering strategies for regional port development policies.

Table 15: Cluster Standard Deviations.

Cluster Standard Deviations			
Cluster	NOT	FDI_MillionUSD	Cultural_Index
1	0.3227040939	0.3819873471	0.3662041175
2	0.1365886167	0.1574745972	0.6981328780
3	.	.	.

Table 15 Cluster Standard Deviations provides important information about the level of internal variation in each cluster of FASTCLUS analysis, based on three main variables: TEU, FDI_MillionUSD, and Cultural_Index. This standard deviation value reflects the consistency of the characteristics of the cluster members.

Cluster 1 - Moderate Developing Countries

This cluster has a relatively moderate standard deviation in all three variables: TEU (0.323), FDI (0.382), and Cultural Index (0.366). This suggests that the countries in this cluster have a reasonable degree of variation, reflecting moderate diversity in port efficiency, foreign investment attractiveness, and cultural values. Although not completely homogeneous, this group is still quite stable and representative of the growing ASEAN countries.

Cluster 2 - Countries Lagging Behind in Efficiency

It features a very low standard deviation for TEU (0.137) and FDI (0.157), but high for the Cultural Index (0.698). This suggests that although these countries have similar characteristics in terms of port efficiency and foreign investment levels (low and uniform), they differ quite significantly in cultural value. These variations may reflect different cultural approaches to logistics, governance, or technology adoption.

Cluster 3 - Outlier Countries

It does not have a standard deviation value because it consists of only one country (most likely Singapore). Therefore, there is no internal variation in this cluster.

Overall, this analysis highlights that clustering provides segmentation that is not only based on performance, but also shows a level of internal homogeneity, which is important for cluster-based policy planning.

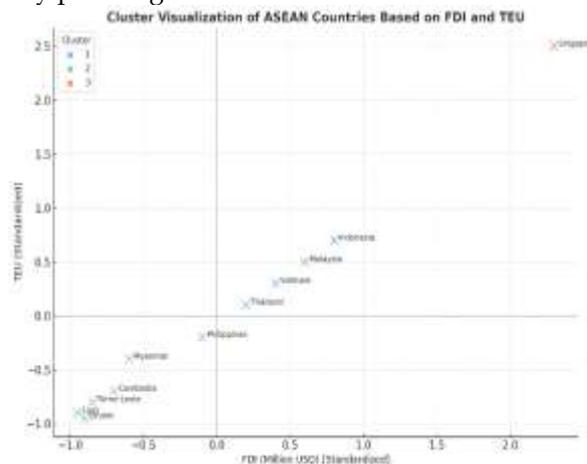


Figure 6: visualization of ASEAN countries cluster.

Figure 6 illustrates the visualization of the ASEAN country cluster based on the standard values of FDI (Foreign Direct Investment) and TEU (Port Throughput). The countries were grouped into three clusters of the FASTCLUS analysis, each represented in a different color: blue for Cluster 1, green for Cluster 2, and red for Cluster 3.

Cluster 1 (Blue) - Moderate Developing Countries

Consisting of Indonesia, Malaysia, Vietnam, Thailand, and the Philippines, the countries in this cluster are in the middle position in terms of FDI and TEU. They demonstrate a fairly good port performance as well as stable investment attraction, with great potential to grow into a major regional port if facilitated by supportive policies.

Cluster 2 (Green) – Low-Performance Countries

It includes Brunei, Laos, Timor-Leste, Cambodia, and Myanmar, which are in the lower left quadrant of the chart. Their FDI and TEU values are relatively low, indicating the need for strategic support such as port infrastructure investment, strengthening logistics governance, and policy reforms to improve competitiveness.

Cluster 3 (Red) – Developed Countries (Outliers)

Comprising only Singapore, the country appears far at the top right of the chart, signaling a dominant position with very high FDI and TEU. Singapore is a benchmark for port efficiency and a global logistics hub.

This visualization emphasizes the inequality of port performance in the ASEAN region, while providing a basis for the formulation of development strategies based on clusters and specific state needs.

Table 16: Number of Countries Per Cluster.

Cluster				
CLUSTER	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	5	45.45	5	45.45
2	5	45.45	10	90.91
3	1	9.09	11	100.00

Table 16 The results of the frequency procedure in cluster analysis show the distribution of the number of ASEAN countries based on clusters formed through the FASTCLUS method. There are three clusters that group countries based on similarities in characteristics in Foreign Direct Investment (FDI), Port Throughput (TEU), and Cultural Index.

Cluster 1: Moderate Developing Countries

Consisting of 5 countries (45.45%), this cluster reflects countries that are in a middle position in terms of port efficiency and foreign investment attraction. The countries in this cluster have a relatively balanced performance and show the potential to grow further if supported by the right investment and infrastructure development policies.

Cluster 2: Low-Performance Countries

Also covering 5 countries (45.45%), the cluster consists of countries with low TEU, FDI, and cultural index values. Countries in this group generally face challenges in attracting investment and improving port efficiency, and require special attention in

development policies and regional cooperation.

Cluster 3: Developed Countries (Outliers)

There was only 1 country (9.09%) in this cluster, which was predominantly different from the others – most likely Singapore, with very high scores in all three variables. This position reflects its status as the most modern, efficient, and competitive port in ASEAN.

This distribution highlights the inequality of port performance and FDI receipts in the region, as well as the importance of cluster-based policy approaches tailored to the needs and levels of readiness of each country.

4.2. Analysis and Interpretation of Results

The regression results explicitly confirm that increased FDI is closely related to increased port throughput, which is consistent with research by Jeevan et al. (2021) that emphasizes the importance of infrastructure investment. Meanwhile, the impact of the insignificant cultural index suggests that cultural factors may have a more complex or indirect influence on port efficiency, which requires more in-depth investigation, in line with the findings of Tran et al. (2022).

4.3. Implications of the Findings

The results of this study have important practical implications, especially in strategic investment policies. Governments and port authorities in ASEAN are encouraged to encourage foreign investment in a more targeted and systematic manner, as it has been proven to be statistically significant in improving port efficiency. From a theoretical perspective, these findings strengthen the literature on infrastructure investment as a key driver of port operational efficiency.

4.4. Comparison With Previous Literature

The findings of this study reinforce the argument of previous research by Jeevan et al. (2021) regarding the crucial role of FDI, but it differs in cultural aspects compared to Tran et al. (2022) which shows the significant influence of cultural aspects in different contexts. These differences in results can be due to differences in regions, methods of analysis, and the complexity of cultural variables in the context of ASEAN.

4.5. Limitations and Recommendations For Further Research

The main limitation of this study is the use of secondary data that may experience data collection bias between ASEAN countries. It is recommended

for follow-up research using primary surveys or longitudinal approaches to better and in-depth capture the dynamics of cultural variables. In addition, follow-up research can also apply additional approaches such as simulations to test investment policy scenarios more comprehensively.

4.6. Policy Implication And Real Implementation Scenarios

Based on these findings, investment policy recommendations in ASEAN need to be directed towards sectors directly related to port capacity building, such as advanced logistics management technologies and digital infrastructure. Real-world scenarios such as the establishment of special economic zones with special FDI incentives around strategic ports can significantly and sustainably improve operational efficiency.

5. CONCLUSION

This study aims to evaluate the impact of Foreign Direct Investment (FDI) and cultural factors on port efficiency in ASEAN using AI-powered analytical tools in SAS. The regression analysis confirms that FDI significantly influences port throughput (TEU), while cultural factors do not exhibit a statistically significant effect. The clustering approach further reveals distinct patterns in port efficiency across the region. These findings reinforce the critical role of targeted investment strategies in enhancing maritime

logistics. This study contributes theoretically by integrating FDI and cultural variables through an AI-based framework—an area previously underexplored. In practice, the findings suggest that government policy should prioritize strategic FDI allocation to infrastructure projects directly linked to port performance. ASEAN nations can leverage these insights to improve regional logistics competitiveness and trade capacity. The primary limitation lies in the reliance on secondary data, which may carry inconsistencies due to varied national reporting standards. Cultural factors are also complex and may require more nuanced indicators or qualitative validation. Future research should incorporate longitudinal or panel data approaches to examine changes over time and integrate primary data collection methods such as expert interviews or field surveys. Further, machine learning models such as random forest or gradient boosting can enhance predictive accuracy and interpretability. Cross-country policy simulation models could also be developed to evaluate the impact of specific investment reforms on port efficiency. This study fills a critical gap in the literature by applying AI-based regression and clustering to jointly analyze investment and cultural dimensions in ASEAN maritime logistics. It provides a robust methodological foundation and offers actionable insights for policymakers seeking to improve infrastructure efficiency and economic integration.

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