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The Econometric Model of Ship-generated Operational Waste: The Underlying Tool for Waste Management in Container Port

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Abstract

Marine pollution prevention through adequate provision of garbage reception facility (GRF) is a legal obligation of every port. According to MARPOL 73/78, each port authority should explore ways to increase its ability to prevent marine pollution from ship-generated waste. The paper supports this legal requirement by developing an econometric model for estimating the amount of operational waste delivered at GRF. The multiple regression with ordinary least squares technique was used to analyze the relationship between the amount of operational waste per month and two explanatory variables – size of ship and travelling distance from the last port of discharge. Data from 2008 to 2014 were obtained from the Port Authority of Thailand. Overall, the adjusted model fits reasonably well with the dataset and all assumptions are satisfied, implying that the estimated coefficients are more practicable to be used by port authority. It is found that, over the past decades, GRF has been provided sufficiently in comparison with the demand. However, the physical adequacy of GRF should be paid special attention during the consideration of phase-3 construction of Laem Chabang Port due to the dramatic growth of the amount of operational waste resulting from an expected rapid increase in maritime traffic.

Keywords: Econometric model; Operational waste; Marine pollution; Garbage reception facility; Laem Chabang Port

Introduction

Marine pollution from ship-originated garbage has been discussed in the international arena since the early 1970s [1]. It has been identified by worldwide scholars as a prime cause of economic loss, environmental degradation, the death of aquatic animals and harm to humans [2-8]. The problem results from a lack of legal enforcement power by legislators, making it easy for ship operators to simply ignore the regulations [9-10]. Another major cause is the inadequacy of garbage reception facilities (GRF) at port [11-12]. The scarcity of GRF discourages ship operators from bringing garbage back to port for disposal [13-14]. As a result, monitoring and providing an adequate GRF become the substantial obligation of every port around the world [12, 15-18].

Since the late 2000s, sea pollution from ship-originated garbage has occurred in Laem Chabang Port (LCP) and nearby communities. According to Nomsin (2007), almost 100 cargo ships coming to berth at LCP ignored the regulation of the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) and illegally dumped garbage into the sea. This unlawful behavior results in marine debris, economic loss, environmental degradation and degradation in the quality of sea water in Laem Chabang Port and adjacent areas [19-20]. As the administrator, Port Authority of Thailand (PAT) launched a series of port regulation and projects in order to control this pollutant [21]. However, the total number of ships at LCP has increased over the past decade, resulting in an ever-increasing amount of operational waste-one category of ship-generated garbage listed in Annex V of MARPOL 73/78, delivered at GRF of LCP [21]. The growing demand for marine transport indicates the risk that increasing amounts of operational waste will be illegally disposed at sea due to port congestion and inadequacy of GRF. Thus, it is inevitable that sooner or later, severe pollution from ship-generated operational waste will become catastrophic. As a result, all related organizations, including PAT etc., need to understand the essential discipline that enables them to improve the effectiveness of their waste management plans.

This paper contributes to the work of practitioners by developing an econometric model for estimating the amount of ship-generated operational waste at GRF. In addition, the paper fills an academic gap by formulating a mathematical model to explain the relationship between the variables, a problem which has not been addressed in the previous literature [1-16]. The aforementioned association was analyzed by the multiple regression with ordinary least square technique (OLS). The first part of the paper describes the background and methodology used in the study, whereas the second part presents the study findings.

Materials and methods

1) Location of study

Laem Chabang Port (LCP) is a major deep-sea port located on the eastern coast of Thailand. Annually, the port deals with almost 80% of the country's entire imported and exported container cargoes [22]. LCP annually experiences an overwhelming stream of cargo vessel from across the world. From 2008 to 2014 the number of ships docking at LCP doubled from 6,107 to 11,974 [22]. The calling ships include cargo vessels from international routes such as general cargo, passenger and container ships, bulk carriers, vehicle and chemical tankers, LNG tankers, and chemical/oil products tankers. In addition, domestic and coastal ships dock at LCP, including barges and offshore supply vessels. Infrequent visitors include special classes of ship such as military ships, US naval vessels, safe- guard-class rescue vessels, and salvage ships. However, only 4 types of ships discharge their operational waste at the garbage reception facility (GRF) provided by the Port Authority: these are container ships, general cargo ships, Ro-Ro vessels and bulk carriers. The remaining traffic uses private GRF provided at terminals [21].

2) Operational waste as described in Annex V of MARPOL 73/78

Operational waste is defined as garbage stemming from the regular operation of a ship's engine room, where the main engine and auxiliary engines are housed. The main engine is driven by bunker oil, and generates various types of waste including carbon ash, smoke and residues [23]. Fuel leakage in the engine room results in oily stains, lubricant dirt and gas blur which is normally removed using rags. Light bulbs and fluorescent tubes are also classed as operational waste, since they contain mercury which is dangerous to the marine environment. It is required that all kinds of operational waste are stored separately from ordinary garbage and kept onboard the ship throughout the voyage and discharged at GRF in the port of discharge [18,24].

3) Data collection

The statistics of ships berthing at Laem Chabang Port from 2008 to 2014 were obtained from the database of the Civil Engineering Division (2015), which records all details regarding ship's name and size (gross tonnage), ship's agent, last port of discharge and next port of loading. The original daily data as received was collated into monthly data for analysis. As the port name was already known, travelling distances from the last port of discharge taken by the ship were obtained from the website of the SEA-DISTANCES organization, created by the International Maritime Organization (IMO) and the United Nations Conference on Trade and Development (UNCTAD). The distance calculation was based on the shipping route, measured in nautical miles. The amounts of operational waste were also obtained from the database of the Civil Engineering Division (2015) and recorded in kilograms. The correctness of data was initially investigated by the data recorder, data recorder's supervisor and a specialist from the Marine Department of Thailand. Then, statistical techniques were used to detect outliers in the dataset. A few observations were identified with extreme values that might influence the result of ordinary least square estimators (OLS). Therefore, the influence values were reviewed and fixed by the data recorder, resulting exclusion of outliers from the dataset. The dataset was validated by a maritime transportation expert, an economist and a statistician. The final dataset comprised 84 observations.

4) Underlying concept of an econometric model

The dependent variable is the monthly amount of operational waste (kilograms) discharged at the garbage reception facility (GRF) in Laem Chabang Port from 2008 to 2014, whereas the explanatory variables can be divided into 2 groups.

4.1 Size and type of ship: ship size is a dominant determinant of the amount of operational waste, because larger engines generate more operational waste. In addition to size, it is postulated that type of vessel represents another independent variable because different types of ship generate different amounts of operational waste [21]. Hence, this variable should be taken into account. However, only four types of ship – container ships, general cargo ships, Ro-Ro vessels and bulk carriers - are included in the analysis, since only these four ship types deliver their operational waste at GRF in Laem Chabang Port (LCP), whilst other types of vessels discharge their operational waste at private GRFs provided by terminal operators. Thus, the first explanatory variable is the total gross tonnage of the four types of ship coming to berth at LCP per month. In the multiple regression analysis, the value of gross tonnage was divided by 1,000 in order to reduce the scale of data. Thus, the unit for this variable was expressed in 1,000 gross tons.

4.2 Travelling distance from last port of discharge: this variable indicates the working time of the ship's engine during the trip. This explanatory variable is the monthly aggregate of nautical miles taken by all ships coming to berth at LCP. In the multiple regression analysis, the value of the travelling distance was divided by 1,000 in order to reduce the scale of the data. Thus, the unit of this variable was represented per 1,000 nautical miles.

5) Multiple regression analysis

The multiple regression with ordinary least square technique (OLS) was used in order to analyze the relationship between the dependent variable (y) - monthly amount of operational waste - and two independent variables - size of ship (x_1) and travelling distance from last port of discharge (x_2). The first independent variable is divided into 4 subcategories based on types of ship that discharge operational waste at the garbage reception facility (GRF) in Laem Chabang Port (LCP), including the sum of gross tonnage of general cargo ships (x_{11}), container ships (x_{12}), bulk carriers (x_{13}) and Ro-Ro ships (x_{14}), whereas the second explanatory variable has no subcategories. In this scenario, the econometric model for operational waste at GRF in LCP can be formulated as equation 1.

$$\hat{y}_i = \hat{\beta}_0 + \hat{\beta}_{11}x_{11} + \hat{\beta}_{12}x_{12} + \hat{\beta}_{13}x_{13} + \hat{\beta}_{14}x_{14} + \hat{\beta}_2 x_2 + \hat{\alpha} \quad (1)$$

Where ŷ is the amount of operational waste per month I

$\hat{\beta}_0$ is an intercept coefficient of the model

$\hat{\beta}_{11}$ to $\hat{\beta}_{14}$ are the partial slope coefficients of the sum of gross tonnage of general cargo ships (x_{11}), container ships (x_{12}), bulk carriers (x_{13}) and Ro-Ro ships (x_{14}), respectively

$\hat{\beta}_2$ is the partial slope coefficient of the sum of travelling distance from the last port of discharge (x_2) while $\hat{\alpha}$ is the residual.

Results and discussion

1) Discussion of the original model

The analysis began with a pair-wise correlation test in order to initially investigate the relationship among pair variables. The result is presented in Table 1.

In accordance with Table 1, the correlation statistics indicates that operational waste (y) has a strong correlation with x_{11}, x_{12}, x_{14} and x_2. This result implies a very low model specification bias. However, operational waste seems to have a sparse relationship with x_{13} due to a weak correlation of 0.194. The test also indicates a weak to moderate correlation among explanatory variables; however, there is a strong correlation among x_{12}, x_{14} and x_2, which might aggravate multicollinearity in the multiple regression model.

Table 1 Pair-wise correlations

		Operational waste (y)	**x_{11}**	**x_{12}**	**x_{13}**	**x_{14}**	**x_2**
Pearson Correlation	Operational waste	1.000	.545	.776	.194	.693	.677
	x_{11}	.545	1.000	.292	.211	.332	.397
	x_{12}	.776	.292	1.000	.079	.650	.585
	x_{13}	.194	.211	0.79	1.000	.182	.164
	x_{14}	.693	.332	.650	.182	1.000	.591
	x_2	.677	.397	.585	.164	.591	1.000
Sig. (1-tailed)	Operational waste		.000	.000	.039	.000	.000
	x_{11}	.000		.003	.027	.001	.000
	x_{12}	.000	.003		.238	.000	.000
	x_{13}	.039	.027	.238		.049	.068
	x_{14}	.000	.001	.000	.049		.000
	x_2	.000	.000	.000	.068	.000	

The next task was to test the linearity assumption of multiple regression because the estimator will either underestimate or overestimate the true relationship if this postulate is violated [25]. To test the linear relationship, a scatter plot between the dependent variable and other five explanatory variables was created, and is presented in Figure 1.

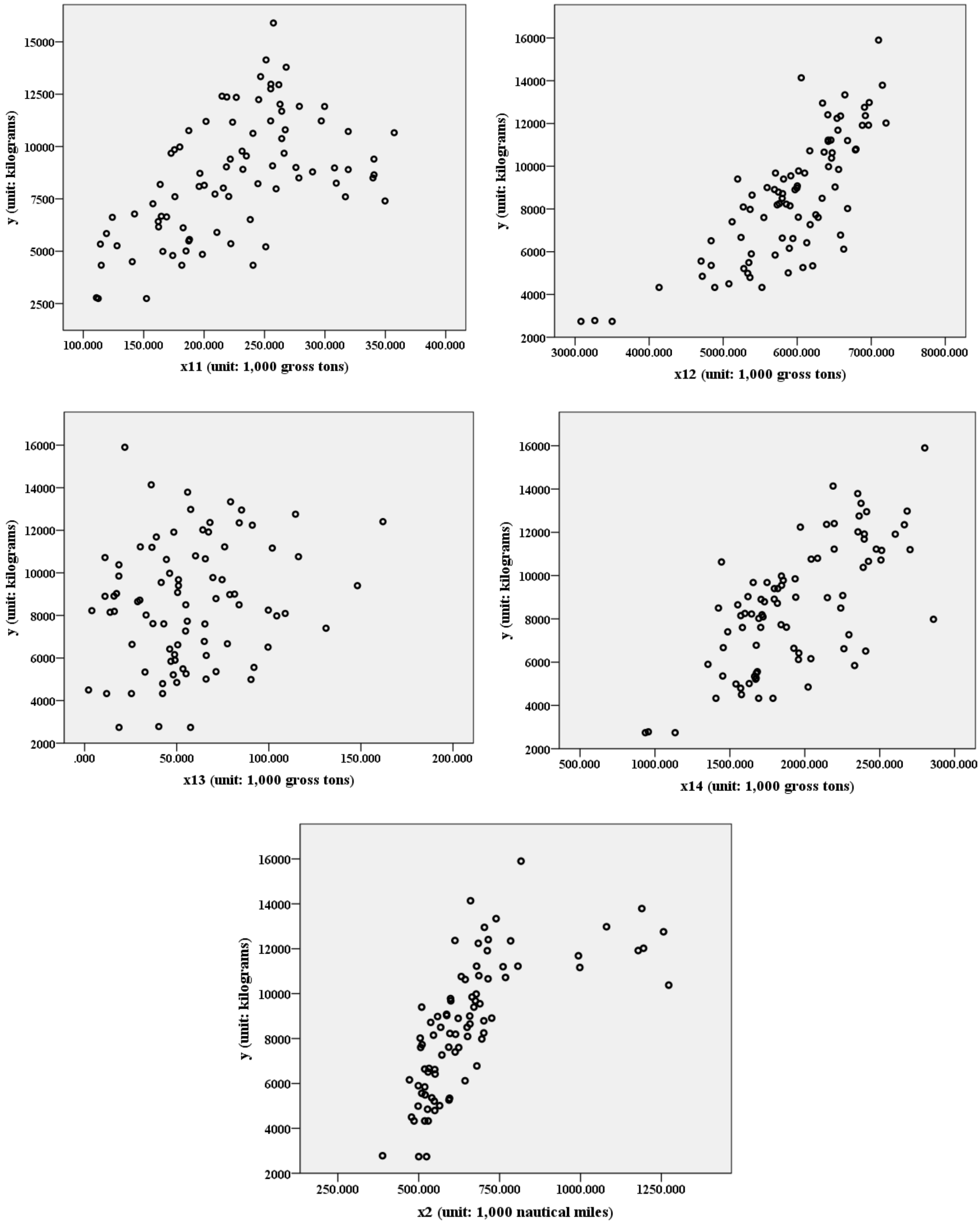

Figure 1 Scatter plot between dependent variable and independent variables.

In Figure 1, the dependent variable (y) seems to have a linear relationship with explanatory variables x_{11}, x_{12}, x_{14} and x_2 since the scatter plot indicates a linear shape. On the other hand, y and x_{13} cannot be visually judged as a linear relationship. This conclusion corresponds to the result of correlation in Table 1. Although it seems worthless to include this variable in an analysis, x_{13} was retained in the original model in order to see its effect on the multiple regression analysis; we can subsequently explain its exclusion from the adjusted model.

Thereinafter, the multiple regression was analyzed using ordinary least square (OLS) technique. The result of the first-round analysis is presented in Table 2, as the original model.

Table 2 Result of multiple regression analysis

Variable	**Original model**			**Adjusted model**		
	Coef.	**Std. Err.**	**VIF**	**Coef.**	**Std. Err.**	**VIF**
Sum of gross tonnage of general cargo ship	12.665	2.889*	1.237	9.761	2.704*	1.307
Sum of gross tonnage of container ship	1.671	0.273*	1.956	1.539	0.248*	1.910
Sum of gross tonnage of bulk carrier	3.327	5.119	1.071		Excluded	
Sum of gross tonnage of Ro-Ro ship	1.302	0.543**	2.012	1.219	0.493**	1.988
Sum of nautical mile of travelling distance from the last port of discharge	2.894	1.173**	1.834	1.626	1.147	1.911
1-period lagged y or $y_{(t-1)}$	-	-	-	0.259	0.061*	1.496
Constant of model		-8763.278			-8391.797	
Adjusted R-squared		0.753			0.79	
Durbin-Watson		1.422			2.052	
F-test		51.502*			62.805*	

Note: *= significant at 1%, **= significant at 5%, ***= significant at 10%

$$\hat{y}_i = -8{,}763.278 + 12.665x_{11} + 1.671x_{12} + 3.327x_{13} + 1.302x_{14} + 2.894x_2 \qquad (2)$$

Where ŷ is the amount of operational waste in month i

x_{11}, x_{12}, x_{13} and x_{14} are the sum of gross tonnage of general cargo ships, container ships, bulk carriers and Ro-Ro ships, respectively

x_2 is the sum of travelling distance from the last port of discharge

According to the result of the original model in Table 2, the relationship between the monthly amount of operational waste and other five explanatory variables can be written as equation 2.

Considering the statistics in Table 2, the original model fits fairly well with the dataset since the Adjusted R-squared is 0.753. The F-test indicates that there is at least one significant explanatory variable in the model including the sum of gross tonnage of general cargo ships (x_{11}) and the sum of gross tonnage of container ships (x_{12}), which are significant at α=1%, and the sum of gross tonnage of Ro-Ro ships (x_{14}) and the sum of travelling distance from the last port of discharge (x_2), which are significant at α=5%. Contrarily, the sum of gross tonnage of bulk carriers (x_{13}) was not statistically significant because, in reality, most bulk carriers rarely deliver the operational waste at the garbage reception facility (GRF) in Laem Chabang Port (LCP) [21], as they normally discharge their operational waste at the GRF provided by the private terminals at which their vessels berth [21]. This is the reason why x_{13} has no ability to explain the change in amount of operational waste (y) and, as a result, it should be excluded from the estimating model.

Then, the normality assumption was tested using normal Q-Q plot of unstandardized residual, as shown in Figure 2, and then using Kolmogorov-Smirnov, as shown in Table 3.

Table 3 Test of normality

	Kolmogorov-Smirnov for original model			**Kolmogorov-Smirnov for adjusted model**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Unstandardized Residual	**.079**	**84**	**$.200^*$**	**.059**	**83**	**$.200^*$**

Corresponding with Figure 2, the spots lie relatively close to the straight line, implying that the residual has a normal distribution, whereas the Kolmogorov-Smirnov of 0.079 is not significant at α=5%, which means that the null hypothesis of the residual with normal distribution is accepted. The homoscedasticity assumption was investigated using a scatter plot between the predicted y and the residual, as shown in Figure 3.

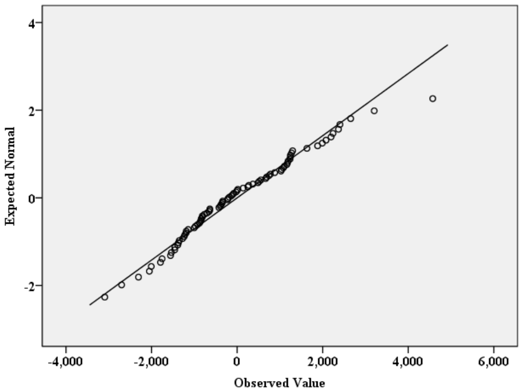

Figure 2 Normal Q-Q plot of unstandardized residual of the original model.

Figure 3 indicates that variance of the residual is relatively constant with a few outliers over the predicted y. This implies that there is no heteroskedasticity in the model. To confirm this result, the heteroskedasticity problem was tested by Breusch-Pagan which provides chi^2 of 0.47 with significance level of 0.494. This results in our acceptance of the null hypothesis of constant variance, meaning that the homoscedasticity assumption is satisfied. The multicollinearity assumption was tested by using the variance inflation factor (VIF) in Table 2. The VIF shows that the relationship among explanatory variables is very low, implying no multicollinearity in the model. However, the autocorrelation problem seems to occur in the original model due to the Durbin-Watson statistic of 1.422 which is less than 2. This means that the $residual_{(t)}$ and $residual_{(t+1)}$ are not independent which makes the estimated partial slope coefficients not the best linear unbiased estimator (BLUE).

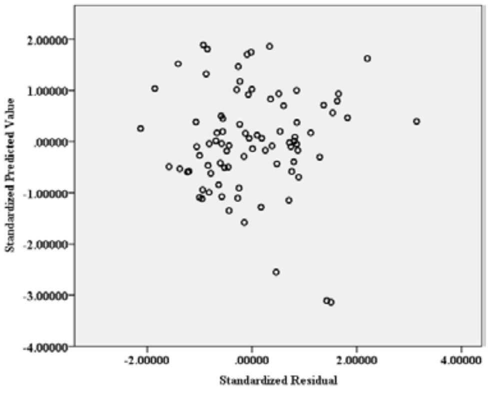

Figure 3 Scatter plot between residual and predicted y of original model.

The problem root of autocorrelation was investigated and the potential cause was explored from the routine operation at the sorting shed in LCP. The operational waste delivered each month must be sorted and stored together with the same type of waste in the storage space. This operation is normally performed by one or sometimes two workers, causing partial accumulation of operational waste at the GRF. For this reason, the amount of operational waste in the previous month (y_{t-1}) also has a positive effect on the amount of operational waste in the next month (y_t). The exclusion of the related independent variable of the original model seems to aggravate the model specification bias which generates autocorrelation [26]. To remedy this problem, the amount of operational waste in the previous month or lagged y was added in the adjusted model.

2) Discussion of the adjusted model

The treatment of the autocorrelation problem in the original model was addressed by adding 1-period lagged y or y_{t-1} into the model as the explanatory variable, as suggested by Gujarati [26]. Therefore, the variable $y_{(t-1)}$ was created in the dataset and then was included in the multiple regression analysis. At the same time, the sum of gross tonnage of bulk carrier (x_{13}) which has a weak correlation with the amount of operational waste (y) as presented in Table 1, was excluded from the model in order to reduce the specification error of the model. As a result, the adjusted model can be formulated as equation 3.

$$\widehat{y}_i = \widehat{\beta}_0+\widehat{\beta}_{11}x_{11}+\widehat{\beta}_{12}x_{12}+\widehat{\beta}_{14}x_{14}+\widehat{\beta}_2x_2+\widehat{\beta}_3y_{t-1}+\widehat{\alpha} \tag{3}$$

Where $\hat{y}$ is the amount of operational waste in month i

$\widehat{\beta}_0$ is the intercept coefficient of the adjusted model

$\widehat{\beta}_{11}$, $\widehat{\beta}_{12}$ and $\widehat{\beta}_{14}$ are the partial slope coefficients of the sum of gross tonnage of general cargo ships (x_{11}), container ships (x_{12}) and Ro-Ro ships (x_{14}), respectively.

$\widehat{\beta}_2$ is the partial slope coefficient of the sum of travelling distance from last port of discharge (x_2)

$\widehat{\beta}_3$ is the partial regression coefficient of 1-period lagged y (y_{t-1}) and $\widehat{\alpha}$ is the residual of the model.

The result of the adjusted model is shown in the right-hand side column of Table 2. Overall, all partial slope coefficients decrease in comparison with those in the original model but are still significant at the same level of significance (α=1%) except for x_2, which is insignificant in the adjusted model. This means that travelling distance from last port of discharge has no influence on y. However, the Adjusted R-squared increases from 0.753 in the original model to 0.79 in the adjusted model and the F-test value also increases from 51.502 to 62.805. This implies an increased ability of the adjusted model to explain the change of y. Furthermore, the standard error of all partial slope coefficients also reduces, indicating the lower possibility for the adjusted model to generate faulty predictions, as compared with the original model. The vital improvement here is the Durbin-Watson statistic, which increases from 1.422 in the original model to 2.052 in the adjusted model. Notice that it is now close to 2, implying that the relationship between the $\text{residual}_{(t)}$ and the $\text{residual}_{(t+1)}$ disappears or, in other words, there is no autocorrelation in the adjusted model. Again, the normality assumption was tested by normal Q-Q plot, as presented in Figure 4. The normal Q-Q plot in Figure 4 indicates that there are more spots staying on the straight line than those in the original model. This implies an improvement in the normal distribution assumption. The Kolmogorov-Smirnov, as presented in Table 3, shows no significance at α=5% indicating that the residual has a normal distribution. The multicollinearity assumption was then investigated by VIF, as demonstrated in Table 2. All explanatory variables indicate very low VIF, showing that there is no multicollinearity problem in the model. The homoscedasticity assumption was initially tested using a scatter plot between the residual and the predicted y, as presented in Figure 5. The scatter plot indicates that variance of the residual is relatively constant over the predicted y, whereas Breusch-Pagantest shows no significance at α=5%. Hence, there is no heteroscedasticity problem in the adjusted model.

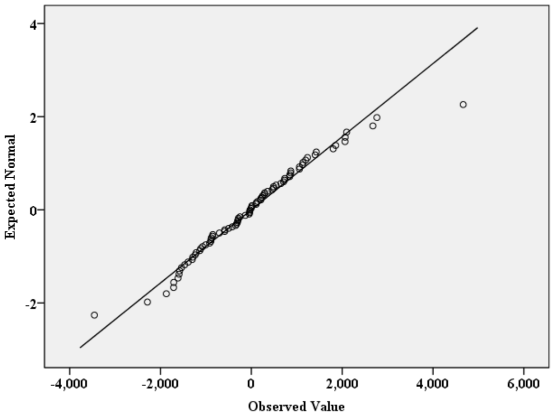

Figure 4 Normal Q-Q plot of unstandardized residual of the adjusted model.

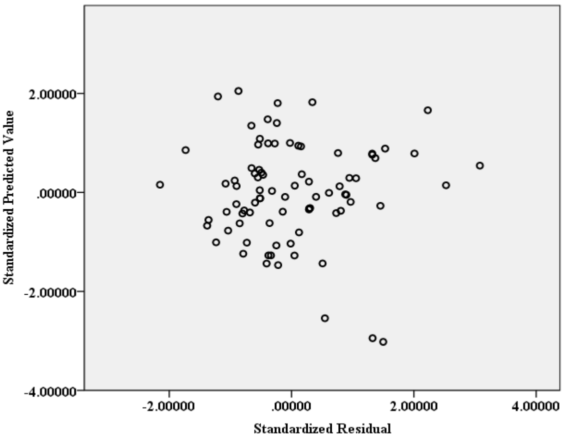

Figure 5 Scatter plot between residual and predicted y of adjusted model.

According to the above discussion, the partial regression coefficients in the adjusted model are now BLUE, making the estimated coefficients more practicable to be used in real-world situations. Thus, the relationship among variables in the adjusted model can be mathematically demonstrated as equation (4).

3) Discussion of waste management in Laem Chabang Port by using econometric model

In order to increase the ability to prevent marine pollution by improving waste management plans, port authorities should be able to forecast the amount of operational waste at the GRF. The adjusted model as shown in equation 4, can assist the port authority to refine its waste management plan because it can be used to provide a more reliable prediction of the amount of operational waste, based on the given values of five explanatory variables including the sum of gross tonnage of general cargo ships (x_{11}), container ships (x_{12}), and Ro-Ro ships (x_{14}), the sum of travelling distances from the last port of discharge (x_2) and the amount of operational waste in the previous month (y_{t-1}). More accurate predicttions of the amounts of operational waste will allow the GRF to operate more efficiently. This has the benefits of shorter waiting times for collecting and transferring waste from ship to the storage facility, and reduced risk of marine pollution from illegal discharge of operational waste into the sea. The model also shows that general cargo ships (x_{11}) have the highest impact on the amount of operational waste at the GRF due to its highest partial slope coefficient (9.761). This is because in practice, most general cargo ships are antiquated vessels with inefficient engines and equipment, resulting in the generation of correspondingly large amounts of operational waste during each voyage. Because these vessels typically generate more waste than other categories of ship, it might be reasonable to levy higher rates than other categories. However, it should be realized at the model will remain viable only for a particular period of time because the obsolete estimator will impair the accuracy of the prediction. Thus, the model needs to be periodically updated using latest datasets. Another caution for the port authority will be to avoid trying to interpret the constant - 8,391.797 because the adjusted model estimates the linear regression line intercepting the y-axis at point (0,-8,391.797). Therefore, the negative intercept coefficient takes place owning to the statistical process, not the error of the estimating model. Ultimately, the port authority might exclude travelling distance from the last port of discharge (x_2), which is statistically insignificant, from the adjusted model; however, it should be borne in mind that all statistics will immediately change, and so all assumptions of multiple regression must be reinvestigated in a new updated model.

$$\hat{y}_i = -8{,}391.797 + 9.761x_{11} + 1.539x_{12} + 1.219x_{14} + 1.626x_2 + 0.259y_{t-1} \qquad (4)$$

Where $\hat{y}$ is the amount of operational waste in month i

x_{11}, x_{12} and x_{14} are the sum of the gross tonnage of general cargo ships, container ships and Ro-Ro ships, respectively

x_2 is the sum of travelling distance from the last port of discharge and y_{t-1} is the total amount of operational waste delivered from ships in the last month.

4) Discussion of the current capacity of GRF and expected impact of Laem Chabang Port - Phase 3

The GRF in Laem Chabang Port (LCP) is comprised of 1) a medium-size shed with four spaces (approx. 4.85 meters × 4.16 meters × 1.12 meters each) for storing different types of operational waste and one large space (approx. 20 meters × 5.84 meters) for sorting operations; 2) three garbage-collecting trucks; 3) two workers working on the collecting truck; and 4) one worker at the sorting shed [21]. Notice that the last three elements of GRF seem to be more flexibly adjusted by Port Authority of Thailand (PAT) than the first element which is permanently fixed on the land. Hence, its capacity and the demand for the use of the storage spaces in the shed, as presented in Figure 6, should be carefully analyzed.

Corresponding with Figure 6, it is estimated that the shed can store a maximum of 90 cubic metres of operational waste, or around 46 tons, while the average amount of operational waste per month from 2011 to 2014 is only 10.15 tons. The figure shows that the demand for the use of the storage spaces is about 25-30% of its maximum capacity. Therefore, there is no concern over the physical adequacy of the shed because its capacity is currently ample. Nevertheless, PAT should pay special attention on the physical adequacy of the storage spaces during the consideration of the phase-3 construction at LCP. This project aims to expand the capacity of LCP by constructing nine new terminals which is expected to result in a doubling in the number of cargo ships berthing at LCP [27]. Assuming that after completion of phase-3 construction, the total gross tonnage of general cargo ships (x_{11}), container ships (x_{12}) and Ro-Ro ships (x_{14}), the total travelling distance from last port of discharge (x_2) and the amount of operational waste delivered in the last one month (y_{t-1}) will double compared with the figures in 2011-2014, the monthly amount of operational waste estimated by equation (4) will also increase as shown in Figure 7.

Figure 7 indicates that the amount of operational waste will grow from the base years by an average factor of 3.5, reaching almost 5.2 times in some months. With this increasing rate, the capacity of the GRF will be quickly exceeded. As a consequence, it is likely that ship operators will illegally dump their operational waste at sea in order to avoid lengthy waiting times. One of the primary ways to pre-empt this problem is to increase the existing capacity of GRF for all types of ship without delay. In addition, PAT should ensure that construction of phase 3 will not aggravate negative externalities for society and the environment. All dimensions of the adequacy of GRF, including parameters such as access to GRF-related information, the location of GRF and the service charging system [18] should be analyzed and addressed in the development plan. In addition, every pollution-prevention measurement should be publicized to the community. Such measures will help mitigate or resolve existing public disputes, and restore public trust in the phase-3 construction project among residents in local communities.

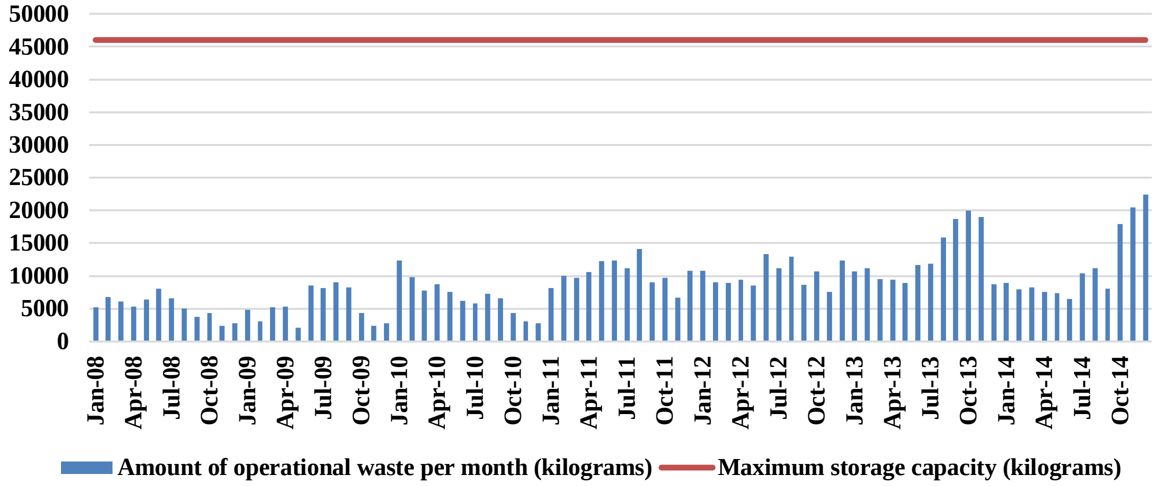

Figure 6 Comparison between maximum capacity of storage space and amount of operational waste in Laem Chabang Port from 2008 to 2014.

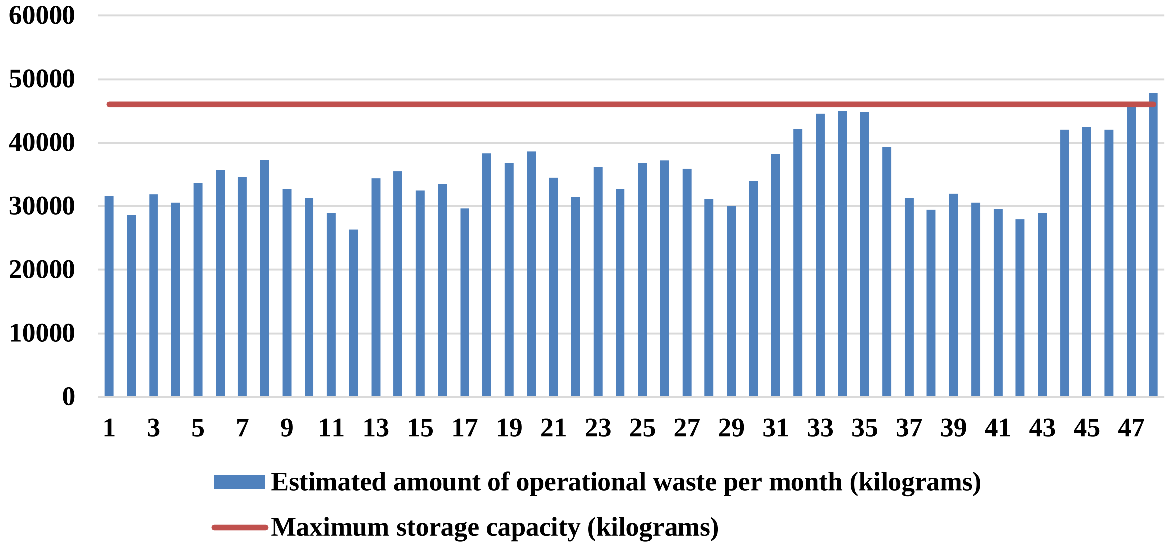

Figure7 Comparison between maximum capacity of storage space and estimated operational waste per month after completion of Phase-3 construction.

Conclusions

The adequacy of garbage reception facilities (GRF) is vital to mitigate the practice of illegal discharge of ship-generated garbage at sea. However, provision of adequate GRF is not easy to accomplish [10]. To address this problem, port authorities should understand the dependency of the amount of waste delivered at GRF with underlying explanatory variables, in order to predict future amounts and make necessary GRF provisions for all ships. Thus, this paper contributes to academic knowledge and practitioners by developing an econometric model for analyzing this relationship using multiple regression analysis with the ordinary least square (OLS) technique. An original model illustrates the potential for predicting the amount of operational waste at the GRF at LCP. However, the serial correlation assumption was violated due to the excluded variable specification bias which makes its estimated coefficients impractical [26]. To remedy this problem, $y_{(t-1)}$ was added into an adjusted model and the irrelevant exploratory variable was also excluded from the analysis in order to reduce specification error. The findings of the adjusted model indicate that the auto-correlation problem was solved and other statistics were also improved. As a result, the partial regression coefficients in the adjusted model are the best linear unbiased estimator (BLUE). Future studies should focus on solving the problem of illegal discharge of ship-generated waste at sea, given that inadequate provision of GRF in LCP seems not to be the real cause of this problem. Moreover, other estimating approaches such as ARIMA should be explored in order to increase prediction accuracy.

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