

# Potential Impacts of International Maritime Transportation Policies on the Pacific Region

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**Abstract:** This paper develops a model to simulate international cargo flows for the Pacific region and examines the potential impacts of policies and investments. First, a model is formulated assuming the user equilibrium principle in a network assignment and considering vessel capacity under the given shipping demand between ports. Next, the model is calibrated with existing databases and local data that are collected through a field survey. The developed model successfully reproduces observed transshipment at worldwide ports, including Pacific ports. Subsequently, the model is applied to three possible scenarios in 2030: the port development scenario, the Honolulu shipping service scenario, and the vessel enlargement scenario. From the scenario analysis, implications are derived regarding future regional trade patterns, inter-port competition, priority of port development, influence of new shipping services, and impacts of vessel enlargement. The results are expected to contribute to policy development regarding the maritime freight transportation in the Pacific region.

*Keywords:* Pacific region, international maritime container, freight network assignment, port development, maritime shipping service, vessel enlargement

## 1. INTRODUCTION

The Pacific region consists of numerous islands dispersed in the southwest of the Pacific Ocean. The region has suffered from high costs of participating in international trade due to its remoteness from the world's major markets. The dispersed nature of the region also leads to transportation services being expensive, especially those connecting smaller remote islands. Such geographical disadvantages and the consequent high trade costs have hampered the economic development of Pacific Islands (PI) (ADB-ADBI, 2015). These problems are similar to those seen in landlocked countries, and the PI region could be referred to as a "sea-locked" area. The development of international transportation infrastructure can be considered essential for the economic growth of sea-locked developing countries, as is typical in the context of land-locked regions (Collier, 2008; World Bank, 2009).

International shipping in the Pacific region relies heavily on maritime transportation. On tonnage basis, over 80% of the international cargo in this region is transported by ship, according to the World Trade Service database (IHS, 2013). A number of issues have been identified in recent studies regarding the maritime transportation sector in the region. A comprehensive study by ADB (2007) focusing on the entire PI region summarized the current situation, identified key challenges, and provided indicative recommendations for each issue. They showed that low port efficiency caused by inadequate port infrastructure and poor

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terminal operation, and the poor connectivity caused by low service frequencies are key challenges. The World Bank (2015) also identified and examined key maritime challenges that are specific to its five study countries and common across the PI region. They pointed out gaps constraining the contribution of this sector to development outcomes and proposed specific sustainable measures and action plans to strengthen port and maritime operations.

However, existing studies are rather qualitative than quantitative despite the latter approach being crucial in discussing the potential impacts of policies and investments. The major reasons for the absence of such discussions are the severely limited availability and reliability of even the most basic data (ADB, 2007) and the lack of a practical analytical tool.

Given this, our study aims to develop a quantitative analysis tool for the international cargo flows in the Pacific region and to examine the potential impacts of policies and investments on PI by applying it. For collecting local data, the authors visited local sites in Fiji, Solomon Islands, Vanuatu, and New Zealand from September 16–27, 2015; interviewees were 22 local experts from national governments, port authorities, shipping companies, regional organizations, and international organizations. One significant feature of the study is the incorporation of such local data into the model development and impact analysis, which contributes to overcoming the poor data availability in the region. Note that this study focuses on international container shipping services, as the majority of international cargo in the region is containerized (ADB, 2007).

The paper is organized as follows. The following section describes the current maritime freight transportation in the Pacific region. Section 3 presents the model development, followed by data preparation (Section 4) and model calibration (Section 5). Section 6 presents the scenario analysis, and lastly, the conclusion and further issues are mentioned in Section 7.

## **2. MARITIME FREIGHT TRANSPORTATION IN THE PACIFIC REGION**

### **2.1 Port Infrastructure**

Each Pacific island typically has one or two international ports. The infrastructure at PI ports ranges from simple wharves to more sophisticated facilities with relatively high capabilities of cargo handling. Even at ports whose capacity is considered sufficient, serious problems are often observed regarding the operational performance of the port infrastructure (ADB, 2007). The Pacific Regional Transport Study (AusAID, 2004), which was prepared for the PI Forum in 2004, points out that the majority of PI ports were built in the 1950s or 1960s, which is before the containerization of international cargo; consequently, the port infrastructure at PI ports fails to meet today's international shipping demands. Container vessels typically need to load and discharge containers at PI ports using their own ship gear due to the lack of modern cargo-handling equipment. On the quayside, obsolete facilities and deteriorated surfaces often prevent smooth stevedoring. Wharves that cannot withstand the weight of a forklift and heavy containers occasionally require double handling of containers. In addition, a lack of adequate maintenance is observed in many PI ports (ADB, 2007).

To address the above issues, port development projects have been proposed and implemented by Multilateral Development Banks (MDBs) and foreign governments. For example, the Asian Development Bank (ADB) has approved port development projects in Fiji, Nauru, Samoa, Vanuatu, and Papua New Guinea (PNG) as of February 2016. The Japanese Government has also been implementing a series of port development projects in the Federated States of Micronesia (hereafter referred to as Micronesia), Solomon Islands, Vanuatu, Kiribati, Tuvalu, Samoa, and Tonga (JICA, 2014).

## 2.2 Maritime Services

The major shipping routes in the region are connected with Asia, North America, Europe, and Oceania, and within the PI. Figure 1 shows the shipping network of container vessels in the Pacific region as of 2013, obtained from the Containership Databank (MDS Transmodal Ltd., 2013). The services are categorized by their annual TEU capacity, which is computed from service frequency and vessel size. The network shown in the figure is consistent with the interview results with local experts; two main streams of international containers exist in the region: (1) connecting North America/Europe with Australia/New Zealand via several Polynesian ports including Papeete (Tahiti), Suva (Fiji), and Noumea (New Caledonia); and (2) connecting East/Southeast Asia with Australia/New Zealand via several Melanesian ports including Lae (PNG), Honiara (Solomon Islands), Port Vila (Vanuatu) and Suva. Australian ports such as Brisbane and New Zealand ports such as Auckland and Tauranga as well as several PI ports such as Suva, Papeete, Noumea, and Lae are regional hubs in the Pacific region.

## 3. MODEL DEVELOPMENT

### 3.1 Model Formulation

A model to simulate international maritime container flows on the actual global maritime shipping network highlighting the Pacific region is developed based on the existing method proposed by Shibasaki and Kawasaki (2016). The model assumes the user equilibrium principle in network assignment considering the vessel capacity with the shipping demand between ports as given. Each container, which is defined on a TEU (twenty-foot equivalent unit) basis, is transported using the route with the minimum total transit time, including the congestion time, from an origin port to a destination port. In other words, shipping routes are selected solely based on shipping time, not considering freight charge. This assumption is based on the understanding that the international maritime container shipping market is highly competitive in terms of price despite its oligopolistic nature. This given, the ocean freight charge can be regarded as the same among different shipping companies.

As each liner has a vessel capacity, the concentration of cargo to a specific service will result in a diseconomy of scale. To describe this, a link congestion is introduced by assuming a flow-dependent link cost function, where the User Equilibrium (UE) principle is applied, based on Wardrop's first principle (1952). The model is formulated as follows:

$$\min_x z(x) = \sum_{a \in A} \int_0^{x_a} t_a(x) dx \quad (1)$$

subject to

$$x_a = \sum_{(r,s) \in O \times D} \sum_{k \in K_{rs}} \delta_{a,k}^{rs} \cdot f_k^{rs} \quad \text{for } \forall a \quad (2)$$

$$\sum_{k \in K_{rs}} f_k^{rs} - q_{rs} = 0 \quad \text{for } \forall r, s \quad (3)$$

$$f_k^{rs} \geq 0 \quad \text{for } \forall k, r, s \quad (4)$$

where  $z(\cdot)$  represents the objective function;  $a$  a link;  $A$  a set of links;  $x_a$  the flow of link  $a$ ;  $t_a(\cdot)$  the cost function (shipping time) of link  $a$ ;  $r$  an origin;  $s$  a destination;  $O$

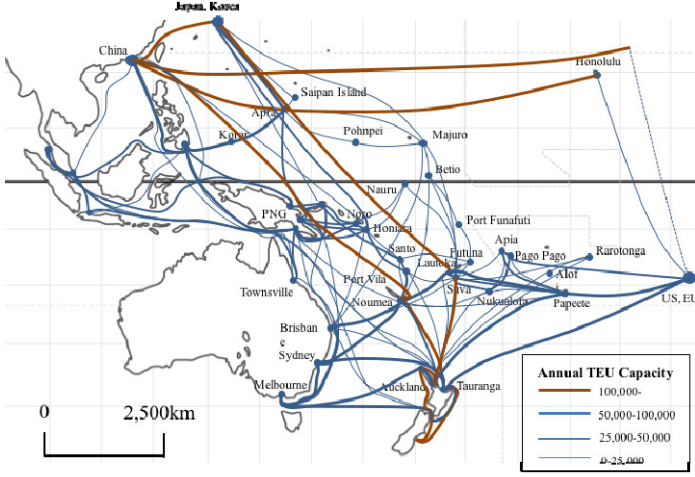


Figure 1. Maritime shipping network in the Pacific region as of 2013

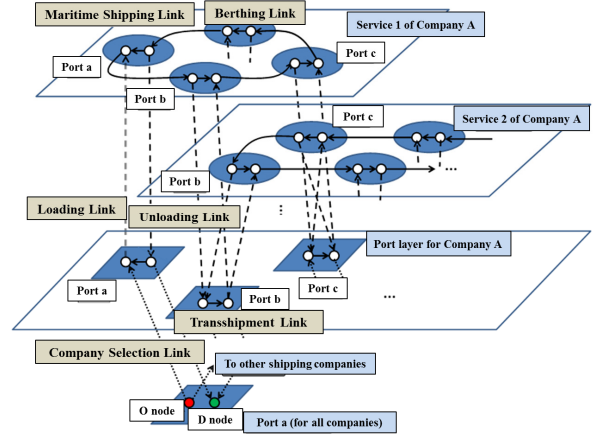


Figure 2. Network structure of the developed model

a set of origins;  $D$  a set of destinations;  $k$  a path;  $K_{rs}$  a set of paths from the origin  $r$  to the destination  $s$ ;  $\delta_{a,k}^{rs}$  the Kronecker delta, which is equal to 1 if link  $a$  belongs to path  $k$  and 0 otherwise;  $f_k^{rs}$  the flow on path  $k$  from origin  $r$  to destination  $s$ ; and  $q_{rs}$  the cargo volume from origin  $r$  to destination  $s$ .

### 3.2 Model Structure

#### 3.2.1 Network Structure

Figure 2 illustrates a conceptual image of the network structure of the developed model, which basically follows the one proposed by Shibasaki and Kawasaki (2016). Note that this study newly allows transshipment between different shipping companies to ensure that all containers to/from the PI are able to reach their destinations. The network has three layers: the geographical network, the company-based network, and the service-based network. They are interconnected by six types of links: maritime shipping link, loading link, unloading link, berthing link, transshipment link, and company selection link.

#### 3.2.2 Navigation Link

The navigation link describes each liner service between ports. The link cost function considers shipping time and congestion due to vessel capacity constraint as:

$$t_m(x_a) = \left( \frac{l_a}{v_a} + \gamma_a^s \cdot TS + \gamma_a^p \cdot TP \right) + TW_{a'} \cdot b_1 \left( \frac{x_a}{cap_a \cdot freq_a} \right)^{b_2}, \quad (5)$$

where  $t_m(\cdot)$  is the shipping time function of maritime shipping link  $a$  (hour);  $x_a$  is the container cargo flow of link  $a$  (TEU/year);  $l_a$  is the distance of link  $a$  (nautical miles);  $v_a$  is the vessel speed of link  $a$  (knot);  $\gamma_a^s$  is a dummy variable for the Suez Canal transit, which is equal to 1 if link  $a$  passes through the Suez Canal and 0 otherwise;  $TS$  is additional time for Suez Canal transit, which is assumed to be 24 hours;  $\gamma_a^p$  is a dummy variable for the Panama Canal transit, which is equal to 1 if link  $a$  passes through the

Panama Canal and 0 otherwise;  $TP$  is the additional time for Panama Canal transit, which is assumed to be 24 hours;  $a'$  is a loading link in the departure port of maritime shipping link  $a$ ;  $TW_{a'}$  is the expected waiting time for loading in loading link  $a'$  (hour);  $cap_a$  is the average vessel capacity of the service of link  $a$  (TEU/vessel);  $freq_a$  is the service frequency of link  $a$  (vessels/year); and  $b_1$  and  $b_2$  are parameters related to congestion.

The first term describes the shipping time without any congestion, while the second term expresses the delay caused by congestion, which is the product of the waiting time for loading  $TW_{a'}$  and the congestion function. The waiting time for loading  $TW_{a'}$  is defined as

$$TW_{a'} = \frac{1}{2} \cdot \frac{YH}{freq_a}, \quad (6)$$

where  $YH$  is a conversion constant from year to hour, which is equal to 8,736 hours per year. The expected waiting time for loading is assumed to be half of the service duration.

### 3.2.3 Loading, Discharging, and Berthing Link

The loading link represents the loading of containers on to a vessel. The link cost function is defined as the sum of the loading time and the expected waiting time for departure:

$$t_l(x_a) = TL_a + TW_{a'}, \quad (7)$$

where  $t_l(\cdot)$  is the shipping time of loading link (hour) and  $TL_a$  is the loading time of loading link  $a$  (hour).

The discharging link represents the unloading of containers from a vessel. The link cost function of the discharging link is expressed as

$$t_d(x_a) = TD_a, \quad (8)$$

where  $t_d(\cdot)$  is the shipping time of discharging link (hour) and  $TD_a$  is the discharging time of discharging link  $a$  (hour).

The model assumes that containers pass the berthing link when they stay on board while the unloading and loading takes place. The link cost function of berthing link is formulated as

$$t_b(x_a) = TB_a, \quad (9)$$

where  $t_b(\cdot)$  is the shipping time of berthing link (hour) and  $TB_a$  is the berthing time of berthing link  $a$  (hour).

### 3.2.4 Transshipment Link

Containers pass the transshipment link when they are loaded on to another service after being discharged. The link cost function of the transshipment link is expressed as

$$t_r^{g_1, g_2}(x_a) = \begin{cases} TRS_a & \text{if } g_i = g_j, \\ TRD_a & \text{if } g_i \neq g_j, \end{cases} \quad (10)$$

where  $t_r^{g_1 g_2}(\cdot)$  is the shipping time of transshipment link;  $TRS_a$  is the transshipment time of transshipment link  $a$  (hour) when the company is the same before and after transshipment;  $g_1$  is the shipping company before transshipment;  $g_2$  is the shipping company after transshipment; and  $TRD_a$  is the transshipment time of transshipment link  $a$  (hour) when the companies are different before and after transshipment.

### 3.2.5 Company Selection Link

The model assumes that containers pass the company selection link when a shipper selects the corresponding shipping company for the containers. The containers are moved from an origin node to a port node in the company layer. The same link cost function is applied to the inverse link, which is passed when the containers are moved from the port node in the company layer to the destination node. The link cost function of the company selection link is expressed as

$$t_c(x_a) = SSN, \quad (11)$$

where  $t_c(\cdot)$  is the shipping time of the company selection link and  $SSN$  is a sufficiently small number. This setting is adopted in order to avoid model calculation with zero cost. This model sets  $SSN$  at 0.01 (hour).

## 4. DATA

### 4.1 Port-related Data

Following the study by Shibasaki and Kawasaki (2016), every port in the world with an annual container throughput of over 500,000 TEU is covered in the model. For the PI region, the model covers all international ports in sovereign PI with at least one appearance in the MDS Containership Databank (MDS Transmodal Ltd., 2013) and relatively large-scale ports in the territories of the United States (US), including Hawaii (Honolulu port) and France. As a result, 200 ports in the world are included in the model: 27 ports in the PI region and 173 ports in other regions of the world.

Data prepared by Shibasaki and Kawasaki (2016) are used for the transshipment time, which is estimated from the comprehensive level of service at each port. The transshipment times of PI ports are also estimated in the same manner, and as a result, 144 (hour) is input for this parameter. In this study, the transshipment time for transshipment between different shipping companies  $TRD_a$  (hour) is assumed to be longer than that of transshipment within the same shipping company  $TRS_a$  (hour) by a factor of  $b_3$ , which is calibrated as an unknown parameter along with parameters  $b_1$  and  $b_2$ . Note that the time for loading and discharging is included in the transshipment time. Thus, a sufficiently small number ( $SSN$ ) (i.e. 0.01 hour) is used as an input in  $TL_a$  and  $TD_a$  to avoid double counting. Also note that the berthing time  $TB_a$  is assumed to be 12 (hours) for every port of every service. These settings also follow the study by Shibasaki and Kawasaki (2016).

### 4.2 Maritime Shipping Network

The maritime shipping network in this model is constructed based on the MDS containership

databank. This database contains information, such as the vessel name, IMO number, service name, operator (company) name, partner company(ies) of the service (if any), slot chartered company(ies) (if any), route category defined by MDS, list of port of calls and its order, service frequency, TEU capacity, DWT, and vessel speed, for each containership vessel. As of June 2013, 5,492 vessels were included in the database. The maritime shipping network is structured after aggregating this vessel-basis data into a service-basis data, which consist of 2,569 services, and eliminating ports that are not included in this model. The vessel speed  $v_a$  (knot), average vessel capacity  $cap_a$  (TEU/vessel), and frequency  $freq_a$  (vessels/year) are acquired for each service from the MDS database as well. The vessel capacity is assumed to be equally divided between each operator when multiple shipping companies operate the service. Slot chartered companies are assumed to have half of the capacity of each operator.

As for the distance between ports  $l_a$ , the dummy variable for the transit in Suez Canal  $\gamma_a^s$ , and that in Panama Canal  $\gamma_a^p$ , the data shown by Shibasaki and Kawasaki (2016) are used. The data of distance between ports were originally acquired from Toriumi (2010), in which every container vessel is assumed to follow the shortest route among the available maritime navigation routes. The data for the newly added Pacific Island ports are collected from available websites such as SeaRates.com and Sea-Distances.org.

Although a global network is structured, liner services provided by smaller local companies that have fewer operations in the PI are excluded for the simplicity of calculation. As a result, the model includes 32 shipping companies: the top 20 of the largest container shipping companies in the world and 12 local companies that provide liner services to PI. The model includes 904 shipping services, covering 88.3% of the world's annual vessel capacity and 96.5% of that in the Pacific region. The developed network consists of 274,088 links.

## 5. MODEL ESTIMATION AND CALIBRATION

### 5.1 Estimation of Origin-Destination Matrix

The estimation of the TEU-basis container shipping demand between ports (i.e., a TEU-basis inter-port Origin-Destination (O-D) matrix) is performed separately for the following three patterns: O-D demand between non-PI ports, O-D demand between PI port and non-PI port, and O-D demand among PI ports. After the estimation, the total O-D matrix is adjusted using the Frater method with the initial total shipping demand for each port as given.

First, following Shibasaki and Kawasaki (2016), the container shipping demand between non-PI ports is estimated based on the World Trade Service (WTS) database provided by IHS Inc., which provides the container shipping demand between countries and regions for each year from 2000 to 2030. The estimation consists of three steps: (1) the O-D matrix among 117 WTS countries and regions is aggregated into a matrix of 46 countries and regions which consider the characteristics of hinterland transportation; (2) the aggregated O-D matrix is divided into a matrix of the 174 non-PI ports (including Honolulu port) in the model, using each port's share of annual container throughput within the aggregated country or region. The port's shares are computed from the annual local container throughput, which is obtained by subtracting transshipped containers from the total annual throughput and then excluding empty containers; and (3) the containers not transported by the 32 shipping companies in the model are eliminated, assuming that the amount of containers is proportional to the percentages of vessel capacity covered by the targeted companies calling at each port.

Second, the shipping demand between each PI port and non-PI port is estimated by

breaking down the shipping demand between non-PI ports and the “New Zealand” (for Tokelau and Niue), “Other Southeast Asia” (for PNG), or “Pacific Islands” (for other PI) WTS regions, estimated in the first step. Since the annual throughput data is not available for most PI ports, the regional share for PI is computed from The United Nations Commodity Trade Statistics Database (UN-Comtrade) by trade partner with consideration to commodities.

Third, the shipping demand among PI is estimated with a gravity model, as the WTS data does not contain intra-regional data. The gravity model is formulated as

$$q_{rs} = \left( \sum_i (Z_0 + \lambda_i Z_i) \right) (GDP_r)^{\theta_r} \cdot (GDP_s)^{\theta_s} (L_{rs})^{\theta_l}, \quad (12)$$

where  $Z_0$  is the intercept;  $Z_i$  is the  $i$ -th dummy variable related to the characteristics of the O-D pair;  $GDP_r$  is the Gross Domestic Product (GDP) of the origin country;  $GDP_s$  is the GDP of the destination country;  $L_{rs}$  is the distance between O-D countries; and  $\lambda_i$ ,  $\theta_r$ ,  $\theta_s$ , and  $\theta_l$  are coefficients. Table 1 shows the estimation results of the gravity model and Figure 3 shows the estimated versus observed trade volumes among PI. The gravity model well reproduces the observed trade volumes in terms of TEU. Note that the individual dummy variables were introduced because the trade volume between those pairs largely distorted the model and the observed trade volume is available in the WTS data or UN-Comtrade.

Table 1. Estimation results of the gravity model for shipping demand among Pacific ports

Variable	Unit		Coefficient	t statistic
GDP of origin country	Million US\$	$\theta_r$	0.891**	4.03
GDP in destination country	Million US\$	$\theta_s$	0.764**	5.27
Distance between O-D pair	Nautical miles	$L_{rs}$	-2.441**	-3.84
Intercept		$Z_0$	3.073	1.57
Country group dummy variables		$Z_1$		
NZ-NZ			1.313**	2.68
NZ-AU			1.646	1.30
AU-US			-4.534**	-3.61
AU-GB			1.184	1.82
US-US			0.849	1.60
GB-GB			1.046*	2.12
FR-FR			-0.514	-0.75
Regional group dummy variables		$Z_2$		
M-m			-0.881	-1.85
m-P			-1.416*	-2.28
P-P			-0.892*	-2.11
P-PNG			-1.110	-1.22
Individual dummy variables		$Z_3$		
NZ and New Caledonia			-0.023	-0.02
NZ and French Polynesia			1.203	0.94
NZ and PNG			-0.689	-0.37
NZ and Vanuatu			-1.192	-0.71
NZ and Fiji			0.967	0.75
Fiji and Vanuatu			1.389	1.10
Adjusted $R^2$			0.588	
Number of observation			92	

Note 1: “NZ,” “AU,” “GB,” and “FR” represent New Zealand, Australia, Great Britain, and France, respectively. “M,” “m,” and “P” represent Melanesia, Micronesia, and Polynesia, respectively.

Note 2: \*\*:  $p < 0.01$ ; and \*:  $p < 0.05$ .



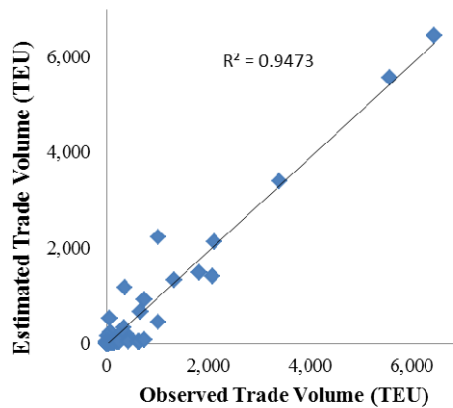


Figure 3. Estimated versus observed trade volume among PI

## 5.2 Model Calibration

First, the two parameters related to congestion in Equation (5) are given as  $(b_1, b_2) = (2.308, 1.017)$ , following the study by Shibasaki and Kawasaki (2016). Next, the remaining unknown parameter, which is the multiplying factor for the transshipment time between different shipping companies  $b_3$ , is computed to fit the estimated transshipments to the observed ones at two PI ports whose transshipment data were available, namely Suva (Fiji) and Apra (Guam). In addition to the transshipment in these two PI ports, the R-squared of estimated transshipment volumes and rates at the world's major hub ports are also considered. As a result of model calibration, the transshipment time between different shipping companies is set to be four times longer, compared to transshipment within the same shipping company. In other words,  $b_3$  is set equal to 4.0.

The UE assignment is performed using the Frank-Wolfe algorithm. Figure 4 shows the convergence rate at each iterative process, which is defined as the square root of quotient to divide the sum of squared differences between each link flow at an iterative calculation and that of the one just before by the sum of squared link flows at an iterative calculation. The figure indicates that the gradient of the convergence rates gradually becomes smaller. Figure 5 shows the comparison between the computed link flows at the 9th iteration and those at the 10th iteration. Note that the 9th iterative process yields the convergence rate of 0.001. Since the link flows in the 9th iterative process are almost identical to those in the 10th iterative process, 0.001 can be regarded as a sufficient criterion for judging the convergence.

Figure 6 shows the comparison between the estimated and the observed transshipment volumes and rates at the world's major hub ports based on data for the year 2013. The total throughput of transshipped containers estimated for all ports in the model is 98.8 million TEU, while the observed throughput is 99.8 million TEU. This observation and Figure 6 indicate that the developed model reproduces maritime container flows in the world reasonably well.

Table 2 shows the estimated versus observed volumes and rates of transshipment containers at major Pacific ports. According to the estimation results, Apra, Lae, and Noumea are mainly utilized for transshipment between East/Southeast Asia and the PI ports, Papeete for transshipment between North America/Europe and the PI ports, and Suva for both. The result that these ports have a relatively large amount of transshipment is consistent with existing literature and information collected through a field survey conducted by the authors.

Meanwhile, the observed transshipment data for PI is available only for Apra and Suva. Of these two ports, the estimated volume at Suva fits the observed volume well. However, the estimated volume at Apra is significantly lower than the observed one. One possible reason

for this is that a significant amount of empty containers is included in the observed data. The observed data in Suva, however, does not include empty containers.

From the above examinations, the developed model is comprehensively considered to describe the actual maritime container flows in the Pacific region at the same level as for those in other regions of the world.

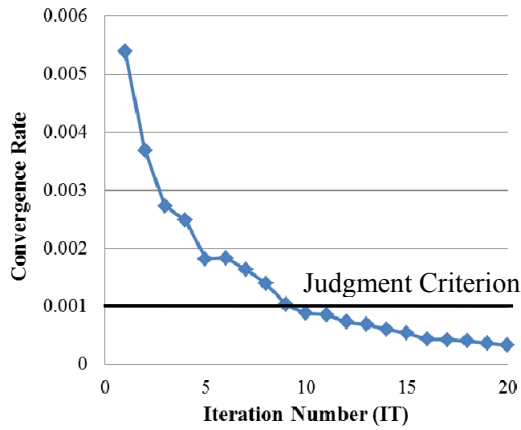


Figure 4. Changes in convergence rate over iterative process

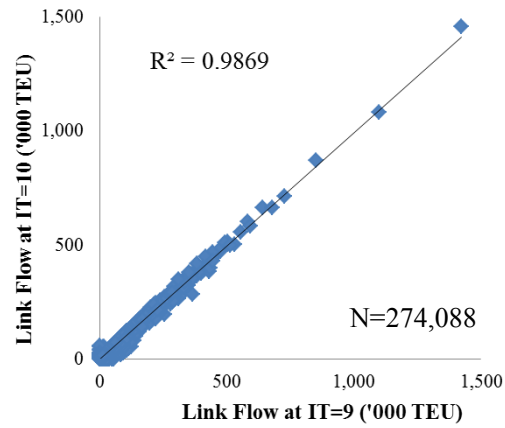


Figure 5. Comparison of link flows at the ninth and tenth iterative process

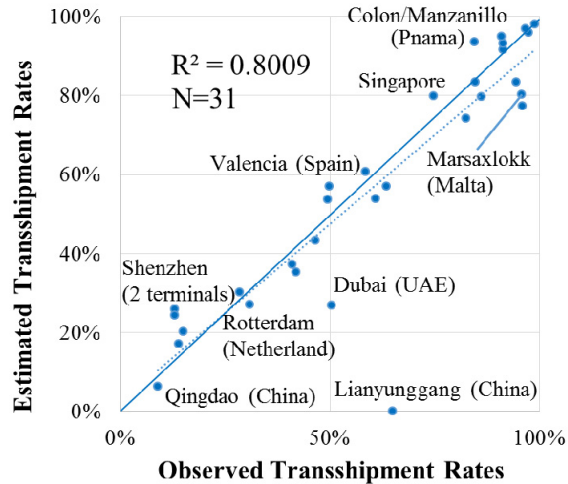
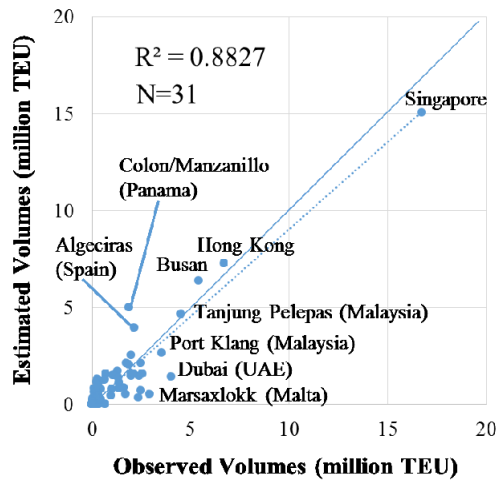


Figure 6. Estimated versus observed transshipment volumes and rates at the world's major hub ports

Table 2. Estimated vs. observed volumes and rates of transshipment at major Pacific ports

Port	Estimated		Observed	
	Volume (TEU)	Percentage	Volume (TEU)	Percentage
Brisbane (Australia)	191,663	25.7%	N.A.	N.A.
Auckland (New Zealand)	174,161	22.6%	173,404 <sup>a</sup>	17.9%
Tauranga (New Zealand)	29,050	4.4%	N.A.	N.A.
Apra (Guam)	4,200	11.1%	42,000 <sup>b</sup>	28.0%
Lae (Papua New Guinea)	7,929	9.0%	N.A.	N.A.
Suva (Fiji)	10,811	15.1%	11,007 <sup>c</sup>	10.0%
Noumea (New Caledonia)	2,695	4.2%	N.A.	N.A.
Papeete (French Polynesia)	8,739	22.0%	N.A.	N.A.
Pacific Islands Total	35,856	6.0%	N.A.	N.A.

Source: a. Data acquired from Ports of Auckland (POAL), 2015; b. Parsons Brinckerhoff, 2013.; c. Data acquired from Fiji Ports Corporation Ltd., 2015.

Note: "N.A." represents that the data is not available.

## 6. SCENARIO ANALYSIS

### 6.1 Overview

This study assumes four scenarios for the year 2030: (1) the “baseline scenario,” (2) the “port development scenario,” (3) the “Honolulu shipping service scenario,” and (4) the “vessel enlargement scenario.” In Scenario (1), the service frequency and vessel capacity of maritime services are increased in accordance with the growth of the world’s shipping demands. Scenario (2) assumes that the service level of a single Pacific port is improved, which is expressed by the reduction of transshipment time in this model. Scenario (3) assumes the commencement of a new shipping service connecting the north and south of the Pacific region in order to complement the existing shipping network in the Pacific region. Scenario (4) assumes the further enlargement of vessels calling on Australia and New Zealand. In the scenario analysis, Scenarios (2) to (4) are compared with Scenario (1) in terms of maritime transportation patterns, which is expressed by the transshipment volume at each port, as well as the performance of regional maritime services, which is evaluated based on shipping time.

Three indices for performance evaluation are calculated based on the average weighted shipping time for containers to and from each PI port  $AT_r$  (hour), which is defined as

$$AT_r = \frac{\sum_s (q^{rs} t^{rs*} + q^{sr} t^{sr*})}{\sum_s (q^{rs} + q^{sr})}, \quad (13)$$

where  $t^{rs*}$  is the converged shipping time from port  $r$  to port  $s$ . Note that the converged shipping time should be equivalent among different paths for each O-D pair.

The first performance index is the regional average weighted shipping time  $AT_p$  (hour), which could represent the efficiency with respect to shipping time. This is defined as

$$AT_p = \frac{\sum_{r \in R_p} \sum_s (q^{rs} t^{rs*} + q^{sr} t^{sr*})}{\sum_{r \in R_p} \sum_s (q^{rs} + q^{sr})}, \quad (14)$$

where  $R_p$  is the set of PI ports.

The second performance index is the standard deviation of average-shipping time  $\sigma_{AT}$  (hour), which could represent the equality among the PI ports with respect to average shipping time. This is defined as

$$\sigma_{AT} = \sqrt{\frac{1}{N_{R_p}} \sum_{r \in R_p} (AT_r - \overline{AT})^2}, \quad (15)$$

where  $N_{R_p}$  is the number of ports in the set of PI ports  $R_p$  (i.e.  $N_{R_p} = 26$ ) and  $\overline{AT}$  is the unweighted average of the average shipping time to and from each PI port  $AT_r$ .  $\overline{AT}$  is calculated as

$$\overline{AT} = \frac{1}{N_{R_p}} \sum_{r \in R_p} AT_r . \quad (16)$$

Lastly, the third performance index is the maximum average-shipping time  $AT_{\max}$  (hour), which could represent the bottom line of the regional maritime service level. This may represent a kind of equity as well, but this study considers that it rather represents the absolute handicap with respect to maritime shipping time in the region. This is defined as

$$AT_{\max} = \max_{r \in R_p} AT_r . \quad (17)$$

## 6.2 Baseline Scenario

The baseline scenario assumes a future situation in 2030 where the international maritime market changes at a business-as-usual growth rate. The shipping demand (O-D matrix) in this scenario is estimated based on the WTS projection data for 2030 when the world's total shipping demand is 2.22 times larger than that in 2013. To retain the balance between shipping demand and maritime service provision, the annual TEU capacity (i.e.,  $freq_a \cdot cap_a$ ) of each shipping service included in the model is assumed to be uniformly increased at this growth rate as follows. First, the annual service frequency is doubled under the condition that it is equal to or less than 52, which indicates a weekly service (i.e. the upper limitation of the service frequency is a weekly service). Next, the vessel capacity is enlarged so that the annual TEU capacity of the service is 2.22 times of that in 2013 under the constraint on vessel size so that whether the vessel is able to transit the Panama and Suez Canals remains unchanged.

In the WTS projection data, the average growth rate of shipping demand to and from the PI is 1.47, which is lower than the world average. On the other hand, the average growth rate for PNG is 3.51, which is exceptionally high. Since this study focuses on the Pacific region, 1.47 is used for services that call at PI ports excluding PNG ports but does not call at PNG ports, and 3.51 is used for services that call at PNG ports.

Table 3 shows the comparison of estimated transshipment volumes in major Pacific ports between 2013 and 2030. Large increases in transshipment volumes are observed in the ports listed in the table, especially in Apra, Lae, and Honiara. On the other hand, the transshipment volume at Papeete shows only a marginal increase. This result implies that Asia is expected to be an important trade partner for the Pacific region in the future.

Table 3. Comparison of transshipment volumes in major Pacific ports between the current condition in 2013 and the baseline scenario in 2030

Port	2013 (TEU)	2030 (TEU)	Change from 2013 to 2030 (TEU)
Apra (Guam)	4,200	9,027	4,827
Lae (PNG)	7,929	13,131	5,202
Honiara (Solomon Islands)	42	9,313	9,271
Suva (Fiji)	10,811	11,996	1,184
Noumea (New Caledonia)	2,695	6,282	3,587
Papeete (French Polynesia)	8,739	9,172	433

### 6.3 Port Development Scenario

The port development scenario assumes 23 cases in which a single PI port out of 23 ports is improved. Note that PI ports with only one shipping service available is excluded from the analysis since transshipment is not possible in such ports. The improvement is assumed to reduce the transshipment time of the targeted PI port to 72 hours, which is half the original transshipment time. The estimation results are compared with the baseline scenario in terms of transshipment volumes at each port and the three performance indices introduced earlier.

Table 4 shows the transshipment volumes and their changes from the baseline scenario in cases where Lae, Madang (PNG), Port Moresby (PNG), Honiara, Suva, Lautoka (Fiji), Noumea, and Papeete are improved, respectively. Only ports that displayed a significant increase in transshipment volumes are shown; significant increases are enclosed by a thick line and significant decreases are shaded. First, improvement of transshipment time in each port significantly increases the number of transshipment containers in that port. In most ports, the number of transshipment containers is expected to be more than doubled. Even in some local ports (such as Madang) where no transshipment containers are estimated in the baseline scenario, some handling of transshipment containers are expected.

Next, focusing on intra-regional competition, two large regional competitions exist in the PI region. The first one is within PNG (i.e. between Lae, Madang, and Port Moresby). When Madang and Port Moresby are each improved, transshipment shifts from Lae to the improved port. The second competition is between Suva, Lautoka, Noumea, and Papeete. The table also shows that transshipment shifts from Australian/New Zealand ports to Lae, Suva, Lautoka and Papeete, respectively, when each of these ports is improved. This may represent the competitive relationship between Australian/New Zealand ports and these ports in the PI region. On the other hand, transshipment in Australian/New Zealand ports is expected to increase when each of the other PI ports is improved. These ports may be in a complementary relationship with Australian/New Zealand ports.

Table 5 shows the changes in the three regional performance indices from the baseline scenario when each Pacific port is improved. Note that PI ports with only one shipping service are not included since transshipment is impossible at such ports. The efficiency ( $AT_p$ ) is enhanced most when Lae is improved, followed by Noumea and Madang. Improving ports with large container handling contributes significantly to reducing the average shipping time per container. The container handling at Lae is particularly large due to the heavily used Asia-Pacific services often calling at Lae. Suva is by far the best choice for equality ( $\sigma_{AT}$ ), followed by Apra. Suva is one of the regional hubs in the Pacific region; therefore, improving its port will benefit the entire region. The bottom line of maritime service levels ( $AT_{max}$ ) is alleviated the most when Apra is improved. Pohnpei (Federated States of Micronesia) has only one shipping service available and has the longest average shipping time  $AT_r$ . By improving Apra, which is the next port of call in this specific service, the shipping time to Pohnpei is improved significantly, thus improving the bottom line of regional maritime services levels. Finally, the most balanced performance is achieved when Noumea is improved, where all three indices are improved by a relatively large degree. This is because Noumea not only has Asia-Pacific services, which are utilized by many containers, but also has services to other PI including the northern PI such as Betio and Majuro.

### 6.4 Honolulu Shipping Service Scenario

The Honolulu shipping service scenario assumes the commencement of a new shipping

Table 4: Estimated transshipment volumes and changes from the baseline at major Pacific ports in the port development scenarios

Transshipment Ports	Data (TEU)	Improved Ports								
		Baseline	Lae	Madang	P. Moresby	Honiara	Suva	Lautoka	Noumea	Papeete
Lae (PNG)	Volume	13,131	28,851	10,942	11,667	12,667	13,502	13,598	13,305	13,237
	Change	-	15,720	-2,189	-1,464	-464	370	467	174	106
Madang (PNG)	Volume	0	0	5,737	0	0	0	0	0	0
	Change	-	0	5,737	0	0	0	0	0	0
P. Moresby (PNG)	Volume	1,277	1,215	1,289	4,126	1,280	1,191	1,266	1,293	1,267
	Change	-	-62	11	2,849	3	-86	-12	15	-10
Honiara (Solomon Is.)	Volume	9,313	9,864	9,036	9,289	20,002	9,193	9,625	9,033	9,561
	Change	-	551	-277	-24	10,689	-120	312	-280	248
Suva (Fiji)	Volume	11,996	12,082	11,876	12,311	12,088	22,035	10,914	11,138	10,648
	Change	-	86	-120	315	93	10,039	-1,082	-858	-1,348
Lautoka (Fiji)	Volume	1,853	1,792	1,560	1,918	1,865	1,853	7,236	267	1,592
	Change	-	-61	-293	65	12	0	5,383	-1,586	-260
Noumea (New Caledonia)	Volume	6,282	5,887	6,327	6,297	6,494	6,122	5,878	15,329	6,069
	Change	-	-395	45	15	212	-159	-404	9,047	-213
Papeete (French Polynesia)	Volume	9,172	8,772	9,565	9,085	9,218	8,560	8,493	8,971	23,340
	Change	-	-400	393	-87	46	-612	-679	-201	14,169
Australia/New Zealand Total	Volume	1,152,159	1,138,966	1,159,518	1,180,061	1,162,818	1,141,239	1,150,505	1,163,824	1,144,438
	Change	-	-13,193	7,359	27,902	10,659	-10,920	-1,654	11,665	-7,721
Brisbane (Australia)	Volume	387,830	372,322	393,774	403,834	390,110	387,992	391,551	397,561	402,286
	Change	-	-15,507	5,945	16,004	2,281	162	3,722	9,732	14,456
Sydney (Australia)	Volume	263,396	265,504	261,204	274,345	270,597	258,567	269,724	275,795	254,691
	Change	-	2,108	-2,192	10,949	7,201	-4,829	6,328	12,399	-8,704
Melbourne (Australia)	Volume	186,474	185,245	181,722	182,786	186,526	177,978	178,586	180,572	178,154
	Change	-	-1,230	-4,752	-3,688	52	-8,496	-7,888	-5,902	-8,320
Auckland (New Zealand)	Volume	253,078	256,928	260,155	255,725	254,818	255,079	251,836	251,216	250,618
	Change	-	3,850	7,077	2,646	1,740	2,001	-1,242	-1,862	-2,460
Tauranga (New Zealand)	Volume	61,381	58,967	62,663	63,371	60,767	61,623	58,808	58,680	58,689
	Change	-	-2,415	1,282	1,990	-615	242	-2,573	-2,702	-2,693

Note: Significant increases are enclosed by a thick line and significant decreases are shaded

Table 5. Changes in performance indices of Pacific ports under the port development scenario

Improved Port	Average shipping time	Standard deviation of	Maximum shipping time in
	$AT_P$ (hour)	average shipping time	the region $AT_{max}$ (hour)
		$\sigma_{AT}$ (hour)	
Apra (Guam)	0.2	-3.8	-32.4
Saipan Island (N. Mariana Is.)	-0.6	-1.3	-21.2
Majuro (Marshall Is.)	-0.4	-0.9	-18.4
Betio (Kiribati)	-0.1	-0.5	-5.6
Port Funafuti (Tuvalu)	1.1	0.3	0.2
Nauru	0.2	0.1	-5.8
Futuna (Wallis&Futuna)	0.4	-0.3	-0.8
Lae (PNG)	-3.8	3.3	18.6
Madang (PNG)	-2.1	-0.6	-1.9
Port Moresby (PNG)	-0.3	0.1	-3.4
Rabaul (PNG)	-1.2	-1.8	-4.8
Honiara (Solomon Is.)	-0.5	-1.0	-6.3
Noro (Solomon Is.)	-1.2	-0.8	-2.1
Port Vila (Vanuatu)	-1.7	-1.5	-8.8
Santo (Vanuatu)	-1.3	-2.7	-7.7
Lautoka (Fiji)	0.0	-1.8	-8.1
Suva (Fiji)	-0.6	-7.3	-5.7
Noumea (New Caledonia)	-2.2	-2.3	-12.5
Apia (Samoa)	-0.4	-0.7	-0.9
Pago Pago (American Samoa)	0.5	-0.6	-0.7
Nukualofa (Tonga)	0.0	0.1	-0.2
Rarotonga (Cook Islands)	0.0	0.5	-0.6
Papeete (French Polynesia)	-0.7	-0.9	-2.0

service directly connecting the north and south of the Pacific region. In the current shipping network in the Pacific region, liner service networks in the Micronesian area are more scarce compared with Polynesia and Melanesia. In addition, no service stretches in the northeast-southwest direction. Therefore, the newly assumed service attempts to complement the current network. Given that Matson (shipping company) operates a large shipping service connecting Honolulu, Apra, and China (the brown line in the north in Figure 1), this scenario assumes that Matson begins a similar service connecting Honolulu, PI, and Brisbane. The ports of call of this new service are assumed to be Honolulu, Majuro, Betio, Nauru, Port A, Brisbane. For Port A, five ports are raised as possible options based on their geographical locations: Lae, Honiara, Port Vila, Noumea, and Suva. Figure 7 shows the new shipping service in green lines.

Table 6 shows the transshipment volumes and their changes from the baseline at a number of Pacific ports in each case of this scenario. Only the ports of call of the new service and ports with significant changes are shown in the table. The ports of call are shaded. In all five cases, the amounts of transshipment at both ends of the new service (Honolulu and Brisbane) are estimated to significantly increase. In this sense, the new service is functioning in the maritime shipping network in the Pacific region in all cases. Among these cases, the increased amount of transshipment in Brisbane port is relatively smaller when Lae or Honiara is selected, which indicates the direct call at these ports can be partly substituted for the feeder transport via Brisbane port.

On the other hand, the amount of transshipment at neighboring regional hubs such as Apra, Auckland and Noumea decreases. Therefore, these ports are considered to be competitive with Brisbane or Honolulu port. The transshipment volumes at Majuro, Betio, and Nauru increase since containers from other PI ports are transshipped on to the new service at these ports, while the changes in transshipment volume of each “Port A” are different among ports.

Table 7 shows changes in the three performance indices from the baseline scenario in each case of this scenario. Note that the numbers in this table are significantly larger than those in Table 5 because the commencement of a new shipping service involves much more containers compared to the improvement of a single PI port. The results show that the impacts of the new service on efficiency ( $AT_p$ ) do not differ significantly among the five cases except for the Noumea case. Similarly, the impacts on equality ( $\sigma_{AT}$ ) do not differ significantly except for the Suva case, and the impacts on the bottom line of maritime services ( $AT_{max}$ ) do not differ significantly except for the Port Vila case and Suva case. The results suggest that calling at Lae or Honiara may be the better choice for the new service based on the three indices.

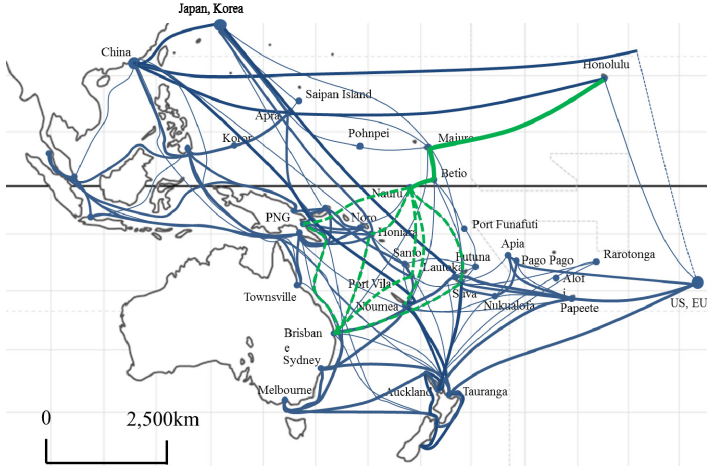


Figure 7. New shipping service under the Honolulu shipping service scenario

Table 6. Transshipment volume and changes by port of call in new shipping service (TEU)

Transshipment Port	Data (TEU)	Port of Call					
		Baseline	Lae	Honiara	Port Vila	Noumea	Suva
Honolulu (Hawaii, US)	Volume	450	46,765	22,138	18,032	19,744	20,726
	Change	-	46,315	21,688	17,582	19,294	20,275
Majuro (Marshall Is.)	Volume	1,015	2,167	2,188	2,862	2,418	2,802
	Change	-	1,152	1,173	1,847	1,403	1,787
Betio (Kiribati)	Volume	0	613	637	697	793	132
	Change	-	613	637	697	793	132
Nauru	Volume	14	1,525	1,369	1,746	1,478	359
	Change	-	1,511	1,355	1,733	1,465	346
Lae (PNG)	Volume	13,131	10,386	13,201	12,844	15,740	11,024
	Change	-	-2,745	70	-287	2,609	-2,107
Honiara (Solomon Is.)	Volume	9,313	4,797	7,760	10,580	2,424	11,300
	Change	-	-4,515	-1,552	1,267	-6,889	1,987
Port Vila (Vanuatu)	Volume	221	129	2,706	67	31	42
	Change	-	-92	2,485	-154	-190	-179
Noumea (New Caledonia)	Volume	6,282	2,956	3,350	2,918	2,984	2,599
	Change	-	-3,326	-2,932	-3,364	-3,298	-3,683
Suva (Fiji)	Volume	11,996	11,800	10,553	29,410	13,027	14,655
	Change	-	-195	-1,443	17,414	1,031	2,659
Brisbane (Australia)	Volume	387,830	438,183	444,740	477,805	487,759	462,580
	Change	-	50,354	56,911	89,975	99,930	74,750
Auckland (New Zealand)	Volume	253,078	234,852	231,991	225,976	231,088	225,237
	Change	-	-18,226	-21,087	-27,103	-21,990	-27,841
Apra (Guam, US)	Volume	9,027	5,998	5,381	7,441	6,046	7,731
	Change	-	-3,029	-3,646	-1,586	-2,981	-1,296

Table 7. Changes in performance indices by port of call of new shipping service

Port of Call	Average shipping time $AT_p$ (hour)	Standard deviation of average shipping time $\sigma_{AT}$ (hour)	Maximum shipping time in the region $AT_{max}$ (hour)
Lae (PNG)	-14.9	-39.5	-152.0
Honiara (Solomon Is.)	-13.6	-45.2	-157.7
Port Vila (Vanuatu)	-12.5	-46.0	-89.3
Noumea (New Caledonia)	-7.1	-41.5	-163.1
Suva (Fiji)	-15.0	-31.5	-62.8

## 6.5 Vessel Enlargement Scenario

The vessel enlargement scenario assumes the further enlargement of vessels in services connecting Australia/New Zealand with non-Pacific regions (hereafter referred to as AU/NZ services), reflecting the recent acceleration of containership enlargement in the trunk routes of the world and its spill-out to other local routes known as a “cascade effect” of containership (OECD, 2015). Note that the vessel size of each liner service is already assumed to be enlarged in the baseline scenario as described in 6.2, in order to meet the growth of future shipping demand. The scenario consists of three cases. In Case 1, further vessel enlargement is assumed only for AU/NZ services (to be multiplied by three from the baseline scenario) not calling at PI ports. Those calling at PI ports remain unchanged from the baseline scenario. In Case 2, further vessel enlargement is assumed for all AU/NZ services including those calling at PI ports. In other words, every PI port where AU/NZ services call at is able to accommodate larger vessels by adequate investment to port infrastructure if needed. Lastly, Case 3 assumes that all AU/NZ services are further enlarged and those with a vessel capacity



of over 4,000 TEU, which is the largest vessel size in the PI region in the baseline scenario, skip PI ports. In other words, this case assumes that no additional investments from the baseline scenario will be made on infrastructure in PI ports.

Table 8 shows the transshipment volumes and changes from the baseline scenario in each three cases. In Case 1, although transshipment at some PI ports slightly decreases and shifts to AU/NZ services, the changes are relatively small. In Case 2, the decrease is greater compared to Case 1. This is because more containers are directly transported instead of being transshipped within the PI region. Also note that in Case 2, a significant increase in transshipment is observed at Tauranga. These containers utilize the enlarged AU/NZ services while inside the Pacific region and are transported between North America/Europe and PI, using Tauranga as their inter-regional hub. In Case 3, transshipment at PI ports almost completely shifts to AU/NZ ports, strengthening the hub-and-spoke network structure.

Table 9 shows changes in the average weighted shipping time  $AT_r$  in each case from the baseline scenario in terms of hours and percentage. Reductions in average shipping time are observed in many PI ports in every case since the enlargement of vessels would result in less congestion, thus shortening shipping time. However, the degree of reduction in Case 1 is small compared to that of Case 2. This shows that if Pacific ports are able to accommodate larger vessels, most of the PI ports would benefit from vessel enlargements. Furthermore, significant reductions can be observed in relatively remote PI, indicating that vessel enlargement inside the region is an effective approach for reducing inequality in terms of shipping time. In Case 3, shipping time to/from a number of major Pacific ports, namely Suva, Noumea, and Papeete increases. This is because these ports are the ones to be skipped by AU/NZ services should they be unable to accommodate larger vessels. Case 3 implies that regional hubs will suffer the most when services skip PI ports. Particularly, the increase in shipping time is exceptionally large at Papeete, highlighting its high level of dependence on AU/NZ services.

Table 8. Transshipment volumes and changes in the vessel enlargement scenario (TEU)

Port	Data (TEU)	Base	Case 1	Case 2	Case 3
Lae (PNG)	Volume	13,131	10,239	4,177	1,770
	Change	-	-2,892	-8,954	-11,361
Honiara (Solomon Is.)	Volume	9,313	7,942	3,594	6,010
	Change	-	-1,371	-5,719	-3,303
Suva (Fiji)	Volume	11,996	12,876	7,481	623
	Change	-	880	-4,514	-11,372
Noumea (New Caledonia)	Volume	6,282	5,838	2,782	2,906
	Change	-	-444	-3,500	-3,376
Papeete (French Polynesia)	Volume	9,172	9,534	8,328	0
	Change	-	362	-844	-9,172
Australia/New Zealand Total	Volume	1,152,159	1,225,238	1,223,250	1,257,362
	Change	-	73,079	71,091	105,203
Brisbane (Australia)	Volume	387,830	438,923	432,947	481,664
	Change	-	51,094	45,118	93,835
Sydney (Australia)	Volume	263,396	257,745	225,078	231,158
	Change	-	-5,651	-38,317	-32,238
Melbourne (Australia)	Volume	186,474	198,533	185,241	119,656
	Change	-	12,058	-1,233	-66,819
Auckland (New Zealand)	Volume	253,078	266,930	272,509	333,637
	Change	-	13,852	19,431	80,559
Tauranga (New Zealand)	Volume	61,381	63,107	107,474	91,247
	Change	-	1,726	46,093	29,866

Table 9. Change in  $AT_r$  (hours) in the vessel enlargement scenario

Port	Case 1		Case 2		Case 3	
	Change	Rate	Change	Rate	Change	Rate
Apra (Guam)	3	0.5%	0	0.0%	-8	-1.5%
Saipan Island (N. Mariana Is.)	4	0.8%	1	0.2%	-8	-1.8%
Koror (Palau)	-1	-0.1%	-8	-1.1%	-20	-2.7%
Pohnpei (Micronesia)	-25	-1.6%	-14	-0.9%	-2	-0.1%
Majuro (Marshall Is.)	-20	-1.7%	-116	-10.6%	-124	-11.4%
Betio (Kiribati)	-19	-1.6%	-142	-12.7%	-146	-13.1%
Port Funafuti (Tuvalu)	-38	-3.0%	-178	-15.6%	-187	-16.5%
Nauru	-12	-0.9%	-262	-24.9%	-260	-24.6%
Futuna (Wallis & Futuna)	-16	-1.2%	-153	-13.2%	-146	-12.5%
Lae (PNG)	-8	-1.0%	-31	-4.2%	-25	-3.4%
Madang (PNG)	-16	-1.8%	-58	-6.9%	-58	-7.0%
Port Moresby (PNG)	1	0.1%	-18	-2.5%	-15	-2.1%
Rabaul (PNG)	-10	-1.2%	-28	-3.4%	-29	-3.5%
Honiara (Solomon Is.)	-2	-0.2%	-28	-3.7%	-15	-2.0%
Noro (Solomon Is.)	5	0.5%	-48	-5.0%	-40	-4.1%
Port Vila (Vanuatu)	-4	-0.6%	-26	-3.8%	-12	-1.7%
Santo (Vanuatu)	-3	-0.4%	-35	-5.7%	-12	-1.9%
Lautoka (Fiji)	-14	-1.6%	-79	-10.4%	-8	-1.0%
Suva (Fiji)	-18	-2.2%	-80	-11.0%	66	7.6%
Noumea (New Caledonia)	-6	-1.0%	-49	-9.0%	24	3.9%
Apia (Samoa)	-2	-0.2%	-88	-9.8%	10	1.0%
Pago Pago (American Samoa)	-12	-1.0%	-97	-9.4%	-5	-0.4%
Nukualofa (Tonga)	3	0.3%	-111	-13.2%	-25	-2.7%
Alofi (Niue)	-32	-2.4%	-219	-19.0%	-225	-19.6%
Rarotonga (Cook Is.)	3	0.3%	-143	-13.2%	-147	-13.6%
Papeete (French Polynesia)	-16	-2.2%	-65	-9.6%	523	41.3%

## 7. CONCLUSIONS

This study developed a model to simulate international cargo flows in the Pacific region and examined potential impacts of policies and investments by applying the developed model. First, the current conditions and challenges of maritime freight transportation in the Pacific region were summarized. Then, an international maritime freight transportation model was formulated. The model applies the user equilibrium principle for network assignment while considering vessel capacity and congestion under given shipping demand between ports, following Shibasaki and Kawasaki (2016). For data preparation, the O-D matrix was estimated by integrating multiple methods since data availability is poor in the Pacific region, along with the preparation of the maritime shipping network and the port data. Next, the model was calibrated based on existing databases and local data collected through a field survey. The developed model successfully reproduced the observed transshipment volumes at ports across the world, including the PI ports. Finally, the model was applied to four scenarios for 2030: the baseline scenario, the port development scenario, the Honolulu shipping service scenario, and the vessel enlargement scenario.

The baseline scenario showed that Asia would become an increasingly important trade partner for PI. The port development scenario showed that improvement in transshipment time results in a significant increase in container handling at the improved PI port. Furthermore, the scenario revealed competition between ports in the PI region. From a regional perspective, competition exists between Australian/New Zealand ports and Lae, Suva, and Papeete. Within a specific regional level, competition exists within PNG and between

Suva, Lautoka, Noumea, and Papeete. The scenario also indicated that, in terms of shipping time, Lae should be improved for regional efficiency, Suva for equality, and Apra for the bottom line. The most balanced outcome is earned when Noumea is improved.

The Honolulu shipping service scenario implied that the commencement of a new shipping service close to the regional hub promotes further transshipment at the hub.

Lastly, the vessel enlargement scenario showed that PI could benefit from the world's vessel enlargement trend given that their ports are able to accommodate larger vessels. However, if this is not possible, the relatively large ports in the PI region will experience longer shipping time and lower accessibility. When focusing on transshipment volumes, transshipment shifts from PI ports to Australia and New Zealand, resulting in a significant decrease in container handling at PI ports.

These results are expected to contribute to policy development regarding maritime freight transportation in the Pacific region.

This study successfully realized a significant breakthrough in the quantitative analysis of maritime freight transportation in the Pacific region. However, it still has a number of further issues. First, the model developed in this study assumes that the shipping route for each container is selected solely by shipping time, and this may be an oversimplification. The incorporation of generalized cost, including both shipping time and freight charge, and the development of a more complex model to describe competition based on contestable market theory are considered as next steps. Second, further validation of the developed model may be considered necessary. Due to the limited availability of data, the reproducibility and reliability of the model need to be examined in various ways from various perspectives. Parallel to the fine-tuning, we hope to apply the model to analyses on individual projects and specific regions such as Melanesia, Polynesia, and Micronesia. Lastly, this study focuses only on international maritime containers. The expansion of the scope for non-containerized cargo such as bulk cargo is one possible topic for further research. Although the inclusion of hinterland transportation is a possible topic as well, its priority is relatively low since the PI mostly rely on maritime transportation for international trade in goods.

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## REFERENCES

- Asian Development Bank, 2007. *Oceanic voyages: Shipping in the Pacific*. Manila.
- Asian Development Bank and Asian Development Bank Institute, 2015. *Pacific opportunities: Leveraging Asia's growth*. Manila.
- Australian Agency for International Development (AusAID), 2004. *Pacific regional transport study. Country reports*. Canberra.
- China Port Yearbook Publishers, 2014. *Chinese Port Yearbook 2014*. Beijing, China.

- Collier, P., 2008. *The bottom billion: Why the poorest countries are failing and what can be done about it*. Oxford University Press, New York.
- Drewry Maritime Research, 2013. *Container Forecaster 2013 Annual Review*. London, UK.
- Drewry Maritime Research, 2014a. *Container Forecaster 2014 Annual Review*. London, UK.
- Drewry Maritime Research, 2014b. *Global Container Terminal Operators, Annual Report 2014*. London, UK.
- Fiji Ports Corporation Ltd., 2015. Data acquired from interview survey.
- IHS Inc., 2013. *World trade service*.
- Japan International Cooperation Agency (JICA), 2014. *Situation of port related projects in the Pacific region*. (in Japanese)
- KPMG website: <http://www.kpmg.com/AU/en/Pages/default.aspx> (last accessed on February 3, 2016.)
- Lloyd's List: Top 100 Container Ports (on-line available only for subscribers)
- Logistics Capacity Assessment website: <http://www.logcluster.org/lcas> (last accessed on February 3, 2016.)
- MDS Transmodal Ltd., 2013. *The containership databank*.
- OECD, 2015. *The impact of mega-ships*. Report presented at the International Transport Forum, 1 May 2015.
- Parsons Brinckerhoff, 2013. *Jose D. Leon Guerrero Commercial Port of Guam Master Plan Update 2013 Report*. Tamuning, Guam.
- Ports of Auckland (POAL), 2015. Data acquired from interview survey.
- Sea-Distances website: <http://www.sea-distances.org/> (last accessed on February 3, 2016.)
- SeaRates LP website: <https://www.searates.com/> (last accessed on February 3, 2016.)
- Shibasaki, R., Kawasaki, T., 2016. Modelling international maritime container cargo flow and policy simulation in South Asia: An application of network equilibrium assignment model on a global scale, Paper presented at the World Conference on Transport Research – WCTR 2016, Shanghai, China, 10-15 July 2016.
- Toriumi, S., Watanabe, D., 2010. Geographical Analysis on Piracy Activity in Maritime Transportation. *Collection of Papers for the GIS Association of Japan Conference, vol.19*. (in Japanese)
- United Nations, The United Nations Commodity Trade Statistics Database, available at <http://comtrade.un.org/> (last accessed on February 3, 2016.)
- Wardrop, J. G., Whitehead, J. I., 1952. Correspondence. Some Theoretical Aspects of Road Traffic Research. *ICE Proceedings: Engineering Divisions* 1 (5), 767.
- World Bank, 2009. *World development report 2009: Reshaping economic geography*. Washington, DC.
- World Bank, 2015. *Supporting safe, efficient and sustainable maritime transport systems: Improving ports and maritime shipping*. Washington, DC.
- World Bank, Container port traffic (TEU: 20 foot equivalent units): <http://data.worldbank.org/indicator/IS.SHP.GOOD.TU/countries> (last accessed on February 3, 2016.)