Simulation Model for International Maritime Container Flow in the Pacific Region and Scenario Analysis on Maritime Transportation Policies

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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 four 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 is essential for the economic growth of sea-locked developing countries, as is typically mentioned 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 all international cargo in this region is transported by ship, according to the World Trade Service (WTS) database (IHS, 2013). Furthermore, as in other parts of the world, containerization is a major trend in the Pacific region. According to the WTS database (IHS, 2013), 1.7 million tons of container cargo was transported to/from the region, accounting for 12.1% of the total seaborne cargo. In 2013, these numbers increased to 2.8 million and 17.3%, respectively. The future projection in the WTS database estimates 4.2

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million and 19.0% for the year 2030.

Consequently, recent studies on transportation in the Pacific region typically put emphasis on maritime transportation, particularly on maritime container shipping. A comprehensive study by the Asian Development Bank (ADB) (2007) focused on the entire PI region and summarized the current situation of shipping in the PI, identified key challenges, and provided indicative recommendations for each issue. Low port efficiency caused by inadequate port infrastructure and poor terminal operation, and the poor connectivity caused by low service frequencies were raised as 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 maritime container 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.

The model developed in this study is based on the method proposed by Shibasaki and Kawasaki (2016) and predicts worldwide container movements on the actual maritime shipping network by applying a network equilibrium assignment methodology. Unlike many other simulation models that compute optimal shipping network and/or level of service in each liner shipping from the viewpoint of shipping companies (e.g. Meng *et al*., 2014; Wang *et al*., 2013; Christiansen *et al*., 2013), this model is developed from the viewpoint of shippers, under the condition that the service levels of each liner shipping service and each port are exogenously determined. Few studies developed models from the shippers' point of view. Exceptional cases are Bell *et al.* (2011) and Tavasszy (2011). The former study applied a frequency-based traffic assignment model to a maritime container assignment problem, in which liner shipping network is assumed given while frequency and other variables are treated as strategic variables. The latter study formulated a path-size logit model for assigning international containers on an intermodal network consisting of land and maritime routes, but this study does not consider real liner shipping services.

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 (French Polynesia), 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, 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:

$$\min_{X} Z(X)=\sum_{a\in A}\int_0^{x_a} t_a(x)dx \tag{1}$$

subject to

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

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

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

where $Z(\cdot)$ represents the objective function; a a link; A a set of links; x_a the flow of link a; X : a vector of link flows; $t_a(\cdot)$ the cost function (shipping time) of link a; r an origin; s a destination; O 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. The objective function $Z(\cdot)$ in Equation (1) expresses the sum of the integrals of the link performance functions while the following three equations represent the constraints regarding flow conservation and non-negativity. Equation (2) requires the flow of each link to equal the sum of the path flows that pass through the link. Equation (3) shows the flow on all paths connecting each Origin-Destination (O-D) pair has to equal the total shipping demand of the O-D pair. Equation (4) simply states that each path flow should be non-negative.

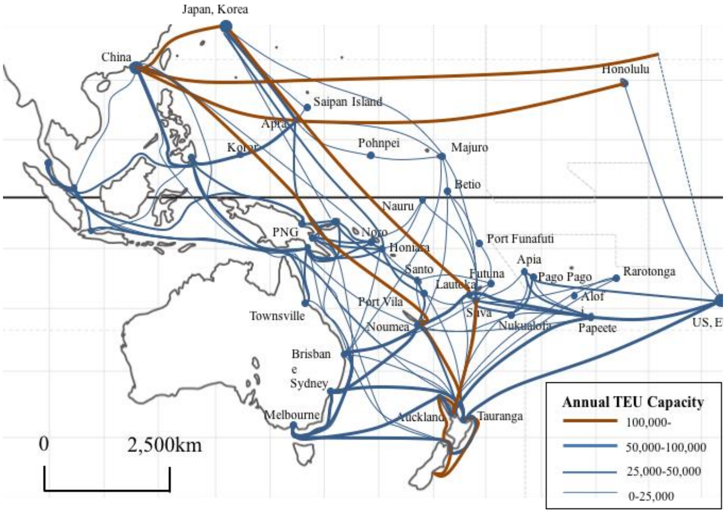

Figure 1. Maritime shipping network in the Pacific region as of 2013

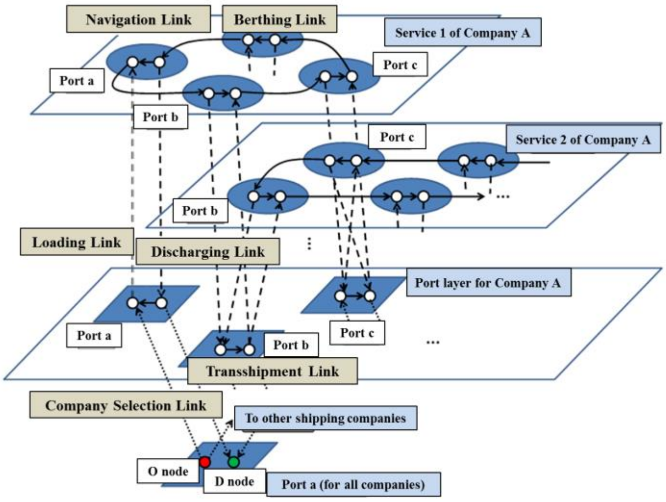

Figure 2. Network structure of the developed model

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. he movement of a container in the developed model is as follows. First, a shipping company is chosen and the container is moved from the origin (i.e. O node) to the port layer of the selected company (company selection link). The container is then moved to one of the service layers of the selected company (loading link). This movement represents the loading of the container onto a shipping service provided by the selected company. Once on the vessel, the container is transported to other ports on the navigation link. After arriving at another port, the container either stays on board (berthing link) or is unloaded from the vessel (discharging link). If unloaded, the container then has the choice of being transshipped to another service (i.e. vessel) or arriving at the final destination (i.e. D node).

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:

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

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); γ_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; γ_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

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

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:

$$t_l(x_a) = TL_a + TW_a \,, \tag{7}$$

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

$$t_d(x_a) = TD_a \,, \tag{8}$$

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

$$t_b(x_a) = TB_a \,, \tag{9}$$

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

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

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

$$t_c(x_a) = SSN \,, \tag{11}$$

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 charted 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 γ_a^s, and that in Panama Canal γ_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 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

$$q_{rs} = \left(\sum_{i} \left(Z_0 + \lambda_i Z_i \right) \right) \left(GDP_r \right)^{\theta_r} \cdot \left(GDP_s \right)^{\theta_s} \left(T_{rs} \right)^{\theta_l}, \tag{12}$$

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; T_{rs} is the shipping time between O-D pairs; and λ_i, θ_r, θ_s, and θ_l are coefficients. Note that the shipping time between O-D pairs T_{rs} is obtained by running the developed model without any cargo demand. 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$	θ_r	0.7728**	3.713
GDP in destination country	Million US$	θ_s	0.5263**	2.853
Shipping time between O-D pair	Hours	T_{rs}	-2.6173**	-4.744
Intercept		Z_0	4.2059	1.892
Free Trade Agreement variables		Z_1		
SPARTECA			1.8260**	5.187
PACER			-1.5398**	-4.294
MSG			-1.5834**	-2.868
Country group dummy variables		Z_2		
AU-US			-5.1016**	-5.208
AU-GB			1.3895*	2.439
US-US			1.6743*	2.291
US-GB			0.6972	1.775
FR-GB			0.5287	1.390
GB-GB			1.5259**	3.493
Regional group dummy variables		Z_3		
M-m			-2.3392**	-4.157
M-P			-1.6751**	-3.289
m-P			-1.9103**	-2.913
P-P			-1.4692*	-2.532
P-PNG			-1.8182*	-2.530
Individual dummy variables		Z_4		
NZ and Fiji			-2.7196*	-2.397
NZ and French Polynesia			-1.4707	-1.375
NZ and New Caledonia			0.8512	0.870
Fiji and Vanuatu			-0.4296	-0.436
Adjusted R^2			0.7693	
Number of observation			89	

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 *: $p<0.05$.

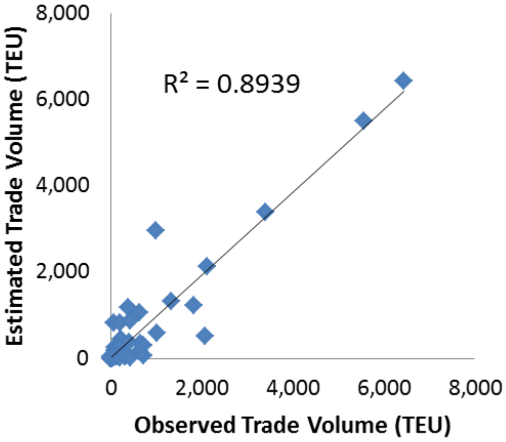

Figure 3. Estimated versus observed trade volume among PI

5.2 Model Calibration

First, $(b_1, b_2) = (2.308, 1.017)$ is given for the two parameters related to congestion in Equation (5), following the study by Shibasaki and Kawasaki (2016). 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 this, the R-squared of estimated transshipment volumes and rates at the world’s major hub ports are considered as well. As a result of model calibration, the transshipment time between different companies is set to be four times longer compared to transshipment within the same 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 10th 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 the results of 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. The estimated volume at Suva fits the observed volume well whereas 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

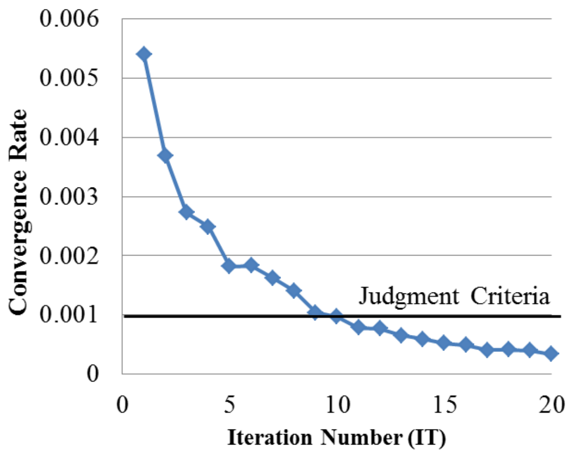

Figure 4. Changes in convergence rate over iterative process

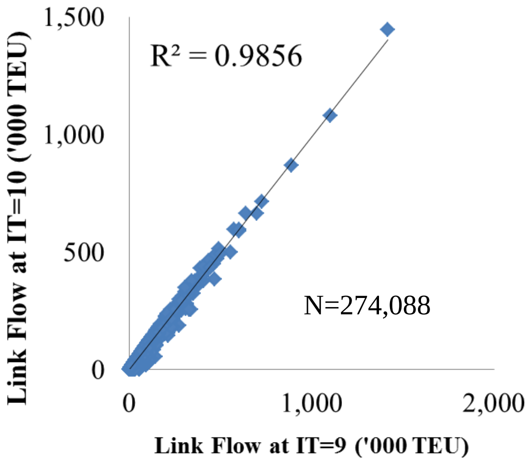

Figure 5. Comparison of link flows at the ninth and tenth iterative process

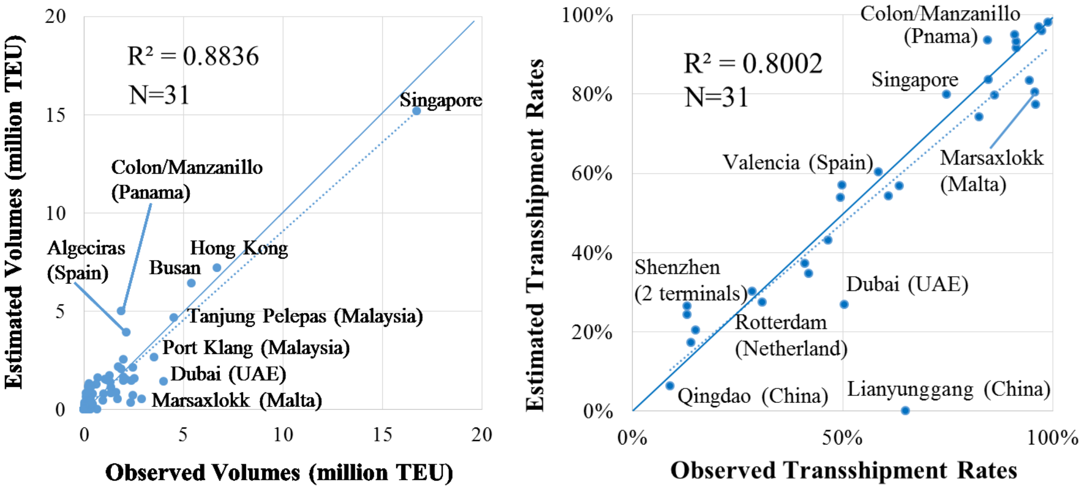

Figure 6. Estimated versus observed transshipment volumes and rates at the world's major hub ports

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

	Estimated		Observed	
Port	Volume (TEU)	Percentage	Volume (TEU)	Percentage
Brisbane (Australia)	194,245	25.9%	N.A.	N.A.
Auckland (New Zealand)	175,244	22.7%	173,404[a]	17.9%
Tauranga (New Zealand)	28,315	4.3%	N.A.	N.A.
Apra (Guam)	4,963	23.3%	42,000[b]	28.0%
Lae (Papua New Guinea)	7,853	9.0%	N.A.	N.A.
Suva (Fiji)	10,770	15.0%	11,007[c]	10.0%
Noumea (New Caledonia)	2,735	4.2%	N.A.	N.A.
Papeete (French Polynesia)	8,697	21.9%	N.A.	N.A.
Pacific Islands Total	36,480	6.7%	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.

data in Suva, however, does not include empty containers. Judging from the above examinations, the developed model is considered to describe the actual maritime container flows in the Pacific region reasonably well.

6. SCENARIO ANALYSIS

6.1 Overview

This study assumes four scenarios for the year 2030: (0) the "baseline scenario," (1) the "port development scenario," (2) the "Honolulu shipping service scenario," and (3) the "vessel enlargement scenario." In Scenario (0), the service frequency and vessel capacity of maritime services are increased in accordance with the growth of the world's shipping demands. Scenario (1) 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 (2) 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 (3) assumes the further enlargement of vessels calling on Australia and New Zealand. In the scenario analysis, Scenarios (1) to (3) are compared with Scenario (0) in terms of maritime transportation patterns, which are 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

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

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

$$AT_P = \frac{\sum_{r \in R_p}\sum_s \left(q^{rs}t^{rs*} + q^{sr}t^{sr*}\right)}{\sum_{r \in R_p}\sum_s \left(q^{rs} + q^{sr}\right)}, \tag{14}$$

where R_p is the set of PI ports.

The second performance index is the standard deviation of average shipping time σ_{AT} (hour), which represents the equality among PI ports regarding shipping time. It is defined as

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

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 AT_r. $\overline{AT}$ is calculated as

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

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

$$AT_{\max} = \max_{r \in R_p} AT_r . \tag{17}$$

6.2 Scenario 0: 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.

Note that although this scenario is named "Baseline Scenario", it is one possible scenario and it is not intended as a fixed and definitive future situation.

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)	4,963	8,027	3,065
Lae (PNG)	7,853	13,543	5,690
Honiara (Solomon Islands)	13	9,344	9,330
Suva (Fiji)	10,770	11,346	576
Noumea (New Caledonia)	2,735	7,243	4,508
Papeete (French Polynesia)	8,697	9,214	517

6.3 Scenario 1: 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 are 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 with significant changes are shown; significant increases are enclosed by a thick line and significant decreases are shaded. First, reduction of transshipment time in each port significantly increases the number of transshipment containers in that port. In most ports, the number is 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 is expected.

Next, focusing on intra-regional competition, two major regional competitions exist among PI. The first one is within PNG. 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 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 PI ports. On the other hand, transshipment in Australian/New Zealand ports is expected to increase when the other PI ports are 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 PI port is improved. Note that PI ports with only one shipping service are not included since transshipment is impossible. 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 (σ_{AT}), followed by Apra. Suva port is one of the major regional hubs in the PI region; its improvement will benefit the entire region. The bottom line of maritime service levels ($AT_{\max}$) is alleviated the most when Apra is improved. Pohnpei (F.S. of Micronesia) has only one shipping service available and has the longest average shipping time AT_r . By improving Apra, which is the prior 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 has services to other PI including the northern ones such as Betio and Majuro in addition to the Asia-Pacific services, which are heavily utilized.

6.4 Scenario 2: Honolulu Shipping Service Scenario

The Honolulu shipping service scenario assumes the commencement of a new shipping service directly connecting the north of the Pacific region with the south of the Pacific region. In the current shipping network, the liner shipping services in the Micronesian area are scarcer than those in Polynesia and Melanesia, and no service stretches in the northeast-southwest direction. This scenario introduces a new service attempting to complement the current network. Given that Matson (shipping company) operates a large shipping service connecting Honolulu, Apra, and China, this scenario assumes that Matson begins a similar service

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

Transshipment Ports	Data (TEU)	Baseline	Improved Ports Lae	Madang	P. Moresby	Honiara	Suva	Lautoka	Noumea	Papeete
Lae (PNG)	Volume	13,543	30,615	10,565	13,462	12,926	13,247	13,759	13,063	12,682
	Change	-	17,072	-2,978	-81	-617	-296	216	-480	-861
Madang (PNG)	Volume	0	0	5,522	0	0	0	0	0	0
	Change	-	0	5,522	0	0	0	0	0	0
P. Moresby (PNG)	Volume	1,281	1,291	1,153	3,954	1,189	1,298	1,278	1,282	1,255
	Change	-	10	-128	2,673	-92	17	-3	1	-26
Honiara (Solomon Is.)	Volume	9,344	11,428	9,970	9,238	22,727	9,225	9,543	9,426	9,429
	Change	-	2,084	626	-106	13,383	-119	199	82	85
Suva (Fiji)	Volume	11,346	11,329	11,168	11,490	11,227	21,940	10,550	11,072	10,230
	Change	-	-17	-178	144	-119	10,594	-796	-274	-1,116
Lautoka (Fiji)	Volume	1,734	1,765	2,130	2,005	2,161	1,485	7,436	475	1,687
	Change	-	31	396	271	427	-249	5,702	-1,259	-47
Noumea (New Caledonia)	Volume	7,243	7,517	6,840	7,303	7,177	7,784	7,125	16,743	7,208
	Change	-	274	-403	60	-66	541	-118	9,500	-35
Papeete (French Polinesia)	Volume	9,214	8,977	8,586	9,311	9,097	8,376	8,305	8,509	22,207
	Change	-	-237	-628	97	-117	-838	-909	-705	12,993
Australia/New Zealand Total	Volume	1,148,411	1,143,325	1,142,712	1,165,747	1,166,141	1,142,421	1,152,379	1,156,985	1,150,999
	Change	-	-5,086	-5,699	17,336	17,730	-5,990	3,968	8,574	2,588
Brisbane (Australia)	Volume	384,811	386,998	393,218	398,659	399,131	392,363	396,550	392,098	402,739
	Change	-	2,187	8,407	13,848	14,320	7,552	11,739	7,287	17,928
Sydney (Australia)	Volume	265,548	257,248	252,699	258,005	260,111	257,506	262,898	275,588	257,258
	Change	-	-8,300	-12,849	-7,543	-5,437	-8,042	-2,650	10,040	-8,290
Melbourne (Australia)	Volume	179,839	181,008	178,936	184,790	182,475	176,834	179,533	182,132	181,308
	Change	-	1,169	-903	4,951	2,636	-3,005	-306	2,293	1,469
Auckland (New Zealand)	Volume	258,848	259,070	262,257	260,094	259,901	256,785	257,605	251,146	250,450
	Change	-	222	3,409	1,246	1,053	-2,063	-1,243	-7,702	-8,398

Tauranga (New Zealand)	Volume Change	59,365 -	59,000 -365	55,601 -3,764	64,201 4,836	64,523 5,158	58,933 -432	55,793 -3,572	56,021 -3,344	59,243 -122

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 AT_P (hour)	Standard deviation of average shipping time σ_{AT} (hour)	Maximum shipping time in the region $AT_{\max}$ (hour)
Apra (Guam)	0.4	-0.4	-19.3
Saipan Island (N. Mariana Is.)	0.6	0.2	3.9
Majuro (Marshall Is.)	0.2	0.5	0.8
Betio (Kiribati)	1.2	-0.2	0.4
Port Funafuti (Tuvalu)	1.3	0.8	10.8
Nauru	1.1	0.4	0.2
Futuna (Wallis&Futuna)	0.7	0.4	8.4
Lae (PNG)	-1.0	0.2	2.4
Madang (PNG)	1.0	3.0	27.8
Port Moresby (PNG)	-0.1	-1.6	0.0
Rabaul (PNG)	-0.6	0.9	11.8
Honiara (Solomon Is.)	-2.0	-1.4	-15.3
Noro (Solomon Is.)	1.2	-0.4	5.5
Port Vila (Vanuatu)	0.7	-1.4	0.0
Santo (Vanuatu)	0.8	-2.3	-1.0
Lautoka (Fiji)	0.2	-2.9	-10.9
Suva (Fiji)	-0.4	-6.1	1.0
Noumea (New Caledonia)	-0.3	-0.9	16.2
Apia (Samoa)	0.8	0.6	3.1
Pago Pago (American Samoa)	1.1	0.7	8.3
Nukualofa (Tonga)	0.8	0.9	7.6
Rarotonga (Cook Islands)	0.9	-0.6	-2.8
Papeete (French Polynesia)	-0.2	-2.0	8.8

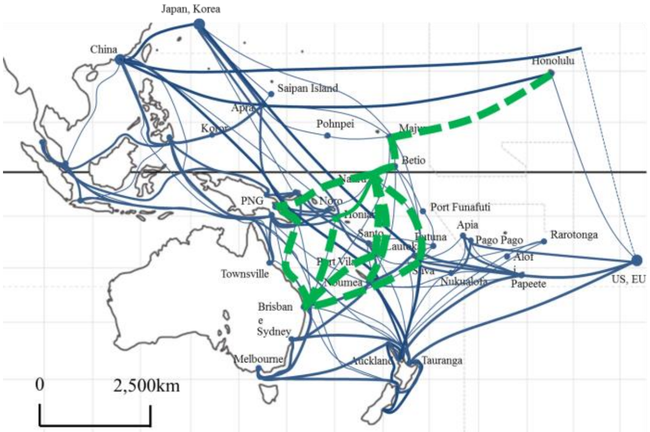

Figure 7. New shipping service under the Honolulu shipping service scenario

connecting Honolulu, PI, and Brisbane. The ports of call of this new service are assumed to be Honolulu, Majuro, Betio, Nauru, a potential port, and Brisbane. For the potential port, 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 thick dotted 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

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

Transshipment Port	Data (TEU)	Baseline	Port of Call				
			Lae	Honiara	Port Vila	Noumea	Suva
Honolulu	Volume	283	24,203	50,155	22,260	20,061	22,103
(Hawaii, US)	Change	-	23,919	49,872	21,977	19,778	21,820
Majuro	Volume	446	2,119	2,069	2,274	2,238	2,081
(Marshall Is.)	Change	-	1,673	1,623	1,828	1,792	1,635
Betio	Volume	0	443	422	449	575	12
(Kiribati)	Change	-	443	422	449	575	12
Nauru	Volume	41	1,311	1,395	1,385	1,733	308
	Change	-	1,270	1,354	1,344	1,692	267
Lae	Volume	13,543	14,136	12,235	14,734	12,905	14,317
(PNG)	Change	-	593	-1,308	1,191	-638	774
Honiara	Volume	9,344	7,738	4,503	9,070	9,020	8,805
(Solomon Is.)	Change	-	-1,606	-4,841	-274	-323	-539
Port Vila	Volume	197	167	184	97	116	48
(Vanuatu)	Change	-	-29	-13	-99	-81	-149
Noumea	Volume	7,243	4,193	4,100	4,569	3,639	2,772
(New Caledonia)	Change	-	-3,051	-3,143	-2,674	-3,605	-4,472
Suva	Volume	11,346	10,812	11,793	11,274	12,074	14,204
(Fiji)	Change	-	-533	447	-72	728	2,858
Brisbane	Volume	384,811	440,670	431,176	475,848	476,860	463,730
(Australia)	Change	-	55,858	46,365	91,037	92,049	78,919
Auckland	Volume	258,848	230,226	235,492	231,488	231,746	224,277
(New Zealand)	Change	-	-28,623	-23,356	-27,361	-27,102	-34,572
Apra	Volume	8,027	5,173	5,529	5,440	6,891	6,925
(Guam, US)	Change	-	-2,854	-2,499	-2,588	-1,136	-1,102

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 σ_{AT} (hour)	Maximum shipping time in the region $AT_{\max}$ (hour)
Lae (PNG)	-12.9	-28.6	-106.5
Honiara (Solomon Is.)	-13.3	-31.7	-111.0
Port Vila (Vanuatu)	-11.3	-29.7	-105.4
Noumea (New Caledonia)	-8.5	-29.5	-112.6
Suva (Fiji)	-13.4	-26.8	-88.9

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. This unveils that the changes under this scenario are more significant than those under the port development scenario because the commencement of the new shipping service involves more containers than the improvement of a single PI port. The results show that the impacts of the new service on average shipping time are similar among Lae, Honiara, Port Vila, and Suva, but smaller in Noumea; the impacts on standard deviation of average shipping time are similar among Lae, Honiara, Port Vila, and Noumea, but smaller in Suva; and the impacts on the maximum shipping time in the region are similar among Lae, Honiara, and Noumea, but smaller in Port Vila and Suva. They suggest that calling at Lae or Honiara may be the better choice for the new service.

6.5 Scenario 3: Vessel Enlargement Scenario

The vessel enlargement scenario assumes the further enlargement of vessels (capacity is multiplied by three) in services between Australia/New Zealand and 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" (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. This scenario consists of three cases. In Case 1, further vessel enlargement is assumed only for AU/NZ services 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, PI ports are able to accommodate larger vessels by adequate investment to port infrastructure. 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 investment from the baseline scenario will be made on port infrastructure in PI ports.

Table 8 shows the transshipment volumes and changes from the baseline scenario in each case. In Case 1, although transshipment at some PI ports shifts to AU/NZ services, the decreases are relatively small. In Case 2, the decreases are 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 transshipped to/from North America/Europe at Tauranga. 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 PI ports would benefit from vessel enlargement. 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	13,543	10,149	4,156	2,824
	Change	-	-3,394	-9,387	-10,719
Honiara (Solomon Is.)	Volume	9,344	7,933	3,591	6,428
	Change	-	-1,410	-5,753	-2,916
Suva (Fiji)	Volume	11,346	12,501	6,903	489
	Change	-	1,155	-4,443	-10,857
Noumea (New Caledonia)	Volume	7,243	6,815	3,217	2,705
	Change	-	-429	-4,026	-4,538
Papeete (French Polynesia)	Volume	9,214	9,288	8,423	0
	Change	-	74	-791	-9,214

Australia/New Zealand Total	Volume	1,148,411	1,227,088	1,225,203	1,288,782
	Change	-	78,677	76,792	140,371
Brisbane (Australia)	Volume	384,811	443,476	440,764	486,071
	Change	-	58,665	55,953	101,259
Sydney (Australia)	Volume	265,548	255,117	224,908	239,540
	Change	-	-10,431	-40,640	-26,008
Melbourne (Australia)	Volume	179,839	196,529	187,522	131,526
	Change	-	16,690	7,683	-48,313
Auckland (New Zealand)	Volume	258,848	268,108	268,765	333,589
	Change	-	9,259	9,917	74,740
Tauranga (New Zealand)	Volume	59,365	63,858	103,244	98,056
	Change	-	4,493	43,879	38,692

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

	Case 1		Case 2		Case 3	
Port	Change	Rate	Change	Rate	Change	Rate
Apra (Guam)	1	0.1%	2	0.3%	1	0.2%
Saipan Island (N. Mariana Is.)	0	0.0%	-0	-0.1%	0	0.0%
Koror (Palau)	-0	-0.1%	-1	-0.1%	0	0.0%
Pohnpei (Micronesia)	11	0.7%	1	0.0%	5	0.4%
Majuro (Marshall Is.)	-16	-1.4%	-99	-9.1%	-101	-9.3%
Betio (Kiribati)	-15	-1.3%	-133	-13.0%	-135	-13.2%
Port Funafuti (Tuvalu)	-13	-1.3%	-138	-15.8%	-140	-16.1%
Nauru	-15	-1.2%	-252	-24.8%	-249	-24.4%
Futuna (Wallis & Futuna)	-14	-1.0%	-167	-14.1%	-154	-12.9%
Lae (PNG)	-3	-0.4%	-25	-3.4%	-20	-2.8%
Madang (PNG)	-10	-1.1%	-53	-6.4%	-53	-6.3%
Port Moresby (PNG)	-4	-0.6%	-24	-3.4%	-18	-2.5%
Rabaul (PNG)	-4	-0.5%	-20	-2.4%	-16	-2.0%
Honiara (Solomon Is.)	-6	-0.8%	-39	-5.5%	-25	-3.4%
Noro (Solomon Is.)	2	0.2%	-60	-6.7%	-49	-5.3%
Port Vila (Vanuatu)	-5	-0.8%	-25	-3.7%	-14	-2.0%
Santo (Vanuatu)	-3	-0.4%	-35	-5.9%	-16	-2.6%
Lautoka (Fiji)	-16	-1.9%	-79	-10.5%	-10	-1.2%
Suva (Fiji)	-17	-2.2%	-81	-11.2%	63	7.3%
Noumea (New Caledonia)	-8	-1.3%	-51	-9.2%	24	3.9%
Apia (Samoa)	-6	-0.6%	-88	-9.5%	9	0.8%
Pago Pago (American Samoa)	-21	-1.8%	-103	-9.6%	7	0.6%
Nukualofa (Tonga)	-1	-0.1%	-115	-11.8%	-25	-2.3%
Alofi (Niue)	-26	-1.9%	-216	-18.7%	-210	-18.1%
Rarotonga (Cook Is.)	-30	-2.5%	-157	-14.5%	-157	-14.5%
Papeete (French Polynesia)	-14	-1.9%	-61	-8.9%	533	41.8%

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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