Submission date: November 15, 2011
Word count 7,497
including 5,997 words and 4 Tables and 2 Figures

Impacts of Maritime Transportation Risk on Maritime Traffic Flows and Regional Economies: The Case Study at the Straits of Malacca and Singapore

Kenta Nakamuara
Department of Civil Engineering, University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
E-mail: nakamura-k@ip.civil.t.u-tokyo.ac.jp

Yukihiro Ogawa
Department of Civil Engineering, University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
E-mail: ogawa-y@ip.civil.t.u-tokyo.ac.jp

Hironori Kato (Corresponding Author)
Department of Civil Engineering, University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
Phone: +81-3-5841-7451; Fax: +81-3-5841-7496
E-mail: kato@civil.t.u-tokyo.ac.jp

Ryuichi Shibasaki
National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism
3-1-1, Nagase, Yokosuka, Kanagawa 239-0826, Japan
Phone: +81-46-844-502
E-mail: shibasaki-r92y2@ysk.nilim.go.jp

Abstract. This paper analyzes the vulnerability of the Straits of Malacca and Singapore (SoMS) to the maritime risks. The impacts of the risk events on the international cargo flows, the transshipment at major ports, and domestic economies are simulated with an international cargo traffic simulation model and a spatial general equilibrium model. Both container cargos and dry/liquid cargos are covered in the simulation analysis. The following three cases are analyzed: sea-lane blockade at the SoMS, stop of the service at Singapore Port, and increase of loading/unloading time at all ports in the world. Results show that the risks which occur at the SoMS impact on the economies in the whole Asia; container carriers may change transshipment ports—from littoral ports to other East Asian ports—if the risk events were to actually occur; and the economic impacts of the risk events depend on the cases and the countries. Finally, the implication to the maritime security policy is discussed.

Keywords. Straits of Malacca and Singapore, maritime risk, international cargo flow, economic impact, container cargo, bulk cargo

INTRODUCTION

Currently, over one-third of the world's maritime cargo is transported to and from Asian countries. This fact reflects the rapid growth of economies in the southeast Asian (SEA) region, which include Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam, as well as the constant growth of economies in the east Asian (EA) region, including China, Japan, South Korea, and Taiwan. Many ports—such as Busan, Hong Kong, Shanghai, and Singapore—have been invested with handling the increased maritime cargo in the SEA and EA regions; they also complement each other in the international hub-and-spoke maritime cargo network. As the importance of the maritime cargo network in these regions increases, the sustainability of the maritime cargo network has also gradually come to be regarded as one of the area's most critical issues. Particularly, it is widely agreed among maritime cargo experts that the Straits of Malacca and Singapore (SoMS) is one of the most essential links in the international maritime network. The SoMS is the shortest sea lane to connect the Pacific Ocean and the Indian Ocean; it is where most of the vessels connecting these oceans pass. However, it is widely known that the sea lane in the SoMS is vulnerable to a variety of risk factors. If the SoMS were blocked at such points, the resulting impacts could be considerably serious.

This paper analyzes the vulnerability of the SoMS to the risk of the sea lane in this marine area. The impact of risk on cargo flows will be evaluated with respect to container cargos and bulk cargos. It also focuses on not only the direct impacts of the risks on the regional maritime cargo flows but also the impacts on regional economies. These impacts will be examined in light of the following three pieces of data: the volume of transshipment container cargo at the ports, the transportation costs associated with container cargo from one port to another, and the domestic economies in the countries in the SEA and EA regions. The impacts and/or scenarios of the vulnerability to the risk in maritime transportation have been discussed by some researchers (for example, *1-5*). One of the originalities of this paper is that the maritime risk is evaluated with the integrated simulation models including the traffic flow analysis of container cargos and bulk cargos as well as the economic impact analysis. This paper extends Ogawa et al. (*6*) by incorporating the impact analysis of bulk cargos and by improving the economic impact analysis. The integrated analysis could contribute to the realistic discussions on the risk prevention/mitigation policy.

The paper is organized as follows: first section provides research background information and the goals of this study. Next section outlines this study's methodology, including the international cargo flow simulation model used. Then, the impacts of the risk events will be analyzed through the use of the international cargo flow simulation model and the spatial general equilibrium model in the three risk cases. Finally, the findings of the case analysis are summarized and further research issues are discussed.

METHOD

Simulation Models

Cargo flows are simulated in a baseline case and in risk cases, to evaluate the potential impacts of risks at the SoMS. The baseline case assumes economic development without a catastrophic risk event at the SoMS until 2020, whereas the risk cases assume that catastrophic risk events have occurred at the SoMS as of the year 2020. Three models are used for the cargo flow simulation. The first is the standard Global Trade Analysis Project (GTAP) model (Hertel, *7*). This model is a spatial computable general equilibrium model by which changes in economic activities as a result of changes in the level of transportation service can be estimated. It covers multiple sectors in multiple regions, with the assumptions of perfect competition and constant returns to scale. The second model is the Model for International Cargo Simulation (MICS), proposed by Shibasaki *et al.* (*8*). This model simulates cargo flows by incorporating market competition among shipping companies and the preferences of container shippers (i.e., route and carrier choices), based on Nash equilibrium. The cargo transportation demand between regions is assigned to the network. The transportation network covers both land and sea transportation. As the flows in the network depend on link performance, the change in transportation time and/or cost as a result of the SoMS blockage will influence the traffic flows of the corresponding links in the network. Increased transportation costs will be also calculated by the simulation. The detail of MICS is presented in Appendix 1. The third model is the Model for International Bulk cargo Simulation (MIBS), newly introduced in this paper. This model simulates the flows of bulk cargo including the dry bulk and the liquid bulk. On the basis of the distribution of current goods transported through the SoMS, it is assumed that the dry bulk is composed of coal, iron ore, grains, and minor bulks while the liquid bulk is the oil only. The model assumes that the bulk ships directly sail from an origin to a destination through the lowest-transportation-cost route without any transshipment. The transportation costs are composed of ship costs and the running costs. The detail of the MIBS is presented in Appendix 2.

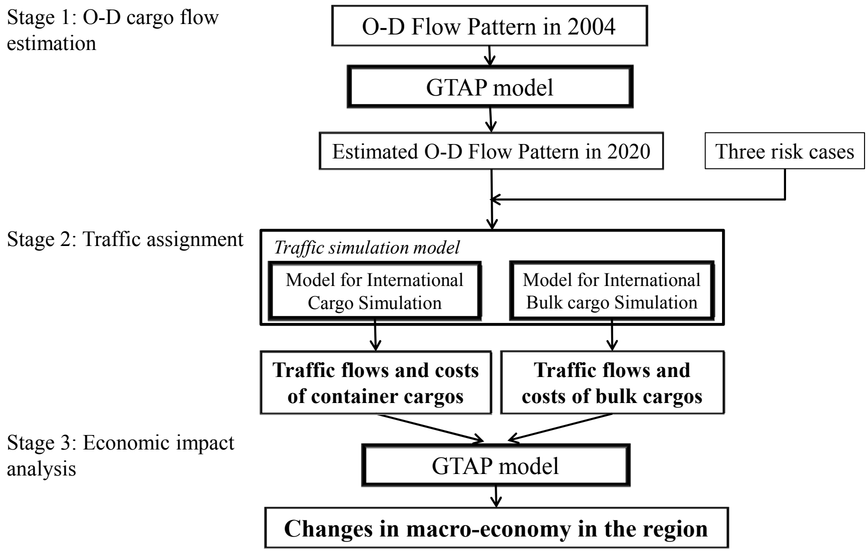

FIGURE 1 Process of simulating the impacts on international maritime flow patterns and the impacts on regional economies

Simulation Process

The simulation process is divided into three stages: origin–destination (O-D) cargo flow estimation, traffic assignment, and economic impact analysis. The simulation process is depicted in **FIGURE 1**. The first stage estimates twenty-foot-equivalent-unit (TEU)-based O-D cargo flows between regions in 2020, using the GTAP model. This stage involves two steps: the estimation of monetary-based O-D flows, and the conversion of monetary-based O-D flows into TEU-based O-D flows. First, the monetary-based O-D flows in 2020 are estimated with the GTAP model. For the estimation, changes in the following factors within each region are forecasted: population, skilled labor, unskilled labor, capital, natural resources, and total factor productivity. Then, the international economy in 2020 is estimated by four sequential simulations (Shibasaki *et al.*, *9*). The first simulation estimates changes from 2001 to 2005 by inputting changes in the above factors into the GTAP model, along with 2001 data. The second simulation estimates changes from 2005 to 2010 by inputting changes in the above factors into the GTAP model, along with the 2005 data estimated by the first simulation. The third simulation estimates changes from 2010 to 2015 by inputting changes in the above factors into the GTAP model, along with the 2010 data estimated by the first simulation. Finally, the fourth simulation estimates changes from 2015 to 2020 by inputting changes in the above factors into the GTAP model, along with 2015 data estimated by the second simulation. Next, the monetary-based O-D flows are converted into TEU-based O-D flows; to do so, the coefficients—including the share of land transportation, share of sea transportation, ratio of value to weight in each transportation mode, containerization rate, and ratio of weight to TEU in sea transportation—are estimated for each commodity and each O-D pair.

The second stage assigns the O-D flows to the transportation network. The network covers sea, road, and rail transportation for container cargo flows while only sea transportation network is considered for bulk cargo flows. The volume of container cargo in each link is estimated by the MICS while the volume of bulk cargo in each route is estimated by the MIBS. This study focuses on not the domestic trade, but the international trade. As for the MICS, the network covers sea, road, and rail transportation. The model covers 182 zones in the world, including 167 zones in SEA/EA and 15 zones elsewhere. The MICS also covers the worldwide transportation network, including 92 ports. It focuses particularly on the sea network of SEA/EA, including 17 ports in Japan, 16 ports in China, 14 ports in Indonesia, 12 ports in Malaysia, nine ports in the Philippines, five ports in Vietnam, four ports in the Indian Ocean Area, three ports in the Bay of Bengal, three ports in Chinese Taiwan, three ports in South Korea, two ports in Russia, and two ports in Thailand. As for the MIBS, for the analytical simplicity, the East, South, and Southeast Asia are divided into 24 regions in which most of the countries with the coastline in this area are allocated to the different regions. Exceptionally Malaysia and Indonesia are divided into three regions since they may be impacted significantly due to its vicinity of the SoMS. Malaysia is divided into the following three regions: the eastern side of the Peninsular Malaysia, the western side of the Peninsular Malaysia, and the northern side of the Borneo Island whereas Indonesia is divided into the following three regions: Sumatra Island, Jawa Island, and the eastern side of Indonesia. Other countries are aggregated, and are divided into 9 regions. It is also assumed that each region has only one representative port.

Note that the capacity of ports in our analysis may be different from that of the real ones because the ports in our analysis are representing multiple ports in the region. The capacity of port is defined by commodities. The capacity with regard to bulk carriers is classified into seven classes, and the capacity with regard to tankers is classified into five classes by dead weight tonnage (DWT).

The third stage estimates the economic impacts of risk events in terms of domestic demand, foreign demand, and real gross domestic product (GDP) in each country. The changes in transportation cost output from the MICS and MIBS are input into the GTAP model again. The transportation cost is estimated as follows. First, it is assumed that the container-based transportation cost does not vary among commodities but vary by O-D pair. This is because the MICS can estimate the transportation cost of a unit container, but not that by commodity. Then, the container-based transportation cost of a given O-D pair is estimated by multiplying the transportation cost of a unit container of the O-D pair with the load-factor of container of the O-D pair. Second, the bulk-based transportation cost by commodity for a given O-D pair is estimated by the transportation cost of the O-D pair by commodity output from the MIBS is multiplied with the bulk rate of the O-D pair by commodity or the tanker rate of the O-D pair. The bulk rate is defined as the share of the cargo volume carried by bulk carrier out of the total non-container cargo by commodity while the tanker rate is defined as the share of the volume carried by tanker out of the total oil volume. It is assumed that the bulk rate and the tanker rate are constant among the different cases.

ANALYSIS OF RISKY CASES AT THE SOMS

Definitions of Cases

The expected damages from the risk events vary with their risk factor. As this paper focuses on the impact of damage on the traffic patterns as well as the regional economy, the impacts of the following three factors will be considered in the simulation analysis: sailing cost, including the sailing time; sailing route; and the ports' service levels. Then, the three cases are considered in our analysis on the basis of the past research on the risks at the SoMS (*10-14*).

First, in the case of "sea lane blockade at the SoMS" (Case 1), it is assumed that vessels cannot pass through the Singapore Straits for a year. The blockade point is assumed to be Raffles lighthouse, which is the west side of the Singapore Port and next to the separation of the sea lanes. Any vessel passing through the SoMS must detour to the Lombok Strait or the Sunda Strait. As the depth of the Sunda Strait is less than that of the SoMS, the vessels whose draft is over 18 meters cannot pass through the Sunda Strait. The tanker whose draft is over 18 meters is categorized into the type of Very Large Crude Oil Carrier (VLCC) whereas the bulk carrier whose draft is over 18 meters is categorized into the Capesize or Very Large Ore Carrier (VLOC). As the draft of container ships is assumed to be less than 14 meters, it is assumed that all container ships can pass through the Sunda Strait in our simulation. The sea routes including the alternative ones are illustrated in **FIGURE 2**.

Next, in this case of "stop of the service at Singapore Port" (Case 2), it is assumed that vessels cannot enter the Singapore port for a year. In this case, all the container cargos transshipped at the Singapore Port must be transshipped at other ports while all the cargos to/from Singapore must be transported by land transportation. To deal with the land transportation of bulk cargos, the land transportation network is newly added to the MIBS

FIGURE 2 Alternative routes in Case 1: "sea lane blockade at the SoMS"

in this case. The land transportation network covers only the road network for analytical simplicity although there is the rail network. The bulk-based transportation cost by the road transportation is estimated on the basis of the data shown by Shibasaki (*15*). It should be noted that the vessels passing through the SoMS without stopping at the Singapore Port do not need to change their routes in Case 2.

Finally, in this case of "increase of loading/unloading time at all ports in the world" (Case 3), it is assumed that the loading and unloading time at all ports over the world will be longer than those in the baseline case for a year. This reflects the expected situation where the security level of inspection or monitoring of the cargos will be reinforced at any port when the some potential risks are identified and/or forecasted by all port operators. For analytical simplicity, the loading/unloading time in Case 3 is assumed to be five time longer than those in the baseline case.

Results of Case Analyses

The estimated average cost of import to major countries; estimated annual volumes of transshipments in major ports; estimated private consumption, government expenditure, and business investment in the major countries of the EA and the SEA regions in the three cases; and estimated export and import in the major countries of the EA and the SEA regions in the three cases are summarized in **TABLE 1, TABLE 2**, **TABLE 3**, and **TABLE 4** respectively.

First, **TABLE 1** shows that, in Case 1, the average import cost to Singapore particularly that of bulk cargo increases most significantly. The average import cost of bulk cargo to the littoral countries of the SoMS including Thailand also significantly increases. This is because the cargos transported from the west side of Singapore Strait to Singapore or to the littoral countries of the SoMS should be detoured and this increases the average transportation cost to there. Second, in Case 1, the change rate of average import cost of bulk cargo is higher than that of container cargo to all countries except India. This is because the bulk cargos are imported more from the west side of Singapore Strait than from the EA region. Third, in Case 2, the average import cost of bulk cargo to Singapore increases by 742.0 % while that of container cargo to Singapore increases by 21.6 %. They reflect the transportation cost of the alternative routes including other ports and land transportation to import the cargos to Singapore. The result suggests that the cost of land transportation of bulk cargo is much higher than that of container cargo. Fourth, in Case 2, the change rate of average import cost of container cargo to Cambodia is significantly higher than those to other countries. This is probably because the ratio of the volume of container cargos transshipped at Singapore to the total volume of Cambodia is much higher than that to other countries. Thus, the stop of the service at Singapore Port significantly impacts the average import cost to Cambodia. Fifth, in Case 3, the import cost increases significantly in all countries of the EA and the SEA regions. This simply reflects the increase of transportation cost in all ports all over the world. Sixth, the change rate of average import cost of container cargos to Singapore is the lowest among the countries. This reflects the fact that the loading/unloading time at Singapore Port is currently much shorter than others due to its high efficiency of port operation. The same increase rate of loading/unloading time at all ports leads to smaller increase of loading/unloading time at Singapore Port than that at other ports. Consequently the service level at Singapore Port becomes relatively better than that at other ports although the service level at all ports becomes worse.

TABLE 2 shows that, in Case 1, the volume of transship container cargos handled at Bangkok, TJ Pelepas, Port Klang, Singapore, TJ Priok, and Berawan decrease by 22.1%, 23.7%, 23.7%, 20.5%, 4.7%, 58.4% respectively whereas those handled at Ulsan, Shanghai, and Kao-shung increase by 6.6%, 24.8%, and 4.7% respectively. These mean that the volume of transship container cargos at the littoral ports of the SoMS decrease drastically while those at East Asia increase. This may be because the carriers change their transshipment ports from the littoral ports of the SoMS to other ports in Korea, Taiwan, and China. The results also show that although the volume of transship container cargos handled at Singapore decrease drastically, it is still more than any other ports in Asia. This means that Singapore still plays the important role of hub in Asia in spite of the blockade of the SoMS. In Case 2, the volumes of transship container cargos handled at the ports in Thailand, Malaysia, Singapore, and Indonesia decrease significantly whereas those handled at Osaka, Kobe, Gwangyang, Shanghai, and Guangzhou increase significantly. This may be because the carriers change their transshipment ports from ports in the SEA region to the other ports in the EA region. Interestingly the volumes of transship container cargos in Busan decreases by 62.3% whereas that in Gwangyang increase by 7.7%. This could mean that the main port in Korea may change when the vessels cannot enter the Singapore port. In Case 3, most of the ports decreases the volume of transship container cargos. For example, Busan, Hong Kong, Kaohsiung, Port Klang, and Singapore lose their volumes of transship container cargos by 0.1%, 31.3%, 0.2%, 9.9%, and 17.5%, respectively. This means that carriers hesitate to transship cargos because longer time is required in transshipment. On the contrary, many ports in China increase the volume of transship cargos. This may be because the container carriers change their transshipment ports into the ports in China since the handling cost of container cargos is cheaper than that at other ports.

TABLE 3 shows that, in Case 1, the decreasing rate of business investment is higher than those of private consumption and government expenditure in all countries. This means that the increase of transportation cost gives significantly the negative impacts on the business investment on their facilities and inventory while that gives less significantly the negative impacts on the domestic consumption. Next, the results show that, in Case 2, the private consumption, the government expenditure, and the business investment in Singapore decrease by 0.61%, 0.38%, and 1.15%, respectively. This means that the stop of the service at Singapore Port significantly damages the domestic demand in Singapore. The results also show that, in Case 2, the business investment in India, Japan, Korea, and Taiwan increases by 0.01%, 0.03%, 0.02%, and 0.02%, respectively. This reflects that the transportation cost of bulk cargo to those countries does not increase significantly. Note that **TABLE 1** shows the average import costs of bulk cargo to India, Japan, Korea, and Taiwan increase in Case 2 by 0.3%, 0.0%, 0.0%, and 0.1%, respectively. As the transportation cost of bulk cargo to the above four countries increase less significantly than other countries, the business in the four countries becomes more attractive than that in other countries. This may promote the business investment in the four countries under the international competition. **TABLE 3** shows that, in Case 3, the increase of loading/unloading time at all ports significantly damages the domestic demand in most countries.

Finally, **TABLE 4** shows that, in Case 1, both the export and the import decrease to/from the littoral countries of the SoMS. This is because the transportation cost increase significantly in such countries. Next, in Case 1, the change rates of export in Japan, Korea, Philippines, and Thailand are 0.06%, 0.03%, 0.04%, and 0.09% respectively while those of import in the four countries are -0.08%, -0.05%, -0.02%, and -0.18% respectively. The exports from those countries increase mainly because the transportation costs from the western side of the SoMS to the EA (mainly China) and/or North/South America regions increase due to the blockade whereas that from the eastern side of the SoMS to the EA and/or North/South America regions are not damaged. This leads to the increase of exports from Japan, Korea, Philippines, and Thailand whereas the decrease of exports from the countries located at the west of the SoMS. Both the export and import increase to/from Hong Kong. The results also show that, in Case 2, the export/import of Singapore significantly decreases. They also show that the export/import in Japan, Korea, and Taiwan does not change or slightly increase in Case 2. One of the possible reasons is that the container carriers change their transshipment ports from ports in the SEA region to the ports in the EA region as shown in **TABLE 2**. The results show that, in Case 3, many countries decrease their import/export significantly.

TABLE 1 Estimated Average Cost of Imports to Countries in EA and SEA in the Three Cases

		Baseline Case	Case1: Sea lane blockade at the SoMS		Case2: Stop of the service at Singapore Port		Case3: Increase of loading/unloading time at all ports	
Country	Vessel type	Import Costs (USD/TEU or ton)	Import Costs (USD/TEU or ton)	Change rate (%)	Import Costs (USD/TEU or ton)	Change rate (%)	Import Costs (USD/TEU or ton)	Change rate (%)
China	Container	17.3	17.4	0.7	17.9	3.3	22.4	29.4
	Bulk	18.0	18.4	2.1	18.0	0.1	23.0	27.9
Hong Kong	Container	10.7	10.8	1.1	11.3	5.6	14.5	35.6
	Bulk	32.7	34.0	4.0	32.9	0.6	46.3	41.6
India	Container	17.9	18.4	2.4	19.5	8.5	26.8	49.6
	Bulk	17.4	17.6	1.0	17.5	0.3	24.0	37.8
Indonesia	Container	18.4	18.7	1.8	20.1	9.0	24.1	31.0
	Bulk	27.4	28.4	3.6	28.2	3.0	40.7	48.4
Japan	Container	13.6	13.7	0.7	14.4	5.4	19.8	44.9
	Bulk	17.9	18.6	3.7	17.9	0.0	24.2	35.2
Korea	Container	13.0	13.1	0.9	13.4	3.4	20.8	60.4
	Bulk	16.7	17.6	5.2	16.7	0.0	20.3	21.3
Malaysia	Container	13.3	13.5	1.3	14.0	4.8	17.4	30.4
	Bulk	25.9	27.2	5.0	26.3	1.3	33.3	28.5
Myanmar	Container	24.2	24.9	2.7	25.8	6.5	28.1	16.0
	Bulk	35.1	37.0	5.4	35.5	1.1	44.8	27.4
Philippines	Container	17.4	17.5	0.6	18.1	4.1	25.0	43.7
	Bulk	22.2	22.9	3.0	22.3	0.4	31.9	43.4
Singapore	Container	10.8	11.3	4.7	13.2	21.6	12.0	10.9
	Bulk	14.4	16.3	13.2	121.4	742.0	17.6	22.2
Taiwan	Container	13.4	13.5	0.9	14.0	4.5	19.5	45.4
	Bulk	20.0	20.9	4.4	20.1	0.1	27.5	37.5
Thailand	Container	15.4	15.5	0.6	16.8	9.1	22.3	44.4
	Bulk	17.2	18.8	9.2	17.3	0.6	21.7	25.9
Vietnam	Container	17.3	17.4	0.4	18.2	4.9	22.5	29.8
	Bulk	25.7	26.8	3.9	28.6	11.2	38.6	49.9

Note: The unit of average cost of container cargo is USD per TEU; the unit of average cost of bulk cargo is USD per ton.

TABLE 2 Estimated Volumes of Transship Cargos in Major Ports at EA and SEA regions in the Three Cases

	Baseline Case	Case1: Sea lane blockade at the SoMS			Case2: Stop of the service at Singapore Port			Case3: Increase of loading/unloading time at all ports		
Port	Volume (million TEU)	Volume (million TEU)	Change rate (%)	Difference (million TEU)	Volume (million TEU)	Change rate (%)	Difference (million TEU)	Volume (million TEU)	Change rate (%)	Difference (million TEU)
Tokyo	2.4	2.6	6.1	0.2	2.5	3.4	0.1	2.4	-1.2	0.0
Yokohama	3.1	3.3	7.1	0.1	2.4	-22.2	-0.7	3.1	-0.2	0.0
Osaka	3.0	3.1	4.6	0.1	7.9	166.4	4.9	2.9	-2.1	0.0
Kobe	2.4	2.5	5.6	0.1	6.4	166.6	4.0	2.3	-1.1	-0.1
Busan	31.6	32.8	6.6	1.2	11.9	-62.3	-19.7	30.7	-0.1	-0.9
Gwangyang	6.8	7.1	7.6	0.2	14.5	112.9	7.7	6.8	0.9	-0.1
Shanghai	6.4	8.0	24.8	1.6	12.4	92.7	6.0	6.9	6.5	0.4
Ningbo	2.9	3.0	5.1	0.1	3.4	17.6	0.5	3.3	13.6	0.4
Shenzhen	4.7	4.5	-4.5	-0.2	7.5	60.1	2.8	4.9	4.1	0.2
Guangzhou	1.1	1.1	2.8	0.0	9.0	717.2	7.9	1.3	17.3	0.2
Hong Kong	19.3	18.5	-3.9	-0.7	13.3	-31.0	-6.0	13.1	-31.9	-6.1
Kaohsiung	17.4	18.2	4.7	0.8	18.1	4.0	0.7	17.3	-0.2	0.0
Manila	1.3	1.4	6.3	0.1	1.5	18.5	0.2	1.2	-5.1	-0.1
Ho-chi-minh	0.7	0.7	0.0	0.0	1.3	84.3	0.6	0.7	-10.7	-0.1
Leam Chamang	4.0	3.6	-9.3	-0.4	1.6	-58.9	-2.3	3.7	-5.7	-0.2
Bangkok	0.4	0.3	-22.1	-0.1	0.0	-94.7	-0.4	0.4	-4.1	0.0
TJ Pelepas	7.9	5.5	-31.2	-2.5	3.7	-54.0	-4.3	5.5	-30.8	-2.4
Port Klang	18.3	14.0	-23.7	-4.3	10.2	-44.5	-8.2	16.5	-9.9	-1.8
Singapore	56.1	44.6	-20.5	-11.5	0.0	-100.0	-56.1	46.3	-17.5	-9.8
TJ Perak	0.2	0.2	4.0	0.0	0.3	22.1	0.0	0.1	-39.3	-0.1
TJ Priok	1.1	1.1	-4.7	-0.1	0.6	-50.9	-0.6	1.0	-11.4	-0.1
Berawan	0.5	0.2	-58.4	-0.3	0.0	-100.0	-0.5	0.5	3.1	0.0
Ujung Pandang	0.2	0.3	9.5	0.0	0.0	-94.0	-0.2	0.1	-62.3	-0.1
Chittaron	0.0	0.0	-57.2	0.0	0.0	-91.9	0.0	0.0	1.5	0.0
JNPT	1.2	1.2	0.2	0.0	0.8	-31.9	-0.4	1.2	-2.0	0.0
Colombo	5.3	5.0	-6.4	-0.3	5.1	-4.0	-0.2	4.8	-10.1	-0.5
Karachi	0.5	0.5	-11.7	-0.1	1.6	208.8	1.1	0.5	-2.3	0.0

TABLE 3 Estimated Private Consumption, Government Expenditure, and Business Investment in the Major Countries of EA and SEA in the Three Cases

		Baseline case	Case 1			Case 2			Case 3		
		Estimated	Estimated	Change	Change	Estimated	Change	Change	Estimated	Change	Change
		Billion USD	Billion USD	%	Million USD	Billion USD	%	Million USD	Billion USD	%	Million USD
China	Private	1866.1	1865.6	-0.03	-476.2	1866.1	0.00	9.2	1857.7	-0.45	-8396.6
	Government	534.0	533.9	-0.02	-83.2	533.9	0.00	-10.7	532.2	-0.33	-1755.2
	Business	878.8	878.4	-0.05	-400.8	878.8	0.00	35.6	874.7	-0.46	-4084.6
Hong Kong	Private	170.6	170.6	0.00	8.0	170.5	-0.02	-27.0	170.6	0.02	37.1
	Government	29.4	29.4	0.00	0.2	29.4	-0.01	-2.3	29.4	0.06	18.0
	Business	27.7	27.7	-0.09	-25.2	27.7	-0.06	-16.8	27.5	-0.84	-233.0
India	Private	959.5	959.2	-0.03	-250.7	959.5	0.00	36.2	954.0	-0.57	-5452.3
	Government	169.4	169.4	-0.02	-37.2	169.4	0.00	0.4	168.6	-0.46	-783.3
	Business	176.2	176.0	-0.08	-142.0	176.2	0.01	14.2	173.2	-1.69	-2975.7
Indonesia	Private	332.0	331.9	-0.05	-157.8	332.0	-0.02	-74.5	330.7	-0.42	-1395.2
	Government	38.8	38.8	-0.01	-4.0	38.8	-0.02	-6.0	38.7	-0.14	-54.3
	Business	45.0	44.9	-0.19	-85.9	44.9	-0.05	-21.7	44.3	-1.36	-613.7
Japan	Private	1233.5	1233.2	-0.02	-300.7	1233.6	0.00	34.7	1226.5	-0.57	-7070.6
	Government	370.1	370.0	-0.01	-37.4	370.0	-0.02	-66.3	369.5	-0.15	-571.7
	Business	452.3	451.6	-0.16	-711.2	452.5	0.03	158.0	443.7	-1.91	-8639.9
Korea	Private	504.0	503.8	-0.04	-223.2	504.1	0.01	42.2	501.1	-0.58	-2923.0
	Government	135.2	135.2	-0.02	-29.4	135.2	0.00	6.1	134.9	-0.29	-392.3
	Business	143.3	143.1	-0.15	-217.2	143.3	0.02	26.3	141.2	-1.48	-2119.4
Malaysia	Private	66.8	66.7	-0.19	-127.9	66.7	-0.09	-58.8	65.7	-1.63	-1088.2
	Government	21.6	21.6	-0.13	-28.4	21.6	-0.07	-14.8	21.4	-1.06	-229.9
	Business	14.9	14.8	-0.71	-105.0	14.8	-0.34	-51.1	14.0	-5.91	-880.3
Myanmar	Private	11.0	11.0	-0.03	-2.8	11.0	-0.02	-2.4	11.0	-0.21	-23.2
	Government	1.9	1.9	0.00	0.1	1.9	0.00	0.0	1.9	-0.10	-1.9
	Business	2.2	2.2	-0.06	-1.4	2.2	-0.03	-0.7	2.2	-0.45	-9.9
Philippines	Private	87.0	87.0	-0.03	-30.4	87.0	0.00	-0.4	86.5	-0.58	-500.5
	Government	13.1	13.1	-0.03	-3.6	13.1	0.00	-0.2	13.0	-0.37	-48.3
	Business	5.8	5.8	-0.25	-14.5	5.8	0.00	0.2	5.6	-3.44	-198.9
Singapore	Private	99.8	99.7	-0.04	-42.6	99.2	-0.61	-606.6	99.8	0.02	15.6
	Government	25.4	25.4	-0.03	-7.1	25.3	-0.38	-96.3	25.4	0.01	2.1
	Business	30.3	30.2	-0.13	-39.1	29.9	-1.15	-349.3	30.2	-0.16	-48.4
Taiwan	Private	232.1	232.0	-0.04	-86.2	232.1	0.01	14.1	230.6	-0.65	-1506.1
	Government	46.9	46.9	-0.02	-7.7	46.9	0.00	1.1	46.7	-0.28	-131.3
	Business	33.5	33.4	-0.17	-57.9	33.5	0.02	6.6	32.6	-2.51	-841.4
Thailand	Private	170.3	170.1	-0.11	-191.2	170.2	-0.06	-94.8	168.3	-1.16	-1972.4
	Government	32.6	32.6	-0.07	-22.5	32.6	-0.04	-11.8	32.4	-0.78	-254.0
	Business	80.2	79.9	-0.36	-288.4	80.1	-0.16	-125.2	77.7	-3.16	-2532.7
Vietnam	Private	63.0	63.0	-0.02	-14.0	62.9	-0.17	-108.8	62.2	-1.24	-780.1
	Government	6.1	6.1	-0.01	-0.4	6.1	-0.11	-6.6	6.1	-0.66	-40.4
	Business	21.2	21.1	-0.13	-28.4	21.1	-0.23	-49.0	20.7	-2.41	-510.3

TABLE 4 Estimated Export and Import in the Major Countries of the EA and the SEA in the Three Cases

		Baseline case	Case 1			Case 2			Case 3		
		Estimated	Estimated	Change	Change	Estimated	Change	Change	Estimated	Change	Change
		Billion USD	Billion USD	%	Million USD	Billion USD	%	Million USD	Billion USD	%	Million USD
China	Export	2294.8	2293.4	-0.06	-1331.7	2294.6	-0.01	-130.5	2260.1	-1.51	-34651.1
	Import	1311.9	1309.8	-0.16	-2146.9	1311.9	-0.01	-83.7	1267.2	-3.41	-44732.0
Hong Kong	Export	266.5	266.5	0.02	50.6	266.5	0.01	18.3	267.5	0.38	1003.7
	Import	189.8	189.9	0.02	33.1	189.8	-0.01	-27.7	190.7	0.43	820.9
India	Export	355.2	355.1	-0.03	-102.4	355.1	-0.02	-83.7	352.2	-0.86	-3055.3
	Import	291.8	291.3	-0.16	-463.2	291.7	-0.02	-51.2	281.5	-3.53	-10296.8
Indonesia	Export	180.2	180.0	-0.12	-209.7	180.1	-0.06	-108.8	178.8	-0.79	-1425.9
	Import	128.2	127.8	-0.34	-430.2	128.0	-0.16	-199.5	125.0	-2.52	-3238.0
Japan	Export	1249.6	1250.3	0.06	729.3	1249.5	0.00	-54.3	1252.2	0.21	2658.6
	Import	316.2	315.9	-0.08	-260.5	316.2	0.02	59.2	304.0	-3.86	-12201.7
Korea	Export	601.0	601.2	0.03	185.8	601.1	0.00	19.3	598.8	-0.37	-2233.1
	Import	415.9	415.7	-0.05	-191.5	416.0	0.02	69.5	409.5	-1.53	-6379.9
Malaysia	Export	260.4	260.1	-0.09	-230.0	260.2	-0.04	-106.4	258.6	-0.68	-1770.3
	Import	163.7	163.2	-0.28	-452.6	163.5	-0.13	-219.1	160.1	-2.18	-3569.2
Myanmar	Export	6.5	6.4	-0.04	-2.4	6.5	-0.02	-1.0	6.4	-0.15	-9.7
	Import	5.4	5.4	-0.11	-6.1	5.4	-0.06	-3.5	5.4	-0.84	-45.4
Philippines	Export	84.7	84.7	0.04	34.8	84.7	-0.01	-7.7	84.7	0.01	12.4
	Import	70.6	70.5	-0.02	-10.8	70.5	-0.01	-9.4	69.9	-0.98	-688.0
Singapore	Export	254.4	254.2	-0.06	-155.9	252.7	-0.66	-1674.7	255.2	0.31	787.2
	Import	226.0	225.8	-0.11	-257.4	223.3	-1.23	-2777.2	226.7	0.30	687.4
Taiwan	Export	331.2	331.2	-0.01	-25.2	331.2	0.00	7.8	328.1	-0.95	-3136.3
	Import	239.4	239.2	-0.07	-159.1	239.4	0.01	25.1	234.0	-2.25	-5374.6
Thailand	Export	156.0	156.1	0.09	135.7	156.0	0.01	11.4	156.5	0.32	505.0
	Import	165.7	165.4	-0.18	-301.3	165.5	-0.12	-198.9	162.0	-2.21	-3661.2
Vietnam	Export	65.7	65.6	-0.09	-59.0	65.8	0.07	46.8	65.3	-0.64	-420.0
	Import	68.9	68.8	-0.13	-90.5	68.8	-0.15	-103.4	67.3	-2.26	-1558.5

DISCUSSION

First, the case analysis shows that the risks which occur at the SoMS impact the economies in the whole Asia. From an economic point of view, not only littoral countries but also other user countries receive the negative impacts caused by the increase of transportation costs. From the freight traffic point of view, since the carriers change their transshipment ports from the littoral ports of the SoMS to other ports in the EA region in case the risks occurred. This may imply that the risks at the SoMS should be discussed not only among the neighbor countries of the SoMS, but by all countries in Asia. However, it should be noted that the negative impacts on the major users of the SoMS, such as Japan, Korea, China, and India, are less than those in other countries. This is probably because the share of cargos to/from those countries passing through the SoMS is smaller than that of neighbor countries. This may mean that it is hard for them to have motivation to support the maritime safety at the SoMS.

Second, the results of the case analysis also show the change of the transportation cost of each region may depend on the pairs of the origin and the destination. In addition to that, the change also depends on the risk cases. The degree of the increased costs of container cargos is smaller than that of bulk cargos in Case 1 while that of container cargo is much larger than that of bulk cargos in Case 2. This may mean that the role of hub port is significantly important for container cargos. The carrier's choices of container ship size and/or on the carrier's choice of transshipment port have large impacts on the decision of the change of transportation cost.

Third, the results show that the change in the domestic demand does not always change the same way as the change of transportation costs. Note that the domestic demand is defined to be the sum of private consumption, government expenditure, and business investment. The reduction of business investment could decrease the domestic demand significantly. The results show that Malaysia, Thailand, and Vietnam receive more negative impacts than other regions. Additionally the results show that the increase of the transportation costs tends to expand the foreign demand due to the reduction of import. Note that the foreign demand is equal to the import plus the export. The results in Case1 and Case3 show that all countries in Asia increase the foreign demand.

Fourth, the results show the growth of the real GDP does not necessary indicate the positive meaning. In Singapore and Hong Kong, the foreign demand tends to change more significantly than the domestic demand because their export/import is greater than that in other regions. Consequently the real GDP can grow even if the transportation costs increase in Singapore and Hong Kong.

Finally, the results of Case1 and 2 show that the carriers tend to substitute the ports in the EA region for the littoral ports if risks occur. However, the total volume of the transshipment cargos in Singapore is the largest in Asia, and it still works as the hub port in Asia even under the risk events at the SoMS as shown in Case1 and Case3. Case2 shows that no port would work as the hub port. This means the transportation system of hub-and-spoke would fail to work in case of the stop of service at the Singapore Port.

CONCLUSIONS

This paper analyzed the impacts of risk events on the international cargo flows and on the regional economies in the EA and SEA regions. The analysis covers the three cases: sea lane blockade at the SoMS, stop of the service at Singapore Port, and increase of loading/unloading time at all ports in the world. The results show that the risks at the SoMS impacted on the economies in the whole Asia; the change of the transportation cost of each region may depend on the pairs of the origin and the destination; the carriers tend to substitute the ports in East Asia for ports in littoral ports if risks occur; the increase of the transportation costs tends to expand the foreign demand caused by the reduction of the amount of import; and the change in the domestic demand does not always change the same way as the change of transportation costs.

Future research issues are summarized. First, the accuracy of the simulation model should be improved. Although the case analysis used the simulation model developed by Shibasaki *et al.* (*8*) in a straightforward manner, it still has some technical issues that should be explored. For example, because the model does not account well for a carrier's choice of adjacent ports in some regions, the estimated volume of container cargo handled at an individual port may not be sufficiently accurate. Although this paper discusses simulation results in terms of aggregated cargo volumes in some regions, future research could examine simulation results in greater detail by making use of estimated cargo volumes at individual ports. Next, the GTAP model uses the conventional approach with the assumptions of perfect competition, constant returns and iceberg transport cost. However, this approach has been criticized by many researchers including new economic geography theorists such as Krugman (*16*). Relaxing these assumptions could change the results, especially at sector level, dramatically. Finally, future research could address political interactions among countries in the SEA and the EA *vis-à-vis* the security of international maritime transportation. Future international policies or institutional systems for promoting safer international maritime transportation could be investigated by analyzing the political behavior of the stakeholders.

APPENDIX 1 MODEL FOR INTERNATIONAL CARGO SIMULATION (MICS)

The MICS simulates cargo flows by incorporating market competition among shipping companies and the preferences of container shippers concerning route and carrier choices. A number of factors—including OD cargo volume; land transportation network and cost function; lead time at port; level of service at ports, including number of berths and port charges; maritime shipping network and cost functions; and initial values such as maritime shipping flows—are input into the MICS. Meanwhile, the cargo flows in the land transportation network, local cargo handled by ports, cargo demands by carrier groups, cargo flows in the maritime shipping network by ship size and carrier, and transshipment cargo volume by port are output from the MICS. The MICS assumes multi-layered equilibria, including the equilibrium between shipper and carrier, equilibria among carrier groups, and the equilibrium in the profit-maximization behavior of each carrier group. The MICS also includes a shipper submodel and a carrier submodel. In the shipper submodel, an individual shipper chooses the import and export ports and land transportation routes, in addition to carriers, by minimizing the perceived cost. A multinomial logit model is used to choose carriers, while the stochastic network assignment model is used to choose the ports and land transportation routes in the shipper submodel. The demand by route output from the shipper submodel is then input into the carrier submodel. In the carrier submodel, an individual carrier group will maximize its income by choosing the prices, ship size, and transshipment ports under the condition that total cost is minimized. It should be noted that this is equivalent to the profit maximization of the carrier group. The income maximization model assumes that the total income of carrier group is maximized on the basis of the Bertrand equilibrium model under differentiated transportation service whereas the cost minimization model assumes that the total cost in the carrier group is minimized under the condition that the demand by route is given. The carrier group then sets the prices, ship size, and transshipment ports to maximize its profit, under the condition that the carrier choice of shippers is given; the prices, ship size, and transshipment ports output from the carrier submodel are then input into the shipper submodel.

APPENDIX 2 MODEL FOR INTERNATIONAL BULK CARGO SIMULATION (MIBS)

The MIBS is the model to calculate the route chosen by vessel from a given origin port to a given destination port. It assumes that the bulk carrier or the tanker chooses the lowest-transportation-cost route. The transportation cost is defined as follows:

$$TC^j_{rsiy} = \left(CO^j_i + CP^j_i\right)\cdot\left(\frac{2N_{rs}}{v^j_i} + S^j_{riy} + S^j_{siy}\right) + CF^j_{ri} + CF^j_{si} + CPS^j_{riy} + CPS^j_{siy} + CPE^j_{riy} + CPE^j_{siy} + CC^j_{rsiy} + CI^j_{rsiy}$$

where TC^j_{rsiy} is the total transportation cost per voyage in US dollar to transport commodity *y* from origin port *r* to destination port *s* by the *i*th level of vessel in carrier type *j*. The carrier type *j* is a bulk carrier or a tanker. The level of vessel means the size of vessel used for transporting the goods. CO^j_i denotes the operation cost of the *i*th level of vessel in carrier type *j*; CP^j_i denotes the capital cost of the *i*th level of vessel in carrier type *j*; N_{rs} denotes the distance between port *r* to port *s* (nm); v^j_i denotes the sailing speed of the *i*th level of vessel in carrier type *j*; S^j_{riy} and S^j_{siy} denote the time (day) to load/unload the commodity *y* at origin port *r* and destination port *s* respectively when the *i*th level of vessel in carrier type *j* is used; CF^j_{ri} and CF^j_{si} denote the freight cost of the *i*th level of vessel in carrier type *j* at origin port *r* and destination port *s* respectively; CPS^j_{riy} and CPS^j_{siy} denote the costs of the *i*th level of vessel in carrier type *j* carrying commodity *y* to stop at ports *r* and *s*; CPE^j_{riy} and CPE^j_{siy} denote the costs of the *i*th level of vessel in carrier type *j* carrying commodity *y* to enter ports *r* and *s*; CC^j_{rsiy} denotes the fuel cost to transport commodity *y* from origin port *r* to destination port *s* by the *i*th level of vessel in carrier type *j*; and CI^{j}_{rsiy} denotes the insurance cost to transport commodity *y* from origin port *r* to destination port *s* by the *i*th level of vessel in carrier type *j*. The data of these costs are collected from the interviews with carriers and/or the related literature.

ACKNOWLEDGEMENTS

This study was funded by the Japan Society for the Promotion of Science (Grant-in-Aid for Scientific Research). The authors greatly appreciate the useful comments made by Professor Naoya Okuwaki (University of Tokyo), Professor Hideaki Shiroyama (University of Tokyo), Professor Robert Charles Beckman (National University of Singapore), Mr. Tomoharu Hase (University of Tokyo), Mr. Takashi Ichioka (Ocean Policy Research Foundation), and Mr. Masayoshi Sumi (Ministry of Land, Infrastructure, Transport, and Tourism).

REFERENCES

1. Fu, X., Ng, K. Y. A., and Lau, Y. Y. (2010) The impacts of maritime piracy on global economic development: the case of Somalia, Maritime Policy and Management, 37(7), pp.677-697.
2. International Risk Governance Council. (2011) Risk Governance of Maritime Global Critical Infrastructure: The Example of the Strait of Malacca and Singapore, Geneva.
3. Raymond, C. Z (2006) Maritime terrorism in Southeast Asia: Potential scenario, Global Terrorism Analysis 4(7), The Jamestown Foundation.
4. Rimmer, P. J. and Lee, P. T. W. (2007). Repercussions of impeding shipping in the Malacca and Singapore Straits. Journal of International Logistics and Trade 5 (1), pp.7-26.
5. Bergin, A. and Bateman, S. (2005). Future unknown: The terrorist threat to Australian maritime security, Canberra: The Australian Strategic Policy Institute.
6. Ogawa, Y., Kato, H., and Shibasaki, R. (2010) Blockade risks of the Straits of Malacca and Singapore: Scenario analysis with international cargo flow simulation, Paper presented at the 3rd International Conference on Transportation and Logistics (T-LOG 2010), CD-ROM, Fukuoka (Japan), September 2010.
7. Hertel, T. W. (1997) Global Trade Analysis: Modeling and Applications. Cambridge University Press, New York.
8. Shibasaki, R., Ieda, H., and Kadono, T. (2005) Model improvement of international maritime container cargo flow and policy evaluation for international logistics in eastern Asia, Paper presented at the 1st International Conference on Transportation Logistics, Singapore, July 2005.
9. Shibasaki, R., Onodera, H., and Watanabe, T. (2010) Forecasting future amounts of trade and maritime container cargo based on international economic scenarios, Paper presented at the 3rd International Conference on Transportation Logistics, Fukuoka, Japan, September 2010.
10. BIMCO (2008) The Co-Operative Mechanism between the littoral States and user States on safety of navigation and environmental protection in the straits of Malacca and Singapore, A paper presented at International Symposium of Safety and Protection of the Marine Environment in the Straits of Malacca and Singapore , November 2008.
11. Chua, T-E, Gorre, I. R. L., Ross, S.A., Bernad, S. R., Gervecio, B., and Ebarvia, M.C. (2000) The Malacca Straits, Marine Pollution Bulletin, Vol. 41, pp.160-178.
12. Japan Association of Maritime Safety (2009) Annual report on the Straits of Singapore and Malacca in 2009 (in Japanese).
13. Research Institute of Peace and Security (2009) Security in Asia 2009. Asagumo Shinbunsha Press, Tokyo (in Japanese).
14. Ursano, R. J., Norwood, A. E., and Fullerton, C. S. (2006) Bioterrorism: Psychological and Public Health Intervention, Springer Tokyo, Tokyo.
15. Shibasaki, R. (2011) Cost Minimization Model of a Large-Scale International Maritime Container Shipping Network regarding Characteristics of Ports, Paper presented at the Transportation Research Board 90th Annual Meeting, Washington D.C., January 2011.
16. Krugman, P. (1990) Rethinking International Trade, MIT Press.