Blockade Risk of the Straits of Malacca and Singapore: Scenario Analysis with International Cargo Flow Simulation

Yukihiro OGAWA
Masters Student
Department of Civil Engineering
University of Tokyo
7-3-1, Hongo, Bunkyo, Tokyo, 113-8656, Japan
Fax: +81-3-5841-8506
E-mail: ogawa-y@ip.civil.t.u-tokyo.ac.jp

Hironori KATO
Associate Professor
Department of Civil Engineering
University of Tokyo
7-3-1, Hongo, Bunkyo, Tokyo, 113-8656, Japan
Fax: +81-3-5841-8506
E-mail: kato@civil.t.u-tokyo.ac.jp

Ryuichi SHIBASAKI
Senior Researcher
National Institute for Land and Infrastructure Management
Ministry of Land, Infrastructure, Transport and Tourism
3-1-1, Nagase, Yokosuka, Kanagawa, 239-0826, Japan
Fax: +81-46-844-6029
E-mail: shibasaki-r92y2@ysk.nilim.go.jp

Abstract: This paper analyzes the vulnerability of the Straits of Malacca and Singapore (SoMS) to the risk of a complete or partial sea-lane blockade. Expected risks to the SoMS are examined, and a series of scenarios are set up in which catastrophic risk events occur. Two cases are then prepared by synthesizing event stories. International cargo flows in southeast and east Asia, under the two scenarios, are then empirically estimated with a maritime cargo flow simulation model; changes in transportation costs between ports are also estimated. Results showed that carriers may change transshipment ports—from littoral ports to other east Asian ports—if the risk events were to actually occur; that the expected impacts would vary; that changes in transportation costs between the port pairs may vary, as well as the risk cases; and that changes in transportation cost may depend on travel direction.

Key Words: *Straits of Malacca and Singapore, risk analysis, container cargo, catastrophic disaster, international cargo flow simulation*

1. 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. The vulnerability of the SoMS mainly stems from its geographical characteristics. Earthquakes often attack the nearby regions and they sometimes generate the critical natural disasters including tsunami. Additionally, a number of reefs and shallow points along the straits physically constrain maritime traffic. At the narrowest point in the SoMS, the width of the sea lane is only about 300 m, while its depth is around 20 m. If the SoMS were to become blocked at such points, the resulting impacts could be considerably serious. A blockade of the SoMS would force shipping companies to choose alternative routes from the Indian Ocean to the EA region; this may place the burden of additional costs on shippers, and it may also have an adverse effect on regional and national economies. A blockade of the SoMS may also create a shortage of energy sources—including crude oil and liquefied natural gas—in many SEA and EA countries; it might also lead to geopolitical risk, in light of national and regional security in those regions.

This paper analyzes the vulnerability of the SoMS to the risk of a complete or partial blockade of the sea lane in this marine area. It focuses on the direct impacts of a blockade on the regional maritime cargo flows, rather than the long-term impacts on international/regional markets and governance systems. These impacts will be examined in light of the following three pieces of data: the volume of container cargo handled at ports, the volume of transship container cargo at the ports, and the transportation costs associated with container cargo from one port to another.

The paper is organized as follows: Section 1 provides research background information and the goals of the present study. Section 2 outlines this study's methodology, including the international cargo flow simulation model used within. Next, Section 3 examines the possible risks pertaining to the SoMS, on the basis of the literature review. The expected events under a blockage of the SoMS will be listed and synthesized into scenarios, and those scenarios will also be summarized as two separate risk cases. In Section 4, the impacts of the blockade will be analyzed through the use of the international cargo flow simulation model and the two risk cases. Finally, in Section 5, the findings of the case analysis are summarized and further research issues are discussed.

2. SIMULATION METHOD

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. Two models are used for the cargo flow simulation. One is the standard Global Trade Analysis Project (GTAP) model (Hertel, 1997). 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 other model is the Model for International Cargo Simulation (MICS), proposed by Shibasaki *et al.* (2005). 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 simulation process is divided into two stages: origin–destination (OD) cargo flow estimation and traffic assignment. The simulation process is depicted in **Figure 1**. The first stage estimates twenty-foot-equivalent-unit (TEU)-based OD cargo flows between regions in 2020, using the GTAP model. This stage involves two steps: the estimation of monetary-based OD flows, and the conversion of monetary-based OD flows into TEU-based OD flows. First, the monetary-based OD 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 GDP. Then, the international economy in 2020 is estimated by four sequential simulations (Shibasaki *et al.*, 2010). 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 OD flows are converted into TEU-based OD 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,

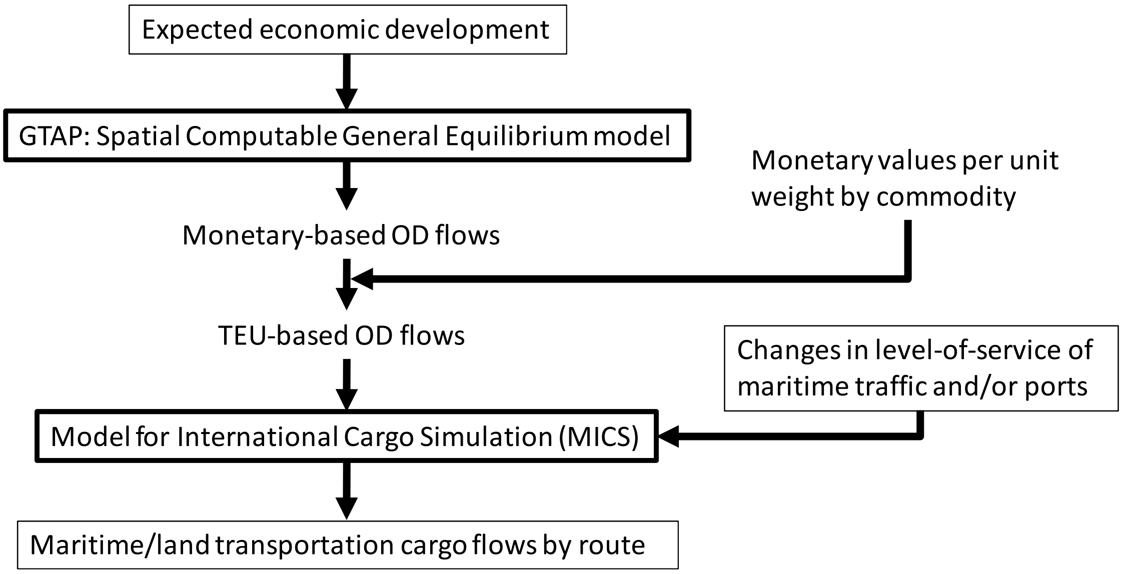

Figure 1 Process of simulating maritime/land transportation cargo flows

containerization rate, and ratio of weight to TEU in sea transportation—are estimated for each commodity and each OD pair.

The second stage assigns the OD flows to the transportation network. The network covers sea, road, and rail transportation. The volume of container cargo in each link is estimated by the MICS, which was developed by Shibasaki *et al.* (2005). 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.

Figure 2 provides an overview of the 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

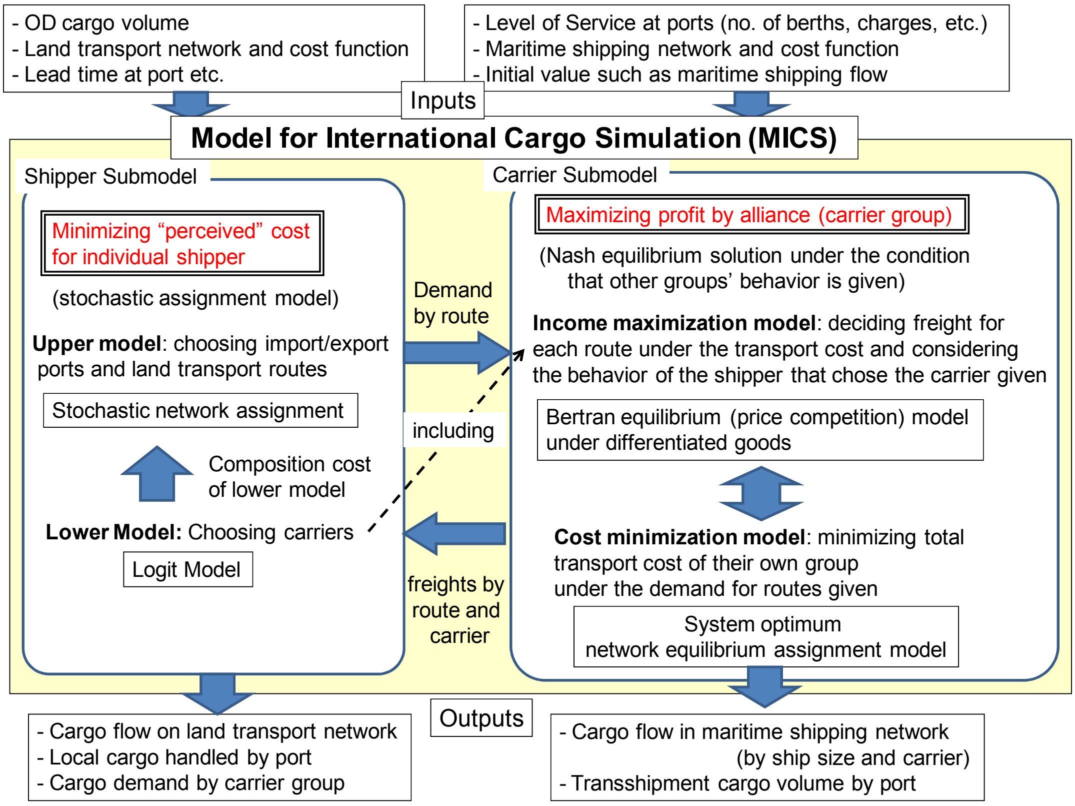

Figure 2 Model for International Cargo Simulation (MICS)

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 profits by choosing the prices, ship size, and transshipment ports that minimize the overall cost. It is assumed 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 sub-model are then input into the shipper submodel.

3. RISK SCENARIOS IN THE SoMS

3.1 Approach

For the case analysis, risk scenarios were developed to analyze the expected damages incurred by a blockade in the SoMS. A number of studies have reported the potential risks in the SEA, including those of the Japan Association of Maritime Safety (2006, 2007, 2008, 2009), the Research Institute of Peace and Security (2007, 2008, 2009), Takeda (2006), Allison (2006), and Ursano *et al.* (2006). To develop the scenarios, three separate elements are examined, each of which is based on the literature: the risk actor, the risk source, and the main target of attack. These elements are summarized in **Figure 3**.

First, the risk actor is the trigger of events that induce risk, either intentionally or unintentionally. There are four categories of risk actors: terrorists, vicious individuals, delinquency, and natural occurrences. “Terrorists” are members of a group or organization that takes part in violent actions in order to achieve political aims or to force a government to act. “Vicious individuals” are people who are driven not by any political aim but by the personal intention to “make their mark.” “Delinquency” refers to unintentional fault or human error. Finally, “natural occurrence” refers to natural phenomena that cause disasters.

Next, the risk sources in maritime transportation are categorized into a six-fold typology: tiny nuclear bombs, high explosives, computer viruses/hacking, biochemical weapons, hazardous freight, and natural sources. First, it is possible that terrorists or another criminal organization could obtain a tiny nuclear bomb from a nuclear-capable nation; if they were to position a bomb inside container cargo and initiate it at a certain port, they could completely destroy the port’s functionality. Second, it is also possible that terrorists or another criminal organization could obtain a high explosive; again, if they were to position such a bomb inside container cargo and initiate it at a certain port, it could obliterate that port. Third, computer viruses and hacking may create vicious disruptions on ports’ system servers. In major ports, most embark/disembark information is controlled electronically, so if one were to falsify or scramble that information, it could disrupt maritime traffic. Fourth, biochemical weapons comprising viruses or bacteria may cause outbreaks of infectious disease among humans; this

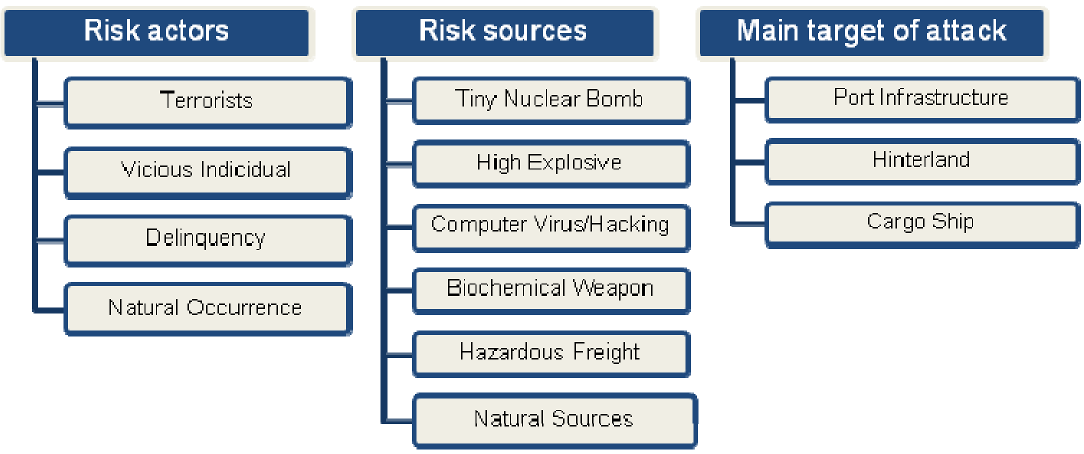

Figure 3 Scenario development framework

may paralyze the functionality of a port, among other things. Fifth, noxious substances can inflict damage or otherwise prove hazardous to humans or the environment; these so-called hazardous noxious substances include xylene, benzene, and other industrial chemicals. Finally, natural sources include the typhoons, earthquakes, tsunamis, and malignant viruses.

Finally, the main targets of attack are the locations in which risk is incurred. They are categorized into port infrastructure, hinterland, and the cargo ship areas. The port infrastructure includes the access/egress sea lane, berths, the container yard, handling machines and facilities, and the port management office. The hinterland refers to the area surrounding the port, including urban areas (e.g., industrial, residential, and commercial areas). Cargo ships, of course, are the vessels or ships that transport goods.

3.2 Risk Scenarios

Theoretically, there are 72 different ways in which one can combine these three elements. However, some combinations—such as one comprising "vicious individual," "natural sources," and "cargo ship"—are either nonsensical or impossible; after eliminating such combinations, seven scenarios were created, as shown in **Table 1**. Note that the typical natural disaster including earthquake and tsunami is not included in the scenarios. This is because this paper highlights unfamiliar risk events rather than the classical/popular risk events.

We then described each scenario in terms of a story, to explain the risk process thereof; this included the risk source, risk actors, main target of attack, and risk results. Although the severity of impacts may vary—even with the same risk sources, risk actors, and main target of attack—the most serious case was assumed in each scenario. We followed expert advice in describing these scenarios. These seven scenarios are described below, in greater detail.

Table 1 Scenarios of maritime risk in SoMS

No.	Risk actors	Risk source	Main target of attack
1	Terrorists	Tiny nuclear bomb/ high explosive	Port/hinterland
2			Cargo ship
3		Biochemical weapon	Hinterland
4	Natural occurrence	Natural sources	
5	Delinquency	Hazardous freight	Cargo ship
6	Terrorists		Hinterland
7	Vicious individual	Computer virus/hacking	Port (control server)

Scenario 1: A small nuclear weapon explodes unexpectedly at a major port

Terrorists have obtained a small nuclear weapon at some country. They transported from there to another country via container cargo. The container cargo containing the nuclear weapon suddenly exploded when it was loaded at a major port. All the buildings near the explosion point were destroyed, and all nearby streets were enveloped in flames and radiation. The incident eventually triggered an increase in insurance costs for cargo, and all traffic was detoured to another sea lane until the radioactive contamination subsided.

Scenario 2: Terrorists attack a cargo vessel with high-explosive weapons

Terrorists obtained small, high-explosive weapons. They embarked each weapon in container cargo and transferred them worldwide from a port. The terrorists detonated them by remote control, one after another. The physical damage inflicted by each explosion would have been small, but shippers may then consider it enormously risky to voyage, severely curtailing traffic. Some of the port control authorities may also decide to inspect all cargo that arrives at or departs from there, resulting in greatly increased shipping costs.

Scenario 3: Terrorists attack a major port and its hinterland with a biochemical weapon

Terrorists obtained a smallpox virus. They succeeded in mass-producing it and spreading it aerially near a major port. Because the disease had been considered virtually eradicated—and hence no one had been inoculated—most of the local citizens near the port became infected. The port authorities may decide to inspect all cargo that arrives at or departs from there, resulting in greatly increased shipping costs.

Scenario 4: Natural occurrence of pandemic

A new and highly toxic virus was found in some cities. The mortality rate of infected patients was considerably high. Governments in other countries immediately prohibited the embarkation to and disembarkation from there. However, the virus had already proliferated to other countries and is already exerting an overwhelming influence. The port authorities may decide to inspect all cargo that arrives at or departs from there, resulting in greatly increased shipping costs.

Scenario 5: Collision between a cargo ship and a crude-oil tanker

A massive forest fire occurred on the areas near the sea lane. Due to the heavy smoke-haze, visibility on the sea lane became seriously obstructed. One mid-class cargo ship incorrectly broke into the sea lane, colliding with a crude-oil tanker. The location of the collision was at the narrowest part of the strait. Spilled crude oil covered the width of the sea lane and interfered with the voyage of other cargo ships. It took three months to clean up the crude oil on the sea lane, and during that time, all ships passing through this area were detoured to the other sea lanes.

Scenario 6: Terrorists attack the hinterland with a crude oil tanker

Terrorists hijacked a crude-oil tanker near a major port. They were able to sail the tanker and attack other crude tankers on the seashore of industrial zone near the port. A massive explosion occurred, spilling crude oil that covered the sea surface of a nearby area. The port was closed for a few days, due to damage inflicted by the explosion and the massive crude-oil spill. Even after the port's functionality was restored, shipping costs remained high because of increased insurance prices.

Scenario 7: Computer-hacking of the port authority's system server

A vicious individual skilled at computer programming was eager to show off his or her computer skills. He or she decided to hack the system server of a major port, which controls all information pertaining to stowage plans and shipping schedules, and scramble all the data therein. The port authority did not notice the computer-hacking prior to receiving many reports of distribution where the wrong container cargo had been received from all over the world. It took one month to completely recover the system. During recovery, the cargo-handling capacity of the port sharply diminished. Even after the port's function was restored, shipping costs remained high because of increased insurance prices.

4. CASE ANALYSIS OF RISK SCENARIOS AT THE SoMS

4.1 Definitions of Cases

The expected damages across the scenarios vary with the risk actor. As this paper focuses on the impact of damage to traffic patterns, 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 scenarios will be recategorized into risk cases, based on the impacts on sailing cost and sailing route. Scenarios 1, 3, 4, 5, and 7 assume that the ships sailing through the SoMS detour to other sea lanes—such as the Sunda or Lombok Strait—while Scenarios 2 and 6 assume that the transportation cost of sailing the devastated sea lane increases drastically.

First, in the case of "increase in sailing cost" (Case 1), it is assumed that the sailing cost will increase 10-fold compared to the baseline case for all vessels passing through the sea lane between TJ Pelepas port and Singapore port, which is the geographical bottleneck of the Singapore Strait, during a year after the risk event occurs, as shown in **Figure 4**. This means that the sailing costs between TJ Pelepas and European ports are not affected by the risk events in Case 1 whereas the sailing costs between Singapore/Pasir Gudang and EA ports are not affected by the risk events in Case 1. Next, in the case of "detour to another sea lane" (Case 2), it is assumed that the SoMS is blockaded at a specific point between TJ Pelepas and

Singapore ports, and so all the vessels passing through the blockaded area are forced to detour to another sea lane, such as Sunda or Lombok Straits, during a year once the risk event occurs (**Figure 5**). This means that the vessels sailing between TJ Pelepas and European ports are not affected by the blockade in Case 2 whereas the vessels sailing between Singapore/Pasir Gudang and EA ports are not affected by the blockade in Case 2. Such detouring brings about changes in route choice, as well as changes in sailing cost or time.

It should be noted that some of the scenarios shown in Section 3 are not reflected fully in the above two risk cases. For example, the impact of destruction of the port may be incorporated into the model by applying another assumption to the empirical analysis. If the destruction of

Figure 4 Case 1: increased sailing cost at the Singapore Strait

Figure 5 Case 2: detouring to the Sunda and Lombok Straits

the port leads to the increase of loading/unloading time at the ports, it can be interpreted as the increase of the cost in loading/unloading link at the ports. If that results in the reduction of port capacity, it may be interpreted as the increase of waiting cost in the access link to the ports. Further research may be needed to identify such mechanism of risk impact. In this sense, the risk cases examined in this paper are regarded as the approximation of complicated mechanism of risk impacts on the cost structure.

4.2 Results of Case Analyses

The estimated annual volumes of container cargo and transshipments in major ports in the three cases are summarized in **Table 2** and **Table 3**, respectively. They are also depicted in the maps in the Appendix.

Table 2 Estimated annual volume of handled container cargos including traded cargos and transshipment cargos in major ports, in the three cases as of the year 2020

	Baseline Case	Case 1: increase in sailing cost			Case 2: detour to another sea lane		
Port	Mil. TEU	Mil. TEU	Change rate	Change in Mil. TEU	Mil. TEU	Change rate	Change in Mil. TEU
Bangkok + Laem Chabang	20.3	18.3	0.90	–2.0	19.6	0.97	–0.7
Belawan	0.4	0.8	1.73	0.3	0.0	0.08	–0.4
Bojonegara	0.5	0.6	1.07	0.0	0.6	1.16	0.1
Colombo	3.9	2.4	0.62	–1.5	1.3	0.33	–2.6
Ho Chi Minh	3.1	3.0	0.97	–0.1	3.7	1.19	0.6
Klang	21.3	20.0	0.94	–1.3	30.4	1.42	9.1
Kuantan	1.7	2.3	1.35	0.6	2.3	1.31	0.5
Kuching	1.5	2.7	1.80	1.2	1.9	1.26	0.4
Manila	3.4	2.8	0.84	–0.5	2.5	0.73	–0.9
Middle China	62.4	63.6	1.02	1.2	64.1	1.03	1.7
Muara	1.9	3.1	1.64	1.2	2.4	1.28	0.5
North China	72.7	72.0	0.99	–0.7	74.0	1.02	1.3
Osaka + Kobe	11.0	11.7	1.06	0.7	12.7	1.15	1.7
Pasir Gudang	2.4	3.5	1.48	1.1	5.1	2.12	2.7
Penang	2.7	3.6	1.37	1.0	2.2	0.81	–0.5
Singapore	72.9	70.0	0.96	–2.9	76.1	1.04	3.2
South China	103.6	97.4	0.94	–6.2	93.4	0.90	–10.2
South Korea	85.7	93.2	1.09	7.5	93.9	1.10	8.2
Taiwan	32.7	43.6	1.33	10.9	47.5	1.45	14.8
Tirawa	0.5	0.5	0.88	–0.1	0.6	1.17	0.1
TJ Pelepas	8.2	3.6	0.44	–4.6	1.3	0.15	–6.9
TJ Perak	6.6	6.4	0.96	–0.3	5.9	0.88	–0.8
Tokyo + Yokohama	14.4	13.7	0.95	–0.7	14.4	1.00	0.0

Table 3 Estimated annual volume of transshipment container cargos in major ports, in the three cases as of the year 2020

	Baseline Case	Case 1: increase of sailing cost			Case 2: detouring to other sea lane		
Port	Mil. TEU	Mil. TEU	Change rate	Change in Mil. TEU	Mil. TEU	Change rate	Change in Mil. TEU
Bangkok + Laem Chabang	4.5	6.0	1.33	1.5	5.9	1.32	1.4
Belawan	0.1	0.2	2.64	0.1	0.0	0.00	–0.1
Bojonegara	0.0	0.0	0.36	0.0	0.0	0.42	0.0
Colombo	2.6	1.1	0.43	–1.5	0.0	0.00	–2.6
Ho Chi Minh	0.6	0.6	0.99	0.0	1.2	1.97	0.6
Klang	12.6	11.8	0.93	–0.9	26.0	2.06	13.4
Kuantan	0.8	1.2	1.48	0.4	1.2	1.49	0.4
Kuching	0.2	0.9	4.17	0.7	0.7	3.03	0.4
Manila	0.6	0.4	0.61	–0.2	0.3	0.44	–0.4
Middle China	12.7	12.6	1.00	0.0	13.5	1.07	0.9
Muara	1.6	2.8	1.74	1.2	2.1	1.33	0.5
North China	15.7	17.1	1.09	1.4	17.9	1.14	2.2
Osaka + Kobe	5.0	6.2	1.24	1.2	7.3	1.46	2.3
Pasir Gudang	0.1	0.2	2.69	0.1	0.7	10.50	0.6
Penang	0.1	0.2	4.57	0.2	0.0	0.12	0.0
Singapore	45.9	45.9	1.00	0.0	46.6	1.02	0.8
South China	55.2	50.0	0.91	–5.2	46.6	0.84	–8.6
South Korea	52.3	59.8	1.14	7.5	60.5	1.16	8.2
Taiwan	13.8	24.7	1.79	10.9	28.6	2.08	14.8
Tirawa	0.1	0.0	0.26	–0.1	0.0	0.05	–0.1
TJ Pelepas	6.6	2.1	0.31	–4.6	0.1	0.01	–6.6
TJ Perak	1.1	0.3	0.24	–0.9	0.4	0.38	–0.7
Tokyo + Yokohama	6.6	6.4	0.97	–0.2	7.1	1.09	0.6

First, **Table 2** shows that, in Case 1, the volume of container cargo handled at Klang, TJ Pelepas, Tirawa, and TJ Perak decreased by 6%, 56%, 12%, and 4%, respectively. **Table 3** shows that, in Case 1, the volume of transship container cargo at Klang, TJ Pelepas, Tirawa, and TJ Perak decreased by 7%, 76%, 74%, and 76%, respectively. These changes indicate that the volume of container cargo handled at the littoral ports of the SoMS decreased mainly on account of sharp decreases in the volume of transship container cargo. **Table 2** also shows that in Case 1, the volume of container cargo handled in South Korea, Taiwan, and South China increased by 9%, 33%, and 6%, respectively.

Second, **Table 2** shows that, in Case 2, the volumes of container cargo handled at Klang increased by 42% and those at Pasir Gudang increase by 112%, whereas those at TJ Pelepas decreased by 85%. **Table 3** shows that the volume of tranship container cargo at Klang increased by 106% and those at Pasir Gudang increase by 950%, whereas those at TJ Pelepas decreased by 99%. This means that the TJ Pelepas port became less attractive as a transshipment point. This is because the TJ Pelepas port became the most distant one from the straits, and this situation led to a shift in transship cargo: in the case of “detouring to other ports,” cargo that had previously embarked to/disembarked from TJ Pelepas in the baseline case tended to move to other littoral ports. **Table 2** also shows that the volume of container cargo handled in South Korea and Taiwan increased by 8.2 TEU and 14.8 TEU, respectively, while the volume of transship container cargo in South Korea and Taiwan increased by the same amounts. This means that the number of vessels that embarked/disembarked transship cargo at these two ports increased sharply in South Korea and Taiwan. The shipping companies changed their transshipment ports, from the littoral ports of the SoMS to other ports in South Korea and Taiwan.

Third, **Table 4** lists the transportation costs to and from Busan, Colombo, Hong Kong, Johor, Klang, Shanghai, Singapore, Taiwan, and Tokyo in the three cases. Note that Johor zone includes Pasir Gudang port and TJ Pelepas port. This shows that in Case 1, the transportation costs from Johor to Busan, Hong Kong, Shanghai, Singapore, Taiwan, and Tokyo increased by 11.7%, 10.8%, 4.9%, 0.0%, 8.0%, and 8.9%, respectively, whereas the transportation costs from Klang to Busan, Hong Kong, Johor, Shanghai, Singapore, Taiwan, and Tokyo increased by 1.6%, increased by 1.8%, increased by 0.0%, decreased by 0.9%, increased by 0.0%, decreased by 0.4%, and increased by 2.3%, respectively. These increases occurred because the sailing cost for passing through the SoMS increased as a result of the risk event. The sailing cost from Johor to Singapore, Singapore to Johor, Klang to Singapore, and Singapore to Klang do not increase in Case 1; this is because the cargos between those ports are transported by land transportation. The transportation cost from Klang to Shanghai and Taiwan decreased in Case 1; this is because the traffic volume from Klang to Shanghai increases sharply, inducing an economy of scale on the vessels that connect these ports. This reflects carrier behavior related to decreasing transportation costs by using larger container ships, under conditions in which there is an increase of transportation cost.

Fourth, **Table 4** shows that, in Case 1, the transportation cost from Busan, Hong Kong, Klang, Shanghai, Singapore, Taiwan, and Tokyo to Johor increased by 1.5%, increased by 0.7%, increased by 0.0%, increased by 0.5%, increased by 0.0%, decreased by 2.6%, and increased by 1.5%, respectively, whereas the transportation cost from Busan, Hong Kong, Johor, Shanghai, Singapore, Taiwan, and Tokyo to Klang decreased by 4.5%, increased by 62.3%, increased by 0.0%, decreased by 3.8%, increased by 0.0%, increased by 69.1%, and increased by 48.5%, respectively. The transportation costs from Busan and Shanghai to Klang decreased, and this may also have been because of the change in ship size. Additionally, the decrease in

Table 4 Transportation costs to/from OD zone including major ports, in the three cases

Origin/ Destination	Cases	Busan	Colombo	Hong Kong	Johor	Klang	Shanghai	Singapore	Taiwan	Tokyo
Busan (Korea)	0	–	2292	1204	1422	1673	1787	1258	1301	1304
	1	–	2225 (–3.0%)	1187 (–1.4%)	1443 (+1.5%)	1596 (–4.5%)	1728 (–3.3%)	1236 (–1.8%)	1244 (–4.3%)	1264 (–3.1%)
	2	–	2309 (+0.7%)	1188 (–1.3%)	1591 (+11.9%)	1087 (–35.0%)	1743 (–2.4%)	1230 (–2.2%)	1252 (–3.7%)	1340 (+2.7%)
Colombo (Sri Lanka)	0	2528	–	2386	2180	1749	3084	2016	2603	2688
	1	2454 (–2.9%)	–	2319 (–2.8%)	2095 (–3.9%)	1664 (–4.9%)	2976 (–3.5%)	1931 (–4.2%)	2510 (–3.6%)	2567 (–4.5%)
	2	2609 (+3.2%)	–	2463 (+3.2%)	2266 (+4.0%)	1836 (+4.9%)	3134 (+1.6%)	2102 (+4.3%)	2655 (+2.0%)	2778 (+3.3%)
Hong Kong (China)	0	1434	2475	–	1502	1071	1843	1339	1518	1597
	1	1430 (–0.3%)	2339 (–1.5%)	–	1513 (+0.7%)	1740 (+62.3%)	1843 (0.0%)	1349 (+0.8%)	1487 (–2.1%)	1578 (–1.2%)
	2	1430 (–0.3%)	2421 (–1.9%)	–	1504 (+0.1%)	1074 (+0.1%)	1843 (0.0%)	1340 (+0.1%)	1489 (–1.9%)	1582 (–0.9%)
Johor (Malaysia)	0	984	1900	889	–	316	1569	1231	1079	1110
	1	1099 (+11.7%)	1945 (+2.3%)	985 (+10.8%)	–	316 (0.0%)	1646 (+4.9%)	1231 (0.0%)	1165 (+8.0%)	1208 (+8.9%)
	2	1050 (+6.7%)	2215 (+16.6%)	953 (+7.1%)	–	316 (0.0%)	1607 (+2.4%)	1231 (0.0%)	1124 (+4.2%)	1232 (+11.0%)
Klang (Malaysia)	0	1312	1885	1177	328	–	1860	811	1375	1434
	1	1334 (+1.6%)	1840 (–2.4%)	1198 (+1.8%)	328 (0.0%)	–	1842 (–0.9%)	811 (0.0%)	1370 (–0.4%)	1467 (+2.3%)
	2	1315 (+0.2%)	1931 (+2.5%)	1174 (–0.3%)	328 (0.0%)	–	1829 (–1.7%)	811 (0.0%)	1348 (–1.9%)	1420 (–1.0%)
Shanghai (China)	0	1750	2821	1760	1950	2206	–	1786	1862	1920
	1	1720 (–1.7%)	2740 (–2.9%)	1760 (0.0%)	1960 (+0.5%)	2122 (–3.8%)	–	1751 (–2.0%)	1795 (–3.6%)	1867 (–2.8%)
	2	1713 (–2.2%)	2829 (+0.3%)	1760 (0.0%)	1914 (–1.8%)	1484 (–32.7%)	–	1750 (–2.0%)	1801 (–3.3%)	1880 (–2.1%)
Singapore (Singapore)	0	1493	2018	1350	1105	674	2048	–	1567	1653
	1	1503 (+0.7%)	1917 (–2.3%)	1349 (–0.1%)	1105 (0.0%)	674 (0.0%)	2025 (–1.1%)	–	1560 (–0.5%)	1617 (–2.2%)
	2	1487 (–0.4%)	2063 (–2.2%)	1340 (–0.1%)	1104 (0.0%)	674 (0.0%)	2012 (–1.8%)	–	1533 (–2.2%)	1656 (+0.1%)
Taiwan (Taiwan)	0	1234	2189	1104	1316	885	1787	1152	–	1407
	1	1208 (–2.1%)	2109 (–3.7%)	1067 (–3.4%)	1282 (–2.6%)	1497 (+69.1%)	1722 (–3.7%)	1118 (–2.9%)	–	1343 (–4.5%)
	2	1213 (–1.7%)	2194 (+0.3%)	1065 (–3.5%)	1277 (–3.0%)	1560 (+76.2%)	1720 (–3.8%)	1113 (–3.4%)	–	1374 (–2.3%)
Tokyo (Japan)	0	1478	2659	1492	1670	1259	2074	1526	1594	–
	1	1466 (–0.8%)	2724 (–2.4%)	1474 (–1.2%)	1715 (+1.5%)	1870 (+48.5%)	2022 (–2.5%)	1516 (–0.6%)	1554 (–2.5%)	–
	2	1464 (–1.0%)	2621 (–1.4%)	1492 (0.0%)	1685 (+0.3%)	1254 (–0.4%)	2040 (–1.6%)	1540 (+0.9%)	1567 (–1.7%)	–

Note 1: "Case 0" refers to the baseline case, "Case 1" refers to the case of "increase of sailing cost," and "Case 2" refers to the case of "detouring to other sea lane."

Note 2: Parentheses indicate the change in percentage from the baseline case to Case 1 or 2.

Note 3: The unit of cost is thousand Japanese Yen per TEU as of the year 2020.

transportation cost from Busan to Klang possibly reflected the transship container cargo volume increase at ports in South Korea.

Fifth, **Table 4** shows that, in Case 2, the transportation costs from Johor to Busan, Hong Kong, Shanghai, Taiwan, and Tokyo increased by 6.7%, 7.1%, 2.4%, 4.2%, and 11.0%, respectively. This is probably because detouring to another sea lane increased the cruising distance and thus increased transportation times and costs. **Table 4** also shows that in Case 2, the transportation costs from Klang to Hong Kong, Shanghai, Taiwan, and Tokyo decreased by 0.3%, 1.7%, 1.9%, and 1.0%, respectively; this may have been because the introduction of a larger ship significantly decreased the sailing cost, although the detouring incurred larger transportation times and costs. It should be noted that the additional cost incurred by detouring to another sea lane from Johor to the EA ports was higher than the additional cost incurred by detouring to another sea lane from Klang to the EA ports. **Table 4** also shows that the transportation costs from Johor to Singapore, Klang to Singapore, from Singapore to Johor, and from Singapore to Klang were not affected by the risk events in Case 2; this is because all container cargo between these regions is transported via the land transportation network.

Sixth, **Table 4** shows that, in Case 2, the transportation costs from Busan, Hong Kong, Shanghai, Singapore, Taiwan, and Tokyo to Johor increased by 11.9%, increased by 0.1%, decreased by 1.8%, increased by 0.0%, decreased by 3.0%, and increased by 0.3%, respectively, whereas the transportation costs from Busan, Shanghai, and Tokyo to Klang decreased by 35.0%, 32.7%, and 0.4% from Hong Kong, Singapore, and Taiwan to Klang increased 0.1%, 0.0%, and 76.2%, respectively. The transportation costs from Busan, Hong Kong, and Taiwan to Johor likely increased because the maritime companies avoided the use of TJ Pelepas port as a transshipment port—due, in turn, to the increased sailing distance; they also changed the container ship so as to use smaller ones, stepping down the vessels' scale of economy. Note that **Table 3** shows that the volume of transship cargo at TJ Pelepas port decreased by 99% in Case 2. **Table 4** also indicates that the transportation cost from Busan to Johor increased by 11.9%, whereas the transportation cost from Busan to Klang decreased by 35.0%. This is because the carriers changed their transshipment port for shipments from Busan to Europe, from via the ports in Johor to via Klang port, due to the larger sailing costs incurred by the detour.

Finally, **Table 3** shows that, in Case 2, the volumes of transshipment cargo increased by 106% at Klang and by 108% at Taiwan. Although it is expected that the transportation cost from Taiwan to Klang decreased in Case 2 on account of the economy of scale, **Table 4** shows that the transportation cost from Taiwan to Klang increased by 76.2%, whereas the transportation costs associated with shipments from many other ports to Klang decreased. Why is this so? It is probably because the shipping companies change the route for the cargo transported between Taiwan and the Middle East region from the route via Klang to the direct route. This implies that Klang competes with Taiwan to be the transshipment port for the cargos transported between the SEA/EA and the Middle East/Europe regions.

4.3 Discussion

First, the results of the case analysis indicated that carriers may change their transshipment ports from SoMS littoral ports to other EA ports if the aforementioned risk events were to actually occur in the SoMS. This means that those risk events would influence not only adjacent regions, but also more distant regions (e.g., South Korea, China, and Taiwan). The risk issues at the SoMS are issues that affect all of Asia, not just the littoral countries of the SoMS or SEA; for this reason, the mitigation of potential risks at the SoMS should be discussed among all SEA and EA countries. Note that in our case analysis, the Singapore port was not significantly impacted by the risk events. There are two reasons for this. First, the Singapore port is attractive for shippers and carriers, even if the risk events were to occur in the SoMS, as it provides them with high-quality services at a low cost. Second, the Singapore port is located so conveniently that it could be accessed by container ships even if they were forced to detour to the Lombok or Sunda Straits.

Next, the results of the case analysis also showed that the expected impacts of an increase in sailing costs in the SoMS differed from the expected impacts of needing to detour to another sea lane at the SoMS littoral ports. At the TJ Pelepas port, the increase of sailing cost would impact the littoral ports in a way almost similar to that seen in detouring to another sea lane; such is not the case, however, with the Klang port. Such differences largely stem from geographical factors. Klang is located further from the blockade point than is TJ Pelepas; for this reason alone, in the case of “detouring to another sea lane,” the transportation costs from TJ Pelepas to the EA ports are larger than those from Klang to the same EA ports.

Third, the results show that changes in transportation costs between ports may vary among port pairs, as well as among risk cases. This depends greatly upon the carrier’s choice of ship size and/or the carrier’s choice of transshipment port. A change in transportation cost would lead to a price increase of imported goods within the importing regions, which may in turn lead to serious economic losses in those regions.

Finally, the simulation results also showed that changes in transportation cost may depend on the direction of shipment between a given pair of ports; this is likely because the choice of transshipment port can vary with direction. A port that attracts a great amount of container-cargo volume can provide carriers with cheaper service, because of economies of scale. In the risk cases, such attractive ports are scattered asymmetrically across the SEA, and this matter of geography may affect differences in transportation cost, depending on direction.

5. CONCLUSIONS

This paper examined the risks of some catastrophic events that could plausibly occur in the SoMS. The literature regarding past similar events was reviewed and the hypothetical risks of future such events were examined. The catastrophic risks included a serious accident involving large-scale ships sailing through the SoMS; a terrorist attack on port facilities or sailing vessels, with a nuclear bomb or massive bomb explosions; a computer-hacking event involving the port-management system at a major international port; a vicious distribution of biochemical weapons in the hinterlands of major ports; the natural occurrence of a pandemic in a hinterland; and a collision between container cargo vessels and a crude-oil tanker. Next, two cases were prepared by synthesizing the event stories. The cargo flows under the two cases were empirically estimated, using the international cargo flow simulation model. Increases in transportation costs between ports were also estimated in the case analysis. The results showed that carriers could change their transshipment ports—namely, from SoMS littoral ports to other EA ports—if the risk events were to occur in the SoMS. Additionally, the expected impacts varied among the risk cases; changes in transportation costs between ports could vary among port pairs, as well as among risk cases; and changes in transportation costs could depend on the direction of travel, even between a given pair of ports. These findings could be useful in discussions regarding anti-terrorism measures and/or risk-mitigation policies in the maritime transportation system of the SEA and EA. The results suggest that international cooperation could be necessary to any efficient and effective discussion of such measures and policies.

There are a number of directions in which future research could proceed. First, future studies could address the maritime traffic of types of cargo other than container cargo. In particular, the SoMS is well-known as a major sea lane for oil tankers, thus connecting Middle East producers with consumers in the SEA and EA; a blockade of the SoMS could have a seriously adverse effect on the crude-oil trade. To broaden the range of goods transported by ship and handled at ports, the simulation model should be extended so as to include the traffic flows of bulk carriers, oil tankers, chemical tankers, and liquefied natural gas tankers. Additionally, air transportation should be incorporated into discussions pertaining to international transportation security, because the demand for air cargo transportation has grown significantly worldwide.

Second, future case analyses should extend to risk cases other than the two analyzed here. Although seven scenarios were extracted from the scenario development described in Section 3, they are not fully reflected in the cases. For example, damages inflicted directly on port facilities as a result of natural disasters or terrorist attacks could significantly impact international cargo flows. Although security policies have been greatly strengthened since the

September 11, 2001 terrorist attacks, there still remain issues that should be examined, if safety in maritime transportation is to be improved.

Third, the accuracy of the simulation model should be improved. Although the case analysis applied, in a straightforward manner, the simulation model developed by Shibasaki *et al.* (2005), 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.

Fourth, the impacts of the risk events on regional/local economy could be explored in addition to the impact analysis on transportation flow patterns. For example, the GTAP may be applied to the economic impact analysis under the conditions that the transportation time and cost are increased in the risk cases.

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.

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APPENDIX: Simulation results in the case analysis

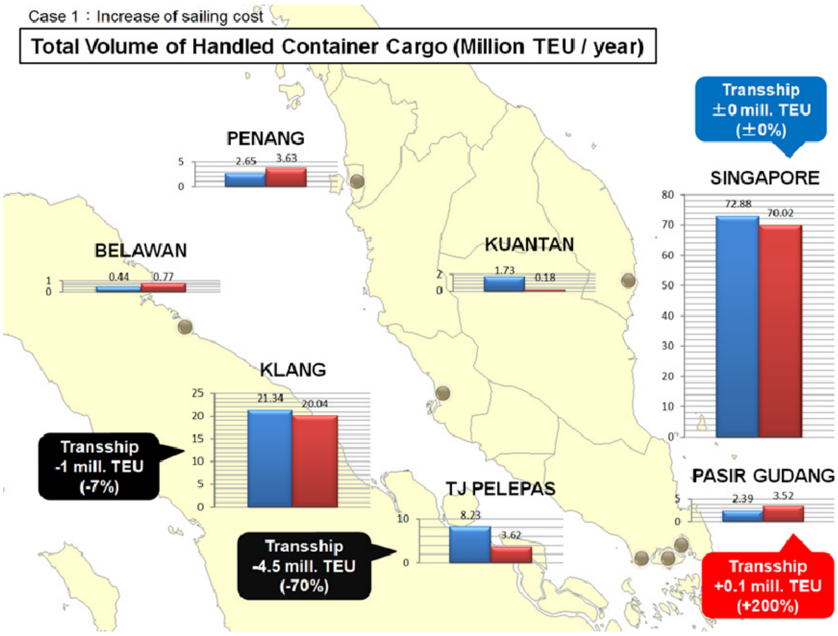

Figure A1 Simulation results in Case 1, at the littoral ports of the SoMS

Note: Blue-colored bars refer to the volumes of container cargo handled at ports in the baseline case; red-colored bars refer to the volumes of container cargo handled at ports in Case 1.

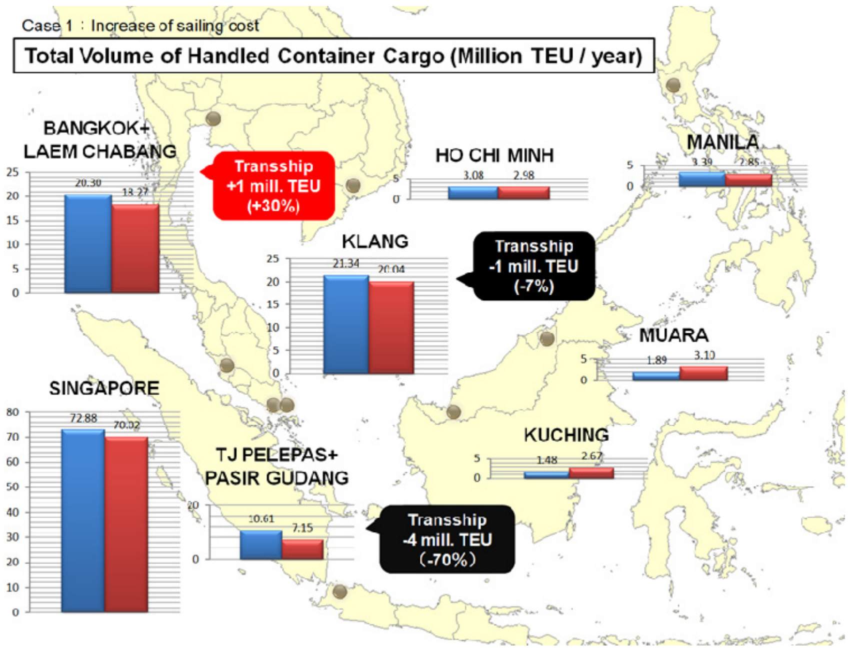

Figure A2 Simulation results in Case 1, in the southeastern Asia region

Note: Blue-colored bars refer to the volumes of container cargo handled at ports in the baseline case; red-colored bars refer to the volumes of container cargo handled at ports in Case 1.

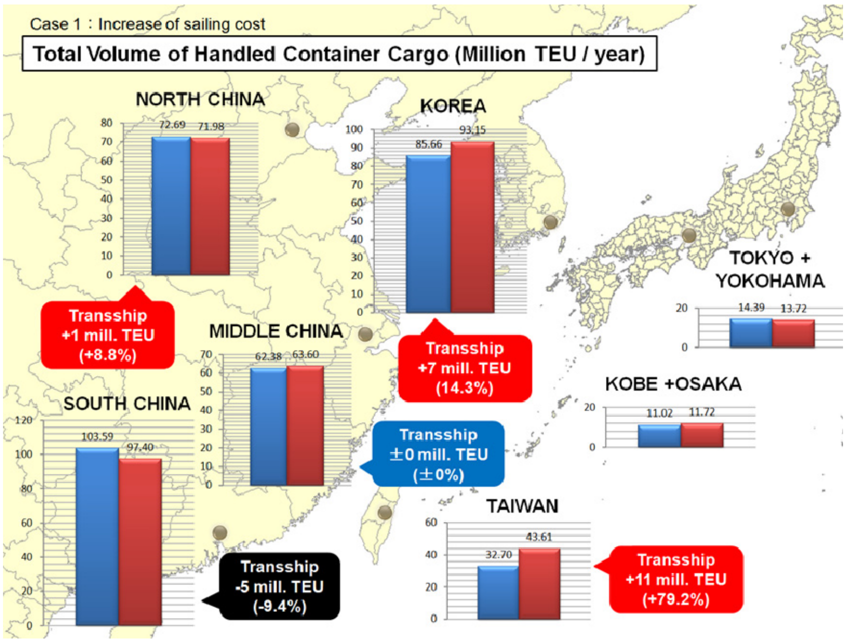

Figure A3 Simulation results in Case 1, in the eastern Asia region

Note: Blue-colored bars refer to the volumes of container cargo handled at ports in the baseline case; red-colored bars refer to the volumes of container cargo handled at ports in Case 1.

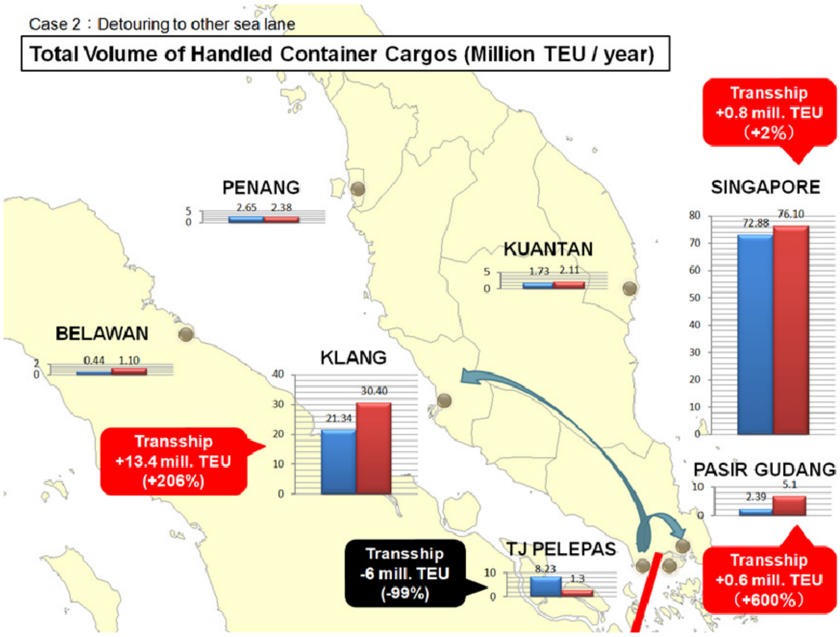

Figure A4 Simulation results in Case 2, at the littoral ports of the SoMS

Note: Blue-colored bars refer to the volumes of container cargo handled at ports in the baseline case; red-colored bars refer to the volumes of container cargo handled at ports in Case 2.

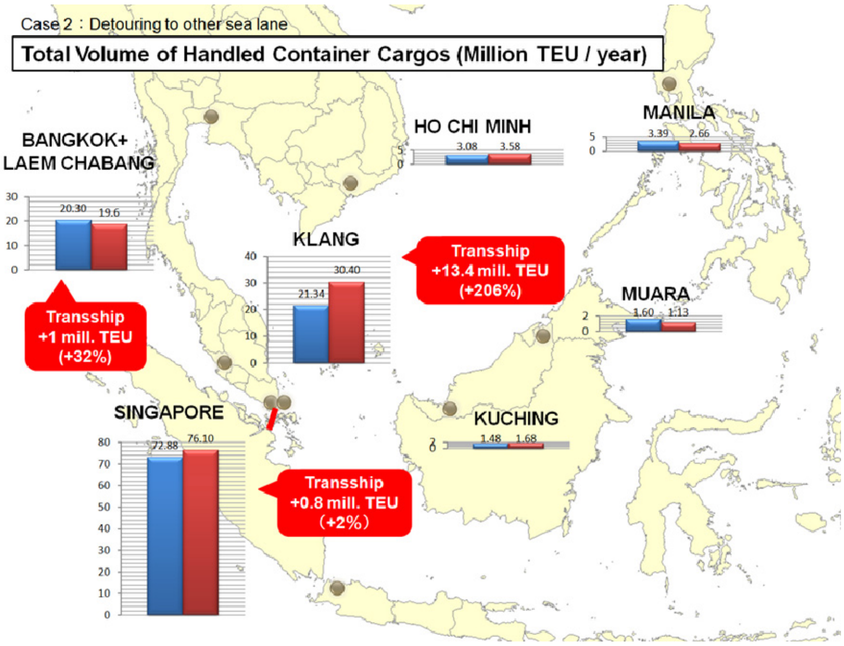

Figure A5 Simulation results in Case 2, in the southeastern Asia region

Note: Blue-colored bars refer to the volumes of container cargo handled at ports in the baseline case; red-colored bars refer to the volumes of container cargo handled at ports in Case 2.

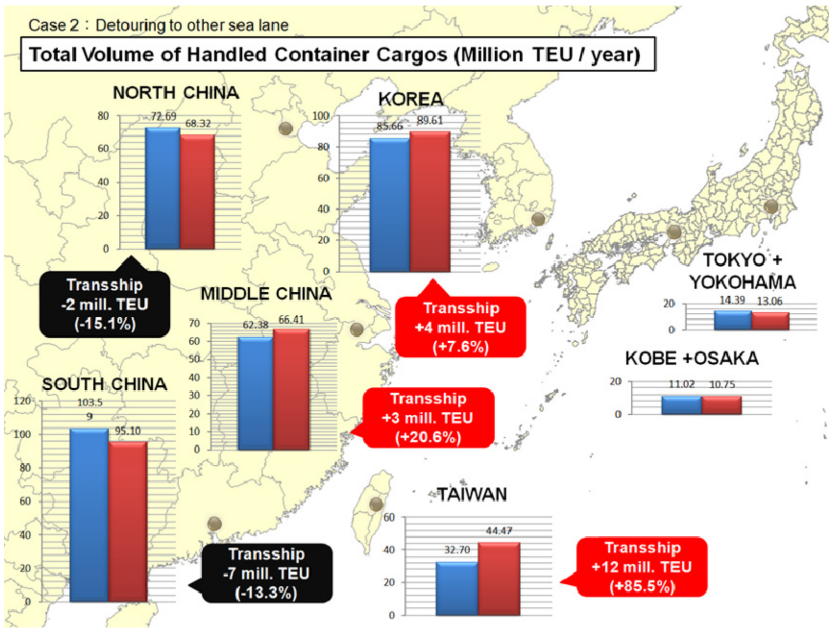

Figure A6 Simulation results in Case 2, in the eastern Asia region

Note: Blue-colored bars refer to the volumes of container cargo handled at ports in the baseline case; red-colored bars refer to the volumes of container cargo handled at ports in Case 2.