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IDE DISCUSSION PAPER No. 568

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March 2016

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Keywords: Kra Canal, Malacca Straits, GIS, simulation model

JEL classification: R40, R13

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Ching-mu Chen† and Satoru Kumagai‡

Abstract

A plan to construct a canal through the Kra Isthmus in Southern Thailand has been proposed many times since the 17th century. The proposed canal would connect the South China Sea and the Andaman Sea, and it would become an alternative route to the over-crowded Straits of Malacca. In this paper, we attempt to utilize a Geographical Information System (GIS) to calculate the realistic distances between ports that would be affected by the Kra Canal and to estimate the economic impact of the canal using a simulation model based on spatial economics. We find that China, India, Japan, and Europe gain the most from the construction of the canal, besides Thailand. On the other hand, the routes through the Straits of Malacca are largely beneficial to Malaysia, Brunei, and Indonesia, besides Singapore. Thus, it is beneficial for all ASEAN member countries that the Kra Canal and the Straits of Malacca coexist and complement one another.

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* We would like to thank Associate Professor Ruth Banomyong, Faculty of Commerce and Accountancy at Thammasat University and his team for the fruitful discussions at the initial stage of this study.

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Introduction

The Straits of Malacca is one of the busiest sea routes in the world. The 70 km-wide straits had significant traffic amounting to 79,344 vessels annually or 217 vessels per day in 2014 (Seatrade 2015). There have been many plans to bypass the straits since the 17th century by constructing a canal through the Kra Isthmus in Thailand. The latest revival of the plan is associated with China's grand development initiative known as "One Belt, One Road."

There is substantial literature that discusses China's energy and national security, and the Kra Canal as a solution to that objective (Lanteigne 2008, Kaplan 2009). Concerning the economic impact of the Kra Canal, the majority of this literature concludes that Singapore's dominance in maritime trade would be significantly eroded (Ronan 1936) and the economic development of Singapore and Malaysia would be negatively affected (Sulong 2013). However, most of the discussions and conclusions were not based on any economic calculations.

Here, we attempt to calculate the economic impact of the Kra Canal by utilizing the Institute of Developing Economies' Geographical Simulation Model (IDE-GSM), a computational model based on spatial economics and developed by the IDE-JETRO (Japan External Trade Organization). The simulation model can calculate the economic impact of various trade and transport facilitation measures for East Asia at the subnational level.

A major problem when conducting a simulation analysis of the Kra Canal is to calculate the numerous sea distances between two arbitrary ports through this hypothetical canal. IDE-GSM has a sea route database, which is based on *Nihon Kaiun Shukaijo* (1983), but certainly there are no sea route distances through the proposed Kra Canal from any current data sources. Thus, we need to calculate realistic distances between hundreds of ports that would potentially be affected by the canal.

In this paper, we utilize a Geographical Information System (GIS) and World Shipping Lane (WSL) data. By combining the GIS and WSL data with our automation scripts, we can automatically calculate numerous sea route distances through the Kra Canal between two arbitrary ports. When these sea route distances are incorporated within IDE-GSM database, it will be possible to conduct economic impact analyses.

This paper is structured as follows. In Section 1, we briefly introduce IDE-GSM and explain how to calculate the economic impact of the Kra Canal. Section 2 shows how to calculate the sea route distances with and without the Kra Canal using a GIS and WSL data, and then to compare the calculated distances with the data from other sources in order to check for accuracy. Section 3 presents the economic impact of the canal, as calculated by IDE-GSM, and outlines some policy implications. Section 4 concludes and outlines some issues that should be addressed in future research.

1. Calculating the Economic Impact of the Kra Canal

1.1 IDE-GSM and TTFM

Since 2007, the IDE-JETRO has developed a GSM with assistance from the Economic Research Institute for ASEAN and East Asia (ERIA), and this model has become a useful tool for policy analysis. IDE-GSM is a general-equilibrium simulation model based on spatial economics in which it is possible to predict the economic impact of various trade and transport facilitation measures (TTFMs) on each region in East Asia at the subnational level.[4]

The model expands upon Krugman's simple model by incorporating numerous realistic features such as multiple industrial sectors with intermediate inputs, a multimodal transport selection model, and the existence of tariff and non-tariff barriers in international trade.

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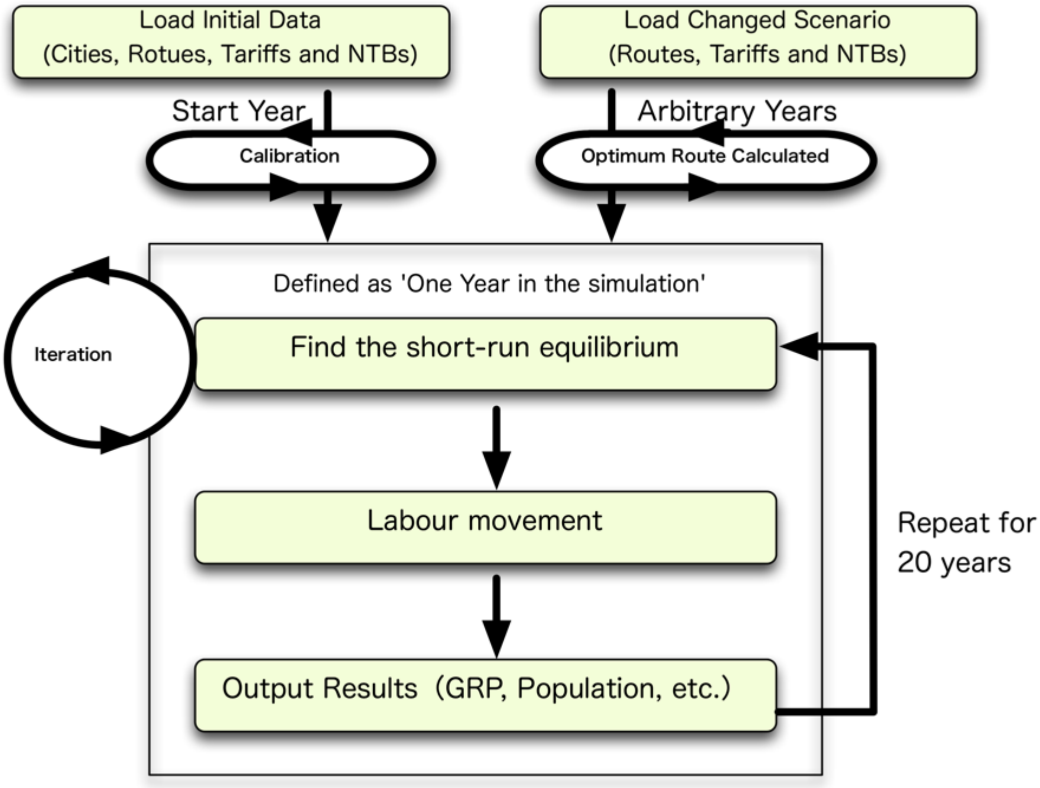
[4] For a more detailed explanation of the model, please refer to Kumagai et al. (2013).

This section explains our simulation procedures, which are depicted in Figure 1. First, with given distributions of employment and regional GDP by sector and region, we obtain the short-run equilibrium values of GDP, price indexes, and nominal and real wages. After observing this achieved equilibrium, workers migrate among the regions/sectors from those with lower wages to those with higher wages, and we obtain a new distribution of workers and economic activities. With this new distribution and predicted population growth, the next short-run equilibrium is obtained for the following year and we subsequently observe migration again. These computations are iterated for 20 years from 2010 to 2030.

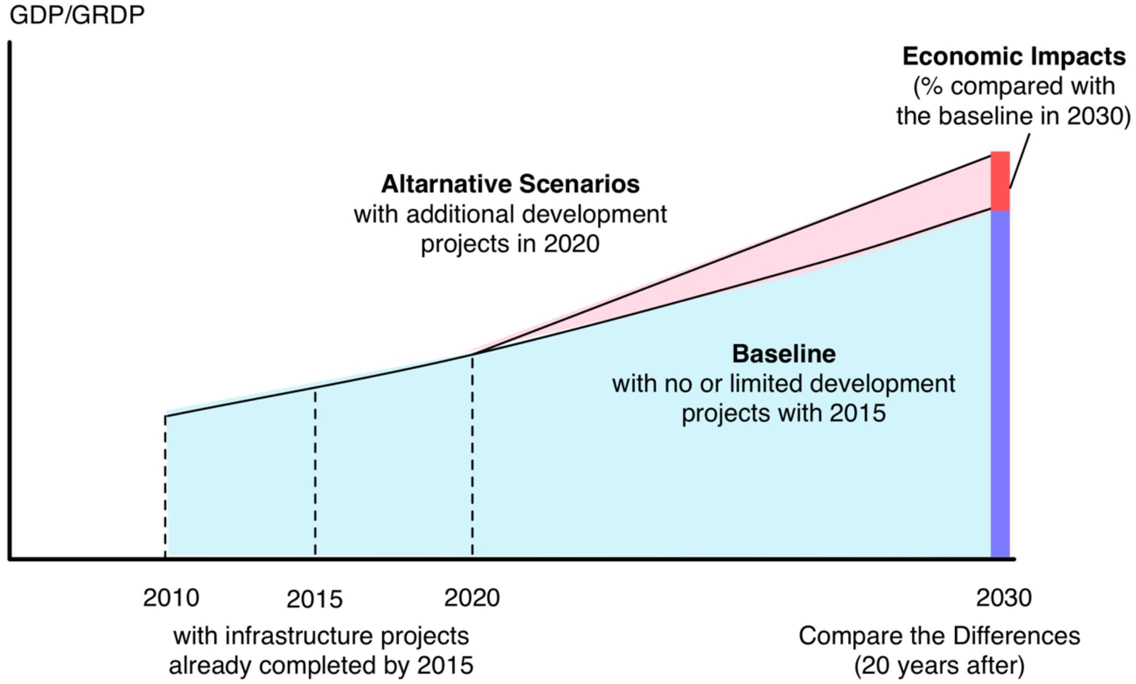
Figure 1. The Procedure of IDE-GSM



Source: Authors.

We calculate the economic impact of a specific TTFM as the difference between GRP/GDP under a specific development scenario and GRP/GDP under the baseline scenario, typically for the year 2030 (Figure 2).

Figure 2. Difference between the Baseline and Alternative Scenarios



Source: Authors

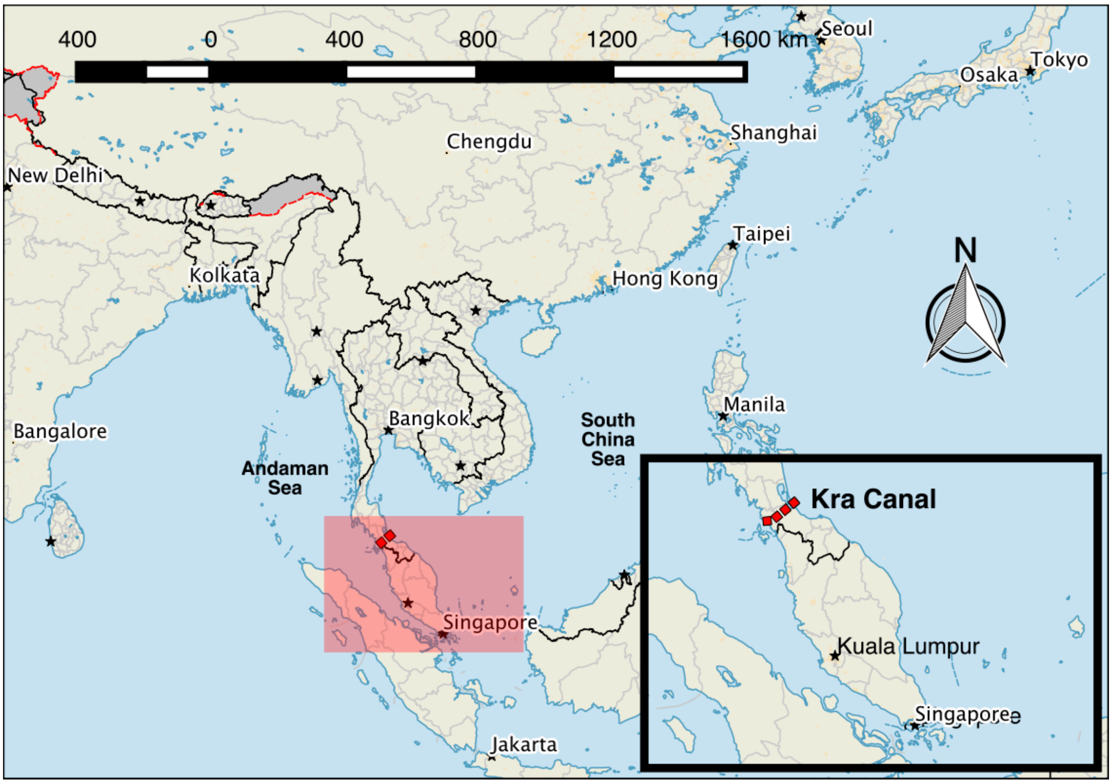
We need to clarify what is included in the economic impact of TTFMs in the analysis by IDE-GSM. First, the economic impact calculated by IDE-GSM does not include the expenditures for the construction of the infrastructure itself or the multiplier effects. All of the economic impacts calculated by IDE-GSM are the increase/decrease in the economic activities of each subnational region that emanates from changes in the transport costs caused by TTFMs.

Second, the transport sector in IDE-GSM is different from the other economic sectors. For the other economic sectors, we define production functions and calculate their production and value added endogenously. For the transport sector, it is not taken into account in GDP because our transport costs are assumed to be the "iceberg" type, which is very popular in spatial economics. Thus, the economic impacts calculated by IDE-GSM do not include the changing GDP of the transport sector.

1.2 Kra Canal and Alternative Plans

The Kra Canal project seeks to construct a canal connecting the South China Sea and the Andaman Sea by excavating the Kra Isthmus in Southern Thailand. The narrowest part of the isthmus is only 44 km, but there are various route plans to avoid mountainous areas and to minimize the excavation costs (Thapa et al. 2007). Via the Kra Canal, the sea route distance between the South China Sea and the Andaman Sea is expected to be dramatically shortened.

Figure 3: Kra Canal



Source: Authors.

As the excavation costs through the isthmus are enormous, there are alternative plans for the proposed excavation. One plan is the construction of a "land bridge" across the isthmus, where two ports located on the South China Sea and the Andaman Sea are connected by highway or railway. Another plan is to construct a pipeline in northern Malaysia to substitute for the numerous oil tankers traveling through the crowded Straits of Malacca.

1.3 The Scenario

In this paper, we set the following three scenarios in our simulation analyses of the development of the Kra Canal:

Scenario 1: The Kra Canal and the Straits of Malacca Coexist

- Excavation of the canal crossing the Kra Isthmus between Songkhla and Satun is completed in 2025.
- A transshipment port is also constructed at the middle point of the canal.
- All sea routes through the Straits of Malacca are also available as before.
- According to the origin–destination combinations, the shortest route through either the Kra Canal or the Straits of Malacca is selected as the optimum route to calculate the transport costs.

There are two things to be noted in this scenario. First, the optimum shipping route by origin and destination is only determined by considering the fixed time and monetary costs of each shipping lane, and it is not affected by the optimum route for other origin–destination combinations; that is, no network effect is assumed. Second, the port located at the middle point of the canal is only for transshipments; that is, no exports from or imports to Thailand are allowed for this port.

Scenario 2: The Kra Canal Only

- Excavation of the canal crossing the Kra Isthmus between Songkhla and Satun is completed in 2025.
- A transshipment port is also constructed at the middle point of the canal.
- All sea routes through the Straits of Malacca are discontinued, and the Kra Canal–Singapore feeder route is opend.

In this scenario, we consider the worst case for Singapore. All traffic through the Straits of Malacca is now replaced by the Kra Canal. This is not a consequence of the economic choice between the transshipments through the Kra Canal or Singapore, but we just assume that the Kra Canal is always the better choice in order to determine the largest possible negative impact for Singapore.

Scenario 3: The Kra Canal plus SEZ in Southern Thailand

- Excavation of the canal crossing the Kra Isthmus between Songkhla and Satun is completed in 2025.
- A transshipment port is also constructed at the middle point of the canal. Now we allow this port to export from and import to Thailand.
- All sea routes through the Straits of Malacca are also available as before.
- According to the origin–destination combinations, the shortest route through either the Kra Canal or the Straits of Malacca is selected as the optimum route in order to calculate the transport costs.
- Special Economic Zones (SEZ) are established in the Songkhla and Satun provinces in 2025. In the provinces assigned as SEZ, we assume the parameter “A,” which means that industrial productivity is increased by 10%.

In this scenario, we intend to use the canal to economically develop Southern Thailand. To satisfy this goal, we allow imports/exports from Kra Port and establish SEZ in the Songkhla and Satun provinces, which are nearest to the canal.

2. **Automatic Calculation of Sea Distances**

2.1 Procedure for the Calculations

To calculate distances between ports along with the shortest sea routes, we modify the dataset of the global shipping lane network, as provided by the Oak Ridge National Labs CTA Transportation Network Group in 2000. We then employ QGIS, a free and open–source GIS software, to display the maps that include all ports and shipping networks. Since QGIS provides network analysis functions, we can automatically calculate the shortest distance based on the world shipping network between any pair of ports using a Python script.

This script uses the QGIS network analysis library to find the routes for each port pair in the input table of all port pairs. This input table lists all routes of interest, defined as a “Start” port and an “End” port. Another input layer is the polyline layer of world shipping lanes, which should be used to determine the various routes. Then, after running the script, the output is a layer consisting of the resulting routes of all port pairs. In this output layer, each feature represents each route of each port pair. Since the resulting routes are not necessarily straight lines but curves consisting of various connected segments along the world shipping network, the calculated distances of the sea routes are more realistic than simply connecting two ports by a straight line. Subsequently, the newly calculated distances of the routes will substitute for the original “distance” column in the attribute table. Thus, the attribute table of the output route layer can be used as the input for the subsequent analysis in IDE-GSM.

Next, we explain how the script finds the shortest sea routes. Once we execute the script, as pointed out in the previous paragraph, we need to specify an input table of all port pairs and an input polyline layer of the world shipping lanes. The latter decides how the resulting sea routes are plotted. Actually, the QGIS network analysis library does not analyze the polyline layer of world shipping lanes directly. A network “graph” is created from the input polyline vector layer. Nodes of the polylines become graph vertexes and segments of the polylines are graph edges. If several nodes have the same coordinates, then they are regarded as the same graph vertex. So, two lines that have a common node are connected to each other. All further actions will use this graph, not the layer.

The script then reads the coordinates of both the “Start” port and the “End” port of each route in the input route table by running a loop. These ports are regarded as the “from” node and the “to” node on the created graph. The QGIS network analysis library provides functions (methods) to answer two questions: Which vertexes are connected and how can the shortest path be found? To solve these problems, the network analysis library uses Dijkstra's algorithm, which finds the shortest route from one of the vertexes on the graph to all the other vertexes, and the shortest distances. The results can be represented as the shortest path tree that possesses the following properties:

- only one vertex has no incoming edges — the root of the tree
- all other vertexes have only one incoming edge
- if vertex B is reachable from vertex A, then the path from A to B is the single available path and it is optimal (shortest) on this graph

Therefore, we use the "dijkstra()" method in the library to get the shortest path tree. It always creates a new graph object after we specify the following three variables:

- source — input graph
- startVertexIdx — index of the point on the tree (the root of the tree)
- criterionNum — number of edge properties to use (starting from 0).

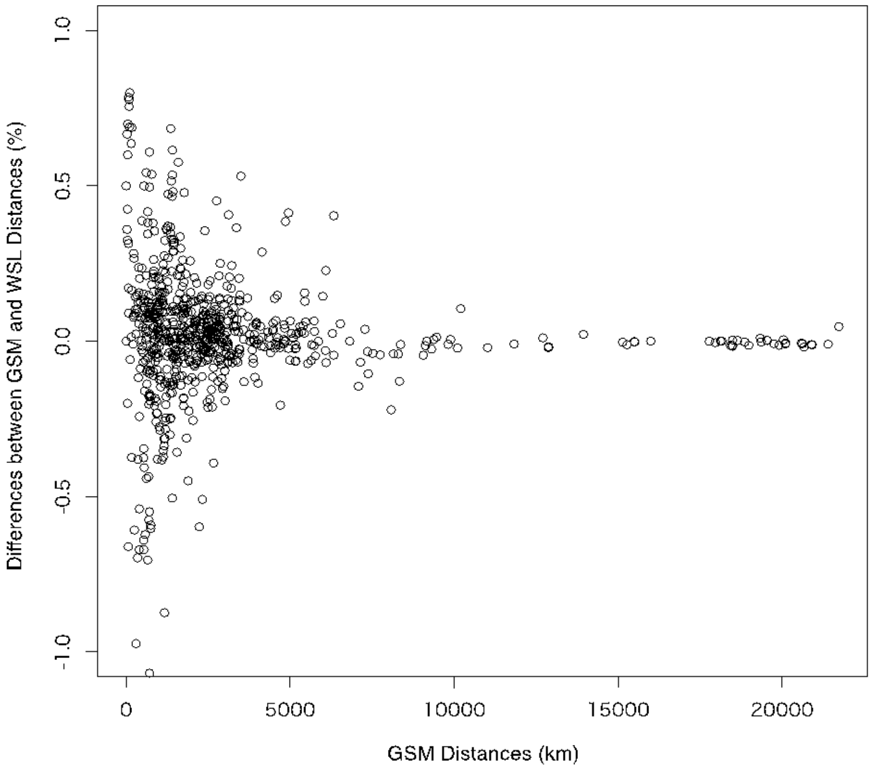
By checking the two returned arrays by the "dijkstra()" method, we get the value of the shortest distance and connect all vertexes along the determined shortest path tree, and present these vertexes as a feature of the route line, which is composed of various segments.

2.2 Comparison of the Calculated Distances with Other Sources

Although the distances automatically calculated from the WSL data seem to be reasonable enough, we need to check the validity of the calculated distances by comparing them with the distances from other sources. IDE-GSM has more than 950 sea routes, mainly adopted from *Nihon Kaiun Shukaijo* (1983), and this source seems to be a reasonable reference.

Figure 4 shows the differences between the sea route distance data in IDE-GSM (GSM distances, hereafter)[5] and WSL distances for the same routes. The horizontal axis is the GSM distances and the vertical axis is the percentage differences between the GSM and WSL distances. It seems that the percentage differences are decreasing as the distances get longer, and the GSM and WSL distances over 10,000 km are almost identical.

Figure 4: Differences between the GSM and WSL Routes by Distance



Source: Authors.

Table 1 shows the distribution of the differences between the GSM and WSL distances. For the routes with a distance less than 100 km, the differences between the GSM and WSL distances are significant, as only 14.3% of the routes have a difference less than

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[5] IDE-GSM contains the sea routes with no distance data (the straight distances are calculated and used) and the sea routes within the European Union (EU), in which inland water routes are used extensively. These two categories of routes are excluded from the comparison with WSL.

20%. This is because the WSL network data is not detailed enough to calculate distances less than 100 km.

For the routes that have distances between 100 km and 1000 km, 65.5% of the routes have a difference less than 20%, and for the routes that have distances between 1000 km and 5000 km, the percentage of routes that have a difference less than 20% increases to 82.8%. Most of the international shipping lanes fall within this greater distance category or longer; thus, the longer WSL distances seem to be somewhat closer to the actual distances of the international shipping lanes.

For the routes that have distances between 5000 km and 10,000 km, 95.2% of the routes have a difference less than 20%, and for the routes that have a distance greater than 10,000 km, all routes have a difference less than 20%. Thus, for the routes greater than 5000 km, we can utilize the WSL distances with less reservation.

Table 1: Differences between the GSM and WSL Routes by Distance

		GSM Distances											
		<100		<1000		<5000		<10000		>10000		Total	
Differences of GSM and WSL routs	<1%	1	4.80%	5	2.90%	59	11.60%	7	11.30%	23	57.50%	95	11.90%
	<5%	1	4.80%	33	19.30%	203	40.00%	40	64.50%	39	97.50%	316	39.50%
	<10 %	2	9.50%	74	43.30%	311	61.30%	52	83.90%	39	97.50%	478	59.70%
	<20 %	3	14.30%	112	65.50%	420	82.80%	59	95.20%	40	100.00%	634	79.20%
	<50 %	8	38.10%	146	85.40%	496	97.80%	62	100.00%	40	100.00%	752	93.90%
	Total	21	100.00%	171	100.00%	507	100.00%	62	100.00%	40	100.00%	801	100.00%

Source: Authors.

2.3 Changes in the Distance for Representative Routes

Although the WSL distances are accurate enough for the longer routes, it is not proper to replace all of the representative routes with the WSL routes because the shorter routes, especially those less than 1000 km, have non-negligible differences. Thus, we need to calculate the representative routes via the Kra Canal by considering both the GSM and WSL distances. Here, we set the distance of the shorter route as follows:

$$T_{OD}^{REP,K} = T_{OD}^{GSM,NK} - (T_{OD}^{WSL,NK} - T_{OD}^{WSL,K})$$

where $T_{od}^{,K}$ is the route distances between ports *o* and *d* via the Kra Canal, and $T_{od}^{,NK}$ is the route distances without the Kra Canal. We subtract the calculated distance savings via the Kra Canal based on the WSL from the original GSM distances for the same origin–destination routes.

Table 2 shows the shortest distances for the representative routes via the Kra Canal in kilometers and percentages. The distance savings are greatest for the routes servicing the ports on the South China Sea and Europe, and the ports on the Andaman Sea. The savings are more than 1300 km. For the routes between ports in Northeast Asia and Europe, and ports on the Andaman Sea, the distance savings are around 900 km. For Manila and the ports in Europe and the Andaman Sea, the savings are around 700 km.

Table 2: Distances between Selected Ports That Benefit from the Kra Canal

Ports		Distance without Kra	Distance via Kra	Distance changed	%
Cai Mep	Yangon	3,229	1,896	-1,333	-41%
Sihanoukville	Yangon	3,269	1,936	-1,333	-41%
Laem Chabang	Yangon	3,521	2,188	-1,333	-38%
Cai Mep	Chittagong	3,969	2,636	-1,333	-34%
Chittagong	Sihanoukville	4,009	2,676	-1,333	-33%
Cai Mep	Madras	4,097	2,764	-1,333	-33%
Madras	Sihanoukville	4,137	2,804	-1,333	-32%
Cai Mep	Colombo	4,160	2,827	-1,333	-32%
Colombo	Sihanoukville	4,200	2,867	-1,333	-32%
Cai Mep	Calcutta	4,216	2,883	-1,333	-32%
Chittagong	Laem Chabang	4,261	2,928	-1,333	-31%
Laem Chabang	Madras	4,389	3,056	-1,333	-30%
Laem Chabang	Colombo	4,452	3,119	-1,333	-30%

Bombay	Sihanoukville	5,739	4,407	-1,333	-23%
Bombay	Laem Chabang	5,991	4,659	-1,333	-22%
Cai Mep	Rotterdam	16,667	15,334	-1,333	-8%
Rotterdam	Sihanoukville	16,707	15,374	-1,333	-8%
Laem Chabang	Rotterdam	16,959	15,626	-1,333	-8%
Hai Phong	Yangon	4,517	3,618	-899	-20%
Hong Kong	Yangon	4,773	3,874	-899	-19%
Kaohsiung	Yangon	5,078	4,179	-899	-18%
Chittagong	Hai Phong	5,257	4,358	-899	-17%
Hai Phong	Madras	5,385	4,486	-899	-17%
Hai Phong	Colombo	5,448	4,549	-899	-17%
Chittagong	Hong Kong	5,513	4,614	-899	-16%
Hong Kong	Madras	5,641	4,742	-899	-16%
Hong Kong	Colombo	5,704	4,805	-899	-16%
Chittagong	Kaohsiung	5,818	4,919	-899	-15%
Kaohsiung	Madras	5,946	5,047	-899	-15%
Kaohsiung	Colombo	6,009	5,110	-899	-15%
Shanghai	Yangon	6,108	5,209	-899	-15%
Tokyo	Yangon	6,770	5,871	-899	-13%
Busan	Yangon	6,879	5,980	-899	-13%
Bombay	Hai Phong	6,987	6,088	-899	-13%
Tianjin	Yangon	7,243	6,344	-899	-12%
Bombay	Hong Kong	7,243	6,344	-899	-12%
Chittagong	Tokyo	7,510	6,611	-899	-12%
Bombay	Kaohsiung	7,548	6,649	-899	-12%
Busan	Chittagong	7,619	6,720	-899	-12%
Madras	Tokyo	7,638	6,739	-899	-12%
Colombo	Tokyo	7,701	6,802	-899	-12%
Busan	Madras	7,747	6,848	-899	-12%
Busan	Colombo	7,810	6,911	-899	-12%
Busan	Calcutta	7,866	6,967	-899	-11%
Chittagong	Tianjin	7,983	7,084	-899	-11%

Madras	Tianjin	8,111	7,212	-899	-11%
Colombo	Tianjin	8,174	7,275	-899	-11%
Bombay	Tokyo	9,240	8,341	-899	-10%
Bombay	Busan	9,349	8,450	-899	-10%
Bombay	Tianjin	9,713	8,814	-899	-9%
Hai Phong	Rotterdam	17,955	17,056	-899	-5%
Hong Kong	Rotterdam	18,211	17,312	-899	-5%
Kaohsiung	Rotterdam	18,516	17,617	-899	-5%
Rotterdam	Tokyo	20,208	19,309	-899	-4%
Busan	Rotterdam	20,317	19,418	-899	-4%
Rotterdam	Tianjin	20,681	19,782	-899	-4%
Manila	Yangon	4,553	3,862	-691	-15%
Chittagong	Manila	5,293	4,602	-691	-13%
Madras	Manila	5,421	4,730	-691	-13%
Manila	Colombo	5,484	4,793	-691	-13%
Bombay	Manila	7,023	6,332	-691	-10%
Manila	Rotterdam	17,991	17,300	-691	-4%
Kelang	Sihanoukville	1,911	1,898	-13	-1%
Kelang	Laem Chabang	2,163	2,150	-13	-1%

Source: Calculated by the authors.

Table 3 shows the origin–destination combinations that do not benefit from the Kra Canal. These are the routes between Oceania and Indonesia, and between Europe and the Andaman Sea.

Table 3: Distances between Selected Ports That Do Not Benefit from the Kra Canal

Ports		Distance without Kra	Disntace via Kra	Distance changed	%
Kelang	Melbourne	7,856	9,662	+1,806	23%
Kelang	Manila	3,195	3,824	+629	20%
Jakarta	Rotterdam	16,483	16,969	+486	3%

Melbourne	Rotterdam	22,652	23,138	+486	2%
Jakarta	Yangon	3,045	3,531	+486	16%
Chittagong	Jakarta	3,785	4,271	+486	13%
Jakarta	Madras	3,913	4,399	+486	12%
Jakarta	Colombo	3,976	4,462	+486	12%
Bombay	Jakarta	5,515	6,001	+486	9%
Melbourne	Yangon	9,214	9,700	+486	5%
Chittagong	Melbourne	9,954	10,440	+486	5%
Madras	Melbourne	10,082	10,568	+486	5%
Colombo	Melbourne	10,145	10,631	+486	5%
Bombay	Melbourne	11,684	12,170	+486	4%
Jakarta	Laem Chabang	2,428	2,886	+458	19%
Laem Chabang	Melbourne	8,597	9,055	+458	5%
Kelang	Tokyo	5,412	5,833	+421	8%
Kelang	Tianjin	5,885	6,306	+421	7%
Kelang	Rotterdam	16,218	16,233	+15	0%
Kelang	Yangon	2,780	2,795	+15	1%
Kelang	Madras	3,648	3,663	+15	0%
Kelang	Colombo	3,711	3,726	+15	0%

Source: Calculated by the authors.

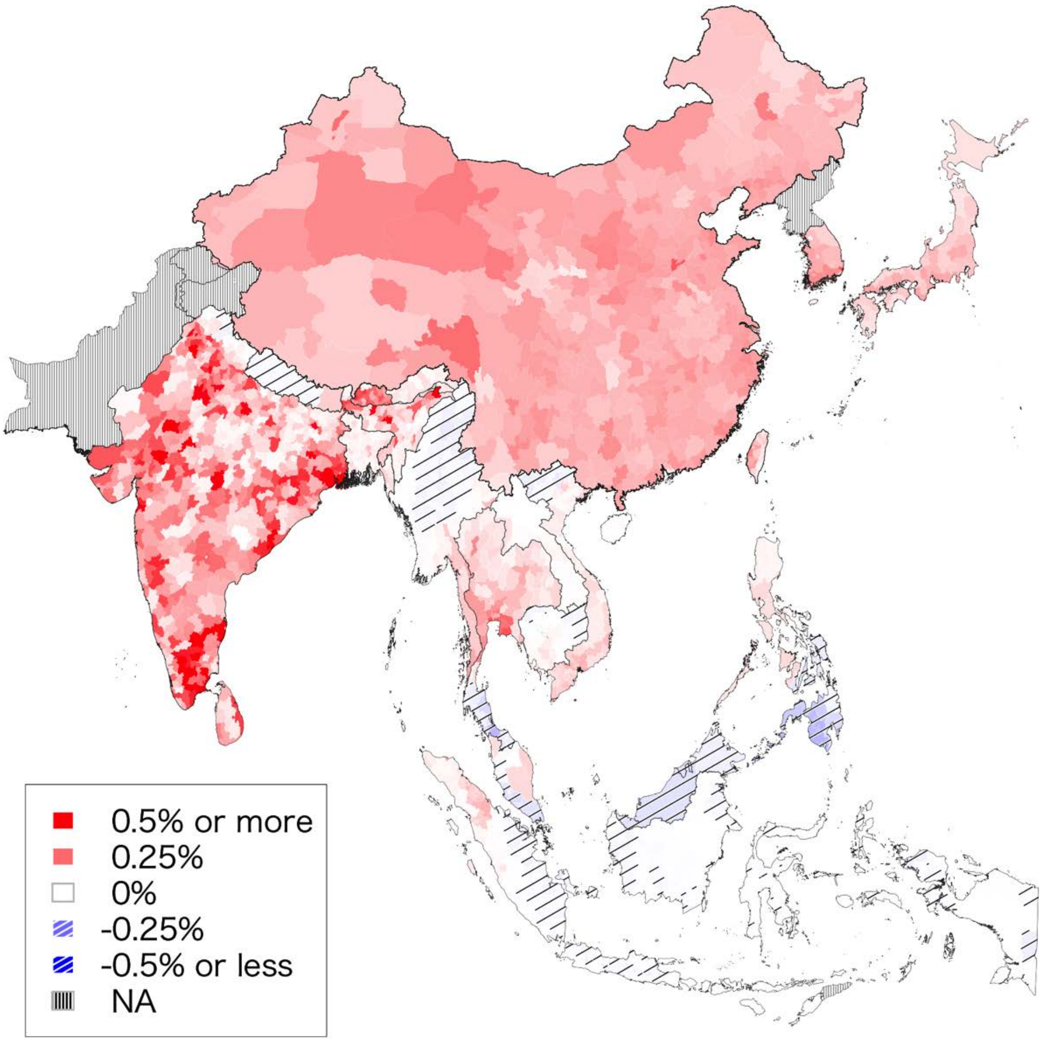
3. **Results and Implications**

3.1 Economic Impacts

Figure 5 shows the economic impacts of the Kra Canal for Scenario 1 (the Kra Canal and Singapore coexist) in 2030 calculated by IDE-GSM. Positive economic impacts are observed in India, China, Korea, Japan, Vietnam, and Thailand. Negative impacts are observed in Singapore, Malaysia, some parts of Indonesia, and, surprisingly, Southern Thailand. This is because the locational advantages of Bangkok are increased by the canal, whereas the canal itself does not produce any economic activity in

Southern Thailand. In Scenario 1, the negative impacts on Singapore and Malaysia do not appear to be very large.

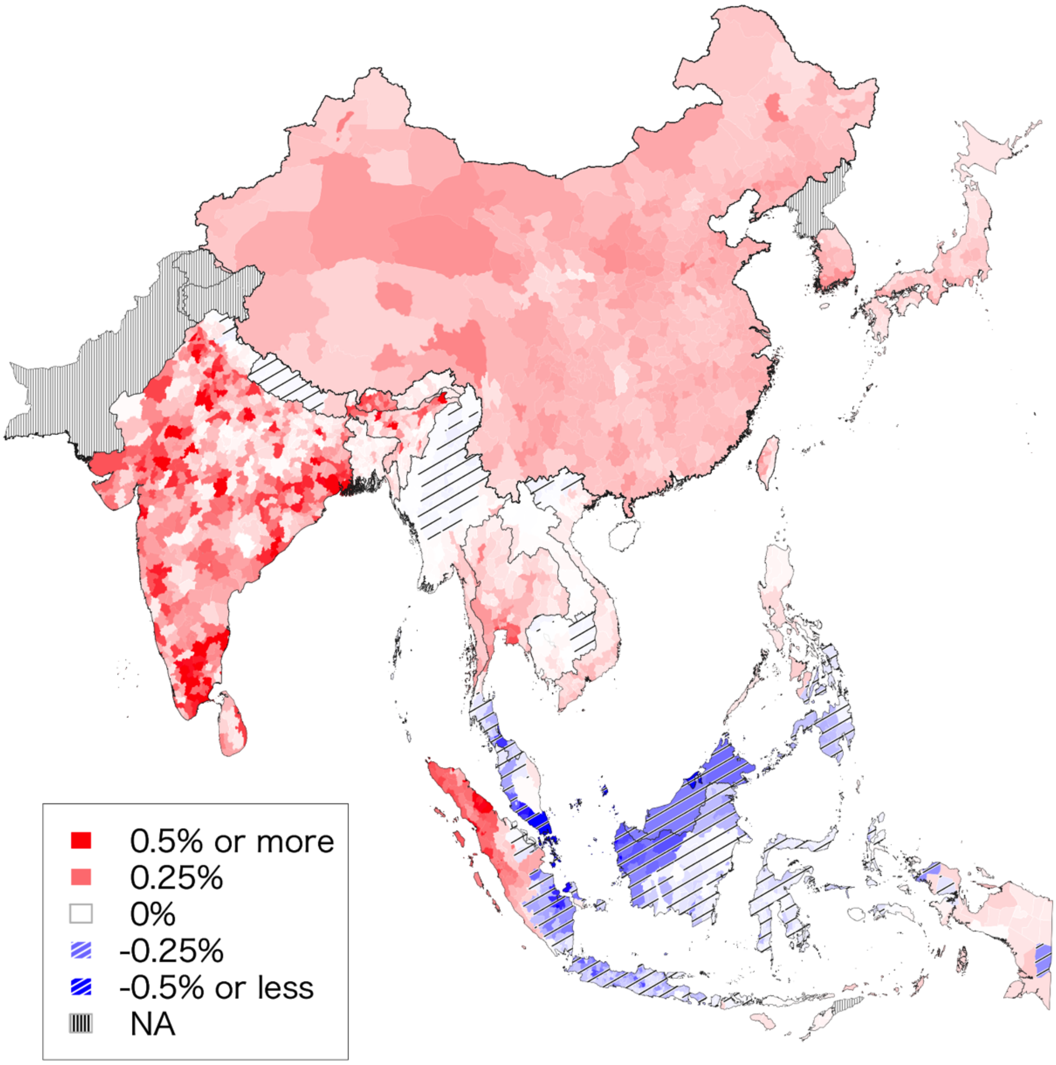
Figure 5: Economic Impacts of the Kra Canal, Scenario 1, 2030



Source: Calculated by IDE-GSM

Figure 6 shows the economic impacts of the Kra Canal for Scenario 2 (the Kra Canal Only) in 2030. Compared with Figure 5, the negative impacts in Singapore, Malaysia, some parts of Indonesia, and Southern Thailand are larger. The positive impacts seem to be almost identical to those in Figure 5. In this scenario, the negative impacts on the regions that currently benefit from their proximity to Singapore are relatively large.

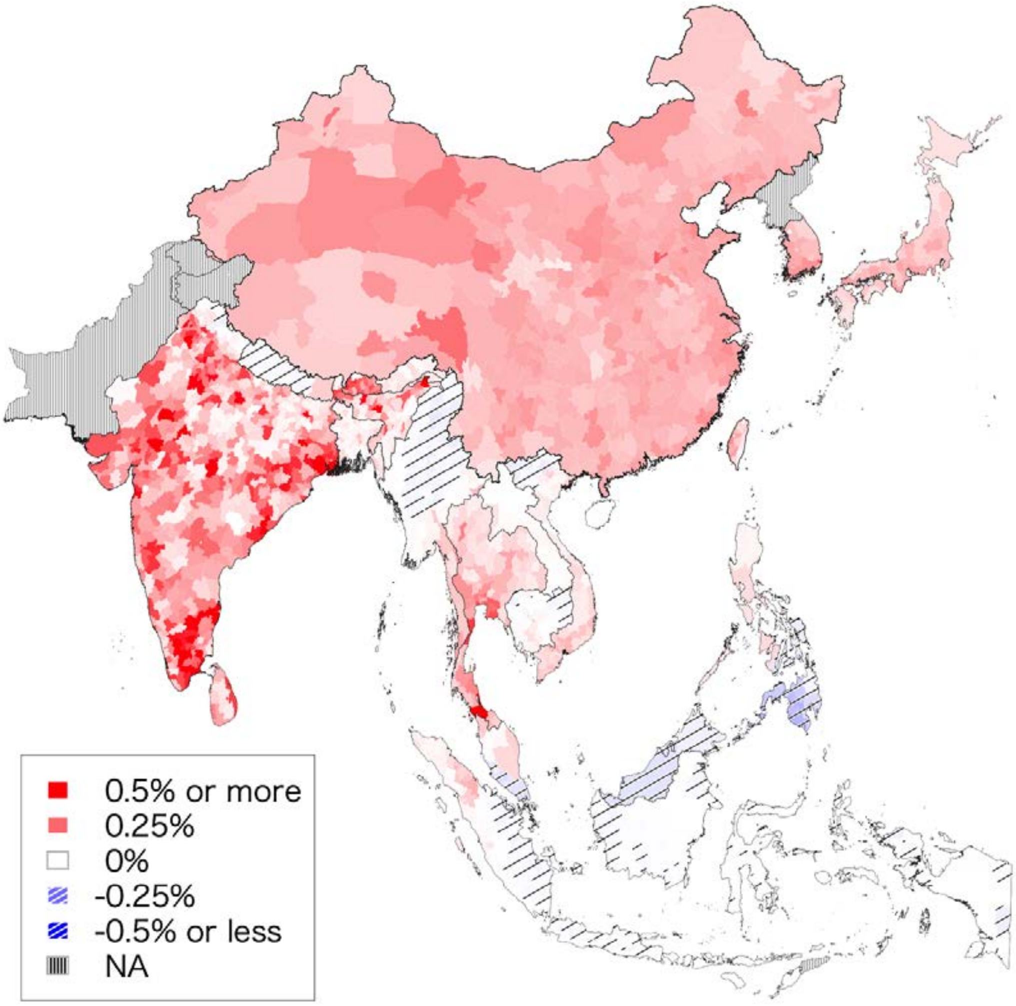
Figure 6: Economic Impacts of the Kra Canal, Scenario 2, 2030



Source: Calculated by IDE-GSM

Figure 7 shows the economic impacts of the Kra Canal for Scenario 3 (the Kra Canal plus SEZ in Southern Thailand) in 2030. Compared with Figure 5, the negative impacts previously observed in Southern Thailand have turned positive. The SEZ in Southern Thailand seems to be effectively working in tandem with the operation of the Kra Canal.

Figure 7: Economic Impacts of Kra Canal, Scenario 3, 2030



Source: Calculated by IDE-GSM

Table 4 shows the economic impacts of the Kra Canal in 2030 by scenario and country. For Scenario 1, China benefits the most from the Kra Canal and the economic impact is USD 21.5 billion. India is the country that has the second-largest economic impact (USD 17.7 billion), followed by Japan (USD 10.6 billion). In percentage terms, Bhutan's GDP increases by 0.26%, followed by Thailand (0.18%) and Sri Lanka (0.17%). Outside of East Asia, the EU gains by USD 23.4 billion, whereas the United States is negatively affected by the Kra Canal. This result is expected due to the trade diversion effects of the closer trade relationships between the EU and East Asia. In total, the gains from the Kra Canal amount to USD 86.3 billion.

Table 4: Economic Impacts of the Kra Canal by Country, 2030

	Scenario 1		Scenario 2		Scenario 3	
	(million USD)	(% of GDP)	(million USD)	(% of GDP)	(million USD)	(% of GDP)
Indonesia	-98	0.00%	-11,660	-0.33%	-83	0.00%
Malaysia	-130	-0.01%	-2,029	-0.21%	-85	-0.01%
Singapore	-371	-0.04%	-7,027	-0.83%	-353	-0.04%
Thailand	2,703	0.18%	2,742	0.18%	4,244	0.28%
Philippines	382	0.04%	359	0.03%	389	0.04%
Brunei	-9	-0.04%	-111	-0.51%	-8	-0.04%
Cambodia	8	0.02%	9	0.02%	9	0.02%
Laos	2	0.01%	2	0.01%	2	0.01%
Myanmar	9	0.01%	9	0.01%	9	0.01%
Vietnam	484	0.09%	486	0.09%	491	0.09%
ASEAN10	2,980	0.03%	-17,221	-0.20%	4,615	0.05%
Japan	10,611	0.08%	9,212	0.07%	10,723	0.08%
Korea	3,405	0.11%	3,116	0.10%	3,219	0.11%
China	21,508	0.13%	17,549	0.11%	20,685	0.13%
Australia	-250	-0.01%	-1,208	-0.07%	-234	-0.01%
New Zealand	-68	-0.02%	-273	-0.07%	-68	-0.02%
Taiwan	897	0.08%	834	0.08%	863	0.08%
India	17,719	0.22%	17,996	0.22%	17,827	0.22%
Bangladesh	100	0.04%	101	0.04%	100	0.04%
Sri Lanka	278	0.17%	281	0.17%	279	0.17%
Nepal	2	0.00%	2	0.00%	2	0.00%
Bhutan	17	0.26%	17	0.27%	17	0.27%
United States	-4,751	-0.01%	-5,355	-0.01%	-4,199	-0.01%
Russia	1,307	0.04%	1,296	0.04%	1,350	0.04%
EU	23,431	0.07%	23,370	0.07%	21,252	0.07%
World	86,311	0.06%	58,879	0.04%	85,103	0.06%

Source: Calculated by IDE-GSM

For Scenario 2, Indonesia is negatively affected the most, and the negative impact amounts to USD 11.6 billion. Singapore (USD -7.0 billion) and Malaysia (USD -2.0 billion) are also affected by a negatively large amount, and in percentage terms, Brunei (-0.51%) is too. The economic impacts for the other countries are not very different from Scenario 1. The economic impact for AESAN10 is USD -17.2 billion; thus, a complete replacement of the routes through the Straits of Malacca via the Kra Canal does not benefit ASEAN as a whole.

For Scenario 3, the economic impacts for Thailand increase to USD 4.2 billion. It seems that the utilization of the Kra Canal combined with SEZs in order to develop Southern Thailand is the right strategy. The economic impacts for the other countries are very similar to Scenario 1.

3.2 Findings and Policy Implications

The simulated economic impacts of the Kra Canal, Scenario 1, are not far removed from our expectations. It is natural that China, India, Japan, and Europe gain the most from the canal because the canal reduces the distances between the South China Sea and the Andaman Sea.

If the routes through the Kra Canal and the Straits of Malacca coexist, the negative impacts for Singapore and Malaysia are rather small. On the other hand, if all the routes through the Straits of Malacca are discontinued, the negative impacts for Singapore and Malaysia, as well as for Indonesia and Brunei, are large and surpass the positive impacts of the Kra Canal for all ASEAN member countries combined.

The simulated economic impacts of the Kra Canal, Scenario 1, show that the regions in Southern Thailand do not benefit from the Kra Canal when only the transshipment port is constructed. This is because the transport sector is not incorporated in the simulation model as a productive industry; thus, no additional economic activities are supposed to occur near the canal in this scenario. In addition, the canal improves the attractiveness of the Bangkok area, leading to even greater negative impacts for Southern Thailand.

On the other hand, as shown in Scenario 3, it seems to be feasible to develop the regions in Southern Thailand with SEZs close to the Kra port, which can be used to export and import goods from and to Southern Thailand.

These findings lead to the following policy implications. First, the sharing of development costs among countries is the key toward realizing the project. The positive economic impacts of the Kra Canal are not mainly enjoyed by Thailand itself but by countries located far from the canal that enjoy relatively larger gains. Thailand can charge tolls for the vessels sailing through the canal, but the upper limit of the toll rate is not that high, considering that the alternative route through the Straits of Malacca is not significantly inferior. This is a very different situation compared with the Suez Canal and the Panama Canal, which have no viable alternative routes.

Second, the Kra Canal cannot completely replace the existing routes through the Straits of Malacca. For Malaysia, Indonesia, and Brunei, as well as Singapore, the routes through the straits are indispensable and cannot be substituted by the Kra Canal. Thus, it is beneficial to all ASEAN countries that the Kra Canal and the Straits of Malacca coexist and complement one another.

Third, if the government of Thailand intends to develop the regions in Southern Thailand traversed by the Kra Canal, the construction of a transshipment port is not enough. As shown by Scenario 3, the establishment of SEZs in Southern Thailand that can take advantage of access to the Kra Canal seems to be a viable policy option.

4. **Conclusions**

In this paper, we automatically calculate the distances of the hypothetical routes through the Kra Canal by a GIS and then simulate the economic impacts of the canal. We find that China, India, Japan, and Europe gain the most from the canal, besides Thailand. On the other hand, the routes through the Straits of Malacca are indispensable to Malaysia, Brunei, and Indonesia, as well as Singapore. Thus, it is beneficial for all ASEAN countries that the Kra Canal and the routes through the Straits of Malacca coexist and complement one another.

There are other factors that need to be taken into account when considering the economic impacts of the Kra Canal in detail. For instance, we need to think more about the complementarity of the two options. If some of the traffic through the Straits of Malacca is diverted through the Kra Canal, then the now over-crowded straits become less congested and safer, potentially reducing the trade costs. In this case, Singapore benefits from the Kra Canal. There is a current plan whereby VLCC (Very Large Crude Oil Carrier) sail through the Kra Canal, whereas container cargos sail through the Straits of Malacca.

In addition to the above, we need to think of the network effects of a logistic hub in evaluating the long-term impacts of the Kra Canal. If the advantages of a logistics hub in Singapore are strong enough, very few shipping lanes would utilize the Kra Canal. However, if the shipping traffic through the Kra Canal becomes large enough, then the stronger hub effect of the Kra Canal would make the Singapore routes less attractive. These effects are non-linear and difficult to simulate. Although the simulation analyses conducted here are useful for a preliminary assessment, these factors need to be addressed in future research.

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Appendix A: Finding the shortest sea route between two ports

1. Add layers from the web and shape files as follows.

OpenStreetMap

EEZ_land_v2_201410.shp

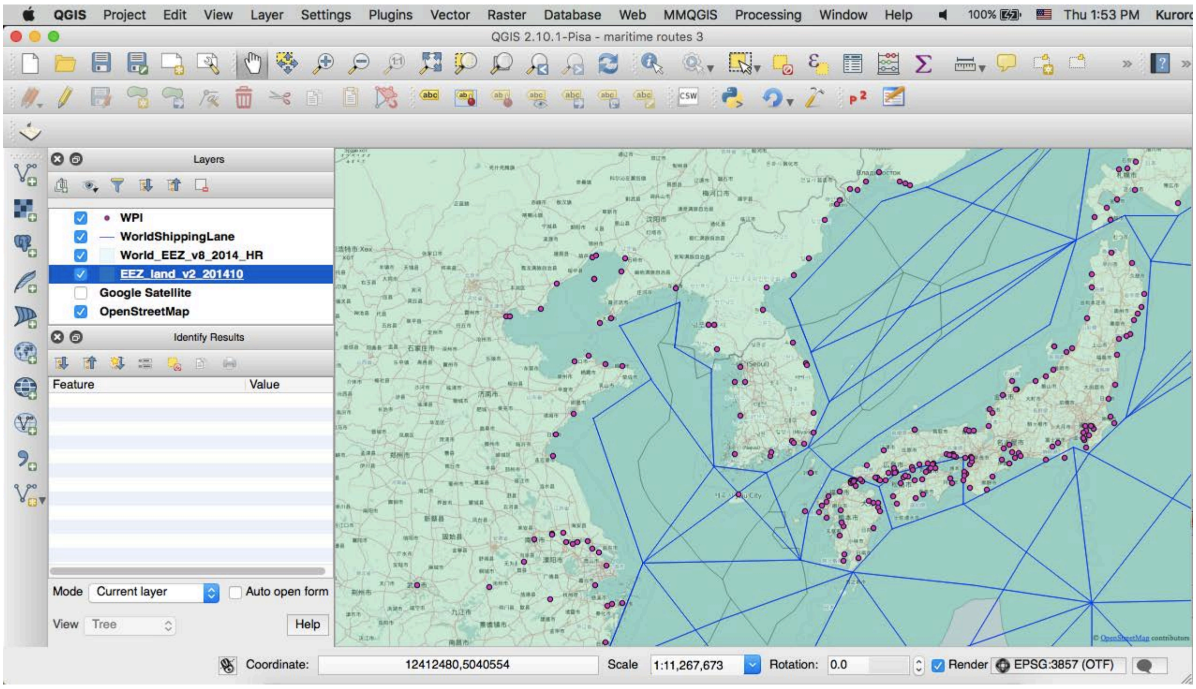
World_EEZ_v8_2014_HR.shp

WorldShippingLane.shp

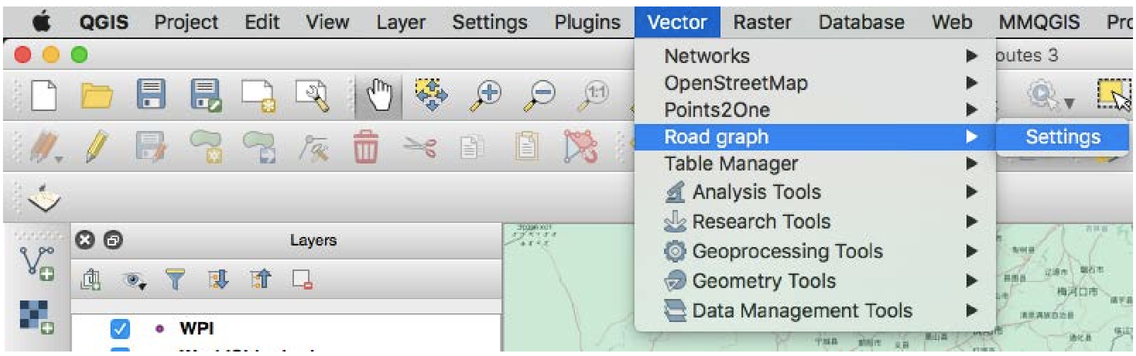
WPI.shp

2. Save all maps as a project [maritime route 3.qgs].

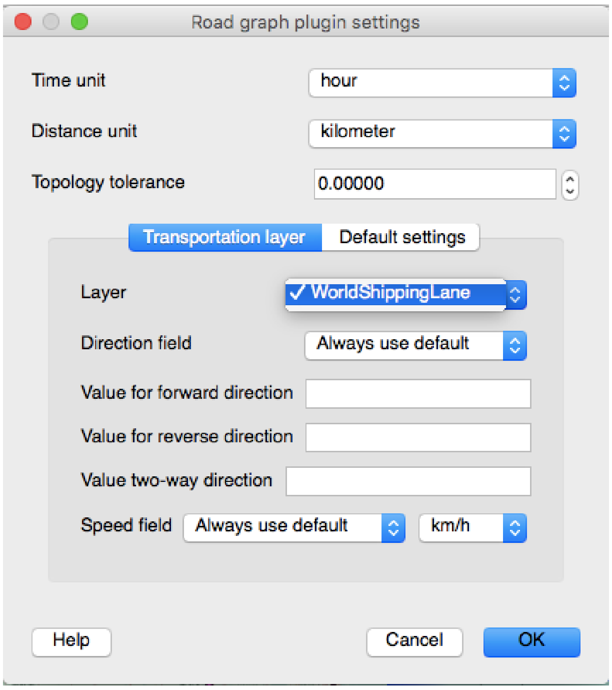
Remember to set project CRS as [WGS84 Pseudo Mercator EPSG:3857] and check the box [Enable 'on the fly' CRS transformation].

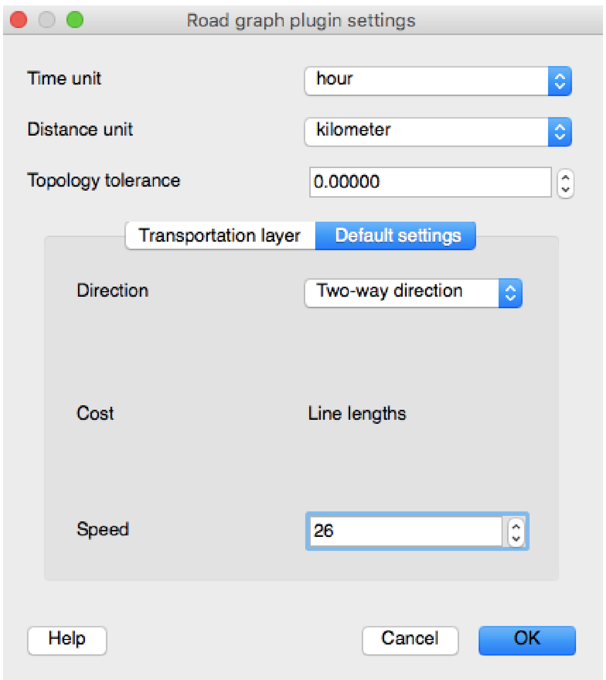


3. Go to [Vector]-->[Road graph]-->[Settings].

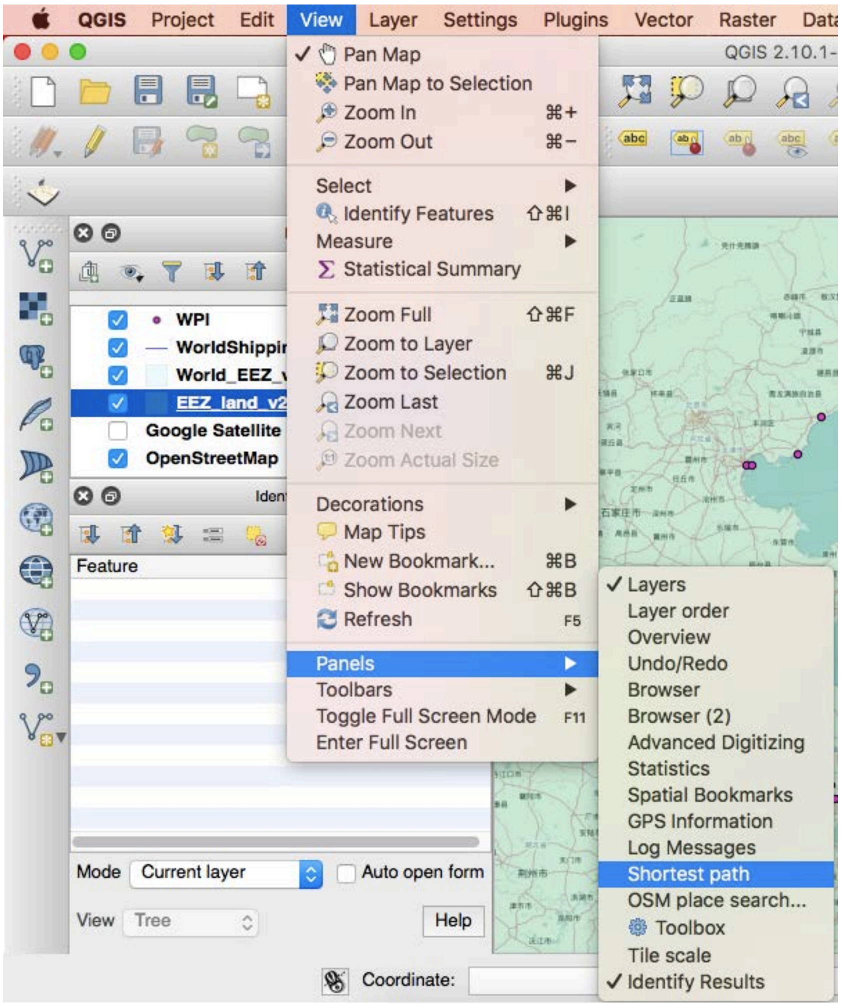


4. In the [Transportation layer] tab, specify layer [WorldShippingLane] as the routing layer. In the [Default settings] tab, set [Two-way direction] for direction and input [26] kilometers per hour as the default speed. Click [Ok].

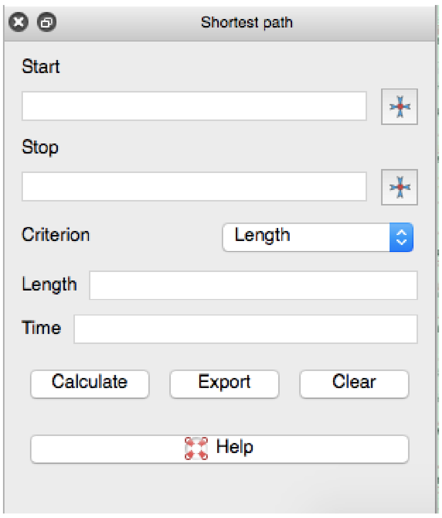




5. Open the [Shortest path] panel by clicking [View]-->[Panels]--[Shortest path].

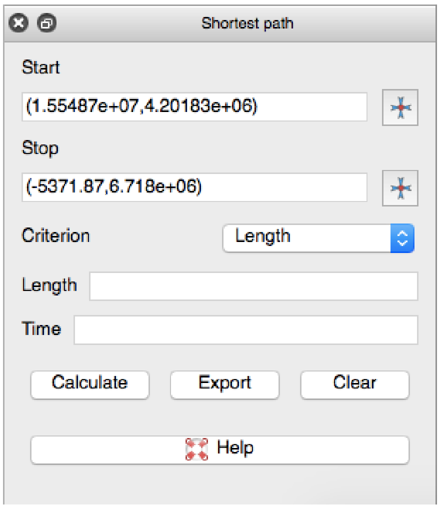


Then, we will see the [Shortest path] panel as follows.



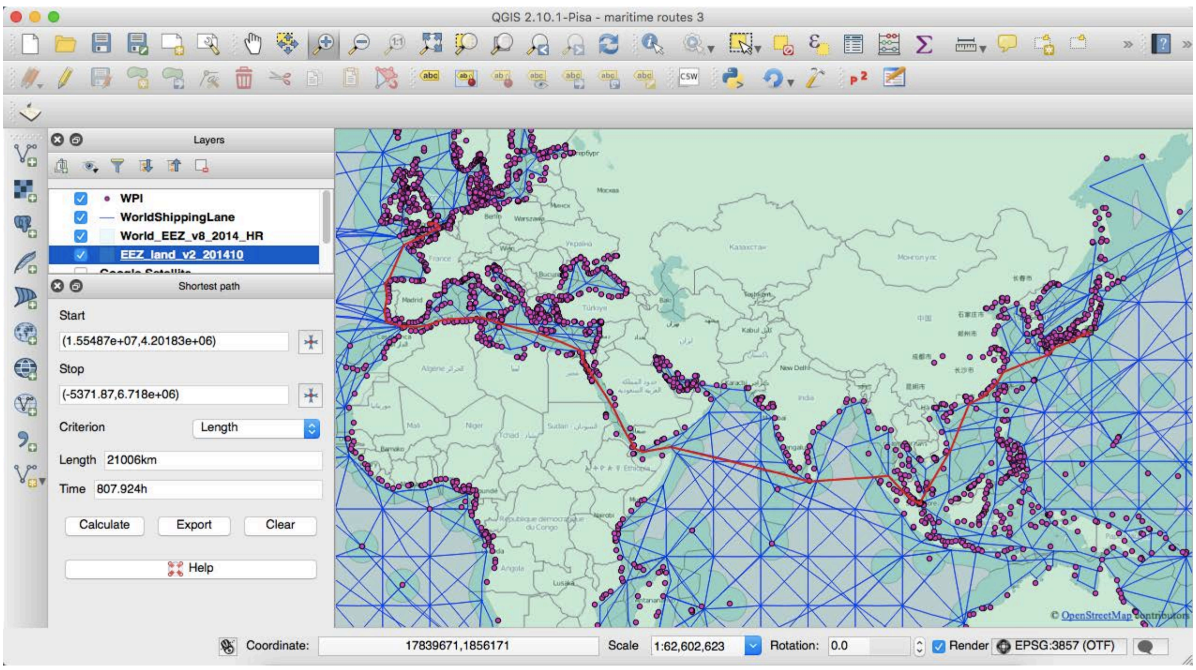
6. Specify the “Start” port and the “Stop” port.

Pan the map to the target area and check the ports of interest.

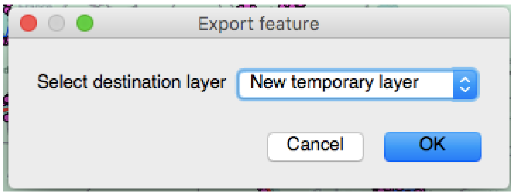


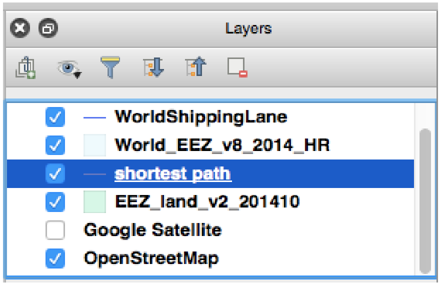
On the panel, click the cross mark of [Start] first and then click the “Start” port on the map. We will see its coordinates shown in the “Start” column on the panel. Similarly, click the cross mark of [Stop] on the panel first and then click the “Stop” port on the map. Its coordinates will show on the panel too.

7. Click [Calculate]. The sea route will be displayed on the map and its “Length” and “Time” will be shown on the panel.



8. Click [Export] on the panel and select [New temporary layer] as the destination layer. We can add the sea route for the two ports as an independent layer, named “shortest path.”

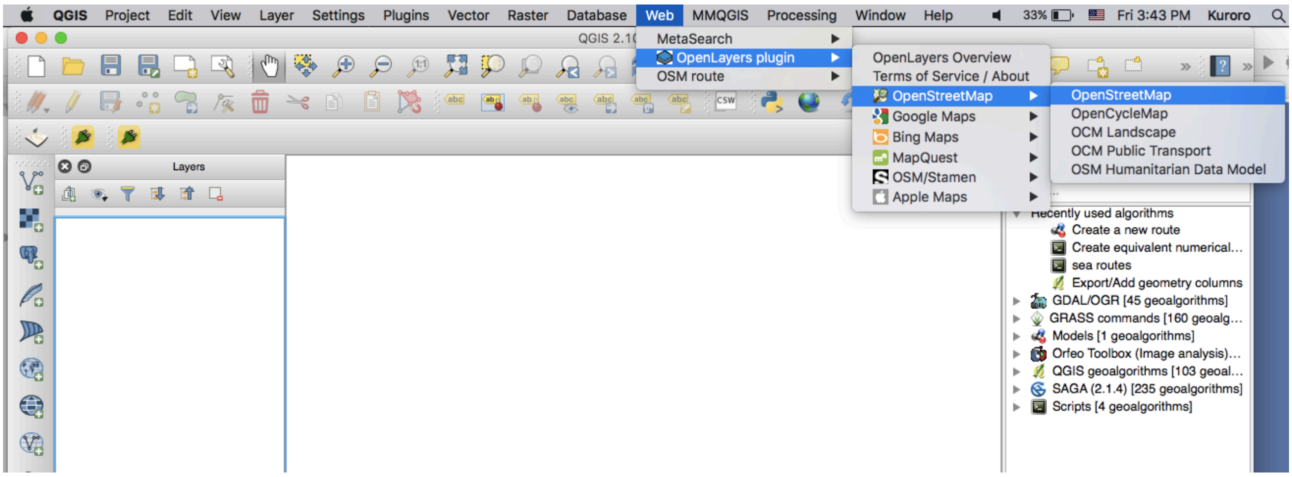




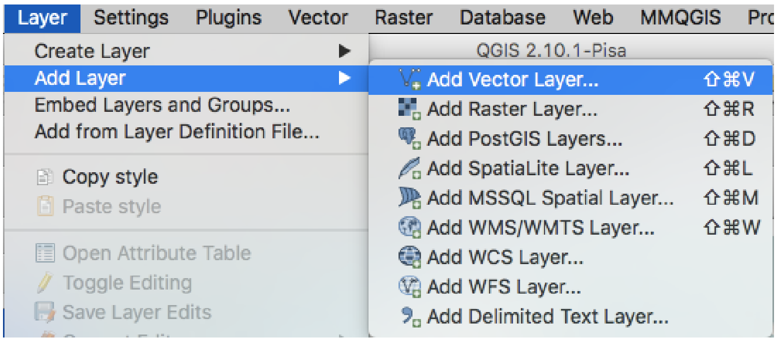
9. Because this new layer is temporary, we should save it as a new shape file. So, right-click this layer and use [Save as...] to save it.

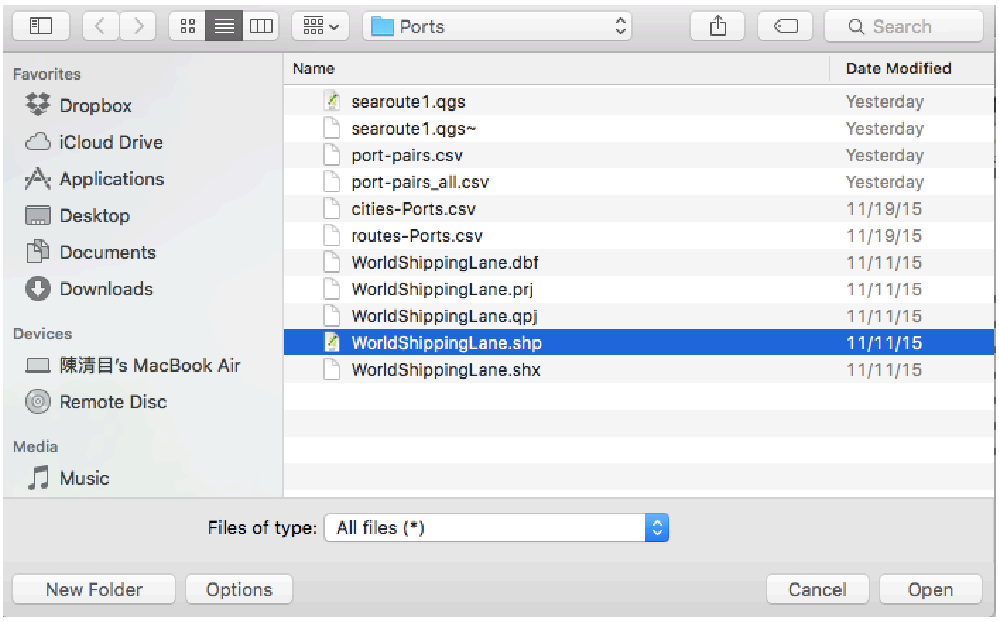
Appendix B: Finding the shortest sea routes for each port pair in a CSV file

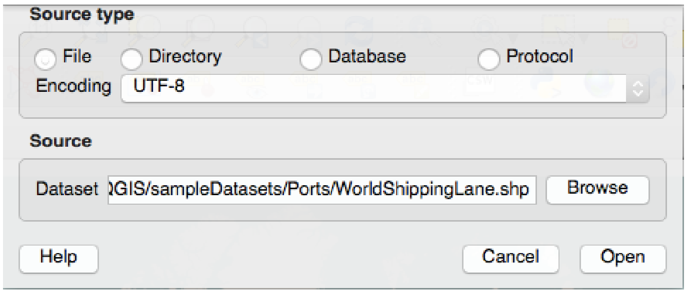
1. Import OpenStreetMap as the base map.



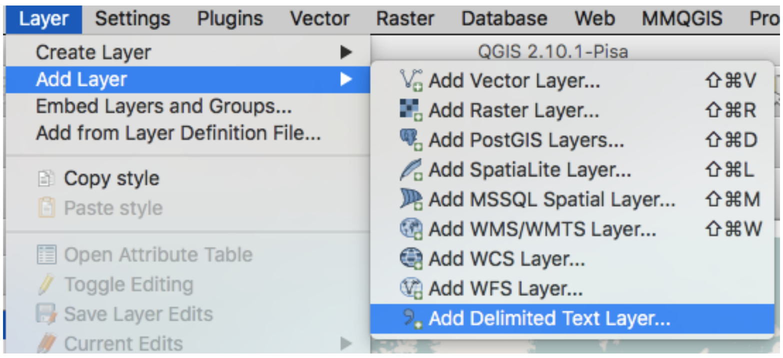
2. Add the [WorldShippingLane.shp] into the map.

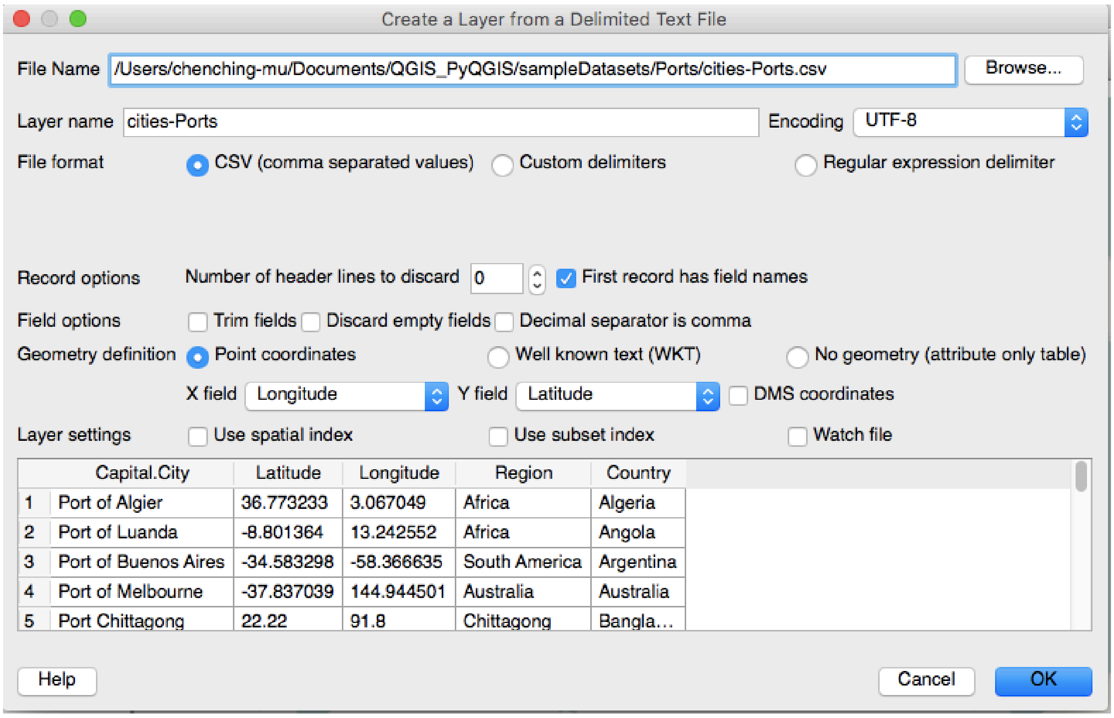




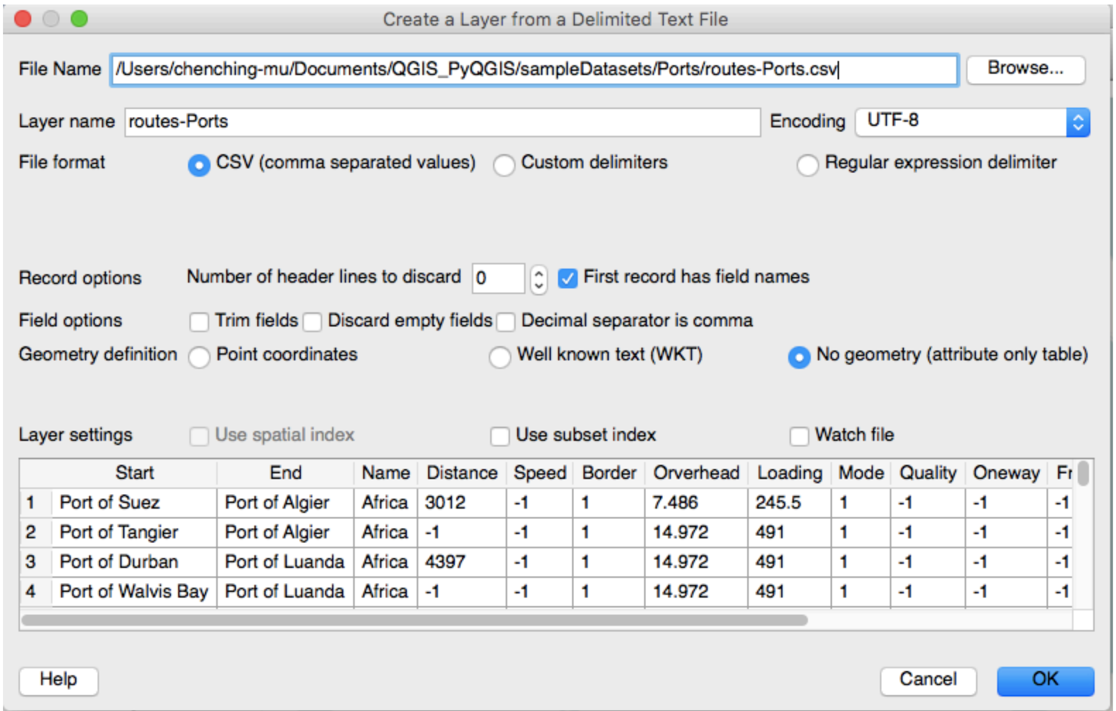


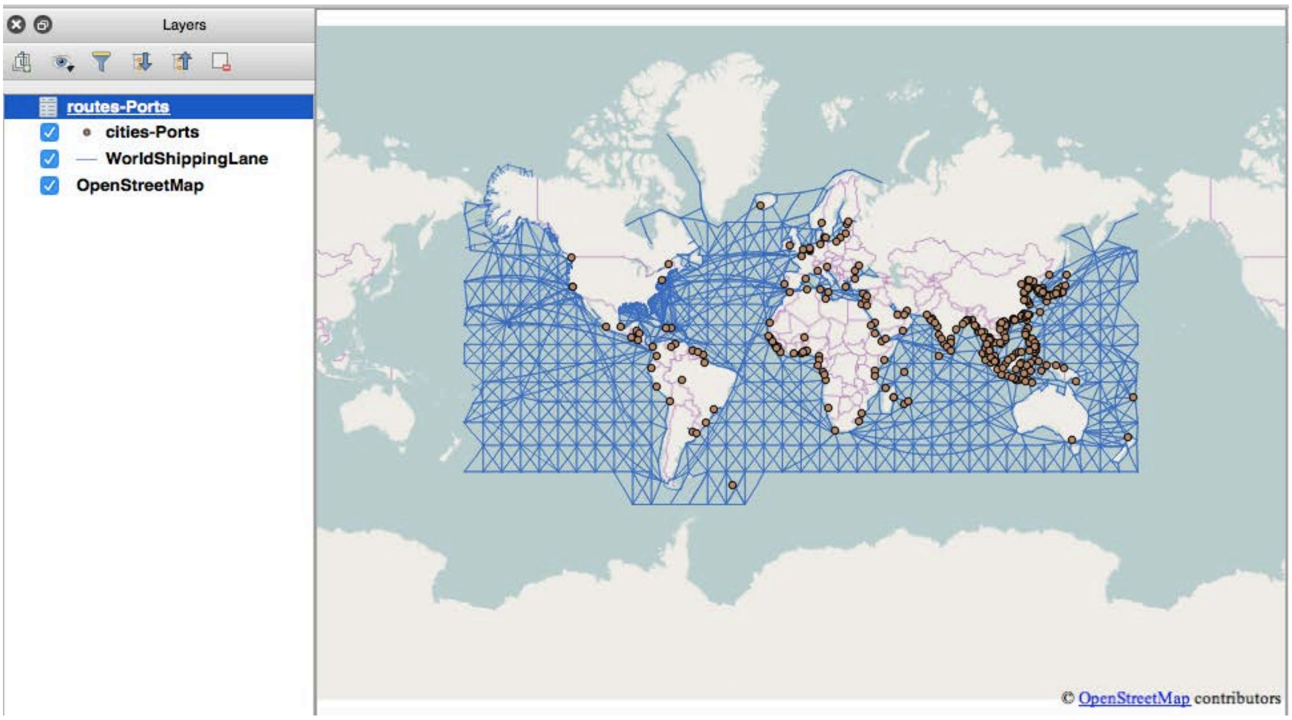
3. Add the [cities-Ports.csv] into the map.



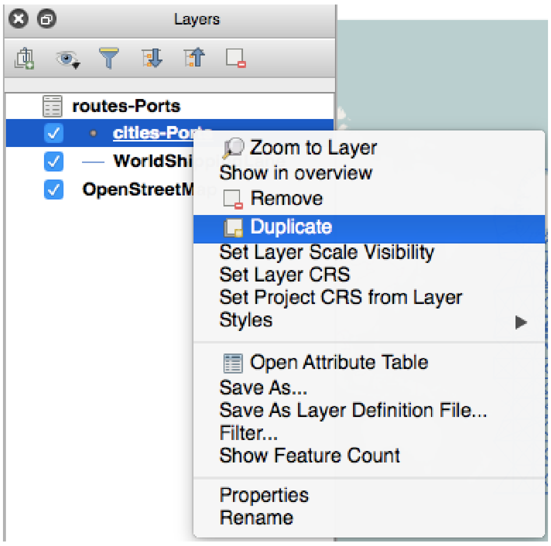


4. Also, add the [routes-Ports.csv] into the map.

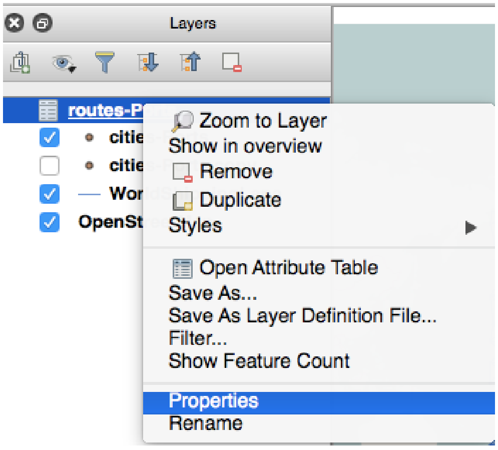


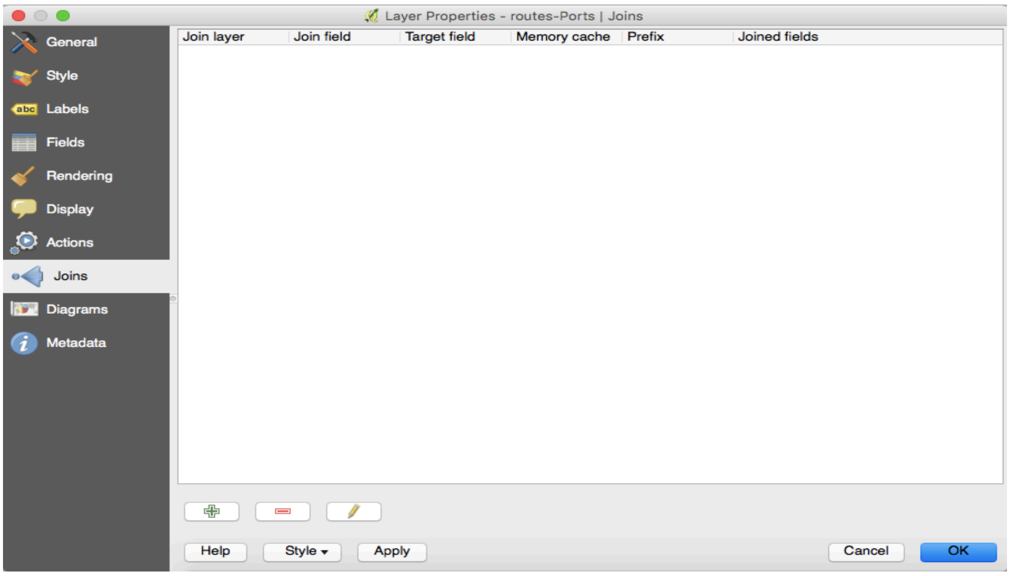


5. Now, we are going to join the coordinates for each port from the [cities-Ports.csv] to [routes-Ports.csv]. Right-click the [cities-Ports] layer and select [Duplicate]. A [cities-Ports copy] layer will be added to the map.

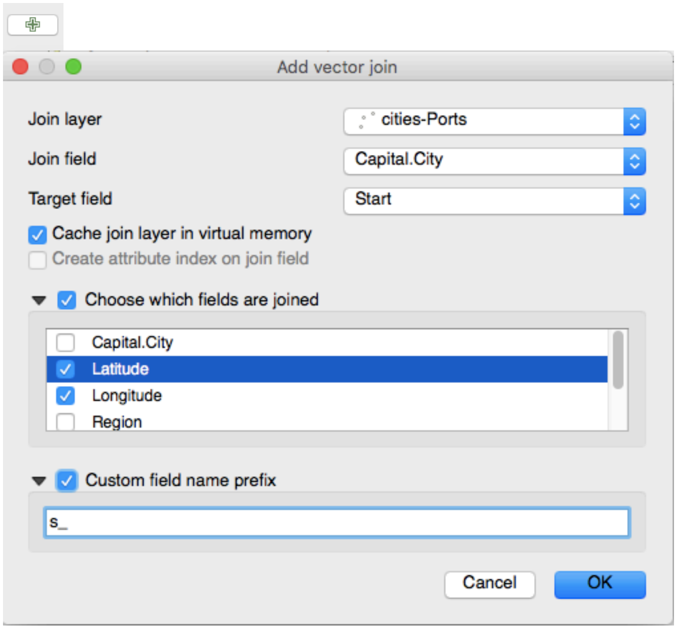


6. Right-click the [routes-Ports] layer and select [Properties]. Go to the [Join] tab.

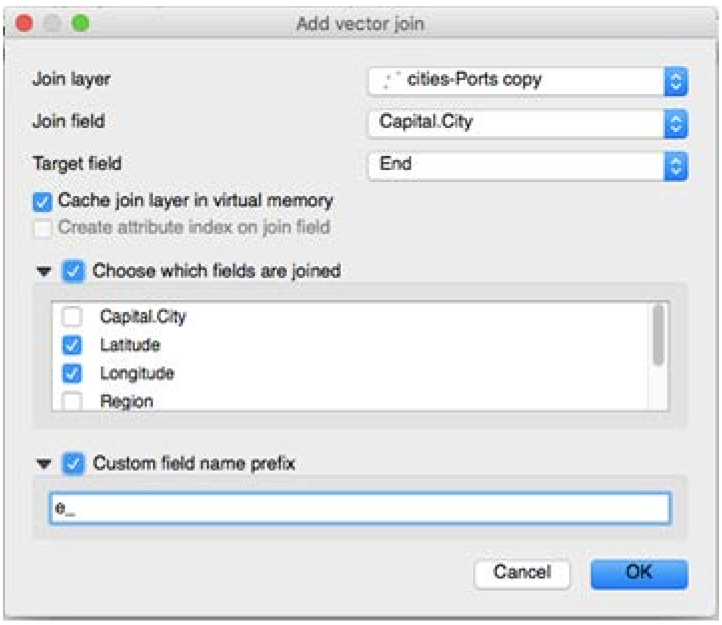




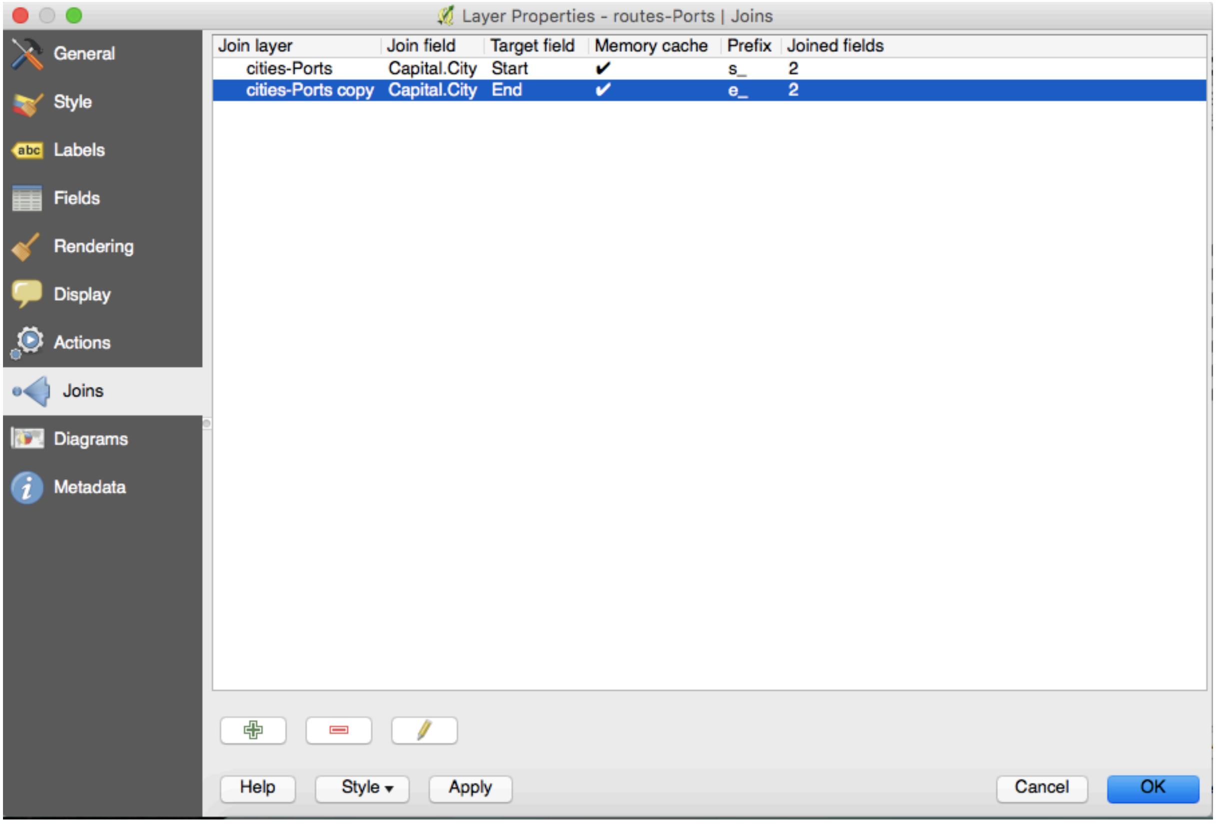
7. Click the cross icon to add a join relation as follows. Select [cities-Ports] as the [Join layer], [Capital.City] as the [Join field], [Start] as the [Target field], check [Choose which fields are joined], select fields [Latitude] and [Longitude], check [Custom field name prefix], and edit the prefix as [s_].

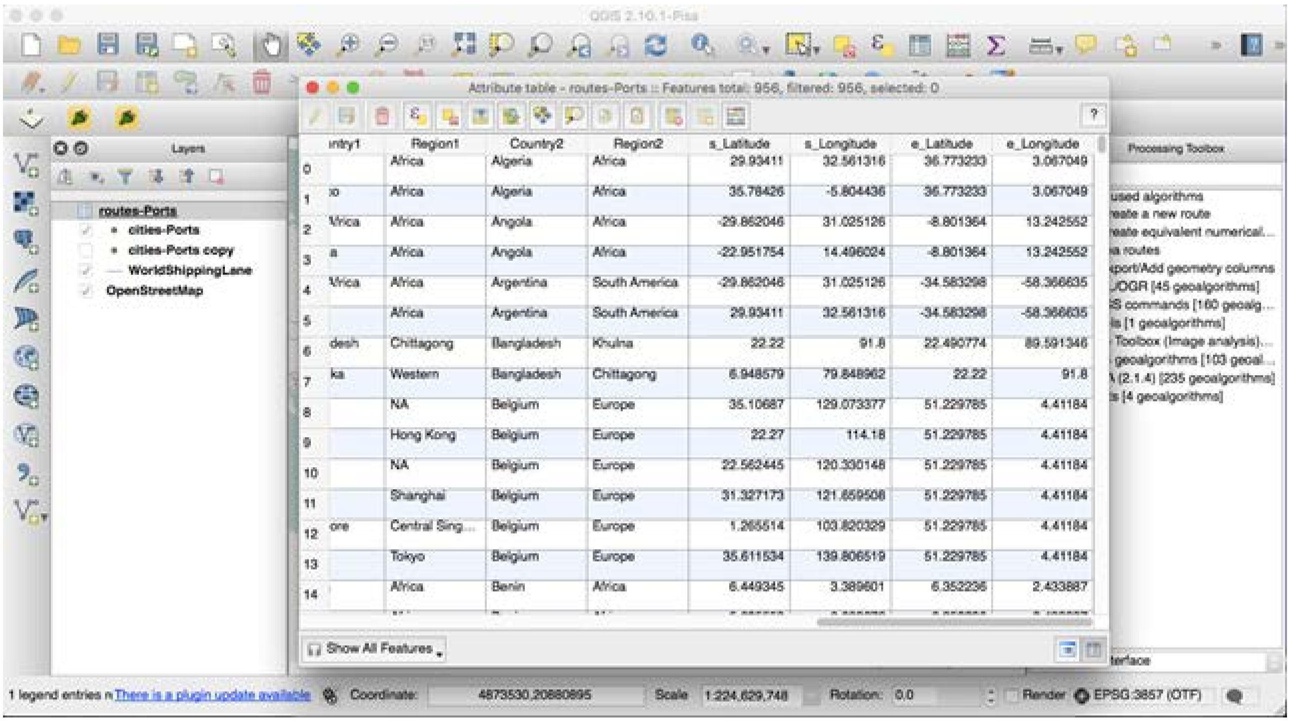


8. Click the cross icon again to add one more join relation. Select [cities-Ports copy] as the [Join layer], [Capital.City] as the [Join field], [End] as the [Target field], check [Choose which fields are joined], select fields [Latitude] and [Longitude], check [Custom field name prefix], and edit the prefix as [e_].

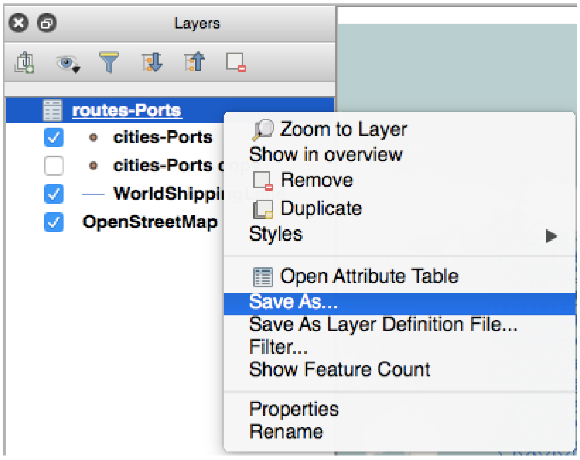


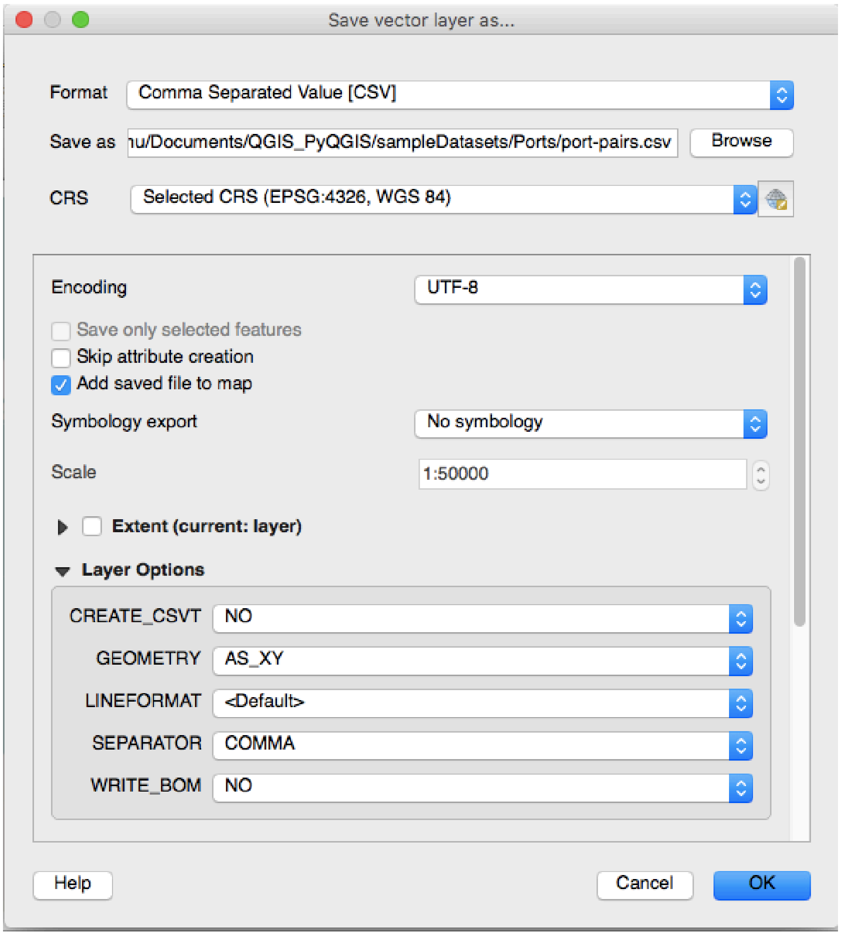
9. After clicking [ok], we can see four joined fields. They are the coordinates of the Start city and the End city.



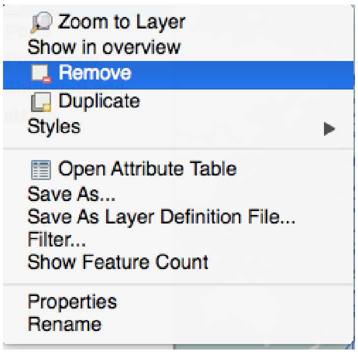


10. Since the joined fields are only temporary, we need to save them as a new table. Right-click the [routes-Ports] layer and select [Save As...] to save it as a new layer [port-pairs.csv].

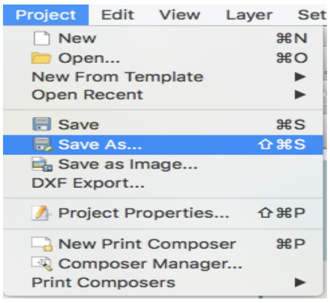




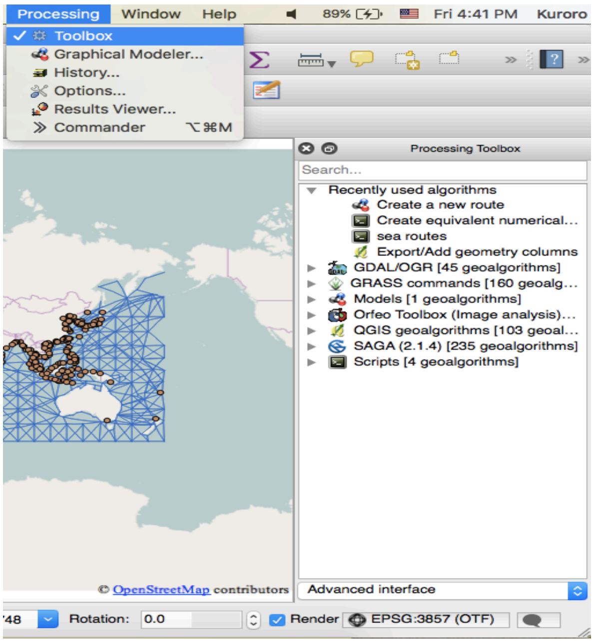
11. Now, we can remove the unnecessary layers from the map. Right-click the [routes-Ports] layer and the [cities-Ports copy] layer and select [Remove].

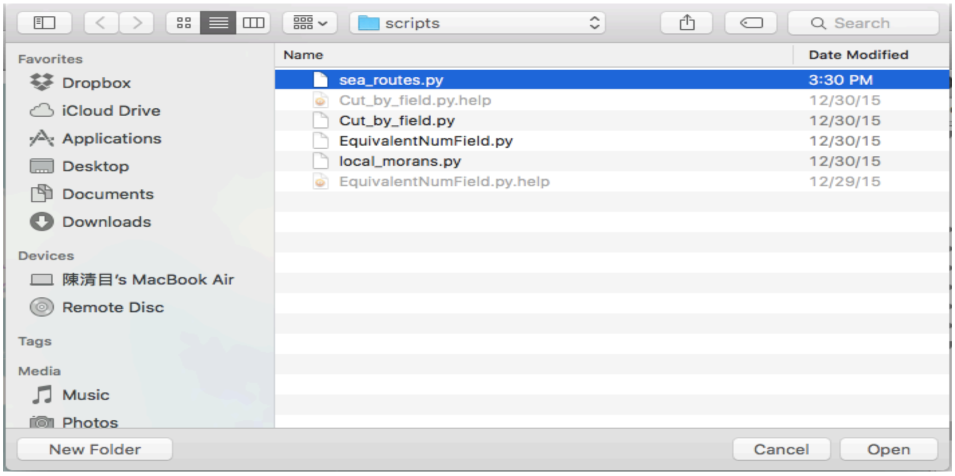


12. Now the input layers are ready. Let us save them as a project. Click [Project] in the main menu and choose [Save As...] to save it as [searoute1.qgs].

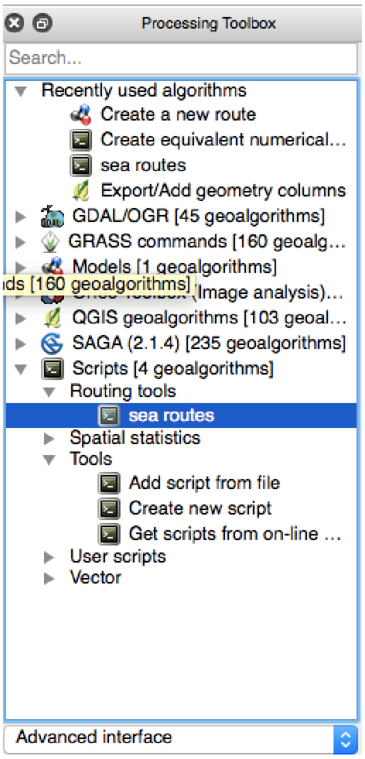


13. Next, we are going to use a script to run the batch job. Thus, we need to add the script to the processing toolbox. Click [Processing] in the main menu and check [Toolbox] to open it. In the [Processing Toolbox], make sure that [Advanced interface] at the bottom has been checked. Then, click [Scripts]/[Tool] and double-click [Add script from file]. We will see a pop-up window to include the Python script [sea_routes.py].

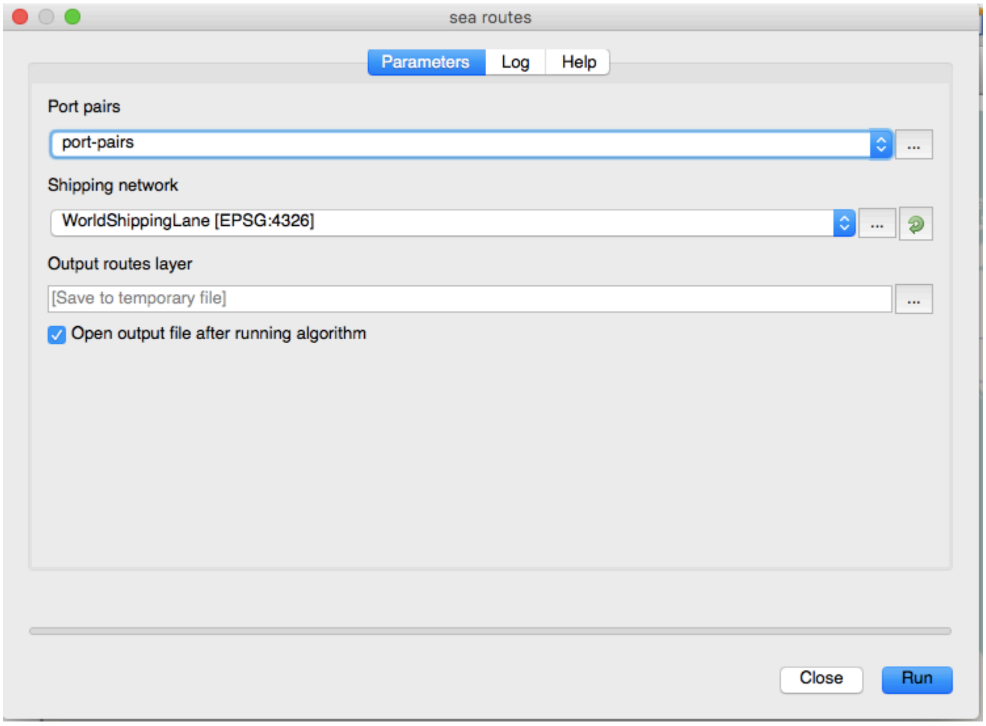


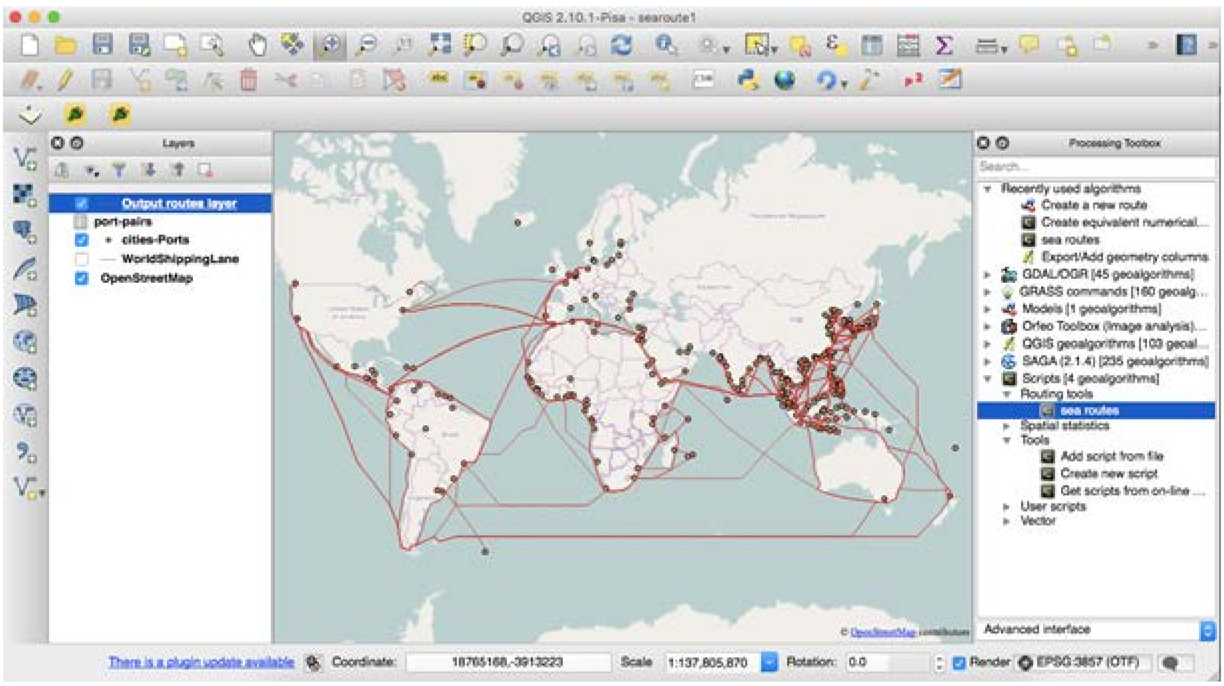


14. When the script is ready, we can see it at [Scripts]/[Routing tools]/[sea routes] in the processing toolbox.

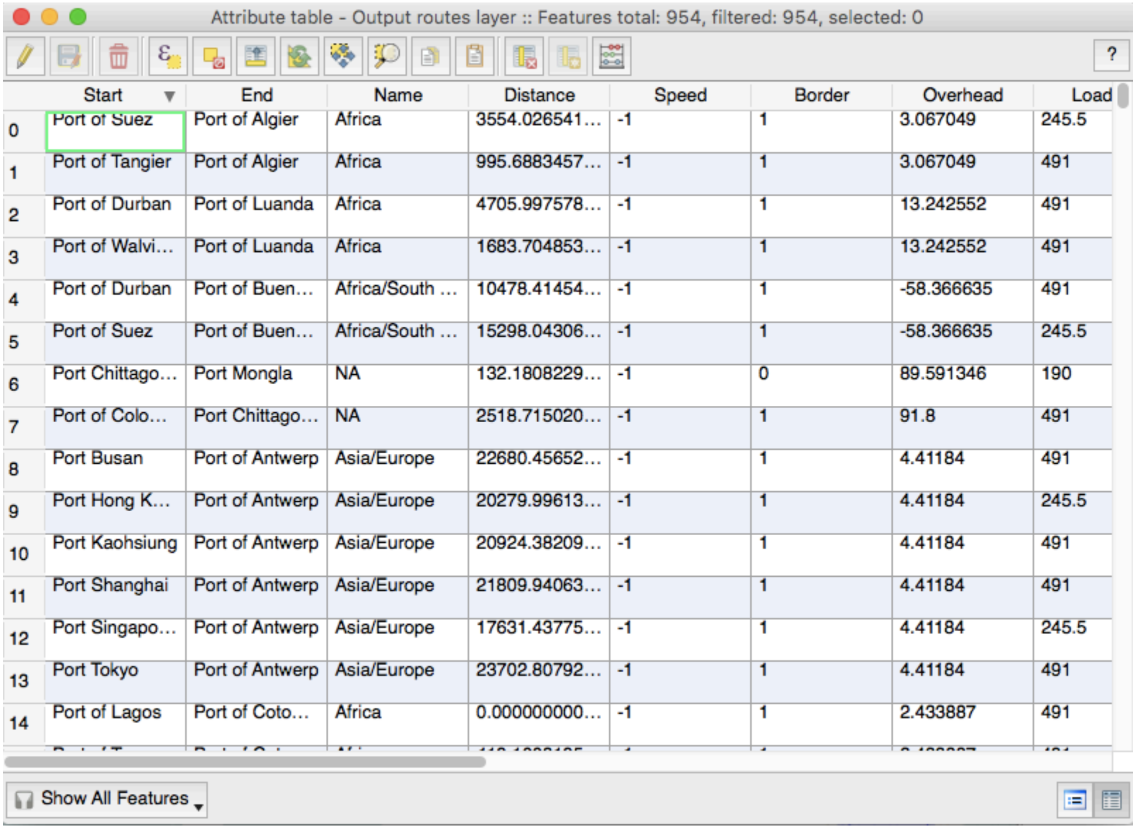


15. Double-click the [sea routes] script. Select [port-pairs] as the input layer regarding port pairs and [WorldShippingLane] as another input layer of shipping networks. Click [run]. The output sea routes layer will be added into the map. As usual, the [output routes layer] is temporary. Please save it as a new layer.





16. Open the attribute table of the [output routes layer]. We can see that a field [Distance] has been calculated by the script.



	Start	End	Name	Distance	Speed	Border	Overhead	Load
0	Port of Suez	Port of Algier	Africa	3554.026541…	-1	1	3.067049	245.5
1	Port of Tangier	Port of Algier	Africa	995.6883457…	-1	1	3.067049	491
2	Port of Durban	Port of Luanda	Africa	4705.997578…	-1	1	13.242552	491
3	Port of Walvi…	Port of Luanda	Africa	1683.704853…	-1	1	13.242552	491
4	Port of Durban	Port of Buen…	Africa/South …	10478.41454…	-1	1	-58.366635	491
5	Port of Suez	Port of Buen…	Africa/South …	15298.04306…	-1	1	-58.366635	245.5
6	Port Chittago…	Port Mongla	NA	132.1808229…	-1	0	89.591346	190
7	Port of Colo…	Port Chittago…	NA	2518.715020…	-1	1	91.8	491
8	Port Busan	Port of Antwerp	Asia/Europe	22680.45652…	-1	1	4.41184	491
9	Port Hong K…	Port of Antwerp	Asia/Europe	20279.99613…	-1	1	4.41184	245.5
10	Port Kaohsiung	Port of Antwerp	Asia/Europe	20924.38209…	-1	1	4.41184	491
11	Port Shanghai	Port of Antwerp	Asia/Europe	21809.94063…	-1	1	4.41184	491
12	Port Singapo…	Port of Antwerp	Asia/Europe	17631.43775…	-1	1	4.41184	245.5
13	Port Tokyo	Port of Antwerp	Asia/Europe	23702.80792…	-1	1	4.41184	491
14	Port of Lagos	Port of Coto…	Africa	0.000000000…	-1	1	2.433887	491