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考慮網路可靠性之可持續貨物複合運輸網路模型之研究
研究成果報告(精簡版)

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中文摘要： 本研究分析了貨運業之外部成本及降低外部成本之政策，根據’污染者自付’的原則，貨運部門應負責他們生產的外部成本。使用的負面影響較少的複合運輸模式已被證明是一個具備經濟效益和可持續的策略，本研究發展了一套貨櫃的複合運輸路網模式，計算台灣內陸之外部成本，並提出並模擬了一下政策敏感因素，包括外部成本內部化和交叉補貼。根據台灣路網的案例，研究結果發現要高度的外部成本內部化才有可能達到運據選擇的顯著轉變。如同時使用交叉補貼，則較低的內部化率可以達到同樣的效果，在推動上是比較能接受的方案。

中文關鍵詞： 排放，外部成本，貨物運輸，複合運輸系統，短程航運

英文摘要： The study presents an analysis on the external costs produced by freight transportation and the policies to reduce the external costs. The ’ polluter-pays’ principle advocates that the freight sector should be responsible for the external costs they produced. Making use of transportation modes with less negative effects, multimodal transportation has been demonstrated to be an economic and sustainable strategy for freight transport. In this study, a multimodal transportation network model for container flow is developed to estimate the inland container movement and the associated external costs. Policy sensitive factors, including external cost internalization and cross-subsidization, are simulated. Based on a case study with the Taiwan network, our result shows that a high internalization ratio of external cost is needed for the modal choice to have a significant shift. With cross-subsidization and improvement of port operations, a lower internalization ratio can achieve the same results, which could be more politically acceptable.

英文關鍵詞： Emissions, External cost, Freight transport, Multimodal, Short sea shipping

摘要

本研究分析了貨運業之外部成本及降低外部成本之政策，根據“污染者自付”的原則，貨運部門應負責他們生產的外部成本。使用的負面影響較少的複合運輸模式已被證明是一個具備經濟效益和可持續的策略，本研究發展了一套貨櫃的複合運輸路網模式，計算台灣內陸之外部成本，並提出並模擬了一下政策敏感因素，包括外部成本內部化和交叉補貼。根據台灣路網的案例，研究結果發現要高度的外部成本內部化才有可能達到運據選擇的顯著轉變。如同時使用交叉補貼，則較低的內部化率可以達到同樣的效果，在推動上是比較能接受的方案。

ABSTRACT

The study presents an analysis on the external costs produced by freight transportation and the policies to reduce the external costs. The "polluter-pays" principle advocates that the freight sector should be responsible for the external costs they produced. Making use of transportation modes with less negative effects, multimodal transportation has been demonstrated to be an economic and sustainable strategy for freight transport. In this study, a multimodal transportation network model for container flow is developed to estimate the inland container movement and the associated external costs. Policy sensitive factors, including external cost internalization and cross-subsidization, are simulated. Based on a case study with the Taiwan network, our result shows that a high internalization ratio of external cost is needed for the modal choice to have a significant shift. With cross-subsidization and improvement of port operations, a lower internalization ratio can achieve the same results, which could be more politically acceptable.

1. INTRODUCTION

The "polluter-pays" principle advocates that the transport sector should be responsible for the external costs they produced (Maibach *et al.*, 2007). The external costs of transport consists of environmental costs (emissions, pollutions and climate change), congestion costs (travel delay to the other travellers), accident costs and infrastructure costs (road construction and maintenances) etc. Among the freight transportation modes, truck traffic on highways is the major source of negative effects to the environment, and there are many studies on the estimation of the external costs produced by urban freight transport (Mayeres *et al.*, 1996; Ozbay *et al.*, 2007; Berechman, 2009). Some consider different policies to internalize the external costs to the transport sector (Piecyk and McKinnon, 2007).

With the growing importance of logistic in a green and environmental friendly way, multimodal transportation has been recognized as an economic and sustainable strategy for freight transport. Whereas most of the cargos are carried by trucks, short sea shipping (SSS) has been widely discussed in Europe and America as a way to migrate the traffic of cargoes from the road network to the sea. Trucks cause traffic congestion problems and produce emissions and air pollutants harmful to the residents. Boats and trains have less negative environmental effects, but they are not seen as a real alternative because of their low flexibility and longer transit time. To achieve a sustainable transport network and motivate modal shift, a proper and practical pricing policy is necessary to reflect the external costs generated by the infrastructure users.

In Taiwan, most of the internal transport flows for non-bulk cargo are transported with trucking via road network, and only a small percentage is transported with barges between domestic seaports. The substitution and complementary effects between trucking and barge transportation have been investigated by several government studies (see MOTC, 1999). Lee *et al.* (2010) investigated the external cost of transportation for domestic cargos with SSS and trucking, and showed that a large amount of external costs was produced by the truck transportation as compared to SSS. This is due to the large amount of container movements between the North and South of Taiwan in consequence of mismatching between handling capacities of ports and demand and supply of cities. The Kaohsiung port in South Taiwan is the main import/export area for international trade containers, while Taipei (the capital) and most of the industrial centers are located on the North. Chou (2005) showed that this amount of inefficient container movements reached a million TEU, incurring a direct transportation cost of 9.9 billion Taiwan dollars each year.

The study of Lee *et al.* (2010) estimated that over 90% container cargo movements between the ports in Taiwan are transported by trucking and less than 10% utilizes SSS. It is emphasized that, by charging the external costs caused by container transport, shifting freight from road transport to intermodal with SSS is considered to be one of the effective ways in solving the high environmental negative impacts of transporting freight. Liao *et al.* (2011) examined the greenhouse gas emissions due to inland container transport in Taiwan, and suggested that shifting truck traffic to sea traffic can reduce a huge amount of emissions. Both studies suggest that the emissions and climate change costs can be greatly reduced if the container cargo movements between the ports on the west coast of Taiwan can make use of SSS.

The above empirical studies only considered the port to port traffic, and did not have an accurate estimation of the inland traffic pattern. To explore the relevant policy options, a detailed estimation of the cargo movement pattern on the network are required. Therefore, the objective of this paper is to analyse policy sensitive factors, including external cost internalization and cross-subsidization, in motivating the modal shift and reducing the external costs. A multimodal transportation network model approach is adopted to estimate the inland container movement and the associated external costs.

2. A MULTIMODAL TRANSPORTATION NETWORK MODEL

We present a multimodal transportation network formulation to model the domestic container cargo movements in a country. The model solves for the modal choices of freight carriers and routes of cargo movements between foreign seaports and domestic cities. The cargoes between foreign seaports and domestic seaports are transported by international vessels, and then transported by highways (i.e. trucks) between domestic seaports and cities. Short sea shipping (SSS) could be used as a transfer mode between domestic seaports. The formulation is given below, and a list of notations of variables is displayed in Table A1 in appendix.

Model formulation

The model is a planning model and optimizes for the total transportation cost, and the behaviour of and interactions between the shippers and carriers are not taken into account. As we are interested to see the reactions to the freight movement with respect to the government policy against the environmental cost produced by each transportation modes, a factor is introduced in the objective function to measure the proportion of environmental cost to be charged. The total transportation cost is composed of transit cost and environmental cost (to be internalized with pricing).

$$Minimize\ Z = TC + w \cdot EC \tag{1}$$

subject to some set of constraint Ω_1, Ω_2, Ω_3, Ω_4, Ω_5, Ω_6 and Ω_7. The objective function, cost functions, and constraints are defined in the following.

Objective function

In the objective function, transit cost (TC) is the generalized cost consisting of the cost for trucks, short sea shipping and international vessels, and the environmental cost (EC) is the corresponding marginal external cost of pollutant emissions to the environment. They are defined as

$$\begin{aligned} TC = & \sum_{j\in J}\sum_{k\in K}\left(c_{jk}^1\left(DI_{jk} + \sum_{t\in J\setminus\{j\}} TI_{tjk}\right) + c_{kj}^1\left(DE_{kj} + \sum_{t\in J\setminus\{j\}} TE_{kjt}\right)\right) + \\ & \sum_{j\in J}\sum_{t\in J\setminus\{j\}}\left(c_{jt}^2\left(\sum_{k\in K} TI_{jtk}\right) + c_{tj}^2\left(\sum_{k\in K} TE_{ktj}\right)\right) + \sum_{i\in I}\sum_{j\in J}\left(c_{ij}^3 SI_{ij} + c_{ji}^3 SE_{ji}\right) \end{aligned} \tag{2}$$

$$\begin{aligned} EC = & \sum_{j\in J}\sum_{k\in K}\left(e_{jk}^1\left(DI_{jk} + \sum_{t\in J\setminus\{j\}} TI_{tjk}\right) + e_{kj}^1\left(DE_{kj} + \sum_{t\in J\setminus\{j\}} TE_{kjt}\right)\right) + \\ & \sum_{j\in J}\sum_{t\in J\setminus\{j\}}\left(e_{jt}^2\left(\sum_{k\in K} TI_{jtk}\right) + e_{tj}^2\left(\sum_{k\in K} TE_{ktj}\right)\right) \end{aligned} \tag{3}$$

The environmental costs of international vessels are excluded here because currently there is no international regulation applied to the fuel consumption or emissions from shipping. The CO_2 emissions from international shipping are also not covered by the Kyoto Protocol on climate change.

Cost functions

The unit transit cost c_{ij}^m on each transportation link between port/city pair $(i, j) \in A$ and mode $m \in \{1,2,3\}$ can be determined by

$$c_{ij}^m = \left(h \cdot t_{ij}^m + p_{ij}^m\right),\ \text{for}\ m = \{1\} \tag{4}$$
$$c_{ij}^m = \left(h \cdot t_{ij}^m + p_{ij}^m + thc_j\right),\ \text{for}\ m = \{2,3\} \tag{5}$$

where h is the inventory holding cost per unit time (per TEU); t_{ij}^m is the transit time of mode m from origin i to destination j; p_{ij}^m is the transit cost per TEU, which corresponds to the inland transit cost by trucks for $m = \{1\}$, and to the sea freight rate for $m = \{2,3\}$; thc_j is the terminal handling charge (per TEU); and e_{ij}^m is the external cost (per TEU) using mode m from origin i to destination j.

The unit environmental cost e_{ij}^m is the emission of environmental pollutants produced by transportation (Mayers et al, 1996; Beuthe *et al.*, 2002; Ozbay *et al.*, 2007; Berechman, 2009). It can be estimated by the avoidance cost approach

$$e_{ij}^m = l_{ij} \sum_p a_p \cdot k_p^m \tag{6}$$

where l_{ij} is the distance (in km) from *i* to *j*; a_p is the avoidance cost of pollutant type *p*; k_p^m is the emission factor of pollutant type *p* of mode *m* per TEU-km. For the shipping modes $m = \{2,3\}$, the factor depends on fuel type, engine type and consumption of fuel, and can be determined as $k_p^m = \sum_l f_l k_{lp}^m$, where f_l is the consumption amount of fuel type *l* and k_{lp}^m is the emission factor of pollutant type *p* by using fuel type *l* for the shipping mode.

Set of constraints

The model is subject to a set of constraints to ensure feasibility of flow movements in the network. Ω_1, Ω_2 and Ω_3 specify the cargo flow conservation; Ω_4, Ω_5 and Ω_6 are related to the operation issues of ports, and Ω_7 is the non-negativity and integer constraints for the variables.

Import and export amount constraints, Ω_1:

$$\sum_{j \in J'} SI_{ij} = sf_i \text{ for all } i \in I \tag{7}$$

$$\sum_{j \in J'} DE_{kj} = sd_k \text{ for all } k \in K \tag{8}$$

$$\sum_{j \in J'} DI_{jk} = dd_k \text{ for all } k \in K \tag{9}$$

$$\sum_{j \in J'} SE_{ji} = df_i \text{ for all } i \in I \tag{10}$$

Flow conservation constraints, Ω_2:

$$\sum_{i \in I} SI_{ij} = \sum_{k \in K} DI_{jk} \quad \text{for all } j \in J \tag{11}$$

$$\sum_{k \in K} DE_{kj} = \sum_{i \in I} SE_{ji} \quad \text{for all } j \in J \tag{12}$$

Direct transport or transfer via Short Sea Shipping port, Ω_3:

$$DI_{jk} = AI_{jk} + \sum_{t \in J \setminus \{j\}} TI_{jtk} \quad \text{for all } j \in J \text{ and } k \in K \tag{13}$$

$$DE_{kj} = AE_{kj} + \sum_{t \in J \setminus \{j\}} TE_{ktj} \quad \text{for all } k \in K \text{ and } j \in J \tag{14}$$

Port capacity constraints, Ω_4:

$$\sum_{i \in I} \left(SI_{ij} + SE_{ji}\right) + \sum_{t \in J \setminus \{j\}} \left(\sum_{k \in K} TI_{jtk} + \sum_{k \in K} TE_{ktj} \right) \le a_j \quad \text{for all } j \in J \tag{15}$$

Determining the number of vehicles/ships with the amount of cargos, Ω_5:

$$AI_{jk} + \sum_{t \in J \setminus \{j\}} TI_{tjk} \leq n_1 \cdot VI^1_{jk} \quad \text{for all } j \in J \text{ and } k \in K \tag{16}$$

$$AE_{kj} + \sum_{t \in J \setminus \{j\}} TE_{kjt} \leq n_1 \cdot VE^1_{kj} \quad \text{for all } k \in K \text{ and } j \in J \tag{17}$$

$$\sum_{k \in K} TI_{jtk} \leq n_2 \cdot VI^2_{jt} \quad \text{for all } j \in J \text{ and } t \in J \setminus \{j\} \tag{18}$$

$$\sum_{k \in K} TE_{ktj} \leq n_2 \cdot VE^2_{tj} \quad \text{for all } t \in T \text{ and } j \in J \setminus \{t\} \tag{19}$$

$$SI_{ij} \leq n_3 \cdot VI^3_{ij} \quad \text{for all } i \in I \text{ and } j \in J \tag{20}$$

$$SE_{ji} \leq n_3 \cdot VE^3_{ji} \quad \text{for all } j \in J \text{ and } i \in I \tag{21}$$

Vehicle capacity constraints, Ω_6:

$$\sum_{k \in K} t^1_{jk} \cdot VI^1_{jk} \leq u_j \quad \text{for all } j \in J \tag{22}$$

$$\sum_{j \in J} t^1_{jk} \cdot VE^1_{kj} \leq u_k \quad \text{for all } k \in K \tag{23}$$

$$VI^2_{ji} \leq v^2_{jt} \quad \text{for all } j,t \in J;\ j \neq t \tag{24}$$

$$VE^2_{tj} \leq v^2_{tj} \quad \text{for all } t, j \in J; t \neq j \tag{25}$$

$$VI^3_{ij} \leq v^3_{ij} \quad \text{for all } i \in I \text{ and } j \in J \tag{26}$$

$$VE^3_{ji} \leq v^3_{ji} \quad \text{for all } j \in J \text{ and } i \in I \tag{27}$$

Non-negativity and integer constraints, Ω_7:

$$SI_{ij}, SE_{ji} \geq 0 \quad \text{for all } i \in I \text{ and } j \in J \tag{28}$$

$$DI_{jk}, DE_{kj} \geq 0 \quad \text{for all } j \in J \text{ and } k \in K \tag{29}$$

$$AI_{jk}, AE_{kj} \geq 0 \quad \text{for all } j \in J \text{ and } k \in K \tag{30}$$

$$TI_{jtk}, TE_{ktj} \geq 0 \quad \text{for all } j,t \in J \text{ and } k \in K \tag{31}$$

$$TI_{jtk}, TE_{ktj} \geq 0 \quad \text{for all } j,t \in J \text{ and } k \in K \tag{32}$$

$$VI^1_{jk}, VE^1_{kj} \geq 0 \text{ and integers} \quad \text{for all } j \in J \text{ and } k \in K \tag{33}$$

$$VI^2_{jt}, VE^2_{tj} \geq 0 \text{ and integers} \quad \text{for all } j,t \in J,\ j \neq t \tag{34}$$

$$VI^3_{ij}, VE^3_{ji} \geq 0 \text{ and integers} \quad \text{for all } i \in I \text{ and } j \in J \tag{35}$$

3. STRATEGIES IN REDUCTION OF EXTERNAL COSTS

The reduction of external costs and emissions produced by freight movement is one of the primary objectives of the government to improve the transportation network. In an environmental perspective, the “polluter-pays” principle is the environmental policy receiving strong supports from US and European countries. In European Union, the Eurovignette Directive, which is the first EU law to implement wider strategy of internalizing the external costs of transportation, has granted the member countries the authority to set road tolls for heavy goods vehicles (Liepe *et al.*, 2011; Maibach *et al.*, 2007).

On the other hand, an argument against the external cost charges is that the tax collected from the freight industry may not necessary be used to invest in the transport network. There is no obligation of the countries on how to use the revenues. Furthermore, the external cost charges may cause additional burden to the freight transport sector as the overall demand decreases with the increasing transport costs.

The successfulness of a new tax or pricing scheme would be highly dependent on the support from the industries and public. The objective of the external cost charges is to encourage the freight transport industry to use more sustainable and environmental friendly way to move the cargos. The revenue collected should be used to improve the existing transportation system. Equity issues among different groups such as freight forwarder, carrier, and transport section should also be taken into account. Take road congestion charging for traffic as an example, an efficient charging scheme requires that part of the revenues collected must be spent on the improvement of transportation system, including building infrastructures, road maintenances, or other alternative modes such as metros and buses (e.g. Litman, 2011; VTPI, 2012). Cross-subsidization between modes is practically possible.

4. A CASE STUDY

In this section, a case study based on Taiwan network and data is used to demonstrate the presented models. The topology network which consists of trucking and short sea shipping is shown in Figure A1 in the appendix. Trains for freight transport in Taiwan is not considered in the model because of the short distance of travel (the distance between the North and South of Taiwan is about 400 km) and thus low efficiency. Trains are lack of flexibility and require transhipment at both ends of the trip. Furthermore, the existing railway system is already in high utilization for passenger transportation, and expansion of the rail system involves very high fixed costs and not a feasible option.

4.1 Data collection

All data are obtained from the transportation research statistics data published by the government (MOTC, 2007, 2008) and the harbour bureaus. The export and import amount of container in Taiwan cities is obtained from MOTC (2008) and shown in Table A2. The travel distances and times between domestic cities and ports are extracted from a web-based GIS system, and shown in Table A3. The capacity of ports is displayed in Table A4. Since the selection of incoming/outgoing domestic ports is not sensitive to the origin/destination of foreign seaports, we simply assume the foreign seaport to be a single source/sink in this example.

On the cost functions, the values for transit costs and terminal handling charges are taken from the data announced by the corresponding harbour bureaus. For trucks, the unit transit cost on average is taken to be $25 TWD per TEU-km, as from real data the transportation cost from Kaohsiung to Keelung is about $8500 to $10000 TWD per TEU. At the ports, the terminal handling charge is relative small and neglected in the example, and the inventory holding cost are taken to be $1800, $1300, and $1500 for Keelung port, Kaohsiung port, and Taichung port respectively. For short sea shipping, the transit costs are $4900 between Keelung port and Kaohsiung port, $3000 between Keelung port and Taichung port, and $3000 between Taichung port and Kaohsiung port (Lee *et al.*, 2010).

The marginal environmental cost is adopted from Lee *et al.* (2010) and displayed in Table A5. The marginal congestion cost for highway is ignored in this study. Wong *et al.* (2010) estimated that the marginal external congestion cost for a tractor trailer to be $0.74 TWD for each TEU-km on average. However, the amount of congestion cost is highly dependent on the traffic conditions (e.g. peak vs. off-peak of traffic), vehicle compositions, and the value of time of drivers (Mayeres *et al.*, 1996; Forkenbrock, 1999). For more accurate estimation of external congestion cost, a more detailed model and calibration against traffic data are necessary.

4.2 Base case

The multimodal transportation network model is solved with the commercial package CPLEX 11.2 using the AMPL interface (Fourer *et al.*, 2002). The multimodal transportation network model is a linear integer programming problem for constant link travel costs. However, if a calibrated link cost functions are available, the transportation network model can be extended with a traffic assignment model for road traffic and thus nonlinear (Yamada *et al.*, 2009). As the amount of freight flow is relatively small to the car traffic, the link costs are usually assumed to be constant in the modelling of freight transport.

The base case is run and internalization of external costs is not considered, and the result is shown in Table 1. The amount of truck and SSS flows are obtained from the model. All containers from or to foreign countries are transported to the ports and then to the cities using trucks for the minimum costs, and SSS is not used. The costs of air pollution and CO_2 emissions are estimated to be 543.5 and 11.6 million US dollars respectively.

Real data from the port authority and Lee *et al.* (2010) also mentioned that there is a certain amount of containers between the three seaports, with 862,164 TEU using trucks and 90,701 via SSS. This is not included in the import/export dataset used to solve the multimodal transportation network model, which is deterministic and returns an all-or-nothing flow between each origin and destination pair. These numbers are also included in the table for comparison. In total, the costs of air pollution and CO_2 emissions produced by transportation of containers are estimated to be 626.3 and 13.5 million US dollars respectively.

4.3 Internalization of external costs

If the external cost is internalized to the freight sectors and they are responsible for part of the environmental cost produced, some of the flows may switch to their path and move via SSS. The decision of path switching depends on amount of external costs to be charged and the difference of total transportation costs between the paths, and therefore hinge on the origin and destination of the trip.

Table 2 shows the change in tuck traffic and short sea shipping traffic against the level of internalization. As the level of internalization increases, the trucking freight cost increases over the intermodal option between some origin and destination pairs, and there is a modal shift from trucking between some port and cities to the SSS with trucking. As a result, the total transportation costs increase but the associated environmental costs produced decrease.

Table 1. Base case scenario

	Amount of flow		Emissions (tonne)					Emissions (USD)		
	TEU	veh-km	PM_{10}	NO_X	VOC	SO_2	CO_2	Air pollution	CO_2	Total
Truck[1]	10,052,091	1,609,616,006	1,207	16,338	1,046	483	445,864	543,529,177	11,592,454	555,121,632
SSS[1]	-	-	-	-	-	-	-	-	-	-
Truck[2]	862,164	233,537,910	178	2,372	150	68	64,690	79,906,868	1,681,939	81,588,807
SSS[2]	90,701	25,167,792	4	161	7	33	8,699	2,853,988	226,164	3,080,151
Total	11,004,956	1,868,321,708	1,389	18,870	1,203	584	519,252	626,290,033	13,500,557	639,790,590

[1]: Obtained from our model based on Import/Export data

[2]: Obtained from real data, for internal container movement between ports

Table 2. Modal split, transportation cost and external cost against the external cost internalization ratio

Internalization	Flow (TEU)		Modal Split (%)		Total transportation cost (million USD)			Total external cost (million USD)		
ratio	Truck	SSS	Truck	SSS	Truck	SSS	Total	Truck	SSS	Total
0.00	10,052,091	-	100.0%	0.0%	1307.8	-	1307.8	556.6	-	556.6
0.10	10,052,091	-	100.0%	0.0%	1307.8	-	1307.8	556.6	-	556.6
0.20	10,052,091	-	100.0%	0.0%	1307.8	-	1307.8	556.6	-	556.6
0.30	10,052,091	-	100.0%	0.0%	1307.8	-	1307.8	556.6	-	556.6
0.40	10,052,091	-	100.0%	0.0%	1307.8	-	1307.8	556.6	-	556.6
0.50	10,052,091	-	100.0%	0.0%	1307.8	-	1307.8	556.6	-	556.6
0.60	9,294,826	757,265	92.5%	7.5%	1185.3	157.5	1342.8	504.4	19.7	524.1
0.70	9,294,826	757,265	92.5%	7.5%	1185.3	157.5	1342.8	504.4	19.7	524.1
0.80	9,294,433	757,658	92.5%	7.5%	1185.2	157.6	1342.8	504.4	19.7	524.1
0.90	9,197,984	854,107	91.5%	8.5%	1165.2	186.5	1351.6	495.9	24.7	520.6
1.00	9,197,984	854,107	91.5%	8.5%	1165.2	186.5	1351.6	495.9	24.7	520.6

4.4 A model of cross-subsidization

Solely charge on the freight sector may raise huge resistance and opposition. The experiences from urban transport pricing show that, to achieve support from the public, the generated revenue must be allocated at an efficient manner considering equity of different groups. We prefer to see a change in the traffic pattern, but not a change in the total transportation demand, as the amount of demand is highly related to the economic development of the country. As suggested in Berechman (2009), promotion (such as subsidization) of short sea shipping operations, railway expansion, and efficient pricing to trucks are possible solutions to mitigate the truck traffic problems. As the strategic objective of the charging is transport sustainability, cross-subsidization to sea transport from road transport can make the mechanism more practically feasible.

We propose a port cost reduction scenario here. We estimate that maximum differences in transit time and costs between dedicated and non-dedicated services are $3500 TWD per TEU and 12 hrs respectively. Therefore, we model that the government may subsidize the port authorities and port operators to lower the port costs for using the SSS service. We would investigate how the level of port cost reduction can work with the external cost internalization to maximize the sustainability.

We performed a number of cases with port cost reduction level and internalization ratio. Table 3 shows the amount of SSS based on the combined effect of port cost reduction and external cost internalization. Recall that, without any port cost reduction, 757,265 TEU of containers will use SSS at an internalization ratio of 0.6.

If the port cost is reduced by 10%, the same level of SSS flow can be achieved with the internalization ratio of 0.4. If the port cost is reduced by 20%, the same level of SSS flow can be achieved with the internalization ratio of 0.1. It is a trade-off between the two policy variables considered to achieve the optimal situation. With a smaller internalization ratio, the impact to the transport sector is reduced and it should be more acceptable to the industry.

Table 3. Combined effects of port cost reduction and external cost internalization

Port cost reduction ratio	Internalization ratio	Amount of SSS (TEU)
10%	0.2	0
	0.3	142989
	0.4	757265
20%	0	0
	0.1	757265
30%	0	757658
	0.1	757658

5. CONCLUDING REMARKS

This paper presents an analysis on the external costs produced by freight transportation and the policies to reduce the external costs. A multimodal transportation network model approach is adopted to estimate the inland container movement and the associated external costs. Based on a case study with the Taiwan network, our result shows that an external cost internalization ratio of 0.6 is needed for the modal choice to have a significant shift. This ratio is high and could be less acceptable, and the revenue collected can be used to improve the freight network. Considering cross-subsidization to shipping from trucks, if the port charge is reduced by 10%, the same level of SSS flow can be achieved with the internalization ratio of 0.4. If the port cost is reduced by 20%, the same level of SSS flow can be achieved with the internalization ratio of 0.1. A lower internalization ratio could be more politically acceptable to the freight sector. Furthermore, our analysis evaluates that promoting multimodal transport can reduce the total external costs from $639.8 to $536.9 million USD. The reduction is due to the mitigation of road traffic and air pollution to the road network. However, the energy consumption and climate change (CO_2) costs may or may not reduce, depending on the network topology and emission factors adopted.

計劃成果自評：

論文已經發表於研討會，並轉投期刊發表：

Wong, K.I., Lee, Paul T.W., and Szeto, W.Y. (2012) Modeling the external costs of domestic container transport in a freight transportation network approach. In *Proceedings of the International Association of Maritime Economists (IAME) Conference*, 6-8th September, Taipei, Taiwan.

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出席國際學術會議心得報告

計畫編號	NSC 99 - 2221 - E - 009 - 094
計畫名稱	考慮網路可靠性之可持續貨物複合運輸網路模型之研究
出國人員姓名 服務機關及職稱	黃家耀 助理教授, 國立交通大學, 運輸科技與管理學系
會議時間地點	17-20 December 2011, Hong Kong
會議名稱	*The 16th International Conference of the Hong Kong Society for Transportation Studies* (HKSTS)
發表論文題目	External costs of intermodal transportation for inland container transport: an empirical study of Taiwan

With the sponsorship of the National Science Council, I have attended the *16th International Conference of the Hong Kong Society for Transportation Studies* (HKSTS). This is the annual international conference in the transportation area of Hong Kong, and is a main gathering of many international scholars and researchers worldwide. The paper was presented in the conference.

Copies of the abstracts are attached for reference.

Publication:

1. Wong, K.I. and Lai, G.H. (2011) External costs of intermodal transportation for inland container transport: an empirical study of Taiwan. *Presented in the 16th International Conference of Hong Kong Society for Transportation Studies* (HKSTS), 17-20 December, Hong Kong.

EXTERNAL COSTS OF INTERMODAL TRANSPORTATION FOR INLAND CONTAINER TRANSPORT: AN EMPIRICAL STUDY OF TAIWAN

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Abstract

Taiwan is an export-based economy, and the important of freight transportation is of no question. Intermodal transportation has been demonstrated to be an economic and sustainable strategy for freight transport. In Taiwan, most of the internal transport flows for non-bulk cargo are transported with trucking via road network, whereas limited containers are transported with barge (i.e. short sea shipping, SSS) between domestic seaports.

Several government reports and studies have investigated the substitutability and complementary effects between trucking and barge transportation (see MOTC, 1999). There are several recent studies to evaluate the benefit of promoting short sea shipping for container traffic inside the hinterland of Taiwan, taking external cost (including air pollution and greenhouse gas emissions) into account. Lee et al. (2010) investigated the external cost of transportation for domestic cargos with SSS and trucking, and showed that a large amount of external costs was produced by the truck transportation as compared to the SSS. Liao et al. (2010) examined the green house gas emissions due to inland container transport in Taiwan and suggested that shifting truck traffic to sea traffic can reduce a huge amount of emissions. Both studies suggest that the emissions and climate costs can be greatly reduced if the container cargo movements between the ports on the west coast of Taiwan can make use of SSS.

However, the above studies only consider the port to port traffic, and did not have an accurate estimation of the inland traffic pattern. To explore the relevant policy options, a detailed estimation of the cargoes movement pattern on the network are required. In this paper, we extend the research by evaluating other key elements of external costs for the inland container movements, which were estimated from a multimodal transportation network model proposed in Wong et al. (2010). Our initial findings suggest that promoting short sea shipping may reduce the air pollution and congestion to the road network, but however, energy consumption and climate change costs may not largely reduce as suggested in previous studies.

Lee, P.T.-W, Hu, K.C. and Chen, T. (2010) External costs of domestic container transportation: short sea shipping versus trucking in Taiwan, *Transport Reviews*, 30(3), 315-335.

Liao, C.-H., Lu, C.-S. and Tseng, P.-H. (2010) Carbon dioxide emissions and inland container transport in Taiwan, Journal of Transport Geography, to appear, doi:10.1016/j.jtrangeo.2010.08.013.

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Wong, K.I., Lee, Paul T.-W., Szeto, W.Y. and Lai, G. H. Lai (2010) A multimodal network design problem for domestic container transportation with short sea shipping. *The 12th World Conference on Transport Research*, 11-15 July, Lisbon, Portugal.

國科會補助計畫衍生研發成果推廣資料表

日期:2012/10/30

國科會補助計畫	計畫名稱: 考慮網路可靠性之可持續貨物複合運輸網路模型之研究	
	計畫主持人: 黃家耀	
	計畫編號: 100-2221-E-009-125-	學門領域: 交通運輸
無研發成果推廣資料		

100 年度專題研究計畫研究成果彙整表

計畫主持人：黃家耀			計畫編號：100-2221-E-009-125-				
計畫名稱：考慮網路可靠性之可持續貨物複合運輸網路模型之研究							
成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	0	0	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	1	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		
國外	論文著作	期刊論文	0	1	100%	篇	研究成果已經發表於 2012 年 9 月之 International Association of Maritime Economists (IAME) 研討會，並已轉投期刊
		研究報告/技術報告	0	0	100%		
		研討會論文	1	0	100%		研究成果已經發表於 2012 年 9 月之 International Association of Maritime Economists (IAME) 研討會，並已轉投期刊
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	

		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	去年進行期刊 Research in Transportation Economics 的 Special Issue ' Freight Transport and Sustainability' 之 Guest editor, 已經完成並送至 Publisher 處理中. 這是一年期的計劃，後續研究為 NSC 101-2221-E-009-130-

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

   ■達成目標

   □未達成目標（請說明，以 100 字為限）

   □實驗失敗

   □因故實驗中斷

   □其他原因

   說明：

2. 研究成果在學術期刊發表或申請專利等情形：

   論文：□已發表 ■未發表之文稿 □撰寫中 □無

   專利：□已獲得 □申請中 ■無

   技轉：□已技轉 □洽談中 ■無

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3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

   研究成果已經發表於 2012 年 9 月之 International Association of Maritime Economists（IAME）研討會，並已轉投期刊。

   研究發現，台灣地區的貨運業如考慮產生之外部成本，可以同時收取陸運額外費用，並補貼港口轉運費用，達到較佳之績效。