Asia-Pacific
Economic Cooperation

Sustainable Intermodal Transportation Network Using Short Sea Shipping:

2nd Phase of Short Sea Shipping Study to Improve Intermodal Efficiency and Reduce Pollution, Congestion, Fuel Costs and Green House Gas Emissions

APEC Transportation Working Group

December 2013

APEC Project TPT 02/2011

Sustainable Intermodal Transportation Network Using Short Sea Shipping:
2nd Phase of Short Sea Shipping Study to Improve Intermodal Efficiency and
Reduce Pollution, Congestion, Fuel Costs and Green House Gas Emissions

Electronically Printed in December 2013

Prepared By
INHA UNIVERSITY
253, Yonghyeon-Dong, Nam-Gu, Incheon 402-751, Korea
Email: ytchang@Inha.ac.kr
Website: www.inha.ac.kr

Project Leader:
Young-Tae Chang (Professor of Inha University)

Project Participants:
Hwa-Joong Kim (Professor of Inha University)
Sang-Hyun Hwang (Research Assistant)
Younghun Song (Research Assistant)

FOR THE ASIA-PACIFIC ECONOMIC COOPERATION
SECRETARIAT
35 Heng Mui Keng Terrace Singapore 119616
Tel: (6568919600 Fax: (65) 68919690
Email: info@apec.org
Website: www.apec.org

APEC#213-TR-01.6

TABLE OF CONTENTS

EXECUTIVE SUMMARY 1

CHAPTER 1. INTRODUCTION AND PROJECT OVERVIEW 7

CHAPTER 2. SUMMARY OF PHASE 1 PROJECT 13

CHAPTER 3. EXTENSION OF PHASE 1 PROJECT MODEL 23

An Optimization Model for the Transportation of Container Cargoes Considering Short Sea Shipping and External Cost: a Korean Case 23

CHAPTER 4. PHASE 2 PROJECT ON SUSTAINABLE INTERMODAL TRANSPORTATION NETWORK USING SHORT SEA SHIPPING 55

Analysis of an Intermodal Transportation Network in Korea from an Environmental Perspective 55

CHAPTER 5. CONCLUSION 89

EXECUTIVE SUMMARY

Major problem considered in the 1st phase of this project was the intermodal routing problem of international container cargoes in Korea, which can be defined as the problem of determining the cargo flow quantity and the transportation mode in each trade route while satisfying the demand. The objective was to minimize the sum of shipping and inland transportation costs. There were two major constraints: maximum cargo volumes capacitated at each seaport and maximum cargo volumes that can be carried by available vehicles of each transportation mode. In order to solve optimally and represent the problem, our research team employed a linear programming model, which is an operations research technique. The problem was formulated by extending the well-known network design problem by considering the two major constraints. The model was solved using CPLEX, commercial linear programming software. The test results using a real cargo flow data in Korea showed that the model represents closely the real situation, and the seaports of Ulsan and Gwangyang should be developed more while the seaports of Busan, Incheon, and Pyeongtaek should be reduced.

The major findings of the 1st phase study can be summarized as follows: Study on Short Sea Shipping has been supported by European Union in the past decade and similar advocacy can be observable in North American continent. It seems to be high time that Asia-Pacific region should develop SSS as early as possible in view of expected benefits ranging from reduced logistics costs, and environmental protection to further utilization of underused seaports in the region. The research team attempted to capture current practices of Short Sea Shipping in major maritime regions and to build

cargo flow network model. Our findings from the models are clear: Short Sea Shipping will provide more transportation and logistics routing choices for various stakeholders; reduce logistics costs; encourage currently underdeveloped or less-used seaports to be further developed and/or used in the future. To do this, new technology such as faster ship and turnaround in major intermodal nodes and policy formulation to expedite cargo movements need be incorporated into the SSS system in the near future.

Various models for this phase 2 project build on its phase 1 models and also its extended models. The original model at the phase 1 intended to analyze the usage of Short Sea Shipping by building multi-model transportation network models. The costs considered in the models were direct logistics costs and time costs. This model did not include any aspects of externalities. Thus, the externalities were added into its extended model. The main focus of this phase 2 project is to assess GHG effects arising from the multi-modal transportation. In addition, the model itself was upgraded to reflect more realistic situations. Once the upgraded model is built, its validation is tested prior to assessing various policy option scenarios. After validation of the model, three scenarios are tested. First, it is assumed that governments will charge portion of externalities more likely in the form of taxes on carbon or environment, similar to European system. This is internalization scenario. Second, it is assumed that government will introduce carbon taxation scheme on consuming fuels. It is carbon taxation scenario. Finally, it is assumed that governments will introduce emission trading scheme (ETS) as observed in numerous advanced economies. It is ETS scenario. Each scenario is assessed by modifying the models slightly.

Result of the External Cost Model

In this test, we attempted to analyze how the container cargoes would shift among different transport modes in Korea and how much total external costs would be changed if the government formulates more eco-friendly policies internalizing the external cost and levying taxes onto carriers. It is presupposed that levied tax onto the carriers will be subsequently transferred to shippers more likely in the form of surcharge as is often the case in transportation sectors. To this end, we tested the external cost model under different taxation factors or varying internalization ratios of the external costs. The varying degrees of internalization ratios were intended to reflect the plausible uncertainty on how much tax would be charged onto carriers by the Korean government.

From the test result, we can draw some policy implications. The transport policy should be directed toward the inclusion of the external costs into carriers' pricing to reduce the externalities. Just a mere initial low percentage of taxation of the external costs would result in significant reductions of the externalities. The excessive taxation on the external cost, however, may not be a good policy instrument for more use of barge and advisable modal shift. Therefore, an optimal amount of tax should be explored looking into not only the reduction of external costs, but also the balance in modal split. Furthermore, the changes in modal split and external costs will be affected by extended linkage among the nodes and expansion of transportation structure along with the enhanced efficiency of the modes. Though the data used and the transportation model built in this study are based on Korean case, the implication of finding optimal taxation and proper modal shift can apply to many other similar countries, which use similar types of intermodal system for their cargo movements.

Result of the Carbon Tax and Emission Trading Scheme Models

In these tests, we attempted to analyze the effect of a carbon tax and an emission trading scheme on the modal split and CO2 emissions. Moreover, we examined which regulation between a carbon tax and an emission trading scheme is more effective to reduce CO2 emissions. First, we tested the carbon tax model under the scenario of different taxes and then tested the emission trading scheme model using the ETS heuristic under the scenario of different CO2 prices and emission limit factors.

In case of the carbon tax model, the share of train increases significantly absorbing most of shares of truck and barge and the total CO2 emissions from all inland transport modes decline along with the increase of the carbon tax. This is very similar to the result of the external cost model. On the other hand, the change in the modal split and the total CO2 emissions under the emission trading scheme model with actual CO2 market prices in recent years is not significant even though the share of train increases slightly as the CO2 price increases and the emission limit factor decreases. This result implies that shippers' modal and route choice may not be significantly affected from an emission trading scheme regulation although the Korean government enforces the regulation and moreover some revenue gained from selling CO2 emissions permits is allocated to shippers in the form of freight rate reduction if current CO2 market prices are maintained.

Comparing the results of the carbon taxation and ETS, the emission trading scheme appears to be a less effective instrument than the carbon tax to reduce CO2 emissions in the transportation sector. This is somewhat surprising result in contrast with those views supporting ETS (Council of the European Union, 2008). The result may have been caused by too low CO2 prices even though the price ranges are based on actual CO2 market prices in recent years. If the carbon prices were as high as the carbon taxes, the results of the ETS would have been much different. We tested this argument using much higher carbon prices in the ETS model. The results show that total CO2 emissions from all inland transport modes declines significantly along with the increase of the CO2 price, while the modal shift is not significant. Therefore, international organizations and governments should devise some policy instruments to increase the CO2 price which is stagnant around several ten US $/ton in the current market. In addition, governments including Korean one seeking for sustainable transportation system should develop a scheme of sharing the burden and benefit of the extra cost and revenue between transport modes arising from the ETS to balance the modal split.

In sum, the emission trading scheme appears to be a less effective instrument than the internalization policy and carbon taxation to reduce CO2 emissions in the transportation sector. Moreover, the change in CO2 emissions and modal split under the ETS was further tested using carbon prices as high as carbon tax rates. The result is not much different from the case using currently prevailing CO2 prices in modal split, but shows considerable improvements in reducing the external costs. This implies that the ETS can be an effective policy instrument when the carbon price is set high in the market driven by international organizations and governments.

CHAPTER 1. INTRODUCTION AND PROJECT OVERVIEW

Context

At the 6th APEC Transportation Ministerial Meeting in Manila, Philippines in 2009, the two goals explained in the next Objective section were strongly and importantly stipulated in the Joint Ministerial Statement. The APEC Ministers instructed the Transportation Working Group to focus on options to help address emissions from transport without unduly affecting the safe and efficient carriage of people and cargo and growth of the transport industry.

The geo-economic characteristics of APEC economies, comprised of islands, peninsulas and coastal states, justify the necessity of developing a more efficient but sustainable intermodal transportation network. The rapidly growing importance of intraregional trade among APEC economies further necessitates and reaffirms the network development in this direction. While developing more sustainable transportation systems within APEC economies is one of key issues of the APEC Transportation Working Group, the group should also work closely with energy officials as planned at the upcoming APEC Joint Transportation/Energy Meeting involving Ministerial level officials. The main objectives and scope of this project are to provide government officials and relevant stakeholders with an excellent opportunity to address and understand various issues of the developed model and policy implications from this project.

Project Objectives

The objective of this project is to extend the original Short Sea Shipping Study, which was funded by the APEC Transportation Working Group in 2007. This new phase of the study intends to achieve two goals: (1) Develop a comprehensive intermodal transportation network model to enhance more seamless, efficient and effective interconnectivity among various modes, while reducing pollution, congestion, noise and other externalities; and (2) Address the issue of greenhouse gas (GHG) emissions from transportation sources to better comply with upcoming regulations on international shipping of the International Maritime Organization (IMO) and surface transportation modes of the Kyoto Protocol. To this end, this project develops several sustainable multimodal transportation models, including SSS. Using these models, the total transportation/logistics cost in a given economy could be minimized. Various policy options and practices are tested and analyzed for the optimal policy formulation. The policy and practices encompass various ranges from infrastructure development and pricing mechanism to environment regulations arising from the IMO and Kyoto Protocol including internalizing external costs, carbon taxation, and Emission Trading Scheme. Therefore, this project can create a framework for analysing various logistics costs, times and environmental effects, including greenhouse gas emissions. The project can help the economies determine the best strategy to develop their optimal sustainable transportation network system. The results of the models and various policy implications from the model outputs can be shared with other APEC economies to enhance the common understanding of how and why each economy should develop sustainable transportation system for mutual benefits of the APEC community.

Work Flow

The project was conducted in a three step process: (1) build the model and collect the data; (2) test the model and conduct policy analysis; (3) complete the report. The detailed work plan following the three step process is delineated as follows:

Step 1. Building the model and data collection

Upon project launch, our research team discussed and focused on the overall project plan and scope of work. The model is, in principle, based on our intermodal transportation model, which was previously developed throughout the first phase of the APEC TPT in 2007. As our new work scope includes a more comprehensive assessment of the environmental damages arising from the intermodal transportation network and also addresses the greenhouse gas emissions, the original model should be modified and expanded to cover these effects. We employed a double track approach: (1) avoidance cost approach; and (2) greenhouse gas (GHG) reduction approach. The avoidance cost approach is something we have already developed. Essentially, the approach features the incorporation of environmental economic theories and methodologies into the multimodal transportation model. We have employed the willingness-to-pay method as a test-bed study for the expected externality arising from pollution of each mode. The GHG reduction approach is our new trial to estimate various policy options to regulate GHG emissions arising from transportation sectors. For the GHG reduction approach, we developed new models to test various policy options including the carbon tax system, Emission Trading Scheme, and internalizing external costs.

The main process of building the model is typical of one found in linear/non-linear programming of the Operations Research arena. First, the model is formulated by revising the original model to incorporate various environment impacts by transportation mode into the model. Greenhouse gas emission effects are also addressed by mode. Second, the model is programmed using a computer language, then verified for any logical errors to determine whether the program runs as well as expected in the logical flows using a small size data set. Third, the model is validated by checking whether the model output can represent the real world or not to the degree that the objective and the scope of the research can be fulfilled. It should be noted here that although any model output cannot represent a real world perfectly, the model is deemed to be validated as long as the model output can represent the reality sufficiently enough for the major issues that the model addresses. Finally, once the model is validated, relevant data is collected. The type of data to run the model can be varied depending upon the developing logical process of the model and availability of the data. Our target data is major container cargo flow data in Korea, categorized in terms of cargo origin and destination by mode (truck, train and water transportation) and between major nodes of transportation including seaports and two Inland Container Depots. We also collect cargo flow data beyond the Korean boundary as the model also aims at measuring cargo flow cost, time and environmental effects internationally. Therefore, the international cargo flow data are collected between major overseas seaports and Korean seaports. In addition to the cargo flows data, we gather the logistics costs and time data of the movement of cargo. Lastly, we estimate and collect the environmental effects of moving cargo by mode. The environmental effects range from air pollution, congestion, noise, infrastructure damages and GHG emissions. All the detailed characteristics of the model building and relevant data can be referenced to the first phase of report and the two published papers from our research team. (Kim et al, Optimizing the transportation of international container cargoes in Korea, *Maritime Policy and Management*, 2008, vol. 35, pp. 103-122; Chang et al., Optimizing model for transportation of container cargoes considering short sea shipping and external cost: *South Korean case, Transportation Research Record: Journal of the Transportation Research Board*, No. 2166, Transportation Research Board of the National Academies, Washington D.C., 2010, pp. 99–108. DOI: 10.3141/2166-12)

Step 2. Testing the model and policy analysis

Once the model is validated, we develop various models which can address various policy options. This process is designed to better understand and assess the differences between the as-is and to-be status. The policy-formulators can then figure out what policy option would result in the best optimal solution for their economies in terms of logistics cost, time and environmental damages and GHG emissions. The major policy options are drawn from interviews with government officials, academia and industry groups in Korea and from overseas as well.

Step 3. Completing the report

We presented our intermediate outputs in major renowned international conferences to receive feedback from world experts and scholars of the co-sponsoring economies. The conferences include: (1) Asia Logistics Round Table (ALRT)'s annual conference held late April/early May, 2012 at the University of British Columbia, Canada; (2) International

Association of Maritime Economist (IAME)'s annual conference held early September, 2012 in Chinese Taipei; (3) Inha-Le Havre biennial international conference mid-October, 2011 in Korea. The feedback received at the conferences was incorporated into revisions of the draft report and models, when necessary. Finally, we complete and submit the report to the APEC Secretariat in December, 2013, inclusive of all previous comments and feedbacks.

CHAPTER 2. SUMMARY OF PHASE 1 PROJECT

Purpose and Methodology of the Project

The main objective of this Project has the specific aim of offsetting and lessening congestion at major hub ports which is expected to worsen substantially as larger ships call on these ports and trade doubles over the next two decade. It consists of three sub-objectives: to integrate underutilized ports to reduce congestion, to create a model in and to facilitate underutilized port development.

The project's methodology by phase are as follows: Phase I - Identify and summarize existing coastal marine freight and passenger services flowing through ports (including ancillary services) along with legal and regulatory considerations between multiple economies in two specified APEC regions; Phase II- Gather data from each of the two regions and build a flow model in which to assess the marine transportation patterns that exist and could exist by application of successful short sea shipping models and technologies and the use of underutilized ports, and then test the flow models; and Phase III - Run "what if scenarios" using the short sea shipping model. Evaluation of model output, along with analysis and recommendation of successful models for short sea shipping in the APEC regions as well as the clustering of economic activities that promotes the inclusion of underutilized ports into the supply/demand chain.

Economic Growth in Asia and Significance of SSS

The accelerated growth of Asian economy, including high rate of Chinese economy, has both influenced and mirrored changes in the scope and operation of shipping connections within Asia and with the rest of the world, causing the repercussions on extra- and intra-Asian container shipping networks. As a result of that, in Europe, Short Sea Shipping (SSS) has grown steadily over the last two decades. Asia needs an efficient logistics transport system combining the benefits of all modes to maintain and increase competitiveness and prosperity in line with the globalized economy in order to overcome less efficient rail and road transportation system and to make many of Asian main industrial centers get close to waterways. Thus, in many cases, SSS routes in Asia may provide the fastest and most reliable service between destinations. Fast growing trends of SSS has been also seen in Asia according to mega-hub port developments and China's high rate of economic growth. Recent years have brought an increasing focus on developing new SSS options that are better suited for moving container cargo, for example in Korea and China, that normally travels by truck and tends to include higher-value and time-sensitive goods.

Fast growth of heavy road transport and related congestion, accidents and pollution are the main economic, social and environmental problems that the policy to promote SSS is worthwhile to address.

Benefits and Obstacles of SSS and How to Solve the Obstacles

SSS may produce public and private benefits, by providing an additional and/or alternative option for transporting passenger and freight. SSS services are more fuel efficient than trucks so that they can contribute to improving air quality and reducing noise. SSS also plays a key role in reducing the road and terminal congestion as well as the number of trucks and trains traveling on crowded port access routes. SSS development may provide a more cost-effective alternative to building new roadways and rail lines in the light of the concept of “Motor Way of Sea” in Europe, which result in reducing the amount of money spent on infrastructure projects, and maintenance costs. Despite of the benefits noted above, the potential obstacles can be identified in terms of legal, operational, and acceptance-related challenges. Legal requirements could present a barrier to SSS development by increasing the start-up or operating costs of operations. Operational challenges involve incompatible infrastructure and potential strains on port capacity. Furthermore, a general unwillingness among logistics providers to switch from well-established modes, such as trucking and rail - even if SSS can be shown to be a competitive option - can present a barrier to SSS development.

SSS Practices in Asia

COSCO Container Lines Company Ltd (Coscon), China’s leading container carrier, plays a key role in intra- and extra-Asian shipping patterns closely parallel shifts in the country’s economic geography, the accelerated growth of Chinese economy over the two decades, and the increasingly competitive global economic environment. In elaborating the maritime environment within which China’s leading shipping company operates the country’s container ports are allocated to one of three regions or port ranges: the northern range around the Bohai Rim, the central range focused on the

Yangzi River Delta and southern range centered on the Pearl River delta. Coscon has intensified traffic within a fully-fledged domestic cabotage maritime circuit between the three port ranges of the Bohai Rim, the Yangzi River delta and the Pearl River delta. This process has confirmed Qingdao, Shanghai and Hong Kong, China as national hubs, the indisputable pivots within these ranges for a large number of domestic links and the bases for tangential services to secondary ports. Coscon's services can become a realistic choice in multimodal logistical transport chains in the intra-Asian market by building on the strengths of the short-sea liner trades and minimizing any weaknesses.

Hong Kong, China is expected to have the ability to respond to the growing competition through its innovative ingenuity thanks to two aspects: the increased use of river barges to lower transport cost between Hong Kong, China and its PRD hinterland, and the penetration to mainland ports by Hong Kong port operators. In addition, because of Hong Kong's established trading networks, legal system, ease of communications, and efficient support services and with China's accession to the WTO, China's international trade and investment would further expand and Hong Kong, China would be playing a key role in providing trading services. In this regard, so long as Hong Kong, China is able to continue to attract international logistics operators to base its regional or international operations in Hong Kong, China, the seaport of Hong Kong, China should be able to continue to maintain a competitive edge over the growing seaports in Southern China. In doing so, short sea shipping development in association with the efficiency of entire shipping chain - barging, trucking, consolidating, and other logistics - is critical to attract transshipment cargo for ports in this region.

The Japanese short sea shipping network comprehensively covers all around the country from the north to the south in 3000 km range. The network involves 23 routes, 48 operators, 101 ships, 112 ports and 196 sailings per week. The majority of ships operated by the short sea shipping in Japan are RORO, Ferry and conventional boats. The size and the capacity of them are moderate and handy to accommodate local niche cargo demand. Therefore, most of the ports called by the short sea shipping are relatively smaller ports in local areas even though some routes call bigger ones like the Port of Tokyo. In contrast, most of the container ports are intensively located in the proximity to the greater metropolitan areas. The reality that the Japanese short sea shipping has been well developed suggests the evidence of great possibilities to create the international short sea shipping network in the Northeast Asia.

In recent years, Korean government has initiated a strategy to build a logistic hub of the Northeast Asia in Korea and a great deal of efforts have been made to implement the strategy. In spite of these efforts, many people argue that there is great inefficiency in transporting international trade cargoes, in particular in the capital region of Korea. Although thirty three per cent of cargoes of national container export and import were generated in this region as of year 2001, most of these cargoes had to be handled in farthest seaports such as the Port of Busan and the Port of Gwangyang rather than its vicinity ports like the Port of Incheon and the Port of Pyeongtaek. This phenomenon causes many problems including road congestion on and damage to major highways between Seoul and Busan, environmental degradation, inefficient infrastructure investment and notably truck drivers' illegal and intentional strike on major highways to block major cargo flows for their bargaining power (the strike started on April 28, 2003 and ended on September 5, 2003.). Under these circumstances, Korean government and industries as well as general public have begun to explore more diverse transportation network for the capital region’s cargoes among coastal shipping, railway , truck and also air transportation. SSS in Korea has not attracted sufficient attention of government. Government seem to be more concerned about developing coastal shipping rather than developing SSS, plausibly due to unawareness of the characteristics and importance of SSS. It is not until recent year that public stakes have been expressed in favor of coastal shipping to resolve inland congestion along major highways and reduce air pollution and other environmental degradation,

SSS Network Model Design and Its Major Findings

The research team has employed two quantitative models in building cargo flow network in the case region. One model is a kind of heuristic approach, particularly using Genetic Algorithms focusing on the Capital region of Korea, and the other is traditional mathematical program - liner programming covering up the whole nation’s international trade. The objective of both models is to find the minimum logistics cost to handle international trade cargoes in the capital region and the whole Korea, respectively.

Prior to building the cargo flow network models, the team first analyzed the data of Korea’s coastal shipping and predicted future demand for the shipping using Origin-Destination matrix of cargoes.

Our research team attempted to analyze container cargo flows generated in capital region of Korea and estimated the logistics cost and time. Based on integer goal programming model, we tried to find optimal solutions for international freight routing problems taking into account the three factors of cost, time and risk of handling cargoes. Genetic algorithms were used to tackle huge number of variables and cases and also considering its flexibility of handling other qualitative variables when our model is extended later on. The most important finding is that Port of Incheon should be utilized in handling the international cargoes of the capital region in both aspects of logistics and time. Under various scenarios such as major liners' calling Incheon or not calling Incheon (as is the case today), using the Port of Incheon shows that we can reduce a great deal of logistics costs and time. This observation can be more vividly reflected in more coming years like year 2008 and 2011 when much increased containers are expected to be generated in the region.

Despite that our findings are temporary ones, we can derive very important implications from our findings as follows: First, we have to maximize using the regional ports of the capital region, namely the Port of Incheon and Pyeongtaek replacing currently road-and-Busan-port dominant transportation system. Second, we should, therefore, develop container ports in Incheon/Pyeongtaek much earlier that ongoing plan. Third, we need to think about designing the ports in Incheon/Pyeongtaek to accommodate major ocean going shipping lines. Our findings in scenario I and II show that we can reduce hundreds of billion Wons (hundreds of million dollars) solely for the capital regional cargoes even excluding the possibility inducing more international cargoes when attracting major lines. Recent movement of major shipping lines' calling Northeastern Chinese ports in the vicinity of the Port of Incheon and increasing foreign direct investment in container terminals in Incheon are likely to justify this argument. This argument has to be tested asking various stakeholders of the ports whether they would use the ports or not. This remains to be our next step study.

Next problem considered in this project is the intermodal routing problem of international container cargoes in Korea, which can be defined as the problem of determining the cargo flow quantity and the transportation mode in each trade route while satisfying the demand. The objective is to minimize the sum of shipping and inland transportation costs. There are two major constraints: maximum cargo volumes capacitated at each seaport and maximum cargo volumes that can be carried by available vehicles of each transportation mode. In order to solve optimally and represent the problem, our research team employed a linear programming model, which is an operations research technique. The problem is formulated by extending the well-known network design problem by considering the two major constraints. The model is solved using CPLEX, commercial linear programming software. The test results using a real cargo flow data in Korea show that the model represents closely the real situation, and the seaports of Ulsan and Gwangyang should be developed more while the seaports of Busan, Incheon, and Pyeongtaek should be reduced.

Concluding Remark

Short Sea Shipping has been supported by European Union in the past decade and similar advocacy can be observable in North American continent. It seems to be high time that Asia-Pacific region should develop SSS as early as possible in view of expected benefits ranging from reduced logistics costs, and environmental protection to further utilization of underused seaports in the region. The research team attempted to capture current practices of Short Sea Shipping in major maritime regions and to built cargo flow network model. Our findings from the models are clear: Short Sea Shipping will provide more transportation and logistics routing choices for various stakeholders; reduce logistics costs; encourage currently underdeveloped or less-used seaports to be further developed and/or used in the future. To do this, new technology such as faster ship and turnaround in major intermodal nodes and policy formulation to expedite cargo movements need be incorporated into the SSS system in the near future.

Recommendation and Necessity of Further Research

Some caveats should be taken in interpreting the results since the results of this study are intermediate ones constrained by lack of data like more detailed level of cost, time and in particular time variances. These lacking data will be further sampled and investigated in the near future in our study if the Phase III-work is approved by APEC in the future as proposed in the original proposal. Even if we attempted to build up the cargo flow network model to test how Short Sea Shipping can affect the total logistics and transportation network in terms of cost and time in the case study, a great deal of factors need to b e further considered in the future to analyze more detailed impacts of the SSS in the APEC region by providing APEC economy-wise specific data and evaluate the validity of our model in these numerous cases. This can be done by

WHAT-IF type analysis as proposed in our proposal.

CHAPTER 3. EXTENSION OF PHASE 1 PROJECT MODEL

After the completion of the 1st phase work, the project team further developed its model by considering environmental impacts arising from cargo flows. The result was published in academic journal so please refer to this paper: Chang et al., Optimizing model for transportation of container cargoes considering short sea shipping and external cost: *South Korean case, Transportation Research Record: Journal of the Transportation Research Board*, No. 2166, Transportation Research Board of the National Academies, Washington D.C., 2010, pp. 99–108. DOI: 10.3141/2166-12). The remainder of this chapter is to describe the extended model and its results of applying the extended model to Korea's intermodal cargo flows taken from the published paper.

An Optimization Model for the Transportation of Container Cargoes Considering Short Sea Shipping and External Cost: a Korean Case

1. Introduction

Due to increased environmental concerns, there is growing recognition that environmental issues should be addressed as a core concern in the transportation sector. One of the environmental problems in the transportation sector in many parts of the world is that a major proportion of freight transportation concentrates on road transportation thanks to its benefits of providing quick door-to-door services. However, trucking incurs more negative externalities such as noise, air pollution and congestion than other transport modes. To alleviate harm to the environment, short sea shipping

(SSS) is gaining popularity in transportation policy formulation as an alternative transport mode for eco-friendly and cost-efficient transportation (European Commission, 2001). SSS is defined as a “maritime highway transportation system” and it includes canals, rivers, other inland waterways as well as coastal shipping system. SSS services are more fuel efficient than trucks and can contribute to improving air quality and reducing noise. SSS can also play a key role in reducing road and terminal congestion as well as the number of trucks and trains traveling on crowded port access routes. Consequently, SSS development may provide a more cost-effective alternative to building new roadways and rail lines. In particular, a new concept of “Motorway of the Sea” in Europe has contributed to reducing the amount of money spent on infrastructure projects, and maintenance costs so that SSS is expected to grow at a rate of 59% in metric tons in Europe from 2000 to 2020 (De Oses and Castells, 2008). The North American continent and the Asia Pacific region have been also discussing similar SSS development in recent years (U.S. GAO, 2005; APEC, 2009). For more details about SSS, refer to Paixao and Marlow (2002) who summarize the strength and weakness of SSS and provide a list of measures for developing SSS.

Following the European initiative in SSS, Northeast Asian countries including Korea have put forward initiatives to develop an advanced SSS system beyond the traditional coastal shipping. Korean SSS system, however, is a rudimentary stage compared with Europe’s and North America’s when measured in terms of its image, legal, institutional and operational aspects. Unlike Korean government’s policy direction toward a more environmentally friendly and energy-efficient system, the transportation of international cargoes inside Korea is heavily dominated by trucking. Since the Korean government has endeavored to develop Korea as a logistics hub in Northeast Asia during the last two decades, it is a thorny issue whether the government can achieve its goal of well balanced modal shifts among different modes. The government is unsure of the benefits of developing a sustainable transportation mode, for instance, SSS, that is an alternative to the current status quo. In addition, there is debate whether and how decision makers should formulate the transportation policy by incorporating environmental aspects. There exist numerous studies to analyze optimization problems of transporting international container cargoes including our own previous work as described in the literature review of the next section. To the best of our knowledge, there have been no studies on how to optimize intermodal container movement incorporating the environmental aspects into SSS network.

Under this context, this project intends to contribute to the literature by analyzing an intermodal transportation problem of international container cargoes (ITP) while incorporating the external costs of the modes into an optimization model in Korea. The objective of the problem is to minimize the total logistic costs, i.e., shipping and land transportation costs, as well as to minimize external costs such as air pollutants (PM_{10}, NO_X, SO_2, VOC) and greenhouse gases (CO_2). In this study, we develop a linear programming model to solve the ITP and perform a case study using the container cargo data in Korea in order to analyze the modal split of each transport mode and transport route in Korea. Then, several policy implications are drawn by relaxing constraints. This research is an extension of our previous work (Kim *et al*., 2008) which suggested an integer programming model for the problem similar to the ITP. However, this project extends the research results of Kim *et al*. (*6*) with respect to the following four points. First, the environmental impacts of each transport mode are analyzed by considering external cost. Second, the model is intensified by adding a coastal shipping network, which is one of important SSS networks. Third, our new model expands its scope into Deep Sea Shipping (DSS) regions and their respective cargoes in the case data in order to consider more realistic import and export data as well as the capacity of Korean seaports. Finally, a linear programming model is suggested instead of the integer programming model in Kim *et al*. (2008) which is commonly known to be mathematically more difficult than linear programming models in obtaining optimal solutions.

The project is organized as follows. The next section summarizes previous researches in the literature related to the ITP and environmental costs. Third section describes the ITP more specifically along with formulating the ITP as a linear programming model and the estimation methods of cost factors, including the environmental costs. The data used in the model are summarized in Section 4 and the test results and their policy implications are described in Section 5. Finally, this study suggests future research directions.

2. Relevant Literature Review

The relevant literature to our problem can be three-fold: the transportation route closely related to the ITP and the network design and multimodal network flow problems; the estimation of environmental costs of various transport modes; and the SSS in the context of intermodal transport problem.

As for the problem of determining the transportation route, several research articles among various works are noteworthy. Min (1991) considers the problem of determining the transportation route and mode (among truck, airplane, and deep-sea vessel) while dispatching cargoes to a destination located in an overseas country, aiming to minimize the cost and time, and risk factors. To solve the problem, he employs a goal programming model subject to a chance constraint needed to calculate the risk. Barnhart and Ratliff (1993) consider the problem of determining the minimum cost routing for each shipment with the combination of truck and rail. The cost includes the transportation and inventory holding costs. To solve the problem, they employ a shortest path and weighted *b*-matching algorithms. More recently, Boardman *et al*. (1997) consider the problem of determining the transportation route and the combination of transport modes (truck, rail, air, and barge) while minimizing cost and time. To solve the problem, they suggest a sort of shortest path algorithm. The ITP considered in this project is a special case of network design and multimodal network flow problems. The network design problem has been widely considered in the literature, in which there are a variety of its applications including transportation, telecommunication, and power systems (Costa, 2005). Magnanti and Wong (1984), Minoux (1989), and Balakrishman (1987) deal with applications, models, and methods of network design. A multimodal network flow problem determines the transportation flow and mode. A thorough review of the methods of the multimodal network flow problem has been made by several scholarly researches of (Crainic and Rousseau, 1986; Guelat *et al*., 1990; Crainic et al., 1990; Drissi-Kaitouni, 1991; Haghani and Oh, 1996; Nijkamp *et al*. 2004).

Previous researches on the estimation of the external costs of transport modes are well reviewed in Lee *et al.* (2010) who estimate the external costs of container transportation in Chinese Taipei and draw several policy implications to reduce harm to the environment. Therefore, we review the research articles herewith, which have not been reviewed in Lee *et al*. (2010). Mayeres *et al*. (1996) consider congestion, air pollution, accidents and noise costs and estimate the external costs of five different transportation modes, i.e., cars, bus, trams, metro and trucks, in Brussels. Janic (2007) develops a cost model combining internal cost and external cost in intermodal and road freight transport network. The internal cost includes ownership, insurance, repair and maintenance, labor, energy, taxes, and tolls/fees and the external cost is estimated indirectly using methods considering willingness-to-pay for avoiding, mitigating or controlling particular impacts. Piecyk and McKinnon (2007) analyze external costs of road freight in the UK. The external cost includes air pollution, greenhouse gas emissions, noise, accidents and congestion. Jakob *et al*. (2006) point out that road transportation has caused a social, environmental and economic problem. They calculate the total external costs (accident, air pollution and climate change) in public/private transport sectors.

The research on SSS is recently growing due to its advantages described earlier. Among numerous previous researches on SSS, the following studies are closely related to the ITP. Martínez and Olivella (2005) argue prerequisites for the success of SSS through analysis of existing research results and data in Spain that multi-purpose and fast ships should be used but fast ships could be justified when serving trips less than 12 hours away and when cost is not so important. Higginson and Dumitrascu (2007) describe the key characteristics of SSS used to examine how these characteristics will impact the development of SSS on the Great Lakes in US. The paper finds that the success of SSS with smaller quantity shipments by smaller vessels should be promoted in the long-distance bulk commodity market while frequent, fast, and reliable services are required in the short-distance RO-RO market. De Oses and Castells (2008) analyze the weather influence on several SSS routes to be served by fast ships. Garcia-Menendez and Feo-Valero (2009) analyze the factors affecting the modal choice among truck and SSS using a binary logit model using a Spanish case. SSS is preferred in the situations where the following conditions exist: the distance is between 1000 and 1500 km: shipment's point of origin is within the destination port's immediate hinterland; shipment size is bigger; an export company handles the transport; and shipment value is lower.

From the above literature review, it is clear that no previous studies have been undertaken yet to analyze intermodal transport problems including SSS in the network model and incorporate the environmental costs of transport modes into the model. This study, therefore, intends to fill the gap in the literature.

3. Model Development

3.1 Characteristics of the Problem and Assumptions of the Network.

The problem considered in this project is to determine the optimal amount of cargoes by mode from the origin to destination between Korean markets (or sources in the case of Korea's export cargoes) and their trading seaports overseas while considering the transportation costs, times and environmental costs *en route* over one planning period. The objective of the problem is to minimize the sum of shipping and land transportation costs, their time values and the external costs while meeting the cargo demands and supplies between Korea and her trading partners. The cargo flow network involves: foreign seaports (as the trading points overseas), Korean seaports, inland container depots (ICD) and Korean cities/towns/subregions as the major nodes; truck, train, DSS for long overseas haul and SSS as the major nodes; and container cargoes exported and imported between Korea and her trading nations.

Figure 3-1 illustrates a simple case of the cargo flow network. In the network, each node corresponds to foreign seaports, Korean seaports, ICD, and Korean cities. For example, there are six nodes in the example network which are Seoul, seaports of Incheon, Busan, Shanghai, and Yamaguchi, and Uiwang ICD. Note that foreign seaports refer to locations outside of Korea such as Shanghai and Yamaguchi seaports in Figure 1. Each arrow represents transportation flow of cargoes: solid arrows mean export flows of Korea and dotted arrows display import flows. Note that SSS is represented by the arrows connected between Korean seaports and foreign seaports in Northeast Asia and also between Korean seaports themselves, i.e., coastal shipping. It is assumed that import and export volumes in the figure are generated only in Korean cities and foreign seaports such as Seoul and Shanghai Seaport in the figure, i.e., Korean cities and foreign seaports are sources of import and export while Korean seaports and ICD are not their sources. Also, we assume without loss of generality that exports are not imported, i.e., exports are transported to foreign countries and never imported back to Korea, and vice versa in case of imports. The transportation to a destination in Korea can be undertaken directly either by trucks or trains, or barges (coastal shipping) or via an ICD.

It is assumed that only one type of truck, train, and barge is operated in the process, respectively. On the contrary, different sizes of international vessels are operated depending on the destination seaports in foreign countries to reflect the real situation more closely. However, the same size of international vessel is operated between the same origin and destination pairs. Also, in the process of transportation from/to ICDs, it is assumed that trains and trucks are operated between seaports and the ICDs while trucks are only operated between ICDs and cities, which is reflective of the real

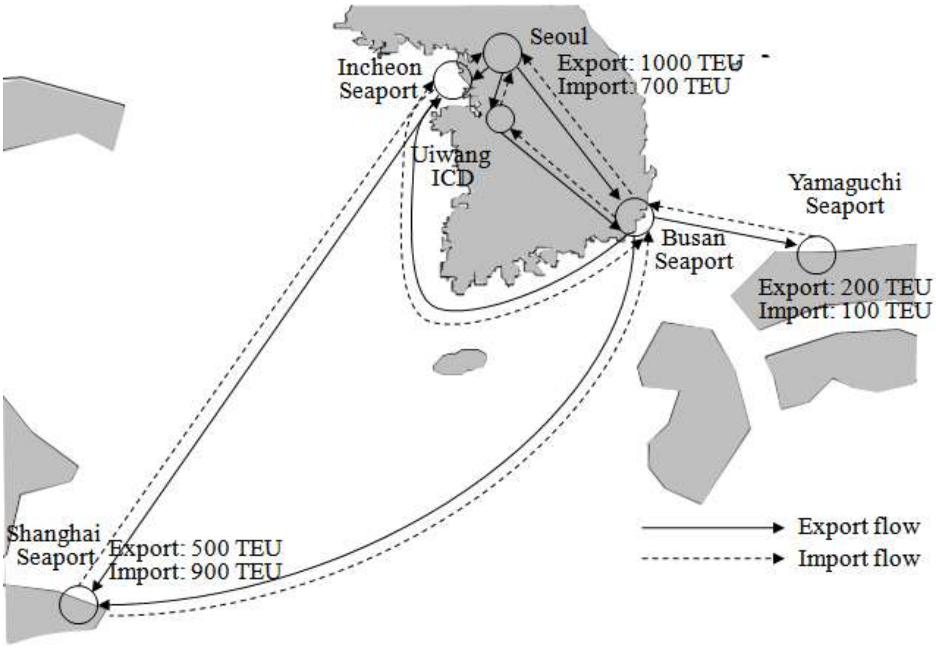

Figure 3-1. **An Example of the Cargo Flow Network**

situation in Korea. The flow between ICDs, cities, foreign seaports is not assumed to occur based on the real situation in Korea.

Finally, other assumptions are summarized as follows:

(a) every parameter used in the model is given and deterministic;

(b) one type of container is used while transporting cargoes without any traffic congestion; and

(c) all transport modes are perfect in state. That is to say, they are not out of order throughout the planning period.

3.2 Formulation of Linear Programming Model

For the convenience of readers unfamiliar with mathematical notations, we place the major notations and constraint functions of the model in the Appendix.

3.2.1 Objective Function

The objective function of the problem is to minimize the sum of shipping and land transportation costs, the time values, and external costs by mode *en route*. Equation (3-1) shows how to calculate the cost summation.

Minimize

$$\begin{aligned}&\sum_{i\in I}\sum_{j\in J} c_{ij4}\cdot(X_{ij}+X_{ji})+\sum_{j\in J}\sum_{k\in K}\sum_{m\in\{1,2\}} c_{jkm}\cdot(Z_{jkm}+Z_{kjm})\\&+\sum_{j\in J}\sum_{b\in J\setminus\{j\}}\sum_{k\in K} c_{jb3}\cdot(Y_{jbk}+Y_{kbj})+\sum_{j\in J}\sum_{c\in C}\sum_{m\in\{1,2\}} c_{jcm}\cdot(Z_{jcm}+Z_{cjm})+\sum_{c\in C}\sum_{k\in K} c_{ck1}\cdot(Z_{ck1}+Z_{kc1})\end{aligned} \tag{3-1}$$

In the objective function, the first term refers to the total shipping cost obtained by multiplying the transportation cost of ships, indexed 4 and the transportation quantity between foreign seaports and Korean seaports. The second term means the land transportation costs of truck and train, indexed 1 and 2 respectively. The third term shows another shipping cost of a coastal barge, indexed 3. Finally, the fourth and last terms denote the transportation cost when transported via ICDs. Since truck and train are used in the transportation between seaports and ICDs as described in Section 3.1, the usage of truck and train is reflected in the fourth term in the equation. On the other hand, the last term indicates that only trucking is used in the transportation between cities and ICDs as described in Section 3.1.

3.2.2 Constraints

For notational form of constraint functions, see the Appendix as mentioned before.

Import and Export Amount Constraints. Constraint (3-2) in the Appendix indicates the export amount restriction, which requires that the total cargo amount exported from a depot should be equal to the export amount at the depot. On the other hand, constraint (3) reflects that the import amount in a foreign seaport and a Korean city should be satisfied.

Flow Conservation Constraints. Constraints (3-4) and (3-5) represent the flow conservation at Korean seaport, which requires that the amount of cargoes coming to a

Korean seaport represented in the left side term in the equation should be equal to the amount of cargoes going out from the seaport represented in the right side term in the equation.

Capacity Constraints. Constraint (3-6) states that the total amount of cargoes handled at a Korean seaport cannot exceed the capacity of the seaport. The first term represents the amount of incoming and outgoing cargoes and the second term represents the amount of transhipment cargoes in the transportation between cities and other seaports. On the other hand, constraint (3-7) implies the capacity restriction on the amount of cargoes handled at ICDs.

Modal Split at Seaports Constraints. Constraints (3-8) and (3-9) represent modal split constraints for the cargoes transported via Korean seaports, where a modal split describes the number of cargoes transported using each transport mode. Constraint (3-8) implies that the amount of cargoes imported from a Korean seaport to a city is transported directly by truck and train, or by coastal barge, or via ICDs. The first term on the left side in the equation indicates the amount of cargoes transported directly from the seaport to the city and the second term implies the amount coming into the seaport from other Korean seaports for transportation from the seaport to the city. On the other hand, the terms on the right side shows the amounts transported by truck, train, barge or via ICDs. The first term implies the transported amount by truck and train. The second term denotes the amount of cargoes transported using coastal barges through other Korean seaports and the last term represents the amount transported via ICDs. Finally, constraint (3-9) reflects the modal split for export of cargoes from cities and Korean seaports.

Modal Split at ICDs Constraints. Constraints (3-10) - (3-13) represent the other modal split constraints for the cargoes transported via ICDs. Constraint (3-10) shows that all cargoes on the path of a Korean seaport, an ICD, and cities are delivered by truck and train, and vice versa in case of constraint (3-11) as described in Section 3.1. Constraints (3-12) and (3-13) mean that cargoes transported between ICDs and cities are delivered only by truck as described in Section 3.1.

Vehicle Capacity Constraints. Constraints (3-14) - (3-24) represent that the total transported amount of cargoes cannot exceed the total volume that can be transported by available vehicles. The capacity constraints are different by transport mode to reflect the real situation that trains, coastal barges, and international vessels are operated on regular train and navigation lines while trucks are operated without regular lines, i.e., trucks can go anywhere. Therefore, we assign the capacity for truck as the multiplication of the carrying capacity of one truck (one TEU: twenty foot equivalent unit) and the total available time of trucks at a depot while the capacities for train and vessel are assigned as the multiplication of the carrying capacity of the corresponding vehicle and the number of vehicles operated during the planning period (one year). In addition, the carrying capacity of an international vessel is assigned differently depending on its direction according to the real situation that ships with different ship sizes are operated if directions are different. The capacity restrictions for trucks, trains, coastal barges, and international vessels are reflected in constraints (3-14) - (3-16), (3-17) - (3-20), (3-21) - (3-22), and (3-23) - (3-24), respectively.

Finally, remaining constraints are non-negativity restrictions on decision variables, i.e., all decision variables are set to be more than or equal to zero in the remaining constraints.

3.3 Cost Factors

The cost factors captured in the model are three-fold: direct transportation cost; the time values of the cargoes as in-transit inventory costs; and the external costs by mode. In determining the optimal cargo flow by each transport mode, we consider the land transportation and shipping costs including external costs. The land transportation cost refers to the total cost charged to cargoes transported in Korea, including the in-transit inventory, transit costs of the cargoes, and the external cost, which is denoted as

$$c_{ijm} = h \cdot t_{ijm} + p_{ij} + w \cdot e_{ijm} \quad \text{for } m \in \{1,\ 2\}$$

The in-transit inventory cost implies the cost incurred by holding cargoes during the transportation obtained by $h \cdot t_{ijm}$ in the equation, while the transit cost is the one charged for transporting cargoes. Finally, the external cost whose equation is explained later implies the cost required to eliminate various pollutants incurred by the traffic of each transport mode. That is, the diesel engine of a truck emits NO_X, SO_2, and VOC and some costs which are the external cost are required to eliminate the pollutants. As can be seen from the above equation, the external cost is internalized by multiplying an internalization factor and the external cost. On the other hand, the shipping costs imply that the total costs charged in the process of cargoes transported between foreign and Korean seaports. They include the in-transit inventory and transit costs, terminal handling charge of cargoes, and the external cost which is denoted as

$$c_{ijm} = h \cdot t_{ijm} + p_{ij} + thc_j + w \cdot e_{ijm} \quad \text{for } m \in \{3,\ 4\}$$

The terminal handling charge is the cost of the stevedoring service of cargoes at seaport. We used the sea freight rate including the terminal handling charge at foreign seaports since our study focuses on different levels of usage at Korean seaports caused by a more distinctive and detailed cost structure.

To estimate the environmental cost, we use the *avoidance cost approach* which is more feasible since the approach is easier to implement than other methods (2007). The calculation of the external cost varies by transport mode because trucks and trains commonly use a single fuel type, i.e., diesel but ships use various fuel types and therefore pollutant types emitted by different transport mode are different (1996). The following equations are obtained from Lee *et al*. (2010) summarizing the equations obtained from the last and most reliable various sources. First, the cost for truck and train is calculated by

$$e_{ijm} = l_{ij} \cdot \sum\nolimits_p a_p \cdot k_p \quad \text{for } m \in \{1,\ 2\}$$

On the other hand, the cost for barge and international vessel is calculated by

$$e_{ijm} = l_{ij} \cdot \sum_p \sum_l a_p \cdot f_l \cdot k_{lp} \quad \text{for } m \in \{3,\ 4\}$$

4. Data Collection

Data were collected from various sources to test and run the linear programming model as formulated in the previous section. Basically, the data used in this research are rooted from the data in Kim *et al*. (2008) and Lee *et al*. (2010). In addition to the data in Kim *et al*. (2008), we collected more data related to external cost, coastal shipping, and DSS. Also, vehicle capacity data were modified after more scrutinizing the data. The data are related to three modes for land transportation (truck, train, and barge), two

ICDs (Uiwang and Yangsan), five Korean seaports (Busan, Gwanyang, Incheon, Ulsan, and Pyeongtaek), and forty-three Korean regions. As in Kim *et al*. (2008), the regions were selected and aggregated on the basis of industrial complex, population map, transportation network, province, metropolitan and special city size.

In the case of foreign seaports, we checked major shipping routes of SSS and DSS, to focus on SSS in more details. Therefore, we attempted to include the SSS related seaports as detailed and numerous as possible. The seaports selected in the group of SSS routes are major ones handling Korea's international container cargoes in the region. Major seaports for the DSS transportation are selected only in terms of cargo trading volumes with Korea. In sum, thirteen DSS seaports and twenty-two SSS seaports were selected for the model. They are located in:

- Western Europe
- Eastern Europe
- North America (except the US)
- USA: Detroit, Houston, Long Beach, New York, Savannah, Seattle
- South America
- Middle East and Central Asia
- Africa
- Japan: Yokohama, Yamaguchi, Tokyo, Osaka, Nagoya, Hakata, other seaports
- Hong Kong, China
- Chinese Taipei: Kaohsiung, Keelung, other seaports
- China: Shanghai, Xingang, Dalian, Qingdao, Ningbo, Weihai, Yantai, other seaports in China

- Singapore, Malaysia, and other seaports in Southeast Asia

Table 3-1. Export and Import Data (TEU)

(a) Foreign Seaport

	WE	EE	NA	DT	HS	LB	NY	SV	ST	SA	ME	CA
Export	659,592	146,124	102,012	0	3,648	161,544	49,164	48,240	125,544	167,364	71,808	59,964
Import	414,295	112,354	180,957	2,506	3,013	366,083	50,201	41,404	182,113	355,768	343,669	173,546
	AF	YK	YM	TK	OK	NG	HT	OJ	HK	KS	KL	OT
Export	22,584	121,560	1,044	94,116	130,056	68,964	101,904	341,016	556,032	479,580	25,008	13,236
Import	178,751	45,706	30,848	72,168	61,287	47,429	27,776	118,043	301,084	62,347	68,662	23,437
	SH	XG	DL	QD	NB	WH	YT	OC	SP	ML	OS	
Export	185,632	205,663	134,818	202,341	82,663	40,196	24,866	108,700	150,612	119,544	17,448	
Import	206,996	234,683	106,751	174,024	81,057	43,575	56,309	19,372	78,326	111,331	402,349	

1. Seaports in DSS region
   WE: Western Europe; EE: Eastern Europe; NA: North America (except the US); DT: Detroit; HS: Houston; LB: Long Beach; NY: New York; SV: Savannah; ST: Seattle; SA: South America; ME: Middle East; CA: Central Asia; AF: Africa
2. Seaports in SSS region
   YK: Yokohama; YM: Yamaguchi; TK: Tokyo; OK: Osaka; NG: Nagoya; HT: Hakata; OJ: Other seaports in Japan; HK: Hong Kong; KS: Kaohsiung; KL: Keelung; OT: Other seaports in Chinese Taipei; SH: Shanghai; XG: Xingang; DL: Dalian; QD: Qingdao; NB: Ningbo; WH: Weihai; YT: Yantai; OC: Other seaports in China; SP: Singapore; ML: Malaysia; OS: Other seaports in Southeast Asia

Source: Korea Customs and Trade Development Institute

(b) Korean Cities

	GW1	GW2	GW3	GG1	GG2	GG3	GN1	GN2	GN3	GB1	GB2
Export	1,545	5,365	3,150	135,168	471,827	138,460	30,257	87,091	75,570	34,504	69,230
Import	657	10,897	9,194	90,985	508,915	71,670	41,459	289,190	183,390	44,027	48,514
	GB3	GJ1	GJ2	DG1	DG2	DJ1	DJ2	PS1	PS2	PS3	SU1
Export	88,778	11,949	11,461	67,686	16,724	40,742	7,600	124,846	56,957	97,515	97,048
Import	286,480	235,019	17,173	63,717	37,957	105,488	6,629	176,397	39,945	43,564	36,597
	SU2	SU3	SU4	SU5	US1	US2	IC1	IC2	IC3	CN1	CN2
Export	426,534	28,509	1,777,007	184,403	28,916	54,112	326	220,836	66,609	8,393	12,639
Import	308,764	13,196	198,946	93,818	79,159	565,335	706	126,240	136,998	7,127	9,231
	CN3	CB1	CB2	CB3	CUN1	CUN2	CUN3	CUB1	CUB2	CUB3	
Export	32,756	68,092	6,035	3,150	12,843	40,051	62,972	74,371	27,717	12,843	
Import	320,270	165,617	5,449	3,782	95,188	96,527	79,344	81,813	33,603	9,243	

GW1: Gangwon1; GW2: Gangwon2; GW3: Gangwon3; GG1: Gyunggi1; GG2: Gyunggi2; GG3: Gyunggi3; GN1: Gyungnam1; GN2: Gyungnam2; GN3: Gyungnam3; GB1: Gyungbuk1; GB2: Gyungbuk2; GB3: Gyungbuk3; GJ1: Gwangju1; GJ2: Gwangju2; DG1: Daegu1; DG2: Daegu2; DJ1: Daejon1; DJ2: Daejon2; PS1: Busan1; PS2: Busan2; PS3: Busan3; SU1: Seoul1; SU2: Seoul2; SU3: Seoul3; SU4: Seoul4; SU5: Seoul5; US1: Ulsan1; US2: Ulsan2; IC1: Incheon1; IC2: Incheon2; IC3: Incheon3; CN1: Cheonnam1; CN2: Cheonnam2; CN3: Cheonnam3; CB1: Cheonbuk1; CB2: Cheonbuk2; CB3: Cheonbuk3; CUN1: Chungnam1; CUN2: Chungnam2; CUN3: Chungnam3; CUB1: Chungbuk1; CUB2: Chungbuk2; CUB3: Chungbuk3

Source: Korea Customs and Trade Development Institute

The number of TEUs transported by a transport unit mode was set to 1 for a truck, 50 for a train, 215 for a coastal barge, while 600 TEU was set for the carrying capacity of international vessels navigating on Northeast Asian routes and 1100 TEU was set for the route to Singapore, Malaysia, and other seaports in Southeast Asia for the SSS region, 6000 TEU was set for the DSS region. All these sizes of carrying capacity by unit mode were based on empirical data in consultation with transportation companies in the region. Tables 3-1 and 3-2 summarize the export and import data in foreign seaports and Korean cities in year 2005, which are different from the data in Kim *et al*. (2008) due to the cargoes for DSS. The holding cost was set to US$10.08 per TEU/day derived from Chang and Sung (2002). The terminal handling charge for imported and exported cargoes from/to foreign seaports was set to US$133, 108, 112, 108, and 108 for Busan, Gwanyang, Incheon, Ulsan, and Pyeongtaek, respectively, while the charge for cargoes in coastal barge was set to 25% of the charge at each seaport. All the port charges were based on the data collected from the port industry.

Table 3-2. Avoidance Cost and Emission Factor of Pollutant Type and Consumption of Fuel Type

Pollutant type	Avoidance cost (US$/ton emission)	Emission factor			
		Truck (gram/TEU-km)	Train (gram/TEU-km)	Vessel (gram/kilogram fuel)	
				Heavy oil	Diesel oil
PM_{10}	375,888	0.75	0.16	1.2	7.6
NO_X	4,992	10.15	6.56	57.0	87.0
VOC	1,390	0.65	0.08	2.4	2.4
SO_2	13,960	0.30	3.85	10.0	54.0
CO_2	26	277.00	184.86	3,170.0	3,170.0
Consumption of fuel type (gram/TEU-km)				103.7	5.3

The data required for calculating the external cost are the distance, the avoidance cost of each pollutant type by transport mode, the consumption of each fuel type and the emission factor of each pollutant type for truck, train, and ship. The distance data are calculated by multiplying the transit time of each mode summarized in Kim *et al*. (*6*) and speed of truck (80 km/hr), SSS vessel (12 knots), and DSS vessel (20 knots). The other data related to external costs are summarized in Table 2 which was derived from Forkenbrock (2001), Lee *et al*. (2010), and Kamp *et al*. (2009), by assuming that the weight of one TEU is 17.5 ton. We set the internalization factor of external costs to 0.59 by averaging 0.3 in Britain and 0.88 in Poland, Greece and Luxembourg (2007) since such data are not available in Korea to the best of our knowledge. Finally, the data for the other sea freight and transit time are the same as the data in (2008). Remaining data such as sea freight and transit time between foreign and Korean seaports, available time of truck, the number of available calls of train, coastal barge, and international vessel and the capacities of each Korean seaport and each ICD are omitted due to the limitation on the number of words given in this project. They, however, can be referenced in Kim *et al*. (2008).

5. Test Results of the Model and Discussion with Policy Implication

This section summarizes test results of the linear programming model using the data given in Section 3 and Appendix. First, the model's result is compared with the real situation in Korea to validate the model before internalization of the environmental costs is incorporated into the model. Then, by relaxing several constraints in the model, we attempt to draw several possible policy implications for the development of SSS. In the test, the model was solved using CPLEX 11.2, a commercial software package.

The test results of the model for the validation are summarized in Table 3-3(a) as the final result after many rounds of running the model by calibrating parameters and checking how well our model represents the real situation in Korea. As can be seen from Table 3, the model generates a similar share of total container cargo volume among Korean seaports and by each transportation mode compared to the real situation. Therefore, our research team concluded that our model was validated at least in that adding environmental costs to the optimization as our study purpose can be tested and also various policy alternatives can be tested using the model. Consequently, we added the environmental costs by mode into the model to measure the environmental impact by mode. Table 3-3(b) shows the external costs generated by each transport mode. As can be seen from Table 3-3(b), the total external cost of truck incurs US$ 509.2 million which is the largest among the three modes and PM_{10} is the most significant among pollutant types.

Table 3-3. Test Results of the Model

(a) Comparison of the Model’s Result with Real Situation

(a.1) Container Cargo Volume at Each Korean Seaport

Port	Model		Real
	TEU	TEU %*	TEU %†
Busan	7,280,193	74.1	78.3
Gwangyang	1,217,787	12.3	8.9
Incheon	1,004,112	11.0	9.0
Ulsan	156,200	1.5	1.7
Pyeongtaek	162,675	1.1	2.0

* (throughput / total cargo volume)·100

† real share in Korea in year 2005

(a.2) Modal Split of Each Transport Mode (%)*

Transport Mode	Model		Real
	TEU	TEU %*	TEU %†
Truck	10,511,462	85.3	87.3
Train	1,731,124	12.9	9.9
Barge	220,160	1.8	2.8

* (cargo volume / total cargo volume)·100

† real modal split in Korea in year 2005

(b) External Costs of Each Transport Mode (million US$)

	PM_{10}	NOx	VOC	SO_2	CO_2	Total
Truck	416.2	74.8	1.3	6.2	10.6	509.2
Train	37.9	20.2	0.1	33.2	3.0	94.4
Barge	10.1	5.2	0.1	3.0	1.5	19.9
Total cost	464.2	100.2	1.5	42.4	15.1	623.4

Once we developed our validated model and were also able to incorporate the environmental costs into our model, we attempted to test how the container cargoes would have been handled at different seaports and by different mode in Korea if government policy had been formulated in more eco-friendly direction. In addition, we estimated how much environmental costs would have been reduced by developing more environmentally sustainable transportation system such as SSS. To this end, we relaxed the capacity and vehicle restrictions as discussed in Section 3.2.2, given that the other constraints and data remain unchanged. In other words, this is to test how optimal logistics system will evolve when considering environmental costs by developing currently underdeveloped seaports and deploying larger vehicles in SSS and train system. The test result is summarized in Table 3-4. From the Table 3-4(a), the throughput share of seaports of Busan, Incheon, and Pyeongtaekwould have been reduced as much as nearly 51.9%, 13.9%, and 94.8%, respectively, while the throughput share of seaports of Gwangyang and Ulsan could have increased by approximately 208.8% and 1446.1%. The results imply that the seaports of Busan, Incheon, and Pyeongtaek would have been less used and the rest of the Korean seaports more utilized if the external costs of the above three transport modes had been internalized. Table 3-4(b) indicates a successful example of modal shift in Korea, which has been one of long-standing policy aims. That is, in case of no restrictions to capacity and vehicle, the model output shows that coastal shipping services would have enormously increased by over five times if the external costs had been internalized. This means if we had further developed seaports and SSS capacity in terms of available number of ships and bigger size ships, SSS would have developed at a higher rate in the region and as a result, the total external cost could have reduced from 623.5 million US$ to 334.1 million US$ as can be seen from Table 3-3(b) and 3-4(c).

From the results, we can draw some meaningful and significant policy implications. First, when considering environmental impacts by mode, more environmentally friendly modes such as SSS and rail can reduce enormous costs to the society in Korea. Such modal development will contribute to reducing air pollution and greenhouse emissions. Second, formulating transport policies toward formally internalizing the environmental costs into cost accounting system of transport network would lead to more balanced modal shift. Therefore, the transport policy should be directed toward capturing the environmental costs. Third, more favorable movements toward SSS would encourage under- or less- developed seaports in peripheral region further developed in the future. In contrast, hub oriented port development as shown in our test case in Korea may play a relatively weak role due to the cargo shifts from the hub to the peripheral seaports. Fourth, pollution caused by ships has lately being reduced more rapidly than by the other transportation modes, since they were previously favored by less stringent rules of regulating ships' pollution. Therefore, if we used more current years' data, the pollution reduction effect by SSS must have been even greater than the results of this study.

Table 3-4. Effects without Capacity and Vehicle Constraints

(a) Container Cargo Volume at Each Korean Seaport

Port	Model		Real	Change ratio‡
	TEU	TEU %*	TEU %†	
Busan	4,542,761	37.7	78.3	-51.9
Gwangyang	3,317,561	27.5	8.9	208.8
Incheon	931,674	7.7	9.0	-13.9
Ulsan	3,250,097	27.0	1.7	1,446.1
Pyeongtaek	12,843	0.1	2.0	-94.8

* (throughput / total cargo volume)·100

† real share in Korea in year 2005

‡ [(mode share – real share) / current share] ·100

(b) Modal Split of Each Transport Mode

Transport Mode	Model		Real	Change ratio
	TEU	TEU %*	TEU %†	
Truck	5,567,541	43.6	87.3	-50.0
Train	4,743,190	37.2	9.9	275.3
Barge	2,454,129	19.2	2.8	586.6

See the footnote in (a)

* (cargo volume / total cargo volume)·100

† real modal split in Korea in year 2005

(c) External Costs of Each Transport Mode (million US$)

	PM_{10}	NOx	VOC	SO_2	CO_2	Total
Truck	64.8	11.7	0.2	1.0	1.7	79.3
Train	79.6	42.5	0.1	69.8	6.2	198.4
Barge	28.8	14.8	0.2	8.6	4.2	56.4
Total cost	173.2	68.9	0.5	79.4	12.1	334.1

6. Conclusions

This project intended to contribute to the literature by analyzing an intermodal transportation problem of international container cargoes (ITP) while incorporating the external costs of the modes into an optimization model in Korea. To optimally solve the problem, we employed a linear programming model and to estimate the environmental cost, we used the *avoidance cost approach* which is more feasible since the approach is easier to implement than other methods (2007). The test results of the model showed a strong foundation to encourage more environmentally friendly modes such as short sea shipping (SSS) and rail and provided reference analysis on how to achieve a well-balanced modal shift if transport policy is formulated in this direction.

There are some avenues for further researches. First, the export and import volume in foreign cities that has not been considered in this project due to intractability of the data is worthwhile to be included for developing more elaborate model if the data are available in the future. Second, the other external factors, such as congestion, noise, and accidents, can be integrated into the model to reflect their external costs more comprehensively. Third, although cost minimization study is a challenging work, future study can be also directed toward maximizing the economic value of transportation, by fully accounting for external costs.

References

APEC Transportation Working Group. 2009. Short Sea Shipping Study: A Report on Successful SSS Models That Can Improve Ports' Efficiency and Security While Reducing Congestion, Fuel Costs, and Pollution

Balakrishnan, A. 1987. “LP extreme points and cuts for the fixed-charge network design problem.” *Mathematical Programming* 39: 263-284

Barnhart, C. and Ratliff, H. D. 1993. “Modeling intermodal routing”. *Journal of Business Logistics* 14: 205-223

Boardman, B. S., Malstrom, E. M., Butler, D. P., and Cole, M. H., 1997. “Computer assisted routing of intermodal shipments”. *Computers and Industrial Engineering* 33: 311-314

Chang, Y.-T. and Sung, S.-K. 2002. "Revisit to estimate the time cost of ships and cargoes.” *Journal of Korean Navigation and seaport Research* 26: 383-390

Costa, A. M. 2005. “A Survey on benders decomposition applied to fixed-charge network design problems.” *Computers and Operations Research* 32: 1429-1450

Crainic, T., Florian, M., and Leal, J. 1990. “A model for the strategic planning of national freight transportation by rail.” *Transportation Science* 24: l-24

Crainic, T., and Rousseau, J. 1986. “Multicommodity, multimode freight transportation: a general modelling and algorithmic framework for the service network design problem.” *Transportation Research-Part B* 20: 225-242

De Oses, F. X. M. and la Castells. M. 2008. “Heavy weather in European short sea shipping: its influence on selected routes.” *Journal of Navigation* 61: 165-176.

Drissi-Kaitouni, O. 1991. “Solution approaches for multimode multiproduct assignment problems.” *Transportation Research-Part B* 25: 317-327

European Commission. White Paper. 2001. European Transport Policy for 2010: Time to Decide. Luxembourg: Office for Official Publications of the European Communities.

Forkenbrock, D. J.. 2001. “Comparison of external costs of rail and truck freight transportation.” *Transportation Research-Part A* 35: 321-337

Garcia-Menendez, L and Feo-Valero, M. 2009. “European common transport policy and short-sea shipping: empirical evidence based on modal choice models.” *Transport Reviews* 29: 239-259

Guelat, J., Florian, M., and Crainic, T. 1990. “A multimode multiproduct network assignment model for strategic planning of freight flows.” *Transportation Science* 24: 25-39

Haghani, A. and Oh, S.-C. 1996. "Formulation and solution of a multi-commodity, multi-modal network flow model for disaster relief operations.” *Transportation Research-Part A* 30: 231-251

Higginson, J. K. and Dumitrascu, T. 2007. “Great Lakes short Sea shipping and the domestic cargo-carrying fleet.” *Transportation Journal* 46: 38-50

Jakob, A, Craig, J. L., and Fisher, G. 2006. “Transport cost analysis: a case study of the total costs of private and public transport in Auckland Astrid.” *Environmental Science & Policy* 9: 55-66

Janic, M. 2007. “Modelling the full costs of an intermodal and road freight transport network.” *Transportation Research Part D: Transport and Environment* 12: pp. 33-44

Kamp, B., Lloyd, M., and Vassallo, W. 2009. Final Report on Environmental Impact Analyses in Transport. Technical Report, The Alliance of Maritime Regional Interests in Europe

Kim, H.-J., Chang, Y.-T., Lee, P. T.-W., and Shin, S.-H. 2008. “Optimizing the transportation of international container cargoes in Korea.” *Maritime Policy and Management* 35: 103-122

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: 315-335

Magnanti, T. L. and Wong, R. T. 1984. “Network design and transportation planning: models and algorithms.” *Transportation Science* 18: 1-55

Martínez, F. X. and Olivella, J. 2005. “Short sea shipping opportunities for the Pyrenean cargo flows.” *Journal of Maritime Research* 2: 65–80

Mayeres, I, Ochelen, S., Proost, S. 1996. “The marginal external costs of urban transport.” *Transport Research-Part D* 1: 111-130

Min, H. 1991. “International intermodal choices via chance-constrained goal programming.” *Transportation Research- Part A* 25: 351-362.

Minoux, M. 1989. “Network synthesis and optimum network design problems: models, solution methods and applications.” *Networks* 19: 313-360

Nijkamp, P., Reggiani, A., and Tsang, W. F. 2004. “Comparative modelling of interregional transport flows: applications to multimodal European freight transport.” *European Journal of Operational Research* 155: 584-602

Paixao, A.C. and Marlow. P. B. 2002. “Strengths and weaknesses of short sea shipping.” *Marine Policy* 26: 167-178

Piecyk, M. and McKinnon, C. M. 2007. “Internalising the external costs of road freight transport in the UK.” Technical Report, *Heriot-Watt University*

U.S. Government Accountability Office (GAO). 2005. Short Sea Shipping Option Shows Importance of Systematic Approach to Public Investment Decisions, Report Number GA0-05-768, July 2005.

van Essen, H. P., Boon, B. H., Maibach, M., and Schreyer, C. 2007. “Methodologies for external cost estimates and internalization scenarios”, Presented at the Workshop on Internalisation, CE Delft and INFRAS, Oude Delft, Delft, The Netherlands

Appendices

A.1 Notations

In the equations and the linear programming model, we consider a set of transport modes denoted as {1, 2, 3, 4} where 1 represents truck, 2 train, 3 costal barge, and 4 international vessel.

Sets

C	set of ICDs
I	set of foreign seaports
J	set of Korean seaports
K	set of Korean cities

Parameters

a_p	avoidance cost of pollutant type *p*
c_{ijm}	transportation cost of transporting one TEU by transport mode *m* from origin *i* to destination *j*
d_i	import amount at depot *i*
e_{ijm}	external cost by transport mode *m* per TEU from origin *i* to destination *j*

f_l	consumption amount of fuel type l per TEU-km
h	inventory holding cost per TEU and unit time
k_p	emission factor of pollutant type p
k_{lp}	emission factor of pollutant type p for ship using fuel type l
K_i	capacity of depot i
l_{ij}	distance from origin i to destination j
n_m	TEUs that can be carried by transport mode m, i.e., carrying capacity of transport mode m
ns_i	TEUs that can be carried by a vessel from foreign seaport i
p_{ij}	sea freight per TEU from origin i to destination j
s_i	export amount at depot i
t_{ijm}	transit time of transport mode m from origin i to destination j
thc_j	terminal handling charge per one TEU
u_i	available time of truck at depot i
v_{ijm}	number of available calls of transport mode m from origin i to destination j
w	internalization factor of external cost

Decision variables

X_{ij}	transport amount from origin i to destination j
Y_{ijk}	transport amount from origin i to destination k via depot j
Z_{ijm}	transport amount via transport mode m from origin i to destination j

A.2. Constraints

Import and Export Amount Constraints

$$\sum_{j\in J} X_{ij} = s_i \qquad \text{for } i \in I \cup K \tag{3-2}$$

$$\sum_{j\in J} X_{ji} = d_i \qquad \text{for } i \in I \cup K \tag{3-3}$$

Flow Conservation Constraints

$$\sum_{i\in I} X_{ij} = \sum_{k\in K} X_{jk} \qquad \text{for } j \in J \tag{3-4}$$

$$\sum_{k\in K} X_{kj} = \sum_{i\in I} X_{ji} \qquad \text{for } j \in J \tag{3-5}$$

Capacity Constraints

$$\sum_{i\in I} (X_{ij} + X_{ji}) + \sum_{b\in J\setminus\{j\}} \sum_{k\in K} (Y_{bjk} + Y_{kjb}) \le K_j \qquad \text{for } j \in J \tag{3-6}$$

$$\sum_{j\in J} \sum_{k\in K} (Y_{jck} + Y_{kcj}) \le K_c \qquad \text{for } c \in C \tag{3-7}$$

Modal Split at Seaports Constraints

$$X_{jk} + \sum_{b\in J\setminus\{j\}} Y_{bjk} = \sum_{m\in\{1,2\}} Z_{jkm} + \sum_{b\in J\setminus\{j\}} Y_{jbk} + \sum_{c\in C} Y_{jck} \qquad \text{for } j \in J \text{ and } k \in K \tag{3-8}$$

$$X_{kj} = \sum_{m\in\{1,2\}} Z_{kjm} + \sum_{b\in J\setminus\{j\}} Y_{kbj} + \sum_{c\in C} Y_{kcj} \qquad \text{for } j \in J \text{ and } k \in K \tag{3-9}$$

Modal Split at ICDs Constraints

$$\sum_{k\in K} Y_{jck} = \sum_{m\in\{1,2\}} Z_{jcm} \qquad \text{for } j \in J \text{ and } c \in C \tag{3-10}$$

$$\sum_{k\in K} Y_{kcj} = \sum_{m\in\{1,2\}} Z_{cjm} \qquad \text{for } j \in J \text{ and } c \in C \tag{3-11}$$

$$\sum_{j\in J} Y_{jck} = Z_{ck1} \qquad \text{for } c \in C \text{ and } k \in K \tag{3-12}$$

$$\sum_{j\in J} Y_{kcj} = Z_{kc1} \qquad \text{for } c\in C \text{ and } k\in K \tag{3-13}$$

Vehicle Capacity Constraints

$$\sum_{k\in K} t_{jk1}\cdot Z_{jk1} + \sum_{c\in C} t_{jc1}\cdot Z_{jc1} \le n_1\cdot u_j \qquad \text{for } j\in J \tag{3-14}$$

$$\sum_{k\in K} t_{ck1}\cdot Z_{ck1} + \sum_{j\in J} t_{cj1}\cdot Y_{cj1} \le n_1\cdot u_c \qquad \text{for } c\in C \tag{3-15}$$

$$\sum_{j\in J} t_{kj1}\cdot Z_{kj1} + \sum_{c\in C} t_{kc1}\cdot Z_{kc1} \le n_1\cdot u_k \qquad \text{for } k\in K \tag{3-16}$$

$$Z_{jk2} \le n_2\cdot v_{jk2} \qquad \text{for } j\in J \text{ and } k\in K \tag{3-17}$$

$$Z_{jc2} \le n_2\cdot v_{jc2} \qquad \text{for } j\in J \text{ and } c\in C \tag{3-18}$$

$$Z_{kj2} \le n_2\cdot v_{kj2} \qquad \text{for } k\in K \text{ and } j\in J \tag{3-19}$$

$$Z_{cj2} \le n_2\cdot v_{cj2} \qquad \text{for } j\in J \text{ and } c\in C \tag{3-20}$$

$$\sum_{k\in K} Y_{jbk} \le n_3\cdot v_{jb3} \qquad \text{for } j\in J \text{ and } b\in J\setminus\{j\} \tag{3-21}$$

$$\sum_{k\in K} Y_{kbj} \le n_3\cdot v_{bj3} \qquad \text{for } j\in J \text{ and } b\in J\setminus\{j\} \tag{3-22}$$

$$X_{ij} \le ns_{ij}\cdot v_{ij4} \qquad \text{for } i\in I \text{ and } j\in J \tag{3-23}$$

$$X_{ji} \le ns_{ji}\cdot v_{ji4} \qquad \text{for } i\in I \text{ and } j\in J \tag{3-24}$$

CHAPTER 4. PHASE 2 PROJECT ON SUSTAINABLE INTERMODAL TRANSPORTATION NETWORK USING SHORT SEA SHIPPING

Various models for this phase 2 project build on its phase 1 models and also its extended models as described in Chapter 3. The original model at the phase 1 intended to analyze the usage of Short Sea Shipping by building multi-model transportation network models. The costs considered in the models were direct logistics costs and time costs. This model did not include any aspects of externalities. Thus, the externalities were added into its extended model. The main focus of this phase 2 project is to assess GHG effects arising from the multi-modal transportation as stipulated in the Objective part of Chapter 1. In addition, the model itself was upgraded to reflect more realistic situations, which will be shown in the remainder of this chapter. Once the upgraded model is built, its validation is tested prior to assessing various policy option scenarios. After validation of the model, three scenarios are tested. First, it is assumed that governments will charge portion of externalities more likely in the form of taxes on carbon or environment, similar to European system. This is internalization scenario. Second, it is assumed that government will introduce carbon taxation scheme on consuming fuels. It is carbon taxation scenario. Finally, it is assumed that governments will introduce emission trading scheme (ETS) as observed in numerous advanced economies. It is ETS scenario. Each scenario is assessed by modifying the models slightly.

Analysis of an Intermodal Transportation Network in Korea

from an Environmental Perspective

1. Introduction

One of the environmental problems in the transportation sector in many parts of the world is high concentration of freight on road transportation. Numerous countries, particularly in Europe and North America have explored to develop more sustainable transportation system (de Oses, 2008; GAO, 2005; Ricci and Black 2005). Along this line academia has attempted to capture the environmental aspects of transportation sectors (Beuthe et al. 2002; David J. 1999; David J. 2001; Emile 2004; Lee et al. 2010; Macharis et al. 2010; Ricci and Black 2005). Following the European initiative, Asian countries including Korea have put forward to develop an advanced intermodal system. Korean government, however, is unsure of the benefits of developing a sustainable transportation mode. In addition, they wonder how they should formulate the transportation policy by incorporating environmental aspects (APEC Transportation Working Group, 2009). Current literature reveals that only a few studies attempted to quantify the externalities of intermodal transportation (Beuthe *et al*., 2002; Chang et al. 2010;David, 1999;Forkenbrock, 2001; Lee *et al*., 2010; Macharis *et al*., 2010; Ricci and Black, 2005). Even fewer researches have incorporated the externalities into optimization models, which includes our own previous work (Chang *et al*., 2010). Furthermore, the scope of externalities in the literature is limited to mostly pollution aspects (Chang *et al*., 2010; Lee *et al*., 2010).

Under this context, this project intends to contribute to the literature by developing a sustainable intermodal transportation network model, which can assess both market and non-market costs. To this end, we analyze the international container movements in Korea and build an intermodal transportation network model. The model captures various cost aspects ranging from direct transportation costs and the time costs of cargoes to various externalities arising from inland transport modes such as air pollution, congestion, accidents, noise, and wear and tear. The real transportation situation in Korea is formulated by a linear programming model. The model is validated first by comparing the model output with actual performance, and then the model is extended by incorporating the externalities. Moreover, the model is further developed for assessing the effects of complying with carbon taxation and emission trading scheme. The carbon tax will be charged based on carbon content of burning fossil fuels. The emission trading scheme is a market-based approach which facilitates trading of emission rights between high and low emitting parties. Either carbon taxation or emission trading scheme seems to loom large in international shipping industry in view of recent years' discussions in the International Maritime Organization (Giziakis and Christodoulou, 2010). To address the environmental damages by transport mode, we employ a willingness-to-pay method. Essentially, the approach features the incorporation of environmental economic theories and methodologies into the multimodal transportation model. We employed the willingness-to-pay method for the expected externality arising from pollution of each mode as in our previous work (Chang *et al*., 2010).

This report is organized as follows. Section 2 describes intermodal transportation network in Korea and section 3 explains the model formulation. Section 4 and 5 describe the data used in the model, and the test results and their policy implications, respectively. Finally the project is concluded suggesting avenue of future research.

2. Intermodal Transportation Network in Korea

This section describes an intermodal transportation network handling international container cargoes in Korea considered in this project. Instead of using a detailed transportation network in Korea, which is quite complex and hence nearly impossible to formulate it using a mathematical model, we use a simplified network consisting of major transportation routes in order to formulate it by mathematical models.

Figure 4-1 is an example network for the export containers originating from Seoul, which consists of one origin (Seoul), two inland container depots (ICD) (Uiwang and Yangsan), two seaports in Korea (ports of Incheon and Busan), and six overseas ports (ports of Quingdao, Shanghai, Osaka, Yokohama, Seattle, and Long Beach). Note that the origin and destination of export containers are a region in Korea and an overseas port, respectively, and vice versa for import containers. In the example network in Figure 1, a container with Seoul origin and Seattle port destination can be transported via three transport routes as follows:

Route 1: Seoul $\xrightarrow[\text{truck}]{}$ Busan port $\xrightarrow[\text{liner ship}]{}$ Seattle port

Route 2: Seoul $\xrightarrow[\text{truck}]{}$ Uiwang ICD $\xrightarrow[\text{train}]{}$ Yangsan ICD $\xrightarrow[\text{truck}]{}$ Busan port $\xrightarrow[\text{liner ship}]{}$ Seattle port

Route 3: Seoul $\xrightarrow[\text{truck}]{}$ Incheon port $\xrightarrow[\text{barge}]{}$ Busan port $\xrightarrow[\text{liner ship}]{}$ Seattle port

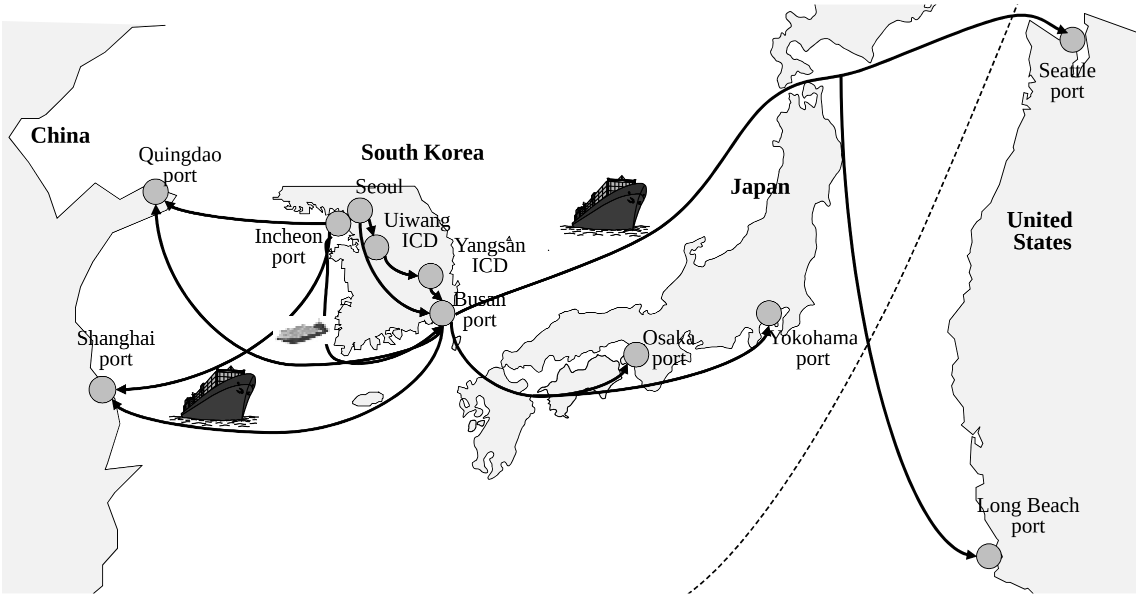

Figure 4-1. An Illustration of the Transportation of Exported Container Cargoes

Although the cargoes can be transported via a train directly from Uiwang ICD to Busan port in reality, we assumed that the cargoes from Uiwang ICD should pass throughYangsan ICD to reach Busan port for the sake of modeling simplicity because Yansan ICD is just in the vicinity of Busan port. The number of possible routes must be more than three as the number of ports in Korea considered in our models is five (described below). Among the routes, our models choose the best route requiring the smallest cost. We assume that the transit time in each node is same for the sake of simplicity of modeling. Especially, the transit time in both Korean ports and overseas ports is assumed to be same although the time can be different according to shipping routes of shipping companies. This assumption of same transit time in each node makes possible to run the model within a reasonable computing time and can be justified as long as the model output can be validated compared with real performance.

The nodes in the network consist of two ICDs (Uiwang and Yangsan), five Korean seaports (ports of Busan, Gwanyang, Incheon, Ulsan, and Pyeongteak), eleven Korean regions (Seoul, Busan, Incheon, Gyeonggi, Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyeongbuk, Gyeongnam), which are provinces and metropolitans and special cities, and thirty four overseas ports, which are selected considering cargo trading volumes with Korea. The overseas ports are: Western Europe (Amsterdam); Eastern Europe (Hamburg); North America except the US (Vancouver); USA (Houston, Detroit, Long Beach, New York, Savannah, Seattle); South America (Santos); Central Asia (Jeddah); Southeast Asia (Singapore, Klang, Other seaports in Southeast Asia); Africa (Durban); Japan (Osaka, Yamaguchi, Yokohama, Nagoya, Hakata, Tokyo, Other seaports in Japan); Hong Kong, China; Chinese Taipei (Keelung, Kaohsiung, Other seaports in Taiwan); and China (Dalian, Ningbo, Shanghai, Qingdao, Xingang, Weihai, Yantai, Other seaports in China).

Four transport modes, such as truck, train, barge, and liner ship, transport the international containers. The transportation between Korean ports and domestic regions is carried out by either truck or train; between Korean ports by barge; between ICDs by train; between ICD and Korean ports and regions by train and truck; and between Korean ports and overseas ports by liner ship.

3. Model Formulation

The problem in this project is to determine the optimal amount of container cargoes by transport mode and route from the origin to destination between Korean major regions and their trading overseas ports. For the problem, this section presents four mathematical models: validation model, external cost model, carbon tax model, and emission trading scheme model. The validation model is developed with a view to representing the real transportation situation in Korea by the model. The other models are extended from the validation model to analyze the impact on the container flows in case when the external costs are internalized and new regulations of either carbon taxation or an emission trading scheme are enforced. The model evaluates the effects of different internationalization ratio considering that Korean government can incorporate different percentages of the total external cost (internalization ratio) as have been practiced in numerous European countries. Our previous models (Chang *et al*., 2010) were based on national economic perspectives, but the models in current study are based on shippers' perspective since the models will be used to analyze how shippers will choose different routes and modes when environmental costs are internalized as in European Union, and also when new regulations on carbon emissions are implemented in the near future. Therefore, shippers choose transport modes and routes in an optimal way considering their transportation costs, time costs, environmental costs incurred by government's internalization policy, and carbon emission payment arising from adoption of either carbon taxation system or emission trading scheme.

The following notations are used throughout this project.

Sets

E	set of externalities
D	set of seaports in Korea

F	set of overseas ports
ICD	set of ICDs
M	set of transport modes: {1, 2, 3, 4} where 1 denote truck, 2 train, 3 barge, and 4 liner ship
R	set of regions

Coefficients

α	internalization ratio of the external cost
c_{mij}	logistics cost of transport mode m from node i to j [US $/TEU] where TEU is a twenty foot equivalent unit
d_{ij}	import or export amount from origin i to destination j [TEU]
e_{me}	external cost of externality e of transport mode m [US $/TEU-km]
$ecap$	CO_2 emission limit [ton]
em_m	CO_2 emissions from transport mode m [ton/TEU-km]
f_{mij}	freight rate per TEU of transport mode m from node i to j [US $/TEU]
l_{ij}	distance from node i to j [km]
p_{GHG}	price of CO_2 emission permits in the CO_2 trading market [US $/ton]
t_{mij}	transit time of transport mode m from node i to j [day]
tax	tax on CO_2 emissions [US $/ton]
tc	daily time cost of a container [US $/TEU]
u	index for Uiwang ICD
y	index for Yangsan ICD

Decision variables

HE	CO_2 emissions from all inland transport modes higher than the emission limit [ton]
LE	CO_2 emissions from all inland transport modes lower than the emission limit [ton]
TK_m	total container movements by transport mode *m* [TEU-km]
X_{mij}^{ab}	container volume transported by transport mode *m* from node *i* to *j* among trading volumes originating from *a* destined to *b* [TEU]

The value of the decision variables is nonnegative.

3.1 Validation Model

To represent the real situation of transporting international container cargoes in Korea, a linear programming model is built because the model is commonly used for transportation-related decisions. The objective of the model is to minimize transportation and inventory costs, which are two major cost centers in logistics decision-making. The transportation cost can be represented by the freight rate of containers and the inventory cost can be estimated by multiplying the time cost of containers by the transit time. The two cost centers are commonly used when shippers select transport mode and route. Therefore, the logistics cost of a container can be expressed as

$$c_{mij} = f_{mij} + tc \cdot t_{mij}$$

Using the transportation network and logistics cost, we suggest a linear programming model. Note again that the linear programming model given below is different from the models in our previous studies (Chang *et al*. 2010; Kim *et al*. 2008) in that the model below considers cargoes from the origin to destination between Korean major regions and their trading overseas ports while the models in our previous studies consider the total number of cargoes supplied or demanded at Korean major regions and their trading overseas ports. In other words, the below model reflects the actual transportation situation in Korea more realistically than the models in our previous studies.

[P1] Minimize

$$\begin{aligned}
&\sum_{a\in F}\sum_{b\in R}\sum_{j\in D} c_{4aj}X_{4aj}^{ab} + \sum_{a\in F}\sum_{b\in R}\sum_{i\in D}\sum_{j\in D-\{i\}} c_{3ij}X_{3ij}^{ab} + \sum_{a\in F}\sum_{b\in R}\sum_{i\in D}\sum_{j\in\{b,y\}} c_{2ij}X_{2ij}^{ab} + \sum_{a\in F}\sum_{b\in R} c_{2yu}X_{2yu}^{ab} \\
&+\sum_{a\in F}\sum_{b\in R}\sum_{i\in D} c_{1ib}X_{1ib}^{ab} + \sum_{a\in F}\sum_{b\in R}\sum_{i\in ICD} c_{1ib}X_{1ib}^{ab} + \sum_{a\in R}\sum_{b\in F}\sum_{j\in ICD} c_{1aj}X_{1aj}^{ab} + \sum_{a\in R}\sum_{b\in F}\sum_{j\in D} c_{1aj}X_{1aj}^{ab} \\
&+\sum_{a\in R}\sum_{b\in F} c_{2uy}X_{2uy}^{ab} + \sum_{a\in R}\sum_{b\in F}\sum_{i\in\{a,y\}}\sum_{j\in D} c_{2ij}X_{2ij}^{ab} + \sum_{a\in R}\sum_{b\in F}\sum_{i\in D}\sum_{j\in D-\{i\}} c_{3ij}X_{3ij}^{ab} + \sum_{a\in R}\sum_{b\in F}\sum_{i\in D} c_{4ib}X_{4ib}^{ab}
\end{aligned} \tag{4-1}$$

subject to

$$\sum_{j\in D} X_{4aj}^{ab} = d_{ab} \qquad \forall\ a\in F,\ b\in R \tag{4-2}$$

$$X_{4ah}^{ab} + \sum_{i\in D-\{h\}} X_{3ih}^{ab} = X_{1hb}^{ab} + \sum_{j\in\{b,y\}} X_{2hj}^{ab} + \sum_{j\in D-\{h\}} X_{3hj}^{ab} \qquad \forall\ a\in F,\ b\in R,\ h\in D \tag{4-3}$$

$$\sum_{i\in D} X_{2iy}^{ab} = X_{2yu}^{ab} + X_{1yb}^{ab} \qquad \forall\ a\in F,\ b\in R \tag{4-4}$$

$$X_{2yu}^{ab} = X_{1ub}^{ab} \qquad \forall\ a\in F,\ b\in R \tag{4-5}$$

$$\sum_{m\in\{1,2\}}\sum_{i\in D} X_{mib}^{ab} + \sum_{i\in ICD} X_{1ib}^{ab} = d_{ab} \qquad \forall\ a\in F,\ b\in R \tag{4-6}$$

$$\sum_{m\in\{1,2\}}\sum_{j\in D} X_{maj}^{ab} + \sum_{j\in ICD} X_{1aj}^{ab} = d_{ab} \qquad \forall\ a\in R,\ b\in F \tag{4-7}$$

$$X_{1au}^{ab} = X_{2uy}^{ab} \qquad \forall\ a\in R,\ b\in F \tag{4-8}$$

$$X_{1ay}^{ab} + X_{2uy}^{ab} = \sum_{i \in D} X_{2yi}^{ab} \qquad \forall\, a \in R,\ b \in F \qquad (4\text{-}9)$$

$$X_{1ah}^{ab} + \sum_{i \in \{a,y\}} X_{2ih}^{ab} + \sum_{i \in D-\{h\}} X_{3ih}^{ab} = X_{4hb}^{ab} + \sum_{j \in D-\{h\}} X_{3hj}^{ab} \qquad \forall\, a \in R,\ b \in F,\ h \in D \qquad (4\text{-}10)$$

$$\sum_{i \in D} X_{4ib}^{ab} = d_{ab} \qquad \forall\, a \in R,\ b \in F \qquad (4\text{-}11)$$

The objective is the sum of the freight rate and time cost of all containers transported via all transport modes and routes. Constraints (4-2)-(4-6) are related to the transport flow of imported containers while the rest constraints are related to that of exported containers. As the transportation flow of exported containers is reverse to that of imported containers, we explain only constraints (4-2)-(4-6) for imported containers. Constraint (4-2) requires that containers with an overseas port origin and a Korean region destination should be imported throughout any port out of the five Korean ports. Constraint (4-3) requires that all import containers originating from an overseas port *a* and destined to a Korean region *b* arrive at Korean ports by liner ships first or by barges from the other Korean ports and then, should be transported from the Korean port to its succeeding nodes (the destination region, an ICD, and the other Korean ports) by inland transport modes, i.e., truck, train, or barge. Constraint (4-4) shows that all import containers moving from Korean ports to Yangsan ICD by train are transported from Yansan ICD to Uiwang ICD by train or to their destination by truck. Constraint (4-5) shows that all import containers moving between Yangsan ICD and Uiwang ICD are transported by train first then transported to their final destinations by truck from the Uiwang ICD. Finally, constraint (4-6) represents that all containers with an overseas port origin and a Korean region destination should be transported to the destination region.

3.2 External Cost Model

The external cost model employs a willingness-to-pay method for various externalities of each transport mode such as pollution, congestion, accidents, noise, and wear and tear. By internalizing the external cost, we aim to analyze the impacts on modal split. We assume that the government imposes a tax on the external cost (as the internalization ratio of the external cost) to carriers and carriers will pass the tax subsequently onto shippers in the form of surcharge. Therefore, the logistics cost per TEU charged to shippers is calculated by adding the multiplication of the taxation factor and the external cost to the freight rate and time cost:

$$c_{mij} = f_{mij} + tc \cdot t_{mij} + \alpha \sum_{e \in E} ec_{me} l_{ij}$$

Note that the external cost of containers transported by liner ships are not needed to consider in the models since the competition on modal and route choices only occurs between inland transport modes and routes and the effect of external cost for liner ships are mostly negligible (Beuthe *et al.*, 2002) or would not affect shippers' modal and route choices owing to no virtual competition with other modes in the sea trade.

3.3 Carbon Tax and Emission Trading Scheme Models

International organizations, regional economic blocs, for example, European Union (EU) and governments are already implementing carbon regulations or soon to choose them between a carbon tax and an emission trading scheme (ETS) in the near future. In 2008, the EU decided to include international aviation in the already existing EU-ETS market (Scheelhaase *et al*., 2010). From 2012, allowances will be required for all international flights landing at, and departing from, any airport in the EU. Although the Kyoto Protocol requires nations to establish CO_2 mitigation policy proposals for sources of domestic land-based emissions, there has been little progress in the international shipping and aviation sectors (Corbett *et al*., 2009). International shipping and aviation are not covered by the Kyoto Protocol or the Copenhagen Accord, due to “lack of reliable emission data and lack of an agreed approach for defining responsibility by country” (SBSTA/INF.2, 2005 cited in Giziakis and Christodoulou, 2010). The United Nations has delegated the reduction framework of greenhouse gas emissions, from international shipping, to the International Maritime Organization (IMO). According to article 2.2 of the Kyoto Protocol, “the parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the IMO, respectively.” The carbon tax is an environmental tax based on the amount of CO_2 emissions from fuel consumption, and therefore, it intends to control the *price* of carbon for the purpose of reducing the *quantity* of CO_2 emissions. On the other hand, the ETS is a market-based approach in which the total amount of CO_2 emissions in a given economy are set by an international organization or government and the total amounts are allocated to companies or sectors in the form of emission permits and the permits are traded in the market between emitters higher than the permit and ones lower than the permit. The ETS intends to control the *quantity* of CO_2 emissions and the *price* is set on the market allowing the permits traded. We aim to analyze the impacts of the two regulation systems on modal split and CO_2 emissions so that we can draw some policy implications from the analysis.

The carbon tax can be incorporated into the model by including the tax into the logistics cost with the same assumption made in the external cost model.

$$c_{mij} = f_{mij} + tc \cdot t_{mij} + tax \cdot em_m l_{ij}$$

To consider the emission trading scheme, we set a CO_2 emission limit from all inland transport modes. To evaluate the effects of introducing the emission trading scheme, we add the following three decision variables into the model. *HE* refers to CO_2 emissions from all inland transport modes higher than the emission limit [ton]. *LE* refers to CO_2 emissions from all inland transport modes lower than the emission limit [ton]. TK_m means the total container movements by transport mode m [TEU-km]. If the total amount of the emissions is more than the limit, the higher emitter should purchase extra permit from lower emitters who have the surplus CO_2 emission permits in a trading market. The purchased amount of CO_2 emissions is $\sum_{m \in \{1,2,3\}} em_m TK_m - ecap$ if $\sum_{m \in \{1,2,3\}} em_m TK_m \geq ecap$ and zero, otherwise, while the sellable amount of CO_2 emissions is $ecap - \sum_{m \in \{1,2,3\}} em_m TK_m$ if $\sum_{m \in \{1,2,3\}} em_m TK_m \leq ecap$ and zero, otherwise. Here, TK_m is the total container movements by transport mode *m*, which is calculated by the following constraints

$$\sum_{a \in F} \sum_{b \in R} \sum_{i \in D} l_{ib} X_{1ib}^{ab} + \sum_{a \in F} \sum_{b \in R} \sum_{i \in ICD} l_{ib} X_{1ib}^{ab} + \sum_{a \in R} \sum_{b \in F} \sum_{j \in D} l_{aj} X_{1aj}^{ab} + \sum_{a \in R} \sum_{b \in F} \sum_{i \in ICD} l_{ai} X_{1a}^{ab} = TK_1 \qquad (4\text{-}12)$$

$$\sum_{a \in F} \sum_{b \in R} \sum_{i \in D} \sum_{j \in \{b,y\}} l_{ij} X_{2ij}^{ab} + \sum_{a \in F} \sum_{b \in R} l_{yu} X_{2yu}^{ab} + \sum_{a \in R} \sum_{b \in F} \sum_{j \in D} l_{aj} X_{2aj}^{ab} + \sum_{a \in R} \sum_{b \in F} l_{uy} X_{2uy}^{ab} = TK_2 \qquad (4\text{-}13)$$

$$\sum_{a \in F} \sum_{b \in R} \sum_{i \in D} \sum_{j \in D - \{i\}} l_{ij} X_{3ij}^{ab} + \sum_{a \in R} \sum_{b \in F} \sum_{i \in D} \sum_{j \in D - \{i\}} l_{ij} X_{3ij}^{ab} = TK_3 \qquad (4\text{-}14)$$

The purchased and sold amount of CO_2 emissions can be expressed by the following constraint:

$$\sum_{m\in\{1,2,3\}} em_m TK_m = ecap + HE - LE \tag{15}$$

Therefore, the extra incurring cost and revenue from purchasing/selling CO_2 emissions permit are $p_{GHG}HE$ and $p_{GHG}LE$, respectively. It is assumed that a more extra cost is allocated to a more-emitting mode while a more extra revenue is allocated to a less-emitting mode. This assumption is expressed as

$$p_{GHG}\frac{em_m}{\sum_{n\in\{1,2,3\}} em_n}HE \quad \text{and} \quad p_{GHG}\frac{em_{\rho(m)}}{\sum_{n\in\{1,2,3\}} em_n}LE \tag{4-16}$$

where $\rho(m)$ is a transport mode contrary to mode *m* in terms of CO_2 emissions, e.g., $\rho(1)=2,\ \rho(2)=1,\ \rho(3)=3$ since truck is the most-emitting mode, train is the least-emitting mode, and barge is the second among them as is described in Section 4. Then, it is assumed that the allocated cost and revenue are proportionally allocated to each container by considering its travel distance as follows:

$$p_{GHG}\frac{em_m}{\sum_{n\in\{1,2,3\}} em_n}HE\frac{l_{ij}}{\sum_{n\in\{1,2,3\}} TK_n} \quad \text{and}$$

$$p_{GHG}\frac{em_{\rho(m)}}{\sum_{n\in\{1,2,3\}} em_n}LE\frac{l_{ij}}{\sum_{n\in\{1,2,3\}} TK_n} \tag{4-17}$$

Finally, the logistics cost per TEU in the emission trading scheme model is

$$c_{mij} = f_{mij} + tc\cdot t_{mij} + p_{GHG}\frac{l_{ij}}{\sum_{n\in\{1,2,3\}} em_n}\frac{(em_m HE - em_{\rho(m)}LE)}{\sum_{n\in\{1,2,3\}} TK_n} \tag{4-18}$$

Due to the last term in the above equation, the emission trading scheme model is a nonlinear programming model, which is summarized as follows:

[P2] Minimize (4-1) subject to (4-2) - (4-15)

Since we could not find an efficient commercial software for solving the nonlinear model requiring a reasonable computation time, we suggest a simple heuristic algorithm to solve the model. In fact, we tried to solve the model by LINGO 12.1, which is a well-known commercial nonlinear programming model solver, but the LINGO did not generate one feasible solution even after 10 hours running the program due to a large number of decision variables, as they are given by the following formula: $2\cdot|F|\cdot|R|\cdot(|D|\cdot|D-1|+4\cdot|D|+3)+2$, where $|\square|$ is the size of set $\square$. The heuristic algorithm is summarized in the following procedure. The algorithm is terminated when the iteration count (*w*) reaches a predetermined limit (*W*).

Procedure. (Solving the emission trading scheme model [P2])

Step 1. Solve the model [P2] after replacing the logistics cost by $c_{mij} = f_{mij} + tc\cdot t_{mij}$ which is called the first-replaced model. Set $he = HE^*$, $le = LE^*$, and $tk_m = TK_m^*$ $\forall\ m \in \{1,2,3\}$ where HE^*, LE^*, and TK_m^* are the optimal solution of the first-replaced model.

Step 2. Set *w* = 1. Let the best solution value be an arbitrary large number.

Step 3. Solve the model [P2] by replacing the logistics cost by

$$c_{mij} = f_{mij} + tc\cdot t_{mij} + p_{GHG}\frac{l_{ij}}{\sum_{n\in\{1,2,3\}} em_n}\frac{(em_m he - em_{\rho(m)} le)}{\sum_{n\in\{1,2,3\}} tk_n}.$$

which is called the second-replaced model. Update the best solution once it is improved. Update $he = HE^{**}$, $le = LE^{**}$, and $tk_m = TK_m^{**}$ $\forall\ m \in \{1,2,3\}$ where HE^{**}, LE^{**}, and TK_m^{**} are the optimal solution of the second-replaced model.

Step 4. Set *w* = *w* +1, If *w* > *W*, stop. Otherwise, go to Step 3.

4. Data Collection

Data were collected from various sources to test the models and the heuristic as given in the previous section. The import and export amount from origin and destination is summarized in Table A1 and A2 in Appendices. The data were obtained from Statistical Yearbook of International Trade and Logistics published by Korea Customs Trade and Development Institute (KCTDI, 2010) and publically available web database of Korea Ministry of Land, Transport and Marine Affairs (http://www.spidc.go.kr:10443/).

Table 4-1. Distance (km)

(a) Between ICD/Port and Region

		Seoul	Busan	Incheon	GG*	GW*	CB*	CN*	JB*	JN*	GB*	GN*
ICD	Uiwang	34.7	312.0	93.3	114.7	160.0	132.0	112.0	162.7	265.3	272.0	241.3
	Yangsan	286.7	25.3	394.7	360.0	393.3	245.3	357.3	266.7	297.3	108.0	108.0
Port	Busan	411.2	20.0	418.4	364.0	412.0	277.6	271.2	268.8	328.8	114.4	80.8
	Gwangyang	361.6	176.0	360.8	356.8	504.8	260.0	203.2	120.8	171.2	191.2	120.8
	Incheon	46.4	412.0	20.8	47.2	175.2	177.6	187.2	245.6	286.4	283.2	356.8
	Ulsan	420.8	92.0	427.2	405.6	423.2	320.0	284.0	339.2	401.6	160.0	120.8
	Pyeongtaek	336.8	360.0	92.0	80.8	187.2	112.8	120.0	177.6	248.0	262.4	336.8

* GG: Gyeonggi, GW: Gangwon, CB: Chungbuk, CN: Chungnam, JB: Jeonbuk, JN: Jeonnam, GB: Gyeongbuk, GN: Gyeongnam

(b) Between ICD/Port and Port

		Port				
		Busan	Gwangyang	Incheon	Ulsan	Pyeongtaek
Yangsan ICD		57.6	57.6	-*	-	-
Port	Busan	-	224.0	752.0	-	728.0
	Gwangyang	224.0	-	665.0	-	641.0
	Incheon	752.0	665.0	-	-	70.0
	Ulsan	-	-	-	-	-
	Pyeongtaek	728.0	641.0	70.0	-	-

* no direct connection

The distance between overseas ports and Korean ports were collected from the website of Sea Rates (http://www.searates.com/). The distances between ports, ICDs and regions in Korea were collected using the website of Naver (http://map.naver.com/) and the results are summarized in Table 4-1. The distance between Uiwang and Yangsan ICDs was set to be 326 km. The transit time between inland nodes was calculated using the distance divided by the speed of corresponding transport modes, i.e., truck: 80 km/h, train: 50 km/h, and barge: 23.5 km/h and adding their loading/unloading time, i.e., truck: 3 h, train: 9 h, and barge: 6 h obtained from Lim (2004). Since train is not connected between all nodes, the connectivity between nodes for train is given in Table A3. The transit time and freight rate between Korean ports and overseas ports were obtained from the website of Schedule Bank (http:// www.schedulebank.com/), which is summarized in Table 4-2. The freight rate for the inland transport modes was calculated by multiplying the distance and the rate: 0.9 US $/km for truck, 0.6 US $/km for train, 0.15 US $/km for barge, and adding the loading/unloading cost: 0 US $ for truck, 33.6 US $ for train, 65.2 US $ for barge, obtained from Lim (2004) and by assuming 1,119 KRW/US $. The freight rate of train was charged at 60 US $ only if the distance is less than 100 km following the pricing plan in the website of KORAIL (http://logis.korail.go.kr/), and since a container should be delivered to a railway station by a truck, we set the freight rate of train as the rate calculated by the distance and speed plus the truck freight rate multiplied by the distance to the railway station, which was set as 30 km.

Table 4-2. Transit Time (Day) and Freight Rate (US $/TEU) of Liner Ship

Port		Busan	Gwangyang	Incheon	Ulsan	Pyeongtaek
USA	Houston	18.73(2393)[*]	18.89(2449)	-[**]	-	-
	Detroit	17.70(2537)	17.81(2593)	-	-	-
	Long Beach	15.80(1657)	15.98(1780)	-	-	-
	New York	18.45(2657)	18.54(2667)	-	-	-
	Savannah	19.51(1732)	19.63(1788)	-	-	-
	Seattle	13.77(1657)	13.93(1780)	-	-	-
West Europe	Amsterdam	30.00(1042)	31.00(1078)	-	-	-
East Europe	Hamburg	30.00(1257)	31.00(1380)	31.00(1447)	-	-
Africa	Durban	25.00(1557)	26.00(1680)	-	-	-
Central Asia	Jeddah	26.00(1857)	25.00(1880)	31.00(1947)	-	-
Southeast Asia	Singapore	5.00(707)	9.00(730)	10.00(747)	7.00(740)	-
	Klang	9.00(851)	10.00(811)	9.00(899)	10.00(815)	-
	others	7.70(779)	7.70(739)	7.70(826)	7.90(742)	-
North America	Vancouver	10.00(1657)	11.00(1780)	-	-	-
South America	Santos	30.00(2357)	31.00(2480)	-	-	-
China	Dalian	1.28(348)	1.14(471)	0.75(438)	1.28(435)	0.76(448)
	Ningbo	1.49(364)	1.32(367)	1.58(400)	1.58(380)	-
	Shanghai	1.35(348)	1.16(471)	1.37(438)	1.43(435)	1.28(448)
	Qingdao	1.30(348)	1.11(471)	0.95(438)	1.34(435)	0.90(448)
	Xingang	1.83(348)	-	1.73(438)	-	1.65(448)
	Yantai	1.20(452)	-	0.75(521)	1.22(480)	0.72(511)
	Weihai	1.11(428)	0.95(403)	0.65(492)	1.13(405)	0.62(488)
	others	1.70(385)	1.60(376)	1.20(449)	1.80(380)	1.20(496)
Japan	Osaka	0.96(548)	1.16(571)	1.40(588)	0.91(535)	-
	Yamaguchi	0.40(609)	0.50(632)	1.40(648)	0.40(595)	-
	Yokohama	1.58(548)	1.78(571)	1.95(588)	1.52(535)	-
	Nagoya	1.16(548)	1.36(571)	1.57(588)	1.11(535)	1.58(468)
	Hakata	0.34(448)	-	-	-	-
	Tokyo	1.59(548)	1.80(571)	1.95(588)	1.54(535)	-
	others	1.20(548)	1.40(543)	2.20(645)	1.20(542)	2.20(475)
Hong Kong China	Honkong	3.32(548)	3.15(571)	3.38(588)	3.41(665)	3.30(598)
Chinese	Keelung	2.15(557)	2.01(580)	2.37(597)	2.23(544)	-

Port		Busan	Gwangyang	Incheon	Ulsan	Pyeongtaek
Taipei	Kaohsiung	2.67(557)	2.53(580)	2.88(597)	2.76(544)	-
	others	18.73(2393)	18.89(2449)	18.61(2537)	18.64(2459)	-

* transit time and freight rate in parenthesis

** no direct connection

Table 4-3. External Cost of Externality (US $/TEU-km)

	Truck	Train	Barge
Pollution	0.789	0.218	0.425
Congestion	0.914	0.000	0.000
Accidents	0.406	0.105	0.000
Noise	0.288	0.134	0.000
Wear and tear	0.088	0.000	0.000

The external cost summarized in Table 3 was calculated by multiplying 36.14 (ton/TEU), 1.2 (US $/EURO), and the external cost (EURO/ton-km) in Beuthe *et al*. (2002). The CO_2 emissions (ton/TEU-km) was set at 0.0019 for truck, 0.0007 for train, and 0.0016 for barge obtained by multiplying 36.14 (ton/TEU) and the CO_2 emissions sourced from Beuthe *et al*. (2002). The CO_2 emission limit was set at $\beta\sum_{m\in\{1,2,3\}} em_m TK_m^*$ where TK_m^* is the total container movement by transport mode *m* obtained by applying equations (4-12)-(4-14) and using the solution of the validation model and β is an emission limit factor used to test the effect of the limit. That is, the target is a $(1-\beta)\cdot 100$ % reduction of the current CO_2 emissions. The daily time cost of a container was set at 130 US $/day after a series of preliminary experiments on the validation model. Since the daily time cost of a container for shippers can be various depending upon different characteristics of cargoes in a container and also shippers, we quantified it by calibrating the validation model to the degree that the solution of the model can most closely reflect the real modal split. Finally, we set the maximum iteration for ETS heuristic as 10 after a series of preliminary experiments (Average objective values for all test instances between iterations are presented in Figure A4-1 in Appendices).

5. Test Results and Implications

This section summarizes test results of the four mathematical models: validation model, external cost model, carbon tax model, and emission trading scheme model using the data explained in Section 4. In the test, the validation, external cost, and carbon tax models were solved using CPLEX 11.2, which is a well-known commercial linear/integer program solver and the heuristic for the emission trading scheme model was developed by a computer language C incorporating the CPLEX to solve the replaced models defined in ETS heuristic.

5.1 Result of the Validation Model

The test results of the validation model are summarized in Table 4-4 as the final result after many rounds of running the model calibrating parameters and checking how well our model represents the real modal split in Korea. As can be seen from Table 4-4, the model generates a similar transport modal split to the real modal split in Korea in 2009 obtained from the website of Korea Maritime Institute (http://www.kmi.re.kr/kmi/kr/). Therefore, the validation model is deemed to suffice to reflect the real situation in Korea and hence the extended models of respective external cost, carbon tax, and emission trading scheme can be further tested.

Table 4-4. Comparison between Validation Model's Result and Real Modal Splits

Transport Mode	Model	Real	Model-Real
Truck	89.8%	90.1%	-0.3%
Train	8.4%	7.5%	0.9%
Barge	1.8%	2.4%	-0.6%

5.2 Result of the External Cost Model

In this test, we attempted to analyze how the container cargoes would shift among different transport modes in Korea and how much total external costs would be changed if the government formulates more eco-friendly policies internalizing the external cost and levying taxes onto carriers. It is presupposed that levied tax onto the carriers will be subsequently transferred to shippers more likely in the form of surcharge as is often the case in transportation sectors. To this end, we tested the external cost model under different taxation factors or varying internalization ratios of the external costs. The varying degrees of internalization ratios were intended to reflect the plausible uncertainty on how much tax would be charged onto carriers by the Korean government.

The test result is summarized in Table 4-5. The train's share sharply increases absorbing the share of truck and even barge. The barge increases in the share are not remarkable even though the share increases from current 1.8% to 4.9% when the internalization ratio is 0.2 then begins to decline gradually to 1.1% when the tax is levied to reflect the whole external costs. This may have been caused by the double size pollution effect of barges compared with train although the barge incurs no congestion, accidents, noise, and wear and tear as can be seen from Table 4-3. On the other hand, the external costs incurred by all inland transport modes decrease sharply along with the internalization ratio's increase. The initial reduction of external costs is remarkable, for instance with 10% internalization, the external costs are reduced by 23%. The reduction of the external costs increases gradually until 50% of internalization ratio then it appears to reach saturation point when internalization ratio is beyond 60%. Note that we did not change all possible links of trains and barge in the test in order to show the results under the current transportation network system. However, if all possible links of trains and barge have been connected, the total external costs would have been much more reduced than the result in Table 5.

Table 4-5. Effect of Taxation of External Cost

Internalization ratio	Modal split			Total external cost	
	Truck	Train	Barge	US $	Reduction ratio*
0.0	89.8%	8.4%	1.8%	1,979,457,974.5[a]	0.0%
0.1	80.4%	17.8%	1.7%	1,528,970,569.9[b]	-22.8%
0.2	76.6%	18.4%	4.9%	1,365,868,713.7[b]	-31.0%
0.3	64.4%	31.2%	4.4%	1,111,425,072.6[b]	-43.9%
0.4	62.9%	33.0%	4.1%	1,079,725,639.7[b]	-45.5%
0.5	62.0%	34.1%	3.9%	1,062,882,179.8[b]	-46.3%
0.6	42.1%	54.2%	3.8%	783,090,973.9[b]	-60.4%
0.7	39.9%	56.3%	3.8%	740,176,901.0[b]	-62.6%
0.8	39.9%	58.2%	1.8%	708,121,474.6[b]	-64.2%
0.9	39.8%	58.4%	1.8%	705,295,432.0[b]	-64.4%
1.0	38.5%	60.4%	1.1%	673,451,621.7[b]	-66.0%

* $(a-b)/a \cdot 100\%$

From the test result, we can draw some policy implications. The transport policy should be directed toward the inclusion of the external costs into carriers' pricing to reduce the externalities. Just a mere initial low percentage of taxation of the external costs would result in significant reductions of the externalities. The excessive taxation on the external cost, however, may not be a good policy instrument for more use of barge and advisable modal shift. Therefore, an optimal amount of tax should be explored looking into not only the reduction of external costs, but also the balance in modal split. Furthermore, the changes in modal split and external costs will be affected by extended linkage among the nodes and expansion of transportation structure along with the enhanced efficiency of the modes. Though the data used and the transportation model built in this study are based on Korean case, the implication of finding optimal taxation and proper modal shift can apply to many other similar countries, which use similar types of intermodal system for their cargo movements.

5.3 Result of the Carbon Tax and Emission Trading Scheme Models

In these tests, we attempted to analyze the effect of a carbon tax and an emission trading scheme on the modal split and CO2 emissions. Moreover, we examined which regulation between a carbon tax and an emission trading scheme is more effective to reduce CO_2 emissions. First, we tested the carbon tax model under the scenario of different taxes and then tested the emission trading scheme model using the ETS heuristic under the scenario of different CO_2 prices and emission limit factors.

Table 6. Effect of Carbon Tax Regulation

Carbon tax (US \$/ton)	Modal split			Total CO_2 emissions	
	Truck	Train	Barge	ton	Reduction ratio[*]
0	89.8%	8.4%	1.8%	1,648,733.5[a]	0.0%
100	82.6%	16.8%	0.6%	1,355,374.4[b]	-17.8%
200	80.2%	19.2%	0.6%	1,299,523.2[b]	-21.2%
300	79.2%	20.2%	0.6%	1,271,809.2[b]	-22.9%
400	78.1%	21.3%	0.6%	1,232,194.4[b]	-25.3%
500	67.1%	32.9%	0.0%	1,099,448.6[b]	-33.3%
600	64.8%	35.2%	0.0%	1,022,488.2[b]	-38.0%
700	63.1%	36.9%	0.0%	1,000,540.7[b]	-39.3%
800	62.6%	37.4%	0.0%	996,039.1[b]	-39.6%

[*] $(a-b)/a \cdot 100\%$

The test results of the carbon tax model and the emission trading scheme model are summarized in Tables 4-6 and 4-7. In case of the carbon tax model, the share of train increases significantly absorbing most of shares of truck and barge and the total CO_2 emissions from all inland transport modes decline along with the increase of the carbon tax. This is very similar to the result of the external cost model. On the other hand, the change in the modal split and the total CO_2 emissions under the emission trading scheme model with actual CO_2 market prices in recent years is not significant even though the share of train increases slightly as the CO_2 price increases and the emission limit factor decreases. This result implies that shippers' modal and route choice may not be significantly affected from an emission trading scheme regulation although the Korean government enforces the regulation and moreover some revenue gained from selling CO_2 emissions permits is allocated to shippers in the form of freight rate reduction if current CO_2 market prices are maintained. Comparing the results of the carbon taxation and ETS, the emission trading scheme appears to be a less effective instrument than the carbon tax to reduce CO_2 emissions in the transportation sector. This is somewhat surprising result in contrast with those views supporting ETS (Council of the European Union, 2008). The result may have been caused by too low CO_2 prices in Table 7 (a) even though the price ranges are based on actual CO_2 market prices in recent years. If the carbon prices were as high as the carbon taxes in Table 6, the results of the ETS would have been much different. We tested this argument using much higher carbon prices in the ETS model and the results are summarized in Table 7 (b). The results show that total CO_2 emissions from all inland transport modes declines significantly along with the increase of the CO_2 price, while the modal shift is not significant. Therefore, international organizations and governments should devise some policy instruments to increase the CO_2 price which is stagnant around several ten US $/ton in the current market. In addition, governments including Korean one seeking for sustainable transportation system should develop a scheme of sharing the burden and benefit of the extra cost and revenue between transport modes arising from the ETS to balance the modal split.

Table 7. Effect of Emission Trading Scheme Regulation

CO_2 price (USD/ton)	Emission limit factor	Modal split			Total CO_2 emissions	
		Truck	Train	Barge	ton	Reduction ratio[*]
0	∞	89.8%	8.4%	1.8%	1,648,733.5[a]	0.0%

(a) Actual CO_2 price in recent years

10	0.9	89.8%	8.4%	1.8%	1,648,733.5[b]	0.0%
	0.7	89.8%	8.4%	1.8%	1,648,733.5[b]	0.0%
	0.5	89.8%	8.4%	1.8%	1,648,733.5[b]	0.0%
20	0.9	89.8%	8.4%	1.8%	1,648,733.5[b]	0.0%
	0.7	89.8%	8.4%	1.8%	1,648,733.5[b]	0.0%
	0.5	90.9%	8.5%	0.6%	1,609,064.6[b]	-2.4%
30	0.9	89.8%	8.4%	1.8%	1,648,733.5[b]	0.0%
	0.7	89.8%	8.4%	1.8%	1,648,733.5[b]	0.0%
	0.5	89.6%	9.8%	0.6%	1,568,108.9[b]	-4.9%

(b) High CO_2 price

200	0.9	89.8%	8.4%	1.8%	1,648,733.5[b]	0.0%
	0.7	89.0%	10.4%	0.6%	1,546,078.9[b]	-6.2%
	0.5	88.8%	10.5%	0.6%	1,525,551.4[b]	-7.5%
500	0.9	84.4%	13.8%	1.8%	1,499,263.1[b]	-9.1%
	0.7	88.8%	10.5%	0.6%	1,529,772.1[b]	-7.2%
	0.5	88.4%	11.0%	0.6%	1,399,639.6[b]	-15.1%
800	0.9	84.2%	13.6%	2.2%	1,516,653.8[b]	-8.0%
	0.7	86.2%	13.2%	0.6%	1,445,549.3[b]	-12.3%
	0.5	84.1%	15.2%	0.6%	1,284,681.6[b]	-22.1%

[*] $(a-b)/a \cdot 100\,\%$

6. Conclusion

This project aimed at analyzing intermodal container movements in Korea incorporating various externalities into cost optimization model to examine how shippers will choose their routes and modes of transportation in case governments formulate environmental regulation policies. After validating the model, three different scenarios of policy-direction were tested among internalization policy of external costs, carbon taxation system and emission trading scheme. The results of the first two policies are similar in that the share of train increases significantly absorbing most of shares of truck and barge and the total CO_2 emissions from all inland transport modes decline considerably. On the other hand, the change in the modal split and the total CO_2 emissions under the emission trading scheme model is not significant even though the share of train increases slightly as the CO_2 price increases and the emission limit factor decreases. Accordingly, the emission trading scheme appears to be a less effective instrument than the internalization policy and carbon taxation to reduce CO_2 emissions in the transportation sector. Moreover, the change in CO_2 emissions and modal split under the ETS was further tested using carbon prices as high as carbon tax rates. The result is not much different from the case using currently prevailing CO_2 prices in modal split, but shows considerable improvements in reducing the external costs. This implies that the ETS can be an effective policy instrument when the carbon price is set high in the market driven by international organizations and governments.

The limitation of this study is using parameters of the external costs from other studies rather than conducting our own estimation of the external cost function relevant to the Korean case due to budget and time constraint. This should be done in future research.

References

APEC Transportation Working Group. 2009. Short Sea Shipping Study: A Report on Successful SSS Models That Can Improve Ports' Efficiency and Security While Reducing Congestion, Fuel Costs, and Pollution.

Beuthe, M., Degrandsart, F., Geerts, J-F. and Jourquin, B. 2002. "External costs of the Belgian interurban freight traffic: a network analysis of their internalisation." *Transportation Research Part D: Transport and Environment* 7: 285-301.

Chang, Y.-T., Lee, P T-W, Kim, H.-J. and Shin, S.-H. 2010. "Optimization model for transportation of container cargoes considering short sea shipping and external cost: South Korean case." *Transportation Research Record: Journal of the Transportation Research Board* 2166: 99-108.

Corbett, J.J., Wang, H. and Winebrake, J.J. 2009. "The effectiveness and costs of speed reductions on emissions from international shipping." *Transportation Research Part D: Transport and Environment* 14: 593-598.

Council of the European Union, 2008. Proposal for a Directive of the European Parliament and of the Council Amending Directive 2003/87/EC so as to include Aviation Activities in the Scheme for Greenhouse Gas Emission Allowance Trading within the Community - Outcome of the Parliament's Second Reading (Strasbourg, 7–9 July 2008), 11498/08, Brussels, 10 July 2008.

David J., F. 1999. "External costs of intercity truck freight transportation." *Transportation Research Part A: Policy and Practice* 33: 505-526.

de Oses, F.X.M. and la Castells, M. 2008. "Heavy weather in European short sea shipping: Its influence on selected routes." *Journal of Navigation* 61: 165-176.

Emile, Q. 2004, "A meta-analysis of western European external costs estimates." *Transportation Research Part D: Transport and Environment* 9: 465-476.

Forkenbrock, D.J. 2001. “Comparison of external costs of rail and truck freight transportation.” *Transportation Research Part A: Policy and Practice* 35: 321-337.

Giziakis, C. and Christodoulou, A. 2010. “Environmental awareness and practice concerning maritime air emissions: the case of the Greek shipping industry.” Proceedings of 2010 annual conference of the International Association of Maritime Economists, Lisbon, July 2010.

KCTDI, 2010. Statisticial Yearbook of International Trade and Logistics. Korea Customs Trade and Development Institute.

Kim, H.-J., Chang, Y.-T., Lee, P T-W, Shin, S.-H. and Kim, M.-J. 2008. “Optimizing the transportation of international container cargoes in Korea.” *Maritime Policy and Management* 35: 103-122.

KORAIL <http://logis.korail.go.kr/> accessed on February 2012.

Korea Maritime Institute <http://www.kmi.re.kr/kmi/kr/> accessed on February, 2012.

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: 315-335.

Lim, Y.-C. 2004. A study on the vitalization of the modal shift and the analysis of obstacle factors in Korea coastal container shipping. MS Thesis at Inha University.

Macharis, C., van Hoeck, E., Pekin, E. and van Lier, T. 2010. “A decision analysis framework for intermodal transport: Comparing fuel price increases and the internalisation of external costs.” *Transportation Research Part A: Policy and Practice* 44: 550-561.

Naver <http://map.naver.com/> accessed on February 2012.

Ricci, A. and Black, I. 2005. “The social costs of intermodal freight transport.” *Research in Transportation Economics* 14: 245-285.

Schedule Bank <http:// www.schedulebank.com/> accessed on February, 2012.

Scheelhaase, J., Grimme, W. and Schaefer, M. 2010. “The inclusion of aviation into the EU emission trading scheme - impacts on competition between European and non-European network airlines.” *Transportation Research Part D: Transport and Environment* 15: 14-25.

Sea Rates <http://www.searates.com/> accessed on January 2012.

U.S. Government Accountability Office (GAO), 2005. Short Sea Shipping Option Shows Importance of Systematic Approach to Public Investment Decisions, Report Number GA0-05-768, July 2005.

Appendices

Table A4-1. Import Amount (TEU)

Origin \ Destination		Seoul	Busan	Incheon	GG	GW	CB	CN	JB	JN	GB	GN
USA	Houston	756	342	101	443	10	100	150	39	35	299	435
	Detroit	0	0	0	0	0	0	0	0	0	0	0
	Long Beach	39573	15452	6557	24488	486	5675	8183	4952	5493	13649	19565
	New York	7449	3049	1140	4599	95	1047	1555	756	814	2691	3870
	Savannah	12676	4915	2002	8828	166	1773	2969	1187	1260	4421	6270
	Seattle	16452	4507	3698	10356	156	2806	3452	4854	5748	4048	5614
West Europe	Amsterdam	30796	11457	5187	18256	352	4750	6311	5476	6273	10100	14471
East Europe	Hamburg	43555	16851	7499	26309	525	6254	8684	5812	6504	14826	21281
Africa	Durban	7034	2893	1147	4245	89	957	1384	650	694	2539	3660
Central Asia	Jeddah	8659	2983	1700	5327	97	1310	1735	1622	1873	2638	3748
Southeast Asia	Singapore	16571	5606	3906	10818	196	2145	3067	2058	2301	4971	7471
	Klang	17994	4826	6186	13608	219	1757	2837	1273	1382	4324	6329
	others	95247	28732	28992	69423	1184	9943	15825	6412	6853	25560	36334
North America	Vancouver	22666	8961	3562	13365	271	3369	4615	3255	3656	7880	11344
South America	Santos	24520	10798	3657	14696	329	3163	4780	1222	1125	9451	13694

Destination Origin		Seoul	Busan	Incheon	GG	GW	CB	CN	JB	JN	GB	GN
China	Dalian	22826	5988	6811	19966	296	2526	5121	1641	1746	5641	7681
	Ningbo	16053	4531	5425	12179	202	1502	2510	753	768	4041	5728
	Shanghai	63813	17824	20555	50156	807	6373	11310	3647	3789	16150	23212
	Qingdao	56611	12074	18913	55309	745	5972	13760	3919	4196	11945	15302
	Xingang	936	388	149	562	12	128	185	86	91	341	492
	Yantai	13497	1495	6691	14337	173	873	2465	362	376	1603	1628
	Weihai	21336	1678	11756	22758	267	1112	3294	450	488	1877	1580
	others	151122	28379	61470	142246	1922	12873	28494	7622	8157	27387	34631
Japan	Osaka	14717	6081	2607	9133	193	1852	2799	867	851	5335	7744
	Yamaguchi	4742	2137	636	2775	63	631	942	266	252	1869	2715
	Yokohama	14327	5677	2835	9110	186	1746	2663	841	828	4992	7352
	Nagoya	8330	3106	1894	5475	107	964	1495	473	464	2741	4148
	Hakata	2897	1262	421	1677	37	390	573	219	219	1109	1742
	Tokyo	2179	347	982	1837	24	192	307	249	293	322	420
	others	28991	11703	5043	17614	366	3868	5626	2643	2801	10295	15408
Hong kong China	Hongkong	21298	5424	7855	16838	266	1878	3222	1004	1057	4860	6567
Chinese Taipei	Keelung	5381	1690	1591	3889	68	557	893	302	312	1498	2112
	Kaohsiung	9596	3200	2450	6539	118	1142	1708	884	970	2832	4033
	others	2038	472	568	1358	19	326	398	598	712	427	577

Table A4-2. Export Amount (TEU)

Destination Origin		Seoul	Busan	Incheon	GG	GW	CB	CN	JB	JN	GB	GN
USA	Houston	87	40	22	70	5	15	49	11	29	84	162
	Detroit	3	1	1	2	0	0	2	0	1	3	5
	Long Beach	24772	9695	5845	18840	1134	4666	14788	10058	50347	22201	39532
	New York	5133	2320	1270	4112	276	911	2908	667	1962	4939	9455
	Savannah	4408	1991	1088	3529	236	783	2500	587	1770	4241	8115
	Seattle	3455	1557	852	2763	185	614	1961	477	1485	3320	6344
West Europe	Amsterdam	20562	8177	4999	15797	960	3810	12139	7359	35928	18494	33359
East Europe	Hamburg	34864	13637	8935	26939	1609	6334	20448	11856	57415	30800	55566
Africa	Durban	22725	7243	8980	18487	900	3315	12095	4249	18224	16245	29340
Central Asia	Jeddah	53641	20718	15443	42260	2472	9252	30432	14144	64703	46118	84316
Southeast Asia	Singapore	13160	5041	3601	10183	598	2308	7467	3921	18554	11338	21681
	Klang	11819	3258	4847	9253	409	1633	5929	2593	12126	7609	17243
	others	87459	24207	37896	70175	3083	11468	44033	12778	51704	55156	121652
North America	Vancouver	16121	7094	3944	12781	840	2898	9238	3000	11569	15304	28909
South America	Santos	40604	16237	12032	32478	1947	6838	22543	7563	30329	35399	66058

Destination Origin		Seoul	Busan	Incheon	GG	GW	CB	CN	JB	JN	GB	GN
China	Dalian	9189	1788	4109	7283	248	1044	5892	1353	5211	4317	11236
	Ningbo	10464	1675	4150	6819	217	1266	4317	3350	17855	4848	25116
	Shanghai	38602	8552	15520	29033	1111	4963	21703	9145	43303	21063	61221
	Qingdao	28883	3733	14953	23185	582	2850	18530	5154	22652	10047	25899
	Xingang	1127	247	166	539	28	172	450	460	2466	698	4735
	Yantai	8786	790	6496	7740	147	578	3463	330	848	2158	3095
	Weihai	12110	541	9258	10743	149	663	5560	379	593	1870	1886
	others	67206	11099	32425	53584	1602	7224	42426	11496	48924	28012	71323
Japan	Osaka	8110	3380	2300	6475	405	1363	4444	1075	3428	7267	14492
	Yamaguchi	1592	724	394	1277	86	282	901	192	522	1536	2948
	Yokohama	3800	1422	1258	3043	173	600	2020	571	2118	3106	6196
	Nagoya	4534	1652	1533	3604	201	698	2359	617	2183	3616	7702
	Hakata	2311	1024	570	1839	121	413	1318	387	1404	2200	4174
	Tokyo	9241	3386	3019	7274	411	1441	4817	1349	4971	7434	16312
	others	16831	7138	4519	13311	853	2863	9222	2175	6712	15329	31796
Hong kong China	Honkong	29920	6770	11924	22591	871	3980	16913	8219	40190	16764	44773
Chinese Taipei	Keelung	5754	1865	1661	4199	222	951	3068	1981	9921	4400	10886
	Kaohsiung	5986	2268	1638	4639	269	1065	3457	2027	9871	5145	9257
	others	3940	792	1032	2634	87	800	2568	4257	24008	2577	3250

Table A4-3. Connectivity of Train

Region Port	Seoul	Busan	Incheon	GG	GW	CB	CN	JB	JN	GB	GN
Busan	-*	-	-	-	O	O	O	O	O	O	O
Gwangyang	-	O**	-	-	-	O	O	O	O	-	-
Incheon	-	O	-	-	-	-	-	-	-	-	-
Ulsan	-	O	-	-	O	O	O	-	-	O	O
Pyeongtaek	-	O	-	-	-	-	-	-	-	-	-

* no direct connection

** directly connected

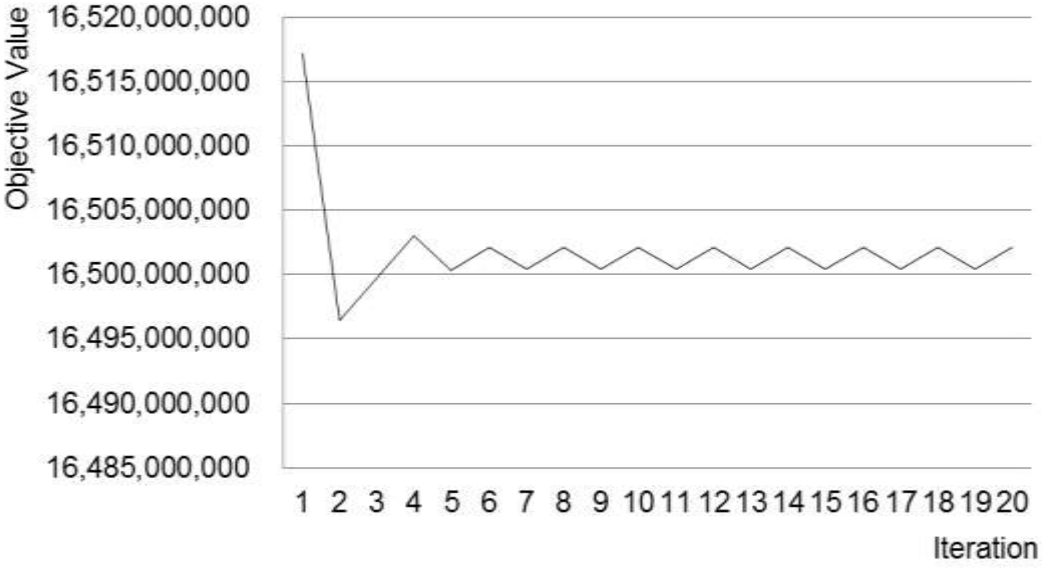

Figure A4-1. Average Objective Values Between Iterations

CHAPTER 5. CONCLUSION

The geo-economic characteristics of APEC economies, comprised of islands, peninsulas and coastal states, justify the necessity of developing a more efficient but sustainable intermodal transportation network. The rapidly growing importance of intraregional trade among APEC economies further necessitates and reaffirms the network development in this direction. While developing more sustainable transportation systems within APEC economies is one of key issues of the APEC Transportation Working Group, the group should also work closely with energy officials as planned at the upcoming APEC Joint Transportation/Energy Meeting involving Ministerial level officials. The main objectives and scope of this project are to provide government officials and relevant stakeholders with an excellent opportunity to address and understand various issues of the developed model and policy implications from this project.

Completing this work as the phase 2 Short Sea Shipping APEC project, major findings can be summarized as follows:

Study on Short Sea Shipping has been supported by European Union in the past decade and similar advocacy can be observable in North American continent. It seems to be high time that Asia-Pacific region should develop SSS as early as possible in view of expected benefits ranging from reduced logistics costs, and environmental protection to further utilization of underused seaports in the region. The research team attempted to capture current practices of Short Sea Shipping in major maritime regions and to build cargo flow network model. Our findings from the models are clear: Short Sea Shipping will provide more transportation and logistics routing choices for various stakeholders; reduce logistics costs; encourage currently underdeveloped or less-used seaports to be further developed and/or used in the future. To do this, new technology such as faster ship and turnaround in major intermodal nodes and policy formulation to expedite cargo movements need be incorporated into the SSS system in the near future.

Various models for this phase 2 project built on its phase 1 models and also its extended models. The original model at the phase 1 intended to analyze the usage of Short Sea Shipping by building multi-model transportation network models. The costs considered in the models were direct logistics costs and time costs. This model did not include any aspects of externalities. Thus, the externalities were added into its extended model. The main focus of this phase 2 project is to assess GHG effects arising from the multi-modal transportation. In addition, the model itself was upgraded to reflect more realistic situations. Once the upgraded model was built, its validation was tested prior to assessing various policy option scenarios. After validation of the model, three scenarios were tested. First, it is assumed that governments will charge portion of externalities more likely in the form of taxes on carbon or environment, similar to European system. This is internalization scenario. Second, it is assumed that government will introduce carbon taxation scheme on consuming fuels. It is carbon taxation scenario. Finally, it is assumed that governments will introduce emission trading scheme (ETS) as observed in numerous advanced economies. It is ETS scenario. Each scenario was assessed by modifying the models slightly.

It was analyze how the container cargoes would shift among different transport modes in Korea and how much total external costs would be changed if the government formulates more eco-friendly policies internalizing the external cost and levying taxes onto carriers. It is presupposed that levied tax onto the carriers will be subsequently transferred to shippers more likely in the form of surcharge as is often the case in transportation sectors. To this end, tested was the external cost model under different taxation factors or varying internalization ratios of the external costs. The varying degrees of internalization ratios were intended to reflect the plausible uncertainty on how much tax would be charged onto carriers by the Korean government.

From the test result, some policy implications are drawn. The transport policy should be directed toward the inclusion of the external costs into carriers' pricing to reduce the externalities. Just a mere initial low percentage of taxation of the external costs would result in significant reductions of the externalities. The excessive taxation on the external cost, however, may not be a good policy instrument for more use of barge and advisable modal shift. Therefore, an optimal amount of tax should be explored looking into not only the reduction of external costs, but also the balance in modal split. Furthermore, the changes in modal split and external costs will be affected by extended linkage among the nodes and expansion of transportation structure along with the enhanced efficiency of the modes. Though the data used and the transportation model built in this study are based on Korean case, the implication of finding optimal taxation and proper modal shift can apply to many other similar countries, which use similar types of intermodal system for their cargo movements.

Then it was attempted to analyze the effect of a carbon tax and an emission trading scheme on the modal split and CO2 emissions. Moreover, it was examined which regulation between a carbon tax and an emission trading scheme is more effective to reduce CO2 emissions. First of all, tested was the carbon tax model under the scenario of different taxes. Then the emission trading scheme model was tested using the ETS heuristic under the scenario of different CO2 prices and emission limit factors.

In case of the carbon tax model, the share of train increases significantly absorbing most of shares of truck and barge and the total CO2 emissions from all inland transport modes decline along with the increase of the carbon tax. This is very similar to the result of the external cost model. On the other hand, the change in the modal split and the total CO2 emissions under the emission trading scheme model with actual CO2 market prices in recent years is not significant even though the share of train increases slightly as the CO2 price increases and the emission limit factor decreases. This result implies that shippers' modal and route choice may not be significantly affected from an emission trading scheme regulation although the Korean government enforces the regulation and moreover some revenue gained from selling CO2 emissions permits is allocated to shippers in the form of freight rate reduction if current CO2 market prices are maintained.

Comparing the results of the carbon taxation and ETS, the emission trading scheme appears to be a less effective instrument than the carbon tax to reduce CO2 emissions in the transportation sector. This is somewhat surprising result in contrast with those views supporting ETS (Council of the European Union, 2008). The result may have been caused by too low CO2 prices even though the price ranges are based on actual CO2 market prices in recent years. If the carbon prices were as high as the carbon taxes, the results of the ETS would have been much different. We tested this argument using much higher carbon prices in the ETS model. The results show that total CO2 emissions from all inland transport modes declines significantly along with the increase of the CO2 price, while the modal shift is not significant. Therefore, international organizations and governments should devise some policy instruments to increase the CO2 price which is stagnant around several ten US $/ton in the current market. In addition, governments including Korean one seeking for sustainable transportation system should develop a scheme of sharing the burden and benefit of the extra cost and revenue between transport modes arising from the ETS to balance the modal split.

In sum, the emission trading scheme appears to be a less effective instrument than the internalization policy and carbon taxation to reduce CO2 emissions in the transportation sector. Moreover, the change in CO2 emissions and modal split under the ETS was further tested using carbon prices as high as carbon tax rates. The result is not much different from the case using currently prevailing CO2 prices in modal split, but shows considerable improvements in reducing the external costs. This implies that the ETS can be an effective policy instrument when the carbon price is set high in the market driven by international organizations and governments.