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*Research Article*

# A System Dynamics Model of the Modal Shift from Road to Rail: Containerization and Imposition of Taxes

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Over the past decade, intermodal transport focused on reducing external cost, congestion, and carbon dioxide emissions, which have been caused by road transportation. Many policy measures for the modal shift from road to rail have been introduced to address these problems. This study aims at examining the impact of policy measures on promoting modal shift. In line with the previous research on modal shift, a system dynamics model, which can calculate both expected and real modal share, was developed. The proposed model was applied to the steel industry for steel rolled coils transport in South Korea. Under our analysis conditions, the modal shift by the containerization occurred more rapidly than taxations. The major contributions of this paper are as follows: (1) supporting the model to anticipate the modal shift from road to rail and (2) suggesting new insight to promote the modal shift using containerization.

## 1. Introduction

Intermodal transport can be a significant alternative to unimodal, especially road, transport in terms of the sustainable development of the freight field. A key aim is to transfer cargo to more eco-friendly modes, such as rail transport [1–6]. Consequently, intermodal transport began focusing on reducing external cost, carbon dioxide emissions, and congestion caused by road transport and several policies aimed and examined at promoting the modal shift from road to rail [7–9]. These policies have induced benefits of the alternative modes of cargo transportation such as intermodal or rail transport [10–12]. Furthermore, specific policies, targeting the offered services and transport or the supply chain, are likely to be more effective in modal shift from road to intermodal transport [13, 14].

However, there are a lot of variables for the modal shift occurred. Alternative modes could hold a dominant position compared to road transport in terms of logistical requirements and suitability of their supply chain conditions. This involves transportation costs as well as logistics costs in a broader sense [10]. A modal shift occurs "when one mode (A; e.g., road) has a comparative advantage in a similar market over another (B; e.g., rail)" [15]. Comparative advantages could influence the ratio of modal shift to more eco-friendly transportation and are economic feasibility, infrastructure capacity, time, flexibility, or reliability [15, 16].

The most important variable that may influence the transport mode choice was found to be the financial factor such as total transport cost and fiscal incentives [9, 17]. Kunadhamraks and Hanaoka tried to identify the causality between a set of intermodal transportation variables. Using the fuzzy-AHP (analytic hierarchy process) technique, they found that the key factor of intermodal transportation was the logistics costs (0.440) [18]. The service quality (0.362), reliability (0.147), and security (0.051) were reported. In addition, several studies addressed that the intermodal transport can be effective in augmentation of road safety and diminution of haulage costs, traffic congestion, and environmental pollution [19, 20].

In South Korea, domestic freight volumes reached a total of more than 810 million tons at the end of 2014 with a

3.35 percent increase compared with 2011. The road transport had the highest percentage of freight transport by mode, ranging from 79.1 percent to 90.7 percent [21]. Therefore, various attempts were performed for decreasing the share of road transport or promoting the modal shift from road to rail as shown in Table 1. The studies also suggested that the logistics cost is the most important factor in the modal shift from road to rail. In addition, there is a case for logistics cost saving through containerization in consequence of the development of new type transport packaging [22].

In this context, this study is divided into two parts. The first part focused on designing a system dynamics model for foreseeable modal share. In the second part, based on the results of the system dynamics model, a case study on the steel industry for steel rolled coils transport in South Korea was presented. Lastly, the conclusions, implications, and limitations of this research were discussed.

## 2. Methodology

*2.1. Principles of Modal Shift.* Based on the previous research [15], principles and theories of the modal shift were defined as three phases as follows: inertia phase, modal shift phase, and maturity phase.

In the inertia phase, the inertia of a high order renders the modal shift slowly occurring by only a few users as part of fiscal supports. The government may provide subsidies in the form of the initial funding to develop related services. In this part, the real modal share is usually much less than the expected modal share with underperformance due to accumulated investments and assets in the existing infrastructures such as transport means and terminals. Thus, even if the new transport means has comparative advantages compared to the existing one, a business company will be reluctant to relinquish their infra resources.

The modal shift phase is the actual transition from one transportation mode to another as the advantages are stabilized by the business. The new transport means changes slowly from a state of underperformance to overperformance.

In the maturity phase, the market opportunities and the new balance in modal share are achieved. The variance of comparative advantages is observed and the incentives for a modal shift are limited.

This study applied a system dynamics model to measure the changes in expected modal share and real modal share induced by the modal shift from road to rail, as shown in Figure 1.

*2.2. Policy Measures Promoting Modal Shift.* Choi et al. developed a model describing the impact of policy measures on fostering the modal shift from road to rail based on structural equation modeling [7]. The direct effect of policy measures on promoting modal shift corresponds to 0.228 in the case of increased road cost or tax and 0.528 for the R&D of new transport equipment such as containers. These variables of policy measures were used in this study as part of initiative factors of the modal share modeling. Because the decision makers of forwarders prefer the current state than future alternatives, they rather choose aids regarding road than alternative transport. The decision makers outlined that the status quo bias could apply in the mode choice decision making because the alternative is compared with the present mode [9].

*2.2.1. Imposition of Taxes.* Many countries are planning to levy a tax or have levied overland transport such as the LKW-Maut in Austria and Germany or the Congestion Charge in London. The impact of an increase in overland freight has been investigated in the literature [10]. Through interview analysis, Woodburn found that road haulage tax levied and imposition of road charging effected on 49 and 46% of road users, respectively, inducing them to transfer to train (or use more rail) [24].

*2.2.2. Containerization.* A freight container has played an important role in intermodal transportation. The container facilitates easy handling between different modal systems. The advantages of containerization are in terms of standardization of transport product, management, speed, flexibility of usage, economies of scale, warehousing, and security [15]. Hesse and Rodrigue suggested that containerization has taken the advantages of economy of scale in respect of small cargo transportation through the consolidation of numerous shipments such as double-stack trains and cellular containerships [25]. Iannone addressed that total external cost savings for shifting containers from road to rail could be leveraged to create funding model for rail container transport by the government [26].

*2.3. Simulation Model*

*2.3.1. Assumptions.* Based on the findings of the existing studies regarding the impact of policy measures on promoting modal shift, the following assumptions have been adopted:

(i) In the beginning, users experiment modal shifts only as a part of a political effect, and the relative influence of each policy measure was affected by the variables mentioned above

(ii) Comparative advantages relate to logistics cost only

(iii) Taxes are imposed on transport cost on the road per unit in ratio form

(iv) The government operates new devices for containerization as a policy measure

*2.3.2. Formulation.* The system dynamics model was developed using the VENSIM PLE software version 6.4. Figure 2 reports a conceptual causal effect diagram of the

Table 1: Previous studies for the policy measure of modal shift in South Korea.

| Policy measure and plan | Comments |
|---|---|
| The rail freight rate policy [5] | To examine the impacts of the rail freight rate policy in Korea in terms of three impacts as follows: (i) on regional economies, (ii) on modal choice, and (iii) on $CO_2$ emissions<br>There is no trade environmental quality for economic efficiency |
| The construction of a new railroad transportation-centered logistics system [6] | To examine the strategic alternative plan of a modal shift for the construction of a new railroad transportation-centered logistics system for environmental-friendly logistics, targeting cargo owners and multimodal logistics businesses in South Korea<br>Companies' recent high interest in environmental-friendly transportation and awareness of green energy caused by the recent rapid increase in oil prices and foreign exchange rate work as positive factors for the modal shift to railroads |
| Subsidy, tax, pricing, services, strategic planning and operation, and infrastructure [7] | To examine the impact of policy measures on promoting a modal shift in South Korea<br>The variables of subsidy, tax, and pricing (0.228), services (0.279), and infrastructure (0.528) have a direct effect on the promotion of modal shift |
| Policies which encourage the use of intermodal freight transport system [23] | To estimate the trade-off relationships among logistics cost, time, and $CO_2$ emissions of the freight transportation system of Korea<br>The logistics costs were minimized when the mode share of the rail-based intermodal system was 35%, and total travel time in the network was at the minimum when the shared ratio of highway was 99% |
| Containerization [22] | To calculate the logistics cost of new devices for containerization as a policy measure; using the new device was more economic than using previous transport packaging |

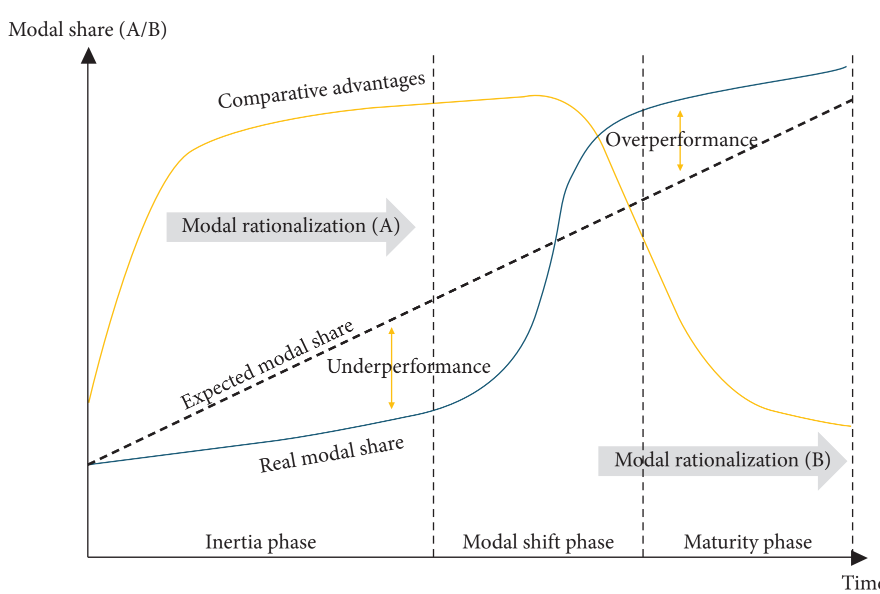


Figure 1: Principles of modal shift (source: Rodrigue et al. [15]).

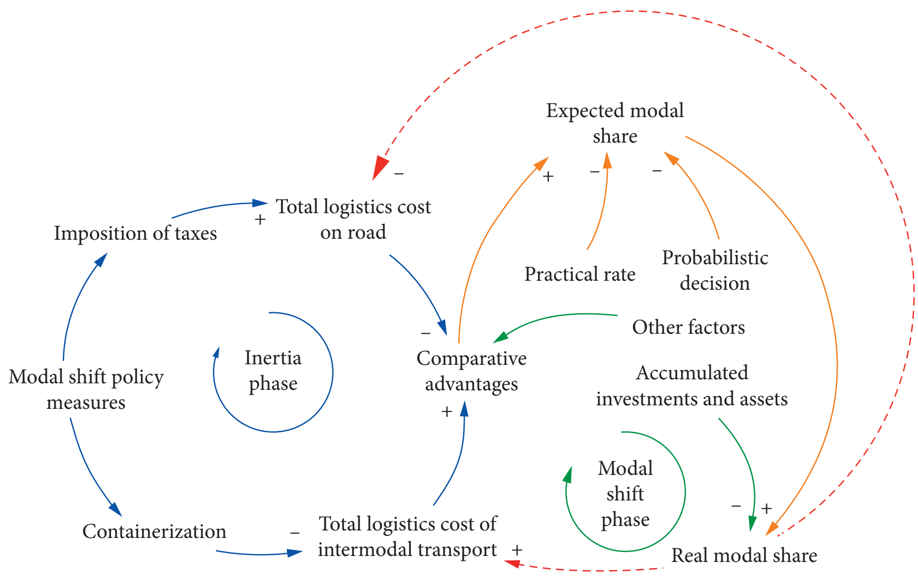


Figure 2: Causal feedback loop diagram of modal share.

system dynamics model, which shows the relationships among the elements of modal shift policy measures, expected modal share, and real modal share. In the diagram, some positive and negative feedback loops can be identified. Real modal share has an impact on total logistics cost on the road and intermodal transport in the modal share rate (road and rail usage) form. Increases in the imposition of taxes generally cause an increase in the total logistics cost of road transport. On the other hand, containerization causes a decrease in the total logistics cost of intermodal transport. These two variables (total logistics cost on the road and cost of intermodal transport) have negative and positive effects on comparative advantages. Expected modal share is predicted by comparative advantages, practical rate, and probabilistic decision. Finally, the real modal share is calculated by the expected modal share and accumulated investments and assets.

The flow diagram of modal share is illustrated in Figure 3. The diagram represented the detailed information and costs flows in the model.

The expected modal share (EMS) can be represented as follows:

$$\mathrm{EMS}_t = \mathrm{EMS}_{t-1} + \int_{t-1}^{t} \frac{(\mathrm{ExiLC} - \mathrm{LCS}) \times \mathrm{PR} \times \mathrm{PD}}{\mathrm{ExiLC}} \, dt, \tag{1}$$

where $t$ denotes time (months); EMS is the expected modal share; ExiLC is the existing total logistics cost on road; LCS is the logistics cost savings obtained through the modal shift; PR is the practical rate; and PD is the rate of probabilistic decisions of stakeholders and it is assumed as 0.1.

The real modal share (RMS) can be represented as follows:

$$\mathrm{RMS}_t = \mathrm{RMS}_{t-1} + \int_{t-1}^{t} \frac{\mathrm{LCS} \times \mathrm{PR} \times \mathrm{PD}}{\mathrm{ExiLC} + \mathrm{AIA}} \, dt, \tag{2}$$

where RMS is the real modal share and AIA is the accumulated investments and assets, which are assumed to be equal to $0.5 \times \mathrm{ExiLC}$.

The logistics cost savings (LCS) obtained through the modal shift can be represented as follows:

$$\begin{aligned}\mathrm{LCS}_t = \mathrm{LCS}_{t-1} + \int_{t-1}^{t} & \mathrm{ExiLC} - (\mathrm{CLCi} \times \mathrm{RaUR}) \\ & + (\mathrm{CLCr} \times \mathrm{RoUR}) \, dt,\end{aligned} \tag{3}$$

where CLCi is the change in the logistics cost per unit obtained through intermodal transport; CLCr is the change in the logistics cost per unit on the road; RaUR is the rail usage rate; and RoUR is the road usage rate.

Total logistics cost includes various variables, such as lashing charge, loading and unloading charge, tally charge, weightage, transshipment charge, and transport cost per unit. The imposition of taxes is assumed to be equal to 0.1, 0.2, and 0.3 for transport cost on the road per unit, and handling charge savings by containerization reflected the information reported in the case study.

## 3. Case Study

*3.1. Description.* The study area is set in the transport section from POSCO (steel company in South Korea) to the Busan Port container yard because there is a case of development of new type transport packaging for containerization as part of policy in South Korea. Busan Port, the main international port in South Korea, is located on the southeastern seaboard, approximately 125.13 km from POSCO on the road. This company manufactures steel coils 15,000 tons per month and exports the entire quantity through Busan Port. In case of intermodal transport, the traffic distance from POSCO to the nearest station is about 11.39 km, the distance on rail is approximately 65.7 km, and the traffic distance from the destination station to the container yard in Busan Port is

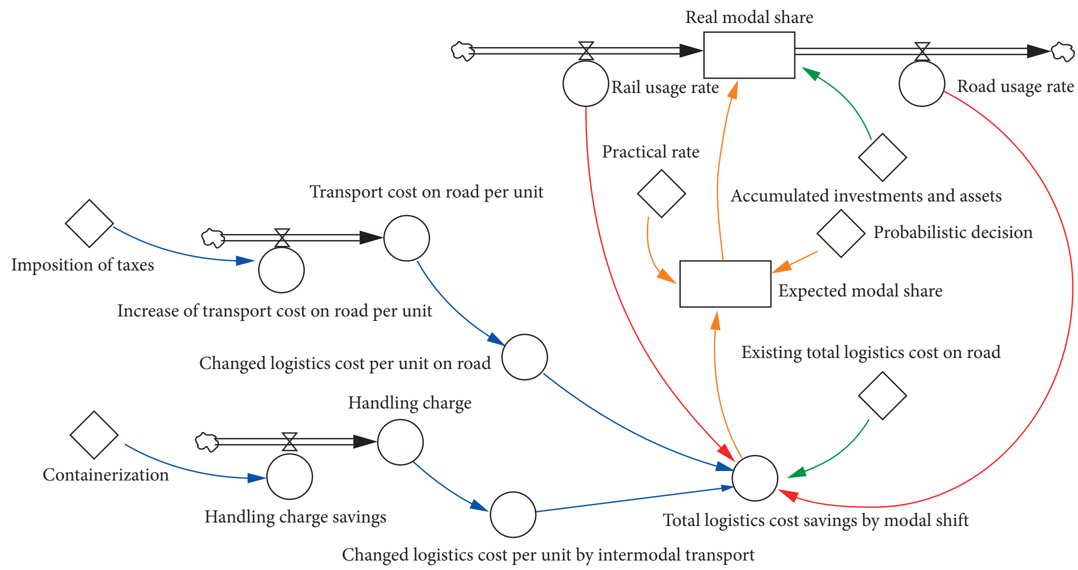


Figure 3: Flow diagram of modal share.

Table 2: Sources of variables for the case study.

| Variables | Source | Value | Unit |
|---|---|---|---|
| Initiative factor by tax | Choi et al. [7] | 0.228 | — |
| Initiative factor by R&D | Choi et al. [7] | 0.528 | — |
| Practical rate | KOTI [28] | 0.206 | — |
| Probabilistic decision | Assumption | 0.100 | — |
| Manufacturing steel coils | Assumption | 15,000 | Tons |
| Handling charge reduced | Choi and Lee [22] | 7 | % |

approximately 7.46 km. The transport cost per unit on the road and rail was 352 and 68 Korea Won/Ton-Km, respectively, in contrast with the case of South Korea [27]. A variable of practical rate (0.206) is reflected in the case study. It means the rate of implementation on modal shift from road to rail regulation in South Korea steel industry [28]. Choi and Lee suggested a new type of cradle funded by the government [22]. The cradle facilitated containerization for steel rolled coils, which can reduce a handling charge by about 7% compared with a traditional method, as utilized in the model. Table 2 shows the sources of variables for the case study.

*3.2. Simulation.* The system dynamics model was analyzed under differing political conditions. The simulation was performed for 100 months and was set in four scenarios as follows: the imposition of tax rates equal to 0.1, 0.2, and 0.3, and containerization.

## 4. Results and Discussion

*4.1. Expected and Real Modal Share.* Figure 4 illustrates the expected modal share and real modal share curves in line with the abovementioned modal share curve (Figure 1). Containerization reached overperformance rapidly (20 months), followed by the tax rate equal to 0.3 (30 months) and tax rate equal to 0.2 and 0.1 (31 months).

*4.2. Comparison of Each Policy Measures*

*4.2.1. Expected Modal Share.* Figure 5 shows the $y$-intercept value divided into two groups according to the political effect: containerization and imposition of taxes. Containerization and tax rate equal to 0.3 reached rate 1 most rapidly. Although the value of the $y$-intercept is lower than containerization, the case of tax rate equal to 0.3 shows the sharpest gradient compared with the curve of other values. The tax rate equal to 0.2 reached rate 1 in 68 months. The tax rate equal to 0.1 attained rate 1 in 71 months.

Therefore, as far as the expected modal share is concerned, containerization is roughly equivalent to the imposition of tax rate equal to 0.3.

*4.2.2. Real Modal Share.* As shown in Figure 5, containerization reached rate 1 in 30 months and tax rate is equal to 0.3 in 38 months, in contrast with the result on the expected modal share. Tax rate equal to 0.2 and 0.3 simultaneously reached rate 1 in 39 months. Thus, there is no significant difference between tax rates compared with

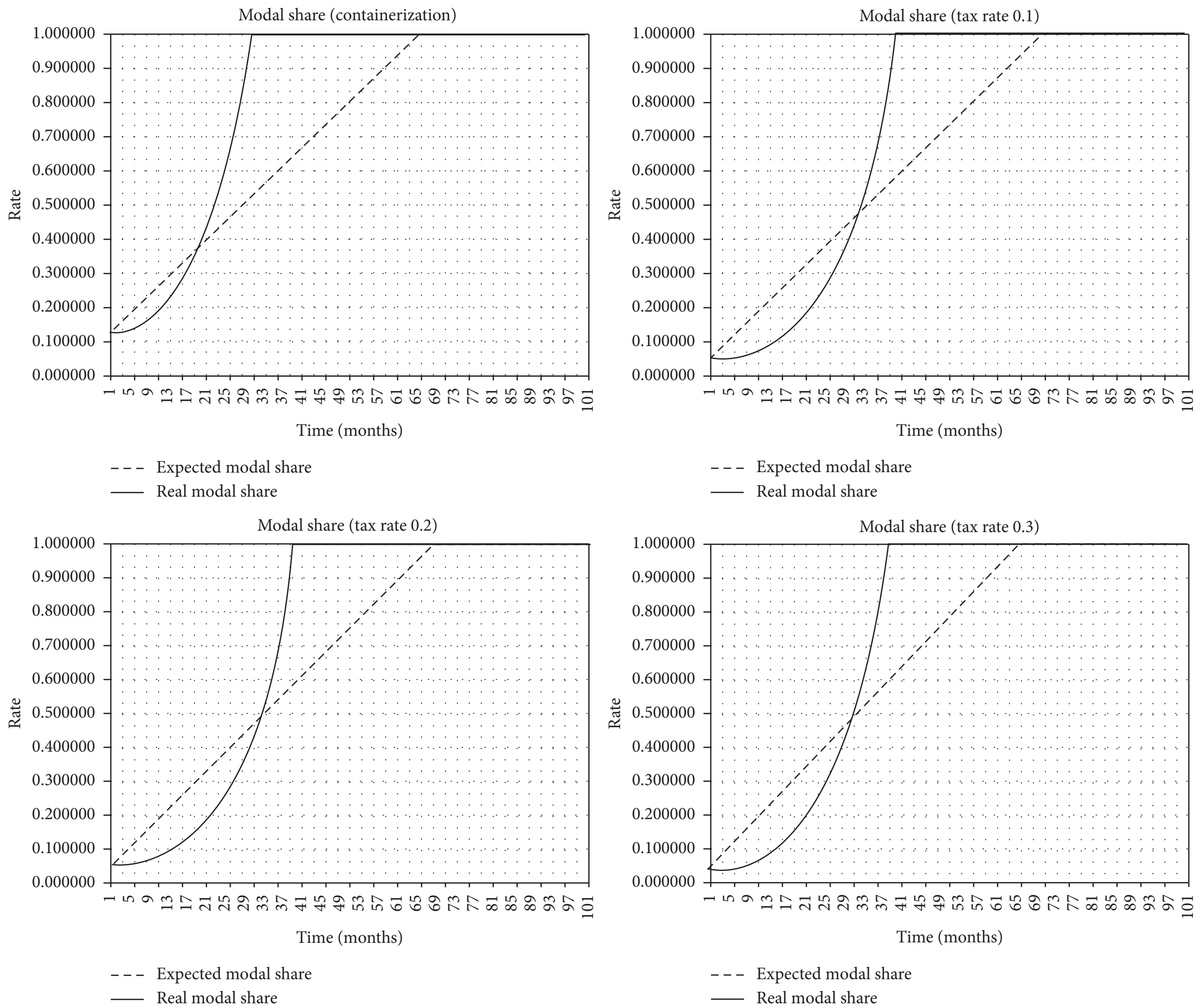


Figure 4: Results of the expected and real modal share.

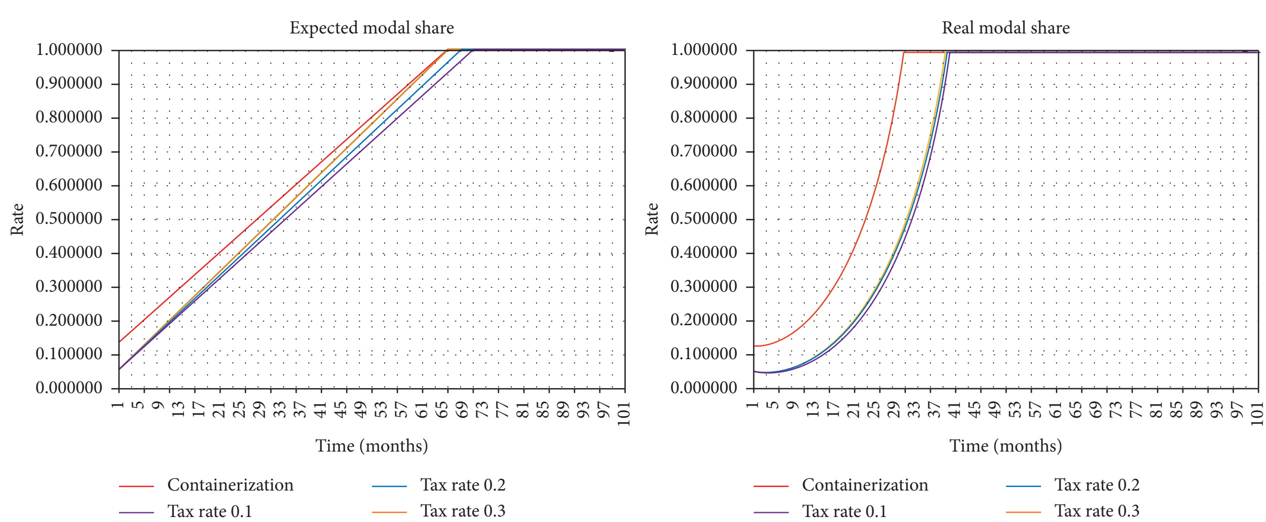


Figure 5: Comparison between expected and real modal share for each policy measure.

containerization. This phenomenon can be explained by the differences between policy measures.

## 5. Conclusion

This study is to examine the changes of modal shift from road to rail by the promotion policies such as containerization and taxation, in line with the previous literature. A modal shift can accomplish with fiscal measure, policy measures, and construction and investment of infrastructure [14]. Based on the previous research in regard to modal shift, a system dynamics model, which can calculate the expected and real modal share, was developed and applied to the steel industry for steel rolled coils transport in South Korea. Under our analysis conditions, the modal shift by the containerization occurred more rapidly than by all kinds (0.1 to 0.3) of taxations. These results signified the development of transport packaging for containerization could be considered as an effective promotion policy of modal shift.

This paper supported the model to anticipate the modal shift from road to rail. The case study dealt with only two policies in this paper; the suggested model could be expanded with various policies related to modal shift. Although the earlier studies were based on theory establishment, the present study is showing a potential for the quantified model to promote modal shift. Through this study, the policymakers could estimate the policy effectiveness of the modal share and the decision makers of a corporation facing a modal choice could facilitate their modal planning.

Furthermore, this paper suggested new insight to promote modal shift. Many studies focused on direct effect to modal shift through financial benefits such as subsidies. However, from the view of logistics cost savings, modal shift could be promoted by various policy measures such as the containerization through the development of new type transport packaging.

Nevertheless, this study has some limitations. First, several factors were excluded in the model such as warehousing and information cost for transshipment, as well as the limitations of intermodal capacity for competing against road transport [29]. Second, the stakeholders in the specific industrial sectors such as medical complex could consider other factors to decide modal choice. As a result, it is difficult to apply and generalize on whole industries.

In further studies, the development of refining model including a subsidy for carbon cost saving seems necessary for an accurate prediction of the modal share. The model can be applied to various industries by applying these additional variables. In addition, a study on comparison between theological model and actual case seems necessary to improve the completeness of the model.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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