Application and Improvement of a System Dynamics Model to Forecast the Volume of Containers

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Abstract

The forecasting of container volumes is a critical component in both the nation’s economy and the development of ports. This paper attempts to generate a model for forecasting container volumes at ports using system dynamics to provide higher forecasting accuracy. First, a regression model and system dynamics model are employed to forecast the container volume in Taiwan, the average forecasting error shows that the system dynamics model has higher forecasting ability. Second, data for the period 1990/2008 in Taiwan and Korea are used to forecast the container volumes for 2016. The total container volumes come from the import/export container volume and transshipment container volume. The input data are divided into two sets — total and import/export — according to the properties of the port or nation. By comparing the error of the result using the two sets of input data, the system dynamics model in this paper is improved and is shown to be a good method for forecasting container volumes at different ports or nations in the world.

Key Words: Forecast, System Dynamics, Regression Model, Vensim Simulation Tool

1. Introduction

With the rapid development of the economy, in the 1960s, the world shipping industry developed a new mode of shipping: container transportation. This has the advantages of safety and rapidity and has greatly improved the efficiency and quality of transportation. After 50 years of development, container transportation has attained a mature transportation organizational form, representing the direction of modern transportation development and playing a significant role in economic development and employment. Therefore, researches all over the world are paying attention to the development of container transportation and focusing on container volume as an important index to measure the progress of national transportation. Therefore, accurate forecasting of container volume is crucial to any port in terms of its operating policy and expansion of its facilities.

There are many factors that influence port container volumes, including the port’s natural conditions, shipping market conditions, global economic conditions and national policy. The uncertainty of these factors creates a lot of challenges when it comes to forecasting port container volumes. Many researchers have attempted to create an optimal forecasting model using various statistical methods such as the regression model, the grey model, genetic programming, the SARIMA model, etc., to reduce forecasting error. A limitation of these studies is that they only consider factors that can influence port container volume, while ignoring the relationships among these factors. The system dynamics model employed in this paper has the function of not only forecasting container volume accurately, but also giving feedback on how the factors interactively affect one another.

A further limitation is that previous researches, using approaches such as the regression method only con-
sidered domestic variables to forecast container volumes and did not look at international variables.

This paper will first compare the forecasting result between the regression method and our system dynamics model and then use the results to improve the system dynamics model and ultimately obtain higher forecasting accuracy. The system dynamics model not only considers domestic variables, but also chooses the appropriate data input according to the properties of the port and the international environment to obtain the ideal forecasting value.

Container volumes include export/import volume and transshipment volume and different ports or nations have different function; therefore, before inputting the data, we should first determine the origin of the port or nation’s main container volume, i.e., whether it is export/import volume or transshipment volume. If the port’s container volume is mainly based on import/export, only the import/export container volume needs to be calculated; however, if the port’s container volume is mostly based on transshipment volume, which is the case in Taiwan, the total container volume data should be used. This view will be demonstrated in the present paper through a comparison of Taiwan and Korea’s container forecast volumes. Using the simulation tool Vensim, the system dynamics methodology and data for the period 1990–2008 are used.

In the past, researchers often made forecasts based solely on past data to determine the trends in container volume, or considered endogenous variables such as population, industrial production index, gross national product (GNP), gross domestic product (GDP), wholesale price, etc. However, modern ports are also affected flexibly by exogenous variables that exist on a global scale. Thus, exogenous variables should be considered, especially in ports whose container volumes mainly originate from international trade and export/import. Exogenous variables include the exchange rate, changes in other nations’ policy, or financial crises. Thus, a system dynamics model considering exogenous variables is an appropriate method to forecast container volume.

This paper is organized as follows. Section 2 gives a literature review. A system dynamics method for forecasting container volume, as compared with the regression model, is proposed in section 3; furthermore, how to accurately forecast volumes according to the characteristics of the port is also shown using the improved method. Finally, conclusions are provided in section 4.

2. Literature Review

More than 300 methods for forecasting have been developed around the world; these may be divided into two types: quantitative forecasting and qualitative forecasting [1]. The qualitative forecasting method is based on personal experience and knowledge, so it is more subjective. In contrast, most researchers prefer quantitative forecasting methods based on historical data and mathematical statistics theory, due to the objectivity of this approach. In the present paper, only quantitative forecasting methods for forecasting container volume are shown.

Wang [2] constructed a one-dimensional linear regression equation to study the relationship between ports and the economy. The research showed that the construction of a port is closely related to a city’s import and export value, GDP, budget revenue and number of practitioners. These four factors have obvious linear relationships with the container volume of a port and the results lay the foundations for future container volume forecasting. Regression models have been applied by many researchers, including Kavoussi [3], Ram [4,5], Edwards [6], Sheehy [7,8], Greenaway and Chong [9], Van [10], Dollar [11], Tyler [12], Feder [13], Moschos [14] and Salvatore and Thomas [15], to forecast international trade volume. However, all of these researchers have ignored exogenous variables.

Chou et al. [16] used a modified regression model to forecast the import container volume of Taiwan. Considering that high-tech import trade activities produce only a few international trade import containers, the “non-stationary contribution coefficient of the independent variable” was added in the forecasting to reduce the error; the result exhibited higher accuracy. However, the modified regression model will only fit a port exactly if it has high import value and will not generally fit in normal forecasting.

Park [17] forecasted container volume using the neural network method based on various factors such as import container volume, export container volume, transshipment container volume and number of ships entering the port. Although the forecast error was small, the factors used only related to the port itself and factors relat-
ing to society and the economy were excluded. Liu and Zhang [18] proposed a time series BP neural network (BPNN) method to forecast port container volume in a short period of five years using solely historical data from 1981–2005, following the variation tendency of the actual volume of containers. The time series BPNN was applied to minimize waste in training samples and exploit the potential of short-period forecasting.

Ma et al. [19] attempted to reduce the mean absolute error and mean relative error of forecasting using a combined model. According to past data on port container volume, cubic exponential smoothing, GM (1, 1) and the combined forecast method were used to forecast the container volume. The results showed that the combined forecast model incorporated the advantages of former methods and obtained the best precision.

Chen and Chen [20] used genetic programming (GP), the decomposition approach (X-11) and the seasonal autoregressive integrated moving average (SARIMA) to attempt to create an optimal model for container volume forecasting at ports. Historical data from a 29-year period in Taiwan’s major ports were used and by comparing the mean absolute percent error levels among the three methods, the researchers inferred that GP is the optimal method for forecasting container volumes.

Peng and Chu [21] presented six univariate forecasting models for container volumes in Taiwan’s three major ports. These were the classical decomposition model, the trigonometric regression model, the regression model with seasonal dummy variables, the grey model, the hybrid grey model and the SARIMA model. Through comparing the forecasts’ mean absolute percent error, the model providing the most accurate forecasting could be identified from the six univariate forecasting models. The classical decomposition model appeared to be the best model for forecasting container volume with seasonal variations.

From the forecasting methods described above, it is clear that such methods are becoming increasingly segmented. To fit the trend of greater accuracy in forecasting container volumes and to take the port’s properties into account, this paper will employ a system dynamics model. Using the Vensim simulation tool, the appropriate data are inputted to obtain an ideal value. System dynamics is an approach geared toward enhancing learning in complex systems; often, computer simulation models are used to help elucidate dynamic complexity, understand the sources of policy resistance, and design more effective models. System dynamics is grounded in the theory of non-linear dynamics and feedback control and is employed to solve important real-world problems [22].

3. Methodology

Our world is becoming more and more complex and any decision that involves a large number of elements should be considered carefully. In the real world, we can easily deal with direct causality, but a direct causal relationship cannot order the relationship between decision-making elements. Using a system dynamics method, we incorporate these causal relationships into simulation modeling and through this operation we can understand the interaction among the factors and obtain an exact result [22]. System dynamics emphasizes the multi-loop, multi-state, non-linear characteristics of feedback systems. In this way, it can show us complex behaviors through feedback among the components of the system.

System dynamics modeling discovers and represents systems through feedback processes, along with stock and flow structures, time delays and non-linearity. There is no set rule for successful modeling, but successful modelers tend to follow a disciplined process introduced by Sterman [22], as shown below.

Step 1. Problem articulation
(1) Theme selection: What is the problem?
In this paper, we attempt to create a common model for port container volume forecasting that considers the properties of the port itself.

(2) Key variables: What are the key variables and concepts that must be considered?
In this forecasting model, both endogenous variables and exogenous variables are taken into account. There are many endogenous variables that may be used to forecast container volumes, including population, GDP, GNP, the industrial production index and so on. Before selecting variables, we should first confirm whether the variables have the repeat part because interactions among the endogenous variables may intensify or weaken the forecasting result. For example, assuming that GDP and GNP are both applied to show the economic size in the model, the repetition involved in the GDP and GNP (the
value created by citizens domestically) as variables will intensify the economic size and therefore intensify the forecasting result for container volumes. Thus, to make the model easy to understand, only GDP was applied in this paper to capture the economic size of the nation. The two-way interactive impact between GDP and economic size can more sensitively reflect the nation’s economic condition. Wang [2] showed that the coefficient of correlation between GDP and container volume is 0.97, which means that the former has a great effect on the latter. Thus, GDP is a representative variable in forecasting. In addition, a representative exogenous variable, i.e., international trade, was used.

(3) Time horizon: How far in the past and into the future should we consider?

Actual volumes of containers and GDP increase rates for Korea and Taiwan were used from the period 1990–2008 to forecast the container volume for 2016.

Step 2. Dynamic hypothesis or theory

Mapping: Developing maps of causal structure based on key variables and other available data.

(1) Causal loop diagrams

Causal diagrams are simply maps showing the causal links among variables with arrows from a cause to an effect. The important feedback loops are identified in the diagram. Variables are related by causal links, as shown by the arrows. Each causal link is assigned a polarity, either positive or negative. A positive link is a reinforcing loop, which means that if the cause increases, the effect will also increase above what it would otherwise have been. On the other hand, a negative link is a balancing loop, meaning that if the cause increases, the effect decreases below what it would otherwise have been [22].

Causal loop diagrams of container volume forecasting are shown in Figure 1. Container volume was affected by economic size (GDP growth), container volume in 1990 and international trade. If the GDP increased, economic size also increased and if the economic size increased, GDP would increase concurrently. Thus, a positive relation can be seen between GDP and economic size. In this case, a “+” sign is shown near the arrows. The relationship between “international trade” and the “international trade increase rate” is the same. Furthermore, an increase in “potential international trade” will increase the “international trade increase rate,” so “+” is shown, and along with the increase in international trade, container volume will also increase. “Container volume 1990” is the volume in 1990, which represents the basic value of forecasting.

(2) Stock and flow maps

One of the most important limitations of causal diagrams is that they cannot capture the stock and flow structure of systems. Causal loop diagrams emphasize the feedback structure of a system, whereas a stock and flow map emphasizes its underlying physical structure. Accumulation of stocks and flow characterizes the state of the system and generates the information upon which decisions and actions are based [22].

The stock and flow maps of container volume in Figures 2 and 3 have been generated based on the causal loop diagrams and decisions. Modelers’ decisions can change the rates of flow, alter the stocks, and close the feedback loop in the system [22].

As a rule, stocks are represented by rectangles. In Figure 2, “economic size” is a stock variable accumulated from “GDP growth.” Inflows are represented by a pipe pointing into the stock. Valves control the flow and clouds represent the sources and sinks for the flows. The rest of the auxiliary variables are connected by arrows to show the relationship and feedback structure among them. When “i” is placed in front of the factor, this refers to the initial value of the factor, while “dc” means constant, “D” stands for database and “p” represents a parameter. Finally, “dmnl” is the range of a factor’s increase or decrease, and has no units.

One of the functions of the Vensim simulation tool is subscript control; this is used to manage the elements of a subscripted variable that are displayed simultaneously. Here, Taiwan and Korea were forecasted at the same time.
time to obtain the container volume. The factors in Fig-
ures 2 and 3 are marked “nation x” because two nations
are modeled at the same time.

The international trade factor was developed from
the Bass diffusion model. The Bass diffusion model, in-
troduced in Bass [23], is frequently applied in usual fore-
casting and strategic planning practice; S-shaped curves
are employed as modular components in many methods
and techniques. An S-curve of cumulative growth is
shown in Figure 4. The rationale of the model is that no
real data can grow (or decline) forever. Eventually, one
or more constraints halt growth. In most cases, applying
an S-curve for forecasting induces the correct measure-
ment of the growth process; this can in turn be applied
to identify the law of natural growth quantitatively and to
reveal the value of the ceiling (upper limits of growth)
and steepness of the growth (slope of curve) [24]. The as-
sumption of this model is used such that international
trade follows an S-shaped curve; with time, the values
change from a slow increase to a sharp increase and then
return to a slow increase.

Step 3. Simulation model formulation to test the dynamic
hypothesis
This step involves the attempt to estimate param-
ters, behavioral relationships, and initial conditions.

Formalization can help researchers to recognize va-
gue concepts and understand the system clearly. The pa-
rameters and equations of factors are shown below, based
on the guides of the most experienced modelers [22].

Time step: Year
nation x: Taiwan, Korea

\[ \text{Container volume nation x} = i \text{ container volume 1990 nation x} \]
* Economic Size dmnl nation x
* International Trade Factor nation x
(\text{Unit: Thousand TEU/Year})

The value of “container volume nation x” is calcu-
lated using a multiplication operation on the container
volume from 1990, the range of economic size in the
forecasting year and the value of the international trade
factor. Economic size dmnl nation x = economic size na-
tion x/dc economic size 1990 nation x. Thus, the value of
“economic size dmnl nation x” is the amount of eco-
nomic increase or decrease compared with the economic
size in 1990.

\[ \text{GDP growth nation x} = \text{Economic size nation x} \]
* IF THEN ELSE (Time < dc current year, \( D \text{ GDP growth rate nation x}/dc 100 p, D \text{ GDP growth rate fu-
ture nation x}/dc 100 p)\)
(\text{Unit: Hundred million dollars/Year})

The value of “GDP growth nation x” is calculated
using a multiplication operation on “economic size na-
tion x” and the GDP growth rate. If the forecasting time
is from 1990 to 2010, the actual GDP will be inputted; if
the forecasting time is from 2011 to 2016, the forecasted
GDP will be inputted. The input data for “D GDP growth

Figure 2. Stock and flow map of container volume.

Figure 3. Stock and flow map of the international trade factor.

Figure 4. S-curve of cumulative growth.
rate” and “D GDP growth rate future” are shown in Table 1 based on data from the International Monetary Fund.

\[
\text{ITF increase rate nation } x = \frac{\text{Potential ITF nation } x \times \text{International Trade Factor nation } x \times p \text{ ITF diffusion coeff nation } x}{p \text{ ITF max nation } x} \quad \text{(Unit: 1/Year)}
\]

Equation (3) is formulated according to the theory of the Bass diffusion model.

Model calibration is a function that compares the model’s behavior to time series data collected in the “real world.” This involves finding the values of the model parameters that make the model generate the behavior curves that best fit the real-world data. Through the function calibration in Vensim, parameters are calculated by simulation; the values of “p ITF diffusion coeff nation x” and “p ITF max nation x” of two nations are calculated by simulation.

Step 4. Model testing

There are various types of model tests; the most common ones compare the forecasting error with other methods or use descriptive statistics to assess the point-by-point fit, then calculate the error between a data series and the model output.

(1) Testing by comparing the forecasting error with other methods

The real container volume data from 1990 to 2008 in Taiwan were used to forecast the container volume for both the regression model and system dynamics model.

In the regression model, \( x \) is GDP (unit: million dollars) and \( y \) is container volume, as shown in equation (4). The result of the regression model is given in equation (5). The \( R^2 \) is 0.869 and the forecasting average error of the two methods is shown in Table 2.

\[
y = a_0 + a_1x_1 + a_2x_2 + \ldots + a_kx_k \quad (4)
\]

\[
y = 39.663x - 1970240.018 \quad (5)
\]

In Table 2, the average forecasting error using the regression model is 8.9% and for the system dynamics model it is 3.7%. This shows that the system dynamics model has more exact forecasting ability than the regression model.

(2) Testing by point-by-point fit

In the next step, the real container volume data from

<table>
<thead>
<tr>
<th>Table 1. GDP data for Korea and Taiwan</th>
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<tbody>
<tr>
<td>Year</td>
</tr>
<tr>
<td>1990</td>
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<td>1991</td>
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<td>2005</td>
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<td>2007</td>
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<tr>
<td>2009</td>
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</tbody>
</table>

Source: International Monetary Fund, World Economic Outlook Database, April 2011.

<table>
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<tr>
<th>Table 2. Forecasting result for Taiwan</th>
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<tbody>
<tr>
<td>Year</td>
</tr>
<tr>
<td>1990</td>
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<td>1991</td>
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<td>2007</td>
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<tr>
<td>2008</td>
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</table>

Average 8.9 3.7
1990 to 2008 in Taiwan and Korea were used and the container volumes were forecasted under the system dynamics model. The result of the forecasting is shown in Table 3.

In Table 3, the average forecasting error for Taiwan is 3.7%, while that for Korea is 9.9%. It is strange that the same modeling was used to forecast the volume of containers for both countries and the results are so different. Why is the error for Korea so unsatisfactory? Looking at the volumes of import/export and transshipment, we can determine that the container volumes of the two nations mainly came from different sources. As we know, the total container volume comes from import/export and transshipment; in the data for the period 1990 to 2008, Taiwan received more than 40% of its container volume from transshipment. On the other hand, Korea obtained 80% of its container volume from import/export and only 20% from transshipment. However, the transshipment container volume in Korea increased sharply after 2010 because of the demand and development from Mainland China. This feature represents unpredictable extraneous interference, as the container volume was not created by Korean ports themselves. Rather, the real function of Korean ports is that of export/import; in the future, with the rapid development of Mainland China’s infrastructure, the temporarily increased transshipment container volume will return to Mainland China. Thus, removing transshipment volume from the equation will result in more accurate forecasting.

The relationship between container volume and the economy is shown in the Figures 5 and 6. From the figures, we can observe that the rate of increase of container volume in Taiwan is falling behind the increase in the rate of the economy; thus, container volume does not contribute much to the economy because a large percentage of the container volume comes from transshipment. As Chou et al. [16] noted, the relationship between container volume and economic growth in Taiwan is not conclusive. In contrast, container volume in Korea is shown to grow in tandem with economic growth because such growth stimulates the increase of import/export container volume.

Step 5. Policy design and evaluation for improvement

(1) Policy design

As a conclusion, container volume should be forecasted according to the properties of the port; this means

<table>
<thead>
<tr>
<th>Year</th>
<th>Taiwan</th>
<th>Korea</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Forecast</td>
<td>Error (%)</td>
</tr>
<tr>
<td>1990</td>
<td>5,463.40</td>
<td>0</td>
</tr>
<tr>
<td>1991</td>
<td>5,838.79</td>
<td>5</td>
</tr>
<tr>
<td>1992</td>
<td>6,269.58</td>
<td>1</td>
</tr>
<tr>
<td>1993</td>
<td>6,753.65</td>
<td>1</td>
</tr>
<tr>
<td>1994</td>
<td>7,236.17</td>
<td>1</td>
</tr>
<tr>
<td>1995</td>
<td>7,754.38</td>
<td>1</td>
</tr>
<tr>
<td>1996</td>
<td>8,296.03</td>
<td>5</td>
</tr>
<tr>
<td>1997</td>
<td>8,790.26</td>
<td>3</td>
</tr>
<tr>
<td>1998</td>
<td>9,274.25</td>
<td>5</td>
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<tr>
<td>1999</td>
<td>9,688.91</td>
<td>1</td>
</tr>
<tr>
<td>2000</td>
<td>10,146.08</td>
<td>3</td>
</tr>
<tr>
<td>2001</td>
<td>10,743.02</td>
<td>3</td>
</tr>
<tr>
<td>2002</td>
<td>10,965.67</td>
<td>6</td>
</tr>
<tr>
<td>2003</td>
<td>11,163.76</td>
<td>8</td>
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<tr>
<td>2004</td>
<td>11,662.39</td>
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<td>2005</td>
<td>12,237.29</td>
<td>4</td>
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<tr>
<td>2006</td>
<td>12,903.79</td>
<td>2</td>
</tr>
<tr>
<td>2007</td>
<td>13,558.02</td>
<td>1</td>
</tr>
<tr>
<td>2008</td>
<td>14,332.18</td>
<td>10</td>
</tr>
<tr>
<td>Average</td>
<td>3.7</td>
<td>9.9</td>
</tr>
</tbody>
</table>
that before forecasting, we should first determine where the port or nation obtains the container volume from and whether this container volume contributes to the economy. If a port or nation mainly receives containers from import/export, like Korea, we should input only the import/export container volume into the model for forecasting, because the port has little transshipment volume and this volume is inconclusive and temporary. However, if the port or nation receives a greater container volume from transshipment and the transshipment container volume is stably growing, as in Taiwan, the total container volume should be inputted, without ignoring the transshipment volume. Thus, the system dynamics model in this paper has been improved by inputting different datasets.

(2) Empirical testing

To test whether the policy designed above is correct, an empirical test was carried out.

Container volume forecasting was implemented twice for Taiwan and Korea using the dataset from 1990 to 2008. In the first instance, we used the total container volumes of the two nations, and in the second, we input only import/export container volumes. The errors of the two forecasts are shown in Table 4.

In Taiwan, the average forecasting error when inputting total container volume was 3.7%, while the average forecasting error when inputting import/export container volume was 15.9%. Thus, for the total container volume, the forecast was four times smaller than when only using the import/export container volume, because both the import/export and transshipment container volumes in Taiwan are stably increasing. Furthermore, since a large proportion of the container volume is from transshipment, it cannot be ignored. In Korea, when inputting total container volume, the average forecasting error was 9.9%, whereas when only the import/export container volume was included, the average forecasting error was 6.5%. Thus, the accuracy improved 34% [(9.9%−6.5%)/9.9%] in the latter case in comparison to inputting the total container volume. Because Korean ports receive a high percentage of their container volume from import/export and the container volume increases mainly due to domestic demand and economic growth, the container volume increase from transshipment is inconclusive and temporary; thus, including transshipment will enlarge the forecasting error. Moreover, the import/export forecast error for 2000 is much larger due to the earthquake that occurred in 2000 in Japan. Because of the damage to ports in Japan, most containers from/to Japan were transshipped via Korea. In 2000, Korea’s container volume increased sharply due to this added transshipment volume; here, if only import/export volume is used, forecasting will exhibit a large amount of error. On the other hand, if the total container volume is used, including the effect of transshipment, then the error will be much smaller. Thus, the policy is shown to be correct.

In this paper, a container volume forecasting model was shown to forecast container volumes according to the properties of a port or nation. There are two determinants that must be verified to confirm the characteristics of the port or nation before inputting data, as shown in Figure 7.

First, it is necessary to determine whether import/
export volume or transshipment volume leads to an increase of container volume. To do this, one must not look at where the container volume mainly comes from in a given year, but rather determine a general trend for the port or nation. Second, whether the increase in container volume is in step with the increase in the economy must be investigated.

The two determinants are not contradictory: If a nation’s container volume mainly comes from import/export, it is certain that an increase in container volume will in step with the increase in the economy, because economic growth can stimulate domestic demand and international trade; this demand also results in an increased of container volume.

The container volumes for Taiwan and Korea were forecasted again according to the policy, fitting the data to the nations’ properties. For Taiwan, total container volume data were used, while for Korea, only import/export container volumes were inputted. The forecasting result for 2016 is shown in Table 5 (Unit: Thousand TEU); the transshipment container volume for Korea is ignored.

4. Conclusion

A container volume forecasting model based on system dynamics was proposed in this paper. Using real container volume data from 1990 to 2008 in Taiwan, the forecasting average error was compared using the regression model and system dynamics model; the system dynamics model exhibited higher forecasting accuracy. From the dynamic hypothesis and empirical testing, the system dynamics model was improved to forecast the container volume according to the properties of a port or nation in order to provide higher forecasting accuracy. Through comparing the error of the results using different input datasets, the policy was proved to be correct and the system dynamics model was shown to be a good method of forecasting the container volumes of different ports or nations in the world.

<table>
<thead>
<tr>
<th>Year</th>
<th>Taiwan (total container volume)</th>
<th>Taiwan (import/export container volume)</th>
<th>Korea (import/export container volume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>20565.84</td>
<td>17975.77</td>
<td></td>
</tr>
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</table>

Modeling is not a one-shot activity; rather, it is an ongoing process of continual cycling between the virtual world of the model and the real world of action. In future research, this container volume forecasting model should continue to be improved by exploring more major factors that affect container volume change. In this paper, only positive links were considered; negative links should also be used in the future to modify the model.

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Manuscript Received: Sep. 7, 2011
Accepted: Jan. 26, 2013