MODELING THE GLOBAL FREIGHT TRANSPORTATION SYSTEM: A MULTI-LEVEL MODELING PERSPECTIVE

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ABSTRACT

The interconnectedness of different actors in the global freight transportation industry has rendered such a system as a large complex system where different sub-systems are interrelated. On such a system, policy-related- exploratory analyses which have predictive capacity are difficult to perform. Although there are many global simulation models for various large complex systems, there is unfortunately very little research aimed to develop a global freight transportation model. In this paper, we present a multi-level framework to develop an integrated model of the global freight transportation system. We employ a system view to incorporate different relevant sub-systems and categorize them in different levels. The four-step model of freight transport is used as the basic foundation of the framework proposed. In addition to that, we also present the computational framework which adheres to the high level modeling framework to provide a conceptualization of the discrete-event simulation model which will be developed.

1 INTRODUCTION TO GLOBAL FREIGHT TRANSPORTATION SYSTEM

Looking at the dynamic developments of the world we can arguably infer that the increase in international trade and transport are the most evident results of globalization. The reductions in trade barrier, the presence of strategic commodities in different regions, altogether with the differences in labor costs worldwide have driven the world economy to be more interdependent and interrelated even to the scope and scale which have never been seen before.

In the past couple of decades, we have seen a rapid growth in both freight transport and international trade. International trade and freight data from different databases such as UNCTAD, EuroStat, WTO, etc. have undoubtedly confirmed this trend and show how international trade and freight transport correlate significantly. As such, many predictions are normally made in favor of growing economy of the world. However, looking at the previous couple of years we have also seen the manifestations of the uncertainties in the world economies and politics which have induced changes in the world trade. One of them is a significant economic crisis which happens in big economic blocks such as European Union (EU) and (North American Free Trade Agreement (NAFTA) starting in 2008 (figure 1).
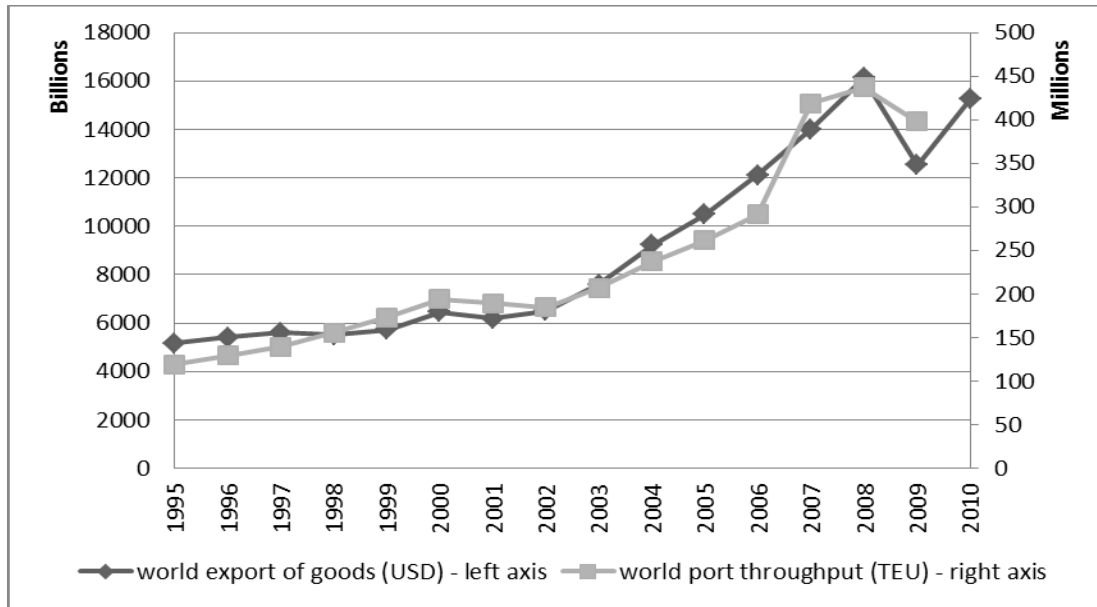
Figure 1 Comparison of theworld export of goods and world port throughput

Source: own compilation based on UNCTAD and Containerization International databases

Not only does this economic crisis influence the future world's trade flows but it is also logical to infer that in the long term, it will influence the global logistics patterns which support international trade, and ultimately, global freight transport patterns. Similar chain of influence would happen in case other forms of uncertainties take place. In fact, there are numerous uncertainties such as war, political incidents, natural disasters, radical global trade and emission policies, etc. which may influence the pattern of world trade and the other intertwined systems. In essence, we can deduct that there are relationships between the world trade, global logistics structure, and freight routing patterns. More importantly, looking at the uncertainties that are faced by relevant decision makers in such a large system, there is a need to structure and explain insightfully the mechanism of the chain of influences in global freight transportation system into a model which has predictive capacity. This model would be of a great value and help to perform policy-related- exploratory analyses which can better prepare the decision makers to deal with uncertainties and to investigate strategic decisions they may make.

Although there are many global simulation models for various large complex systems there is unfortunately very little research aimed to develop a global freight transportation model (Caschili & Medda, 2012). We argue that one of the crucial problems is caused by the absence of a clear and detailed modeling framework which can facilitate the model developers to 1) create a shared understanding of what should be modeled in global freight transport systems and its limitation and scope 2) avoid developing an integrated model which sub-models don't exhibit a coherent functional behaviors making integrated comprehensive analysis difficult (Liedtke, Tavasszy, & Wisetjindawat, 2009).

In the last decade a number of advances were made in freight modeling from different disciplinary angles, that have not yet been brought together in this context. This research is intended to fill this gap and produce instruments that can be the basis of new strategic decision support systems by firstly providing a clear and technically sound framework that identifies and structures all sub-systems that are relevant for the global freight transportation model. Secondly, by presenting a computational framework that is consistent with the high level modeling framework to exemplify how this high level modeling framework can be transformed into an implementable integrated model with a coherence in the functional behaviors of its sub-models.

The rest of the paper is organized as follows. Section 2 delineates the relevant research for the development of the proposed framework. This is then followed by the elaboration of the challenges in developing global freight logistic models in section 3. Next, based on these challenges, section 4 presents the conceptual design of the proposed framework, together with a computational framework that's consistent with the conceptual framework. In section 5 an example of the result of the model's execution is presented. Finally, section 6 presents the conclusion and the future work that arises from this research.

2   RELEVANT WORK

During the past couple of decades, various freight models have been developed. Tavasszy (2006) and Tavasszy et.al (2010) review the evolution of these freight models and provides the current state-of-the-art in freight transport demand modeling. The current conceptual framework which is laid as a foundation to analyze and model the relationship between trade, and freight transport is the five-steps framework (figure 2) which is developed based on the four steps modeling approach of passenger transport (Tavasszy, 2006) (Tavasszy, Ruijgrok, & Davydenko, 2010). This framework divides freight transportation systems into five layers: production and consumption, trade, logistics, transportation ervices and network services.
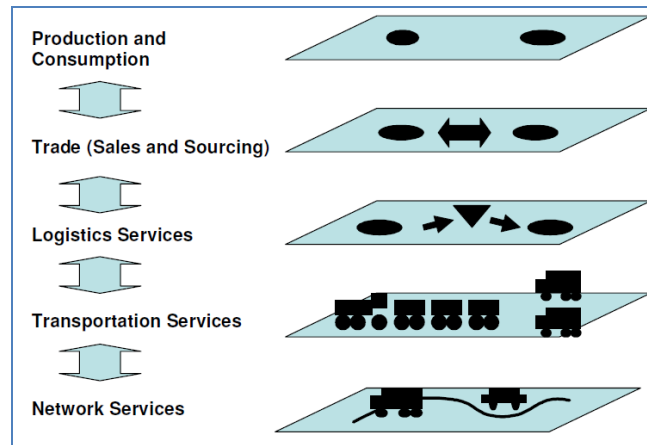

Figure 2 Multi-step freight modeling framework (Tavasszy, 2006)

Departing from the framework above, there are several problems that have to be addressed in the effort of developing a global freight transportation model. Firstly, there are unfortunately not so many models which have been developed having the capability to investigate freight transportation systems in the global scale. Many of the freight models available are developed for the national level (Chow, Yang, & Regan, 2010; Friedrich & Liedtke, 2010). There are only a few models which are developed for global scale such as World Container Model (Tavasszy, Minderhoud, Perrin, & Notteboom, 2011), Container World (Sinha-Ray et al., 2003), GloTram-2 (Smith, Barrett, Parker, & Eoin O, 2011), WorldNet (http://www.worldnetproject.eu/documents/default.aspx). There is also a model which is developed for the continental (EU) level such as TRANSTOOL ("TOOLS for TRansport Forecasting ANd Scenario testing") and ASTRA (ASsessment of TRAnsport Strategies).

While the previously mentioned models are developed to analyze the future patterns in the global freight maritime transportation system, there are also models that are developed to perform static analysis, to characterize and mine information from current the global-cargo shipping network (GCSN)(Ducruet & Notteboom, 2012; Kaluza, Kolzsch, Gastner, & Blasius, 2010). Both models utilize network theory to analyze the emerging structures in the growing GSCN.

Secondly, as there is a growing need to use global models for the analysis of the global freight transportation system, many of these models are built with different modeling objectives. This translates in different levels of detail of the system elements modeled (e.g. one model has more details on the infrastruc-

ture network system and less detail on the transportation system). Consequently, this makes them difficult to be compared and utilized to deal with the same problem.

Thirdly, many of the global models are developed using different modeling formalisms, and methods (for example, only Container world uses discrete event modeling formalism). This hampers the exchange of technical knowledge among the model developers.

Last but not least, except from the global models mentioned above, there are very few models that integrates logistic dimension into the freight models (Tavasszy, et al., 2010). This is a downside since a logistic model plays an important function in describing the spatial pattern of the actual inter-regional freights flows (e.g. the structure of global logistic networks, spatial distribution of warehouses and distribution centers worldwide, etc.). As such, accurate analysis of the actual routing of freight flows between production, transshipment, distribution, and consumption locations is not possible with the current models.

Given the problems mentioned above, there is a need for a clear and detailed framework which can facilitate the development of global freight models that are consistent with the 5-steps modeling approach. In this research we propose both a high-level conceptual model and a computational frameworks which are intended to 1) help creating a shared understanding of the system elements commonly defined in a global freight transportation systems 2) help avoiding developing an integrated model whose sub-models do not exhibit coherent functional behaviors 3) demonstrate an implementation approach that is consistent with the 5-step modeling approach and is able to answer effectively the modeling objectives.

The next section will underline important challenges that have to be addressed in the effort of building such a framework.

3   CHALLENGES IN DEVELOPING AN EFFECTIVE GLOBAL FREIGHT TRANSPORTATION MODEL

In this section, we first discuss some of the important challenges in developing a global freight transportation model. These challenges are derived directly from the modeling objectives and they will be used as the foundation to build the modeling framework proposed in this paper.

The aim of developing a model is to answer research questions. These research questions are the drivers that motivate the modeling project. Therefore, they shape to a large extent the modeling objectives and the modeling framework. Ultimately, it is the modeling objective that will enable the creation of a model which can capture/reproduce specific behaviors of the system of interest. This is done by making the right abstractions (Zeigler, Praehofer, & Kim, 2000).

The global freight transportation model proposed in this research will be used as a decision support system to:

> 1. *Explain the impacts of trade pattern changes on the spatial pattern of the routing of the global strategic commodities (descriptive).*
> 2. *Perform explorative investigations regarding the uncertainties which may influence the future spatial pattern of the global freight flows (explorative).*
> 3. *Support policy making processes which can foster cooperation among important stakeholders (such as ports and terminals) in the presence of competition (normative).*

We use the following definition to clarify the focus on the logistic model in this research:

> *A model which aims to reproduce the most likely geographical locations of pivotal points for the freight flows such as warehouses, storage points, and intermediary stops for various types of goods shipped worldwide. The input of the model shall be among others: the locations of production, consumption sites, known pivotal point locations such as ports and terminals, and the amount of commodities shipped being traded.*

The abovementioned definitions would be used as a basis of the discussions in the following sections and the design of the framework proposed.

3.1 Building the Model using the right Perspective: Time Horizon and Structure of the complex global Freight Transport System

One of the most difficult challenges encountered to model the changes in global freight flows for long time horizon (e.g. 50 years) lies in using the appropriate modeling perspective. At the present time, there is not a model to support policy making in freight transport which takes into account global insights. The difficulty stems from the fact that there are not so many modeling frameworks developed to answer policy questions at global level. Next to the challenges posed by the scale of the model, it is also partially caused by the complexities that one has to address in considering different time horizons within which the decisions/actions of different actors/entities in such a large system are made.

Given the modeling objectives above, an important relevant question is the necessity to model the dynamics in the interactions of decisions made by actors in such a system. As different global freight transport actors (such as producers, consumers, warehouses, and ports) have different time horizons in making decisions, it is an important modeling decision to model how the actions of one actor would be influenced by the decisions of the other actors. Such decision would lead to a specific modeling technique commonly used to deal with such problem either dynamic simulation-based model or static-equation based model. In both cases, further investigation into the theories and disciplines which can help explaining the emergence of such logistic entities is needed.

Another challenge presents itself in the lack of explanation in the general structure of relationships between different sub-systems in global freight transportation system. As we can see, the multi-step modeling framework presented above has not specified, in detail, the relationships between each of the global freight transportation sub-systems. This is because it is an adaptation of the four step modeling framework which originally explains the sequence with which passenger traffic can be estimated and there hasn't been any effort done to make the framework more comprehensible. To address this problem, we need a better explanation of the structure and relationship of sub-systems of the global freight transport. In this context, we propose to use multi-perspective modeling method in constructing the modeling framework for system of systems such as global freight transportation system (Tekinay, Seck, Fumarola, & Verbraeck, 2010). By employing multi-perspective modeling, we can treat each layer of the steps as an independent sub-system for which the interaction to the other sub-systems can be substantiated.

Ultimately, all these considerations delineated above have to be taken into account in choosing a specific modeling technique for the global logistic model. From the implementation view it is also useful to review all the existing models which are going to be integrated with the global logistic model.

3.2 Use of the Model for explorative and normative Modeling Objectives

While the primary objective of the model development, as substantiated in the previous section, is to firstly attain descriptive capacity of the behavior of the real system, we also aim to apply the model to perform explorative and normative analysis.

Exploratory analysis is going to be used to answer the questions pertaining to the uncertainties of the future spatial patterns of the freight flows. In this context, a method which is currently growing rapidly is the exploratory modeling (Halim, Tavasszy, & Seck, 2012). Essentially, exploratory modeling uses a method similar to that of the design of experiments where different parameters of the model are altered systematically in a big range to traverse all possible system behaviors. This way, the resulting behaviors which are hard to predict and counter intuitive can be mapped out and investigated.

Another important application that is aimed with the model is to answer normative questions such that normative policy recommendations can be derived from the analysis of the model results. One example of promising modeling approach is to model the formation of the global logistics network as a competitive

network design problem (CNDP). The ultimate objective of the model is to predict the structure of the global logistics network as the optimal outcome of the interactions of all the decision makers/actors (often called Evolutionary Stable Strategies) in the freight transportation system under investigation (Dimitriou & Stathopoulos, 2009). The optimal-stable system variables of interests where all actors can't make further improvements (e.g. the amount of freight flows transshipped, profit of the actors) can be then extracted as the final results to construct normative recommendations. However, the explanatory power of this model comes with a considerable challenge. The model requires broad and deep knowledge in simulation-based optimization, agent based modeling, freight modeling, and game theory. In this research, a similar approach to derive normative recommendations for competitive network design is proposed. One important distinction here is that the decisions made by logistic agents such as warehouses and distribution centers are going to be incorporated in our model.

4   MULTI-LEVEL MODELLING FRAMEWORK

In this section we present both the high level multi-level modeling framework and computational framework. In this section we present both the high level multi-level modeling framework and computational framework that are coherent with the modeling objectives presented in previous section. The terms multi-level modeling framework is used here to put an emphasis on the different sub-systems that have to be modeled separately. As such, employing multi-perspective modeling approach would be beneficial to define the entities that should be taken into account in the modeling process.

4.1   High level Multi level Modeling Framework

The figure below presents the multi-steps modeling framework which has been enriched with the relationships between the subsystems therein.
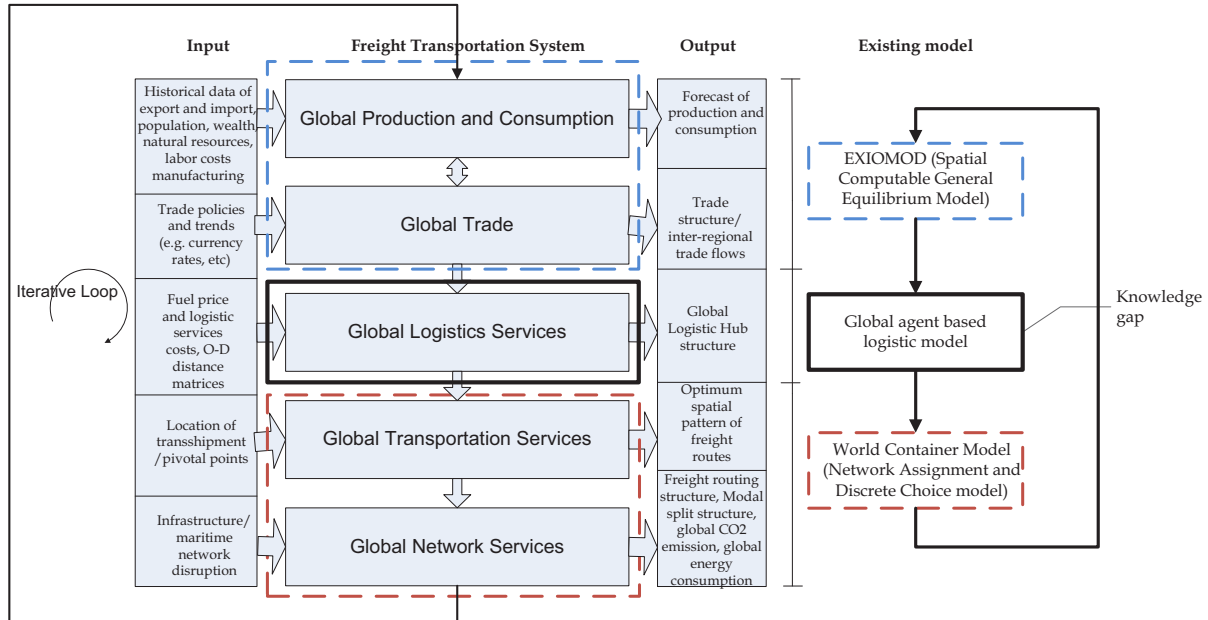

Figure 3 The Multi-level modeling framework

4.1.1 Definition of the Modeling Framework

Important foundations upon which the proposed framework is built are the modeling objectives presented in section 3.1. The modeling objectives presented are the basis for the level of details/resolutions of the integrated global model we're going to build. Furthermore, using the multi-perspective modeling approach, we can see each level of the framework above as an independent system.

- **Global production and consumption and global trade systems**

The aim of the interaction of the first two systems is to find the state of equilibrium in price in the global trade, with which the values of the commodities traded between regions worldwide can be forecasted. We can see that there is a sequential flow from one system to the other system except between the first two systems. This is because the iterative process between production-consumption and trade in finding the equilibrium for the price. There are few papers that provide an extensive description on the mechanism of how these first two sub-systems can be incorporated into an integrated global model, interested readers can refer to in Tavasszy et al. (2010).

We can model the actors in the first two systems representing regions worldwide that perform economic trade transactions of different commodities. There are currently 45 countries which have a significant role in the world trade which we can incorporate in the model of the first two systems.

Currently, there are a few of global models which implement the first two sub-systems most of which are based on Computable General Equilibrium (CGE) models (e.g. GTAP (Global Trade Analysis Project). In our research they are implemented in one model called EXIOMOD. EXIOMOD is a model which uses the framework of Computable General Equilibrium Model where its foundation is built by modern micro-economic theory. In EXIOMOD, aggregate agents are used to represent the behavior of the whole population group or industrial sector as a single economic agent. These agents are modeled with an assumption that their behavior follows cost-minimizing behavior in performing their trade transactions. The price equilibrium conditions follows basic market condition in which there has to be a balance in the demand and supply level. This equilibrium is solved in yearly basis, thus the model gives output of the forecasted yearly trade between the economic agents.

- **Global logistics system: Transshipment and Storage**

An important modeling objective for the global logistics system is to be able to reproduce the adaptation of the supply chain networks for different strategic global commodities as its response to changes happening in the other sub-systems. The resulting network would identify the locations of the pivotal points for the freight flows (such as distribution centers and warehouses, new hubs and terminals) by taking into account the locations of the production- consumption and the trade-off between costs and time incurred to use such facilities in different regions of the world.

Important actors that are involved in this system are the logistic decision makers which influence the locations of the pivotal points/hubs such as ports, warehouses, distribution centers, intermodal freight terminals.

This far, there has not been many logistic model developed aimed to close the knowledge gap in the freight modeling field. State-of the art research to incorporate logistic dimension can be found in Tavasszy et al. (2010). In our framework, there are two possible ways to implement logistic model: using equation-based modeling or simulation model. While the first is relatively less complicated, the latter enables the study of the dynamics and path dependence within the global logistic system. The time horizon within which the equilibrium state of the model is solved can be determined by the longest time horizon needed by one of the logistic actors to evaluate and perform new decision. Section 5 focuses the discussion on this knowledge gap and research opportunity therein.

- **Global freight transport/carrier service and infrastructure network model**

We integrate the construction of the models of the last two sub-systems into one model as we don't need to have a high resolution on the maritime transportation service system but a rather high resolution on the global infrastructure network service.

Global freight carrier service model is used to calculate the split between modalities used to ship the freight from an origin to destination. This is done by taking into account the time value of the goods shipped and the available carrier services. On the other hand, the global infrastructure network model is used to assign the freight shipment to the shortest possible paths based on the locations of all facilities in the supply chain network. There are different types of route choice models which have been developed to calculate the choice probabilities for a shipper to select a certain route. The common way of modeling choice probability is to calculate it as a function of route specific generalized costs. In the world container model, the path size logit model is used to handle the problem of networks with the overlapping routes (Tavasszy, et al., 2011). In this model, routes that incur lower generalized transportation cost would have higher probability to be chosen by the shippers to ship their goods. In Tavasszy, et al. (2011) several scenarios are investigated to demonstrate the capacity of the model to explore some future uncertainties that may impact the throughput of the European Ports. The results of the model are shown in terms of changes in container TEU that flow into the European Ports. It's clear that the model has promising calibration result with less than 10% error in approximating the sum of the absolute difference between the approximated and actual flows of the ports.

In these sub-systems, the actors involved which have to be taken into account are mainly the shippers (producing regions) who would choose the shortest route to transport the shipment.

Given the spatial structure of the global logistic networks which includes the locations of the production, consumption and the pivotal points, the spatial pattern of the global freight flows can be estimated. At this stage, the system states of interest can be derived and analyzed to make policy recommendations i.e. port profit, the level of global CO_2 emissions, the generalized transport costs from the origin and destinations, global energy consumption, modal split structure.

In our modeling framework the World Container Model (WCM) is used to represent the last two-sub systems. Finally, the changes in the generalized transport costs driven by the changes in the global logistics structure would be used as an input for the EXIOMOD model where new equilibrium for trade flows for the new decision's time horizon would be solved. This way, the whole global freight transportation system is modeled using dynamic simulation-based approach.

4.1.2 Modeling Challenges and Strategies

There are three challenges which are inherently visible in the modeling process: 1) data availability and inconsistency, 2) trade-offs between model detail and execution speed, and 3) model validation. The first challenge stems from the fact that there are currently very little data available for the location of warehouses and distribution centers in different parts of the world and it's difficult to find such data. In addition to that there is also inconsistency in the international trade data found in different databases. To overcome the data problem for the warehouse locations, we propose to use interview to stakeholders which may represent the shippers as the decision makers for the usage of warehouses or distribution centers. Subsequently, operations research modeling technique (such as facility location model) which requires little amount of data is also going to be used, taking into account the interview results. For the data inconsistency problem, we are going to address it by investigating different existing databases and perform statistical analysis which enables us to pick the most reliable database.

Next, since the multi-steps modeling framework might be modeled as system of systems, there are many sub-systems which have their separate parameters, hence there are numerous parameters to be experimented. Applying exploratory modeling to such a model would be reasonably challenging due to the computational power it requires. One alternative to solve this problem is to develop a model which is

simple and computationally efficient such that large number of simulation runs can be made possible within reasonable amount of time. This gives a challenge, in particular, in making the appropriate trade-offs between the level of detail of the model and the computation resource it needs. Discussions with experts both from simulation and freight modeling field would have to be performed to ensure the appropriation of the decision taken in realizing the modeling objectives.

Last but not least, validating an integrated model which consists of many different big models also possesses challenges. The models have to be validated separately before the integrated model can be validated. Historical data such as international trade and container flows worldwide would be used together with the expert opinions as means of validation.

4.2 Example of Computational Framework

As we also aim to use the model to devise normative recommendations to policy problems found in the global level, in this section, we propose the preliminary computational framework which is designed to reach that goal using the combination of various modeling techniques. The computational framework is designed with a close adherence to the high-level modeling framework presented in section 4.1.
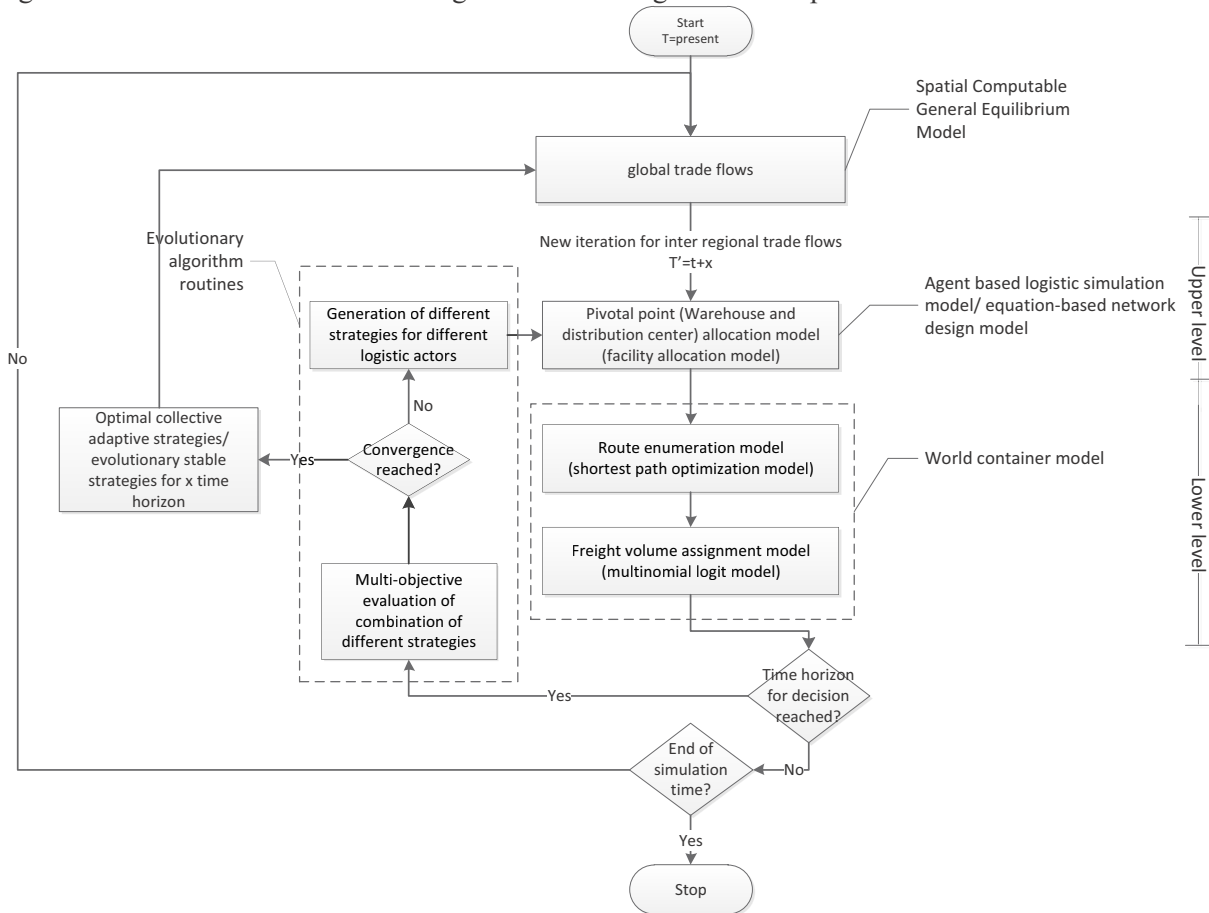

Figure 4 Computational framework

The computational framework presented above is a form of multi-level programming approach which is commonly used in addressing complex design problem in freight transportation sector. Yamada, et al. (2009) uses similar computational framework to find the best strategies to perform freight transportation infrastructure improvements in Indonesia (Yamada, Russ, Castro, & Taniguchi, 2009). Furthermore, Dimitriou & Stathopoulos (2009) uses combination of agent based model, evolutionary algorithm and sto-

chastic user equilibrium in multi-level programming approach to investigate the evolutionary stable strategies (Dimitriou & Stathopoulos, 2009).

The integrated model would make use the output of EXIOMOD (location of production and consumption sites and the values of the commodities traded between the origin and the destination) as its input. First we would use the facility location problem such as p-median problem as the upper level optimization problem with which the emergence of new facilities that serve as the pivotal points for the freight flows is approximated. Afterwards, the world container model would make use the locations of these facilities to perform route choice approximation for the container flows. This way, the full spatial pattern of freight flow of the world from the origin to the destination can be approximated.

It's important to notice that the model which is going to be developed here is different than those of conventional models. The decentralized nature of the decisions made by different logistic actors such as port authorities, warehouse, distribution center operators and shippers are taken into account in this model. Using the paradigm of game theory, we can model the strategies/decisions made by these different actors (e.g. investments in the infrastructures made by the ports, usage of warehouses or distribution centers made by shippers) and simulate the emerging results of the interactions. In order to do that, different strategies for different actors have to be first defined as a finite possible range of strategies and simulative approach has to be employed. This brings us to the possible application of agent based modeling technique.

Next, given a finite set of strategies, we can find the optimal stable combination of these strategies where the system is defined to have reached equilibrium- a condition where all actors can't improve their utility any better by changing their strategies against the strategies of the others. However, as the number of the actors and the set of strategies which can be defined for these actors increase, the possible number of combinations of these strategies would increase exponentially. This condition can be best modeled as a large scale multi-objective combinatorial optimization problem for which an efficient multi-objective optimization algorithm is needed. Therefore, to deal with this problem, we propose to use simulation-based optimization approach where the simulation model is coupled with the optimization method (Fu, 2002; Fu, Chen, & Shi, 2008; Fu, Glover, & April, 2005).

However, in order to use simulation-based optimization method effectively, a framework which facilitates the implementation of such method is needed. In this context, we propose to use the Simulation-based Multi-objective Evolutionary Algorithm (SIMEON) Framework for the computational framework presented above (Halim & Seck, 2011). In this framework an optimization algorithm which belongs to the class of evolutionary algorithm is used. This is motivated by the efficiency this type of algorithm offers in solving multi-objective optimization problem (Deb, Pratap, Agarwal, & Meyarivan, 2002; Ding, Benyoucef, & Xie, 2009). By using this type of algorithm, the equilibrium state of the system can be observed when the algorithm reaches convergence. In addition to that DSOL library (Jacobs, Lang, & Verbraeck, 2002) will be used to develop the whole simulation routine which integrates various models elaborated above.

After the whole simulation run of the global logistic model is finished, the resulting outcome would be the information of the complete structure of the global supply chain: production site-warehouse-distribution center-consumption site. Using such information, the world container model would assign the volumes of the freight to different routes/supply path which costs elements are determined by the supply chain structure found earlier. This way, whenever there are changes in the structure of the global supply chain, there would be changes in the spatial pattern of the freight routings. Finally the changes on the generalized transport costs would be used as the input for the EXIOMOD to perform the new iteration at time (T) = earlier time stamp where decisions are reviewed (t') + the longest time horizon where decisions of the all actors are incorporated (x).

5   USER INTERFACE AND VISUALIZATION MEANS

One important and valuable feature which should be developed in the global freight transportation model is the explicit incorporation of the model visualization. This way, the users can validate and ana-

lyze the changes in the spatial patterns of the global freight flows conveniently. Figure below depicts the user interface, of the world container model which visualization will be used as user interface for the integrated model. The figure below depicts the approximated freight flows in 2030 in which international trade between China and Europe and the United States is assumed going to increase steadily over time. All the freight volumes assigned onto the global maritime network are displayed in proportion to the boldness of the lines. Different ports and infrastructures together with their capacity are also represented with diagram such as pie chart (for Port) and number (for maritime or rail links).
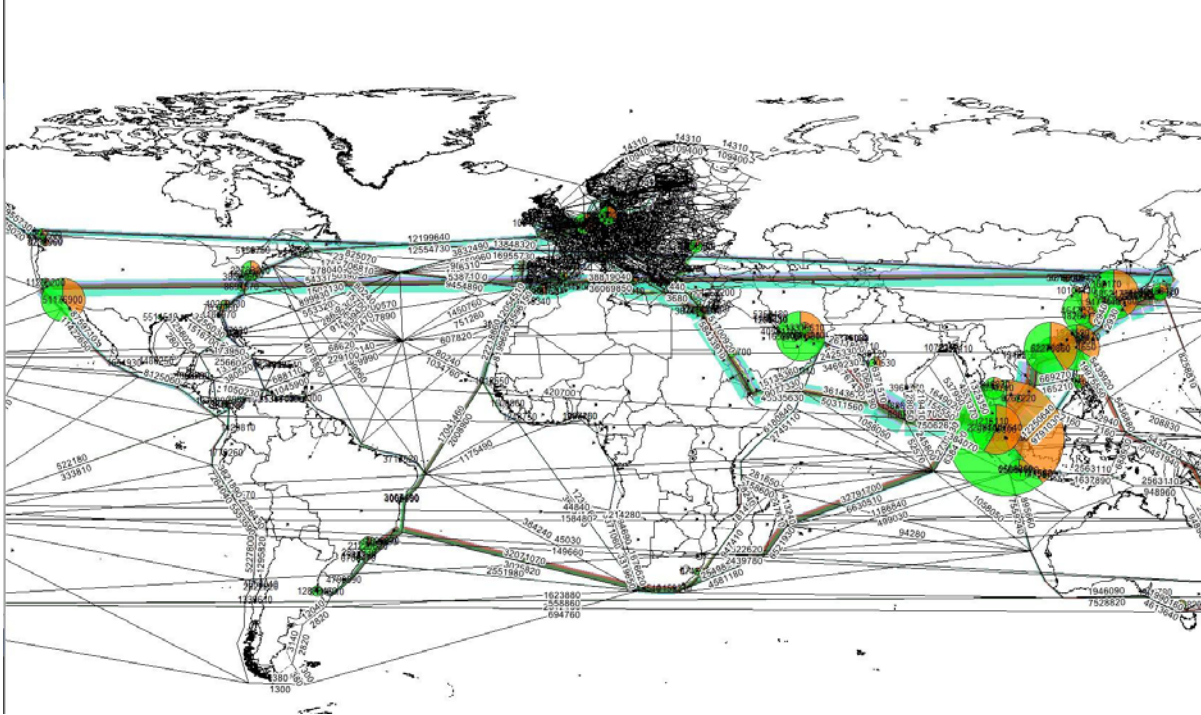

Figure 5 Global Freight flows in 2030 produced by world container model

6   CONCLUSION AND FUTURE RESEARCH

Freight models have to a great extent evolved separately along the lines of the original multi-step modelling framework presented above, with very few integrative attempts. This explains the scarcity of integrated global freight models while the need to use such models is growing. As Liedtke et al (2009) point out, a risk of the traditional multi-step transportation modelling framework is the mismatch between the functional behaviour of the different sub-models making construction of comprehensive choice models problematic. Our objective in this paper is to provide a multi-level modelling framework that can facilitate the development of an integrated global freight transport model in which functional behaviour is aligned between sub-models.

We have explained the problems that are caused by the absence of a detailed and comprehensive modelling framework for the global freight transportation system. In relation to that, we also explain the challenges that have to be addressed in building such a framework which we use as the basis of our framework design. Moreover, based on the modelling objectives presented, we presented design of a framework that is able to answer explorative and normative questions.

We hope to contribute to the creation of shared understanding of the definition and structure of the global freight transportation system by delineating in detail what subsystems should be modelled and how they interact together. Furthermore, we ensure that all the sub-models can be developed with uniform functionality by reaching consistency in the input and output variables used between the different layers of the model framework. Ultimately, to ensure the coherency of the model discussed here we also have

exemplified the whole process of transforming modelling objectives into computational framework that is operational.

For the future research we plan to implement the computational framework using various open source Java-based libraries that have been developed during the past couple of years such as DSOL (Distributed Simulation Object Library), for the discrete event simulation of the global logistic system and underlying simulation engine for the integrated model (Jacobs, et al., 2002), WCM (World Container Model), for the global freight network transportation system (Tavasszy, et al., 2011), and SIMEON (Simulation based Multi-objective Evolutionary Optimization Framework) for the simulation and optimization modules of the computational framework (Halim & Seck, 2011). Applying framework of analysis offered by complex adaptive system to implement the computational framework presented is also one of our research interests as there has been a promising development in the application CAS in global freight maritime network (Caschili & Medda, 2012).

Finally, there are three contributions to real-world problems that this model has to make. The first is to contribute to the better understanding of the mechanism of how the future global logistics structure would evolve and how it would influence the other global freight transportation sub-systems and vice versa. The second is to enable explorative investigations in regards to the exogenous uncertainties which may influence the future routing of global freight flows. Lastly, is to support policy making processes which can foster international trades which promotes a fairer distribution of global wealth.

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