Modeling the Empty Container Flow: An Application of System Dynamics

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ABSTRACT
The volume of container traffic has increased many folds during the last two decades owing to increased globalization of trade. The imbalance of trade has also increased along with the increase in global trade. Presently, trade imbalance exists along all the major trading routes in the world. The increased trade imbalance has resulted in significant cost to the marine industry for handling and repositioning of empty containers. Although trade imbalance is the major cause, many other factors like tariffs, cost of repositioning, cost of new containers and dynamics in leasing industry also impact the flow of empty containers. Detailed analysis of the factors and the dynamics affecting this flow has been made in the relevant literature. However, no attempt has been made so far to model and simulate this system. The purpose of the present study is to model the dynamics of empty container flow using system dynamics. System dynamics gives the user an ability to model relationship among multiple interacting factors, and study the resultant behavior of the system, which precisely, is the purpose of this study. As such the use of system dynamics as the modeling tools seems justified. A simple two port container port system is developed. The model is validated through comparison of actual and simulated container flow for the Port of Los Angeles for a specified time span. Such a model would provide a tool to the decision makers to evaluate various what-if scenarios, which would give them better visibility of the system and assist them in taking the appropriate decisions, from policy point of view.

Keywords: empty container flow, system dynamics

1. INTRODUCTION

With rapid globalization container volumes in global trade have increased many folds in the last couple of decades. The Asian countries particularly China and Korea have evolved into major manufacturing centers for consumer goods sold in the United States. At the same time, export of US goods to the Asian countries has not increased at the same rate in volume and value. The resulting trade imbalances have been a major reason for the rapid increase in the number of empty containers in various ports around the world. Boile (2006) has identified the following as the root causes for empty container accumulation 1.Trade imbalance, 2.Rate imbalance, 3.New container prices vs. cost of inspecting and moving empties, 4.Un-timely shipment and delivery of containers, 5.High storage fee in areas of high demand. The accumulated empty containers can either be repositioned at an interregional level or a global level for reuse, or they may be scraped or sold in a secondary market depending on their residual life. Since the imbalance of trade is not regional but global, the problem of empty container reuse cannot be sufficiently addressed without considering global repositioning. This paper would address issues particularly related to global repositioning and the term ‘repositioning’ would invariably be used in context of global repositioning.

The causes for empty container repositioning enumerated above are not only responsible for accumulation of empty containers in a particular geographical area but also for the changing location and magnitude of this issue depending on the interplay between these factors. For example, the acute problem of empty container accumulation in the US ports was partially resolved due to the steep increase in the cost of new container boxes in 2003-04 which made the option of repositioning the empty containers to Asia economically feasible (Boile, 2006). Today a large portion of the outbound containers from the United States is composed of empty containers e.g. 45% in 2010 from the Port of Los Angeles (Port of Los Angeles, 2010). On similar lines the ports in Asia were clogged with empty containers in 2009 due to the slump in demand for goods in the United States as the economic recession spread (Bloomberg, 2009). On the other hand some ports might offer reduced rates and incentives for storage of empty containers for attracting business during economic slowdown or as leverage against competing ports in the region prompting an accumulation of empties in that area (Tirschwell, 2009).

The point to be made in the arguments above is that, empty container dynamics are highly subjective to the interactions between large numbers of factors. The complexity of the container industry in general with a multitude of players from the ocean liners to the container leasing agencies and intermodal transporters as well as different options for possession of containers, such as, multiple leasing arrangements, buying new, repositioning, and actual ownership add further dimensions and complexity to the problem of managing empty containers. To avoid the costly repositioning activity a shipping company had the option of leasing containers in a high demand area and off-leasing them in the low demand area. With the purpose of obtaining a greater integration and visibility in the system and a better management of equipment inventory the shipping companies have increasingly moved to direct ownership of containers in recent years, with about 59% of the container being owned by the shipping companies in 2007 (Theofanis & Boile, 2009). Thus the option of off-leasing is significantly diminished. The option of buying new containers in the demand areas and disposing them in surplus areas is also not feasible owing to the high cost of manufacturing new containers, for the past several years. The cost of new containers is currently at a record high (Barnard, 2010). Under this scenario repositioning of empty containers is the only economically feasible option. The advantage associated with this scheme is the reduction in the accumulation of empty container and high utilization of the containers, which is evident from the fact that in 2009, about 95.6 % of the leased containers were on active operating leases (Theofanis & Boile, 2009).

Although reasons for the accumulation of the empty containers may vary, there is little doubt that an excessive accumulation of empty containers and the resulting cost of repositioning empty containers is a major concern. Empty container accumulation is a source of critical social, traffic, environmental and aesthetic problems (Boile, 2006). Also according to Boile (2006), excluding the cost of storage and repositioning over land, the estimated total cost of empty movements in 2003 was 11 billion dollars with an estimated cost of about thousand dollars per container.

The purpose of this paper is to utilize system dynamics to model the complexities associated with the movement of containers between the economic geographies. For the sake of demonstration the author has attempted to model the flow of containers between the Asian region and the United States. The particular advantage of using system dynamics lies in its capability to model multiple interacting factors that affect the system. This allows the user to observe the combined effect of these factors under various scenarios. This model should provide a useful insight in container flow and accumulation to shipping companies and policy makers. The model would prove to be useful in efficient planning and allocation of resources. In the next section the literature relevant to this topic would be reviewed. This would be followed by the model description and demonstration. The paper would conclude by providing a discussion of the results and future work.

2. LITERATURE REVIEW

This section would discuss some of the relevant literature in this field of study. The discussion would be limited to papers addressing issues related to global repositioning of empty containers.

The problem of empty containers repositioning has generally been addressed as an inventory problem, with the objective of determining the optimum quantity of containers to be stored at a port while minimizing the total cost involved (Cimino, Diaz, Longo, & Mirabelli, 2010). These problems have been characterized as dynamic allocation problems by Dejax and Crainic, (1987). Lam et al. (2007) have classified the literature dedicated to empty flows in terms of their application area as operational, tactical and strategic. While the operational models deal with day to day decision making process, the strategic models address long term planning issues like depot location, sizing and so on. Their survey shows that a major section of papers have been dedicated to the operational aspects of this problem.

Li et al. (2004) have proposed a ‘two-point-critical’ policy for minimizing the transport and leasing costs associated with empty containers for a single port. The policy consists of a lower and an upper bound on inventory levels. The port would export empty containers if the inventory rises above the upper bound while it imports containers if the level falls below the lower bound and incur an export or import cost per container respectively. Any shortage of containers is met through leasing the required number of containers in that period which would incur a leasing cost. The results have been extended to a multi port case in Li et al. (2007). However, both these studies have assumed deterministic costs in their analysis. However, costs do change and the preferences of the shipping companies also change with the changing costs. It is also not clear how the policy would function if all the ports exceed their upper limits. This scenario is possible if there is a significant drop in demand as has been observed during the recent recession years. This would lead to a net excess of containers in the global system and an accumulation should be observed somewhere in the system.

Di Francesco et al. (2009) address the repositioning problem under a scenario in which some of the ports in the network do not allow long term storage of empty container and no reliable historical or current information is available to formulate the policy for the next period. They provide a multiple scenario modeling approach where multiple scenarios are generated according to the guesstimated values of the uncertain parameters. The mathematical model is solved by incorporating the generated multiple scenarios to get the optimum number of empty containers to be stored at the given port in the particular time period. Song and Carter (2009) analyze the empty container repositioning problem at a macro level and evaluate four strategies based on coordination of route-sharing and container-sharing on major ocean routes. They report that significant savings can be achieved by combining route-sharing and container-sharing strategies. Dong and Song (2009) use a simulation based optimization approach utilizing genetic algorithm and evolutionary strategies to solve the combined problem of container fleet sizing and empty container repositioning. Their objective is to minimize the total cost associated with this operation under a multi-port, multi-vessel and multi-voyage scenario. This study considers a much more generalized shipping system than considered by previous studies done on similar lines. Lam et al. (2007) have proposed a dynamic programming approach for addressing the issue of empty container relocation. They have used a simulation based approach called temporal difference (TD) learning to derive effective operational strategies that would minimize the average cost associated with empty container relocation. All the above studies have been dedicated to the operational aspects of empty container management. The purpose of the present study is to develop a tool to analyze long term trends in container movement, container fleet size and container accumulation. As such the present study may be classified as addressing the 'strategic' aspects as per the criterion by Lam et al. (2007). The survey by Lam et al. (2007) shows that relatively few papers have addressed the strategic aspects of empty container management. Gendron and Crainic (1995) and Bourbeau and Crainic (2000) use branch and bound techniques to solve the depot location allocation problem for marine container management. The problem addressed in general is to locate depots to receive and store empty containers such that the total cost associated with the movement of container between customers and depots and between depots is minimized. Two recent studies can be found using system dynamics for analysis of marine systems. Amongst them Choi et al. (2007) have used system dynamic to analyze the long term effect of introduction of new technology and equipment on the efficiency of a container terminal. Ho et al. (2008) address the impact of infrastructure investment on port throughput and capacity. Although neither of these studies is related to empty container management, they are relevant to the present study since they are amongst the few, using system dynamics for marine logistics application and are dedicated to the strategic aspects. The discussion above indicates that most of the research on empty container repositioning has been centered on the operational aspects. A few studies dedicated to the strategic aspects have addressed issues such as depot location-allocation and investment impact on port efficiency, throughput and capacity. An excellent analysis of various factors impacting the flow of empty containers and their accumulation has been provided by Boile (2006) and Theofanis and Boile (2009). However, to the author's knowledge no attempt has been made so far to model and simulate a container flow system that incorporates these factors. The authors believe that such an approach would be beneficial to analyze various what-if scenarios and provide useful inputs to decision makers on issues like capacity and tariff structure. It would also assist the shipping companies to comprehend the global container flow trends at a macro level, under various conditions, which can help them manage their operations more efficiently. In the next section the authors would introduce and discuss the salient aspects of the proposed model.

3. MODEL DESCRIPTION

The authors propose to build a simple two port system with a trade imbalance such that one of the ports has an excess of empty containers. Naturally, the port with a positive trade imbalance would have the option of either importing containers from the other port or purchasing new containers. However the preference for this decision would depend on the relative cost of repositioning vs. the cost of purchasing new containers. If the repositioning cost is high, the corresponding cost of leasing new containers would also be high, as the leasing agency would attempt to pass on the high cost of repositioning to the shipping company so as to remain profitable. As such, we assume that leasing of containers and repositioning are equivalent options and hence assume that no leasing option is separately available. Thus the only options available are repositioning or purchasing new. On the other hand the port with a negative trade imbalance would have excess of empty containers and would prefer to export them to the port with high demand. Again, this would be subject to the relative cost of repositioning to the cost of purchasing new containers. If the cost of repositioning is less that the cost of buying new containers, the port with an excess of empty containers would export those to the deficit port. Thus the total shipment from any port would be the loaded export containers plus the empty containers that the port may choose to reposition depending on the cumulative effect of the factors affecting the economic feasibility of the operation. The shipment of loaded containers (prospective) would be contingent upon the availability of empty containers. If the storage tariff at a particular port is low, it would become the preferred location for the storage of excess empty containers and an accumulation of containers could possibly be observed at that port depending on the trends in the volume of the trade. It would be more likely to observe an accumulation if the volume of global trade drops. Figure 1 below displays the system dynamics representation of the discussion above. It can be observed in the figure that the term 'Total inflow USA' is equivalent to the total number of empty containers available. Depending on the number of empty containers available the 'Containers ready for shipping' can be made ready for shipment. The 'Load empty containers' rate disposes off the quantity of empty containers equivalent to the 'Outbound containers/empty container availability' rate, so that the outbound containers are not double counted. The 'Total inflow USA' rate and the 'Containers loaded on ship' rate are limited by the available throughput of the port. Finally the 'repositioning' adds outbound empty containers to the total shipment. The same logic is followed for the second port. This flow model is tied to a simple capacity model for each port, which would decide the possible throughput of containers through that port. The capacity model consists of a stock of available capacity which would decide the throughput of the port. The difference between the available and desired capacity would drive investment in additional capacity and maintenance, while the deterioration of resources over time would reduce the available capacity of the port. Thus if no investment in additional capacity are made the available capacity would deteriorate over time. The capacity model is displayed in Figure 2. A twenty day transit time is assumed for the flow of container to reach from one port to another. Looking at the macro-scope of this study factors such as ship capacity and ship schedules have been ignored. The effect of these factors is assumed to be accommodated in the twenty day transit time.

The integration of the models described above would result in a two port container flow system as displayed in Figure 3 below. Another aspect added to the holistic model is that of 'information delay'. If the trade imbalance between the ports starts to change over time, an attempt would be made to adjust the repositioning policy so that excessive accumulation would not occur in any of the ports. However, trade imbalance is a stochastic parameter and would always change over time. As a result any significant shift in the trend of the trade imbalance can only be appreciated with a certain lag of time. The concept of 'information delay' has been incorporated to take this phenomenon into account. This parameter is the authors attempt to take into account the lack of accurate information and inability to accurately forecast trends, which is experienced in any decision making process in general. A delay of sixty days is thus introduced, before the decision makers can appreciate a significant change in trend of trade imbalance and make corrective actions to their policy.

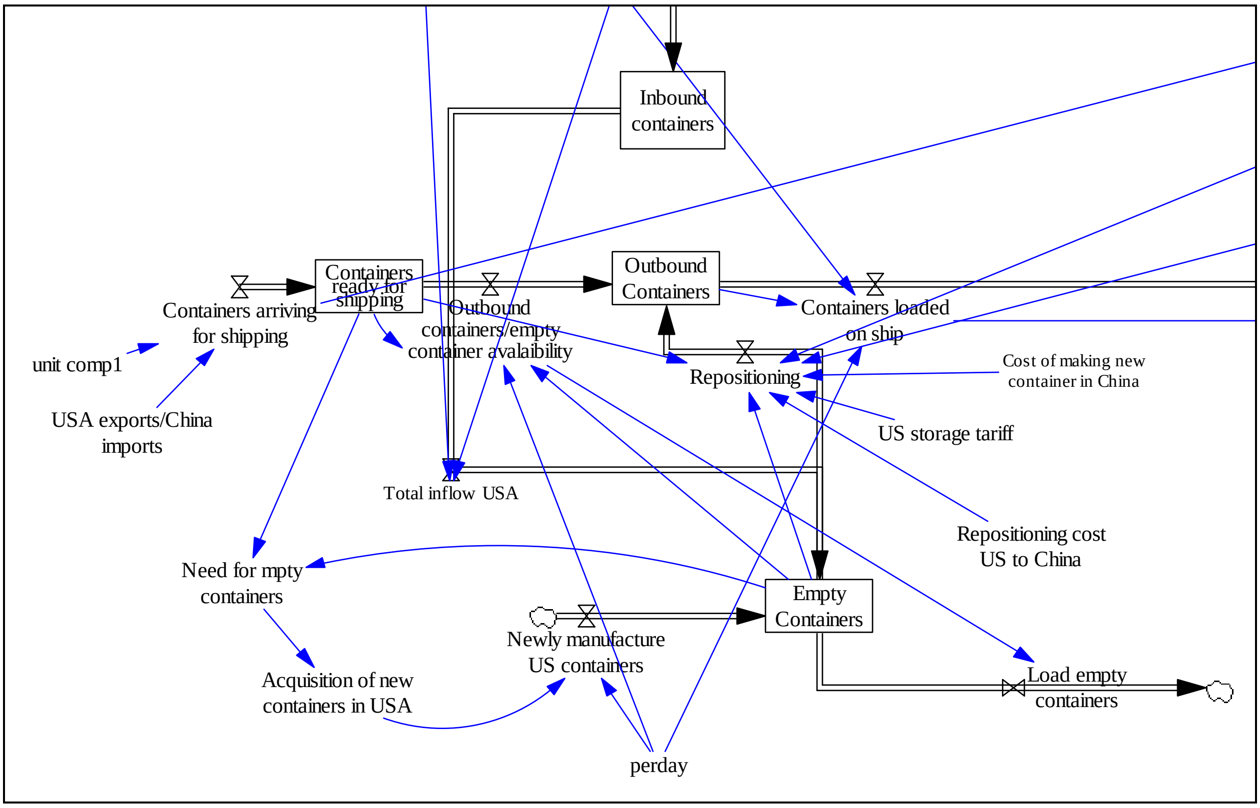

Figure 1: System dynamics representation of container flow for a single port

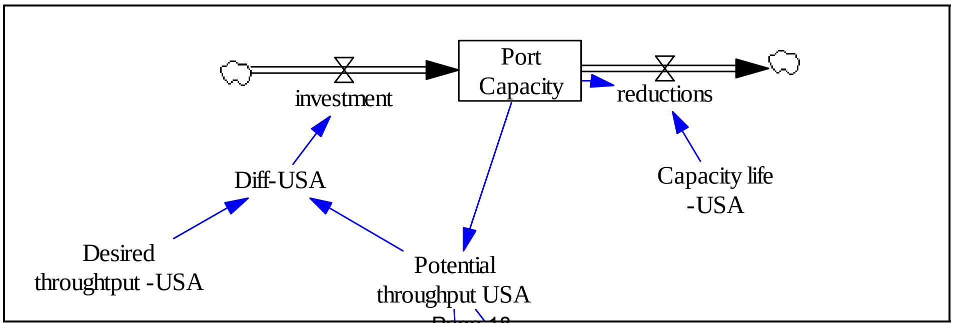

Figure 2: Simplified system dynamics model for port capacity

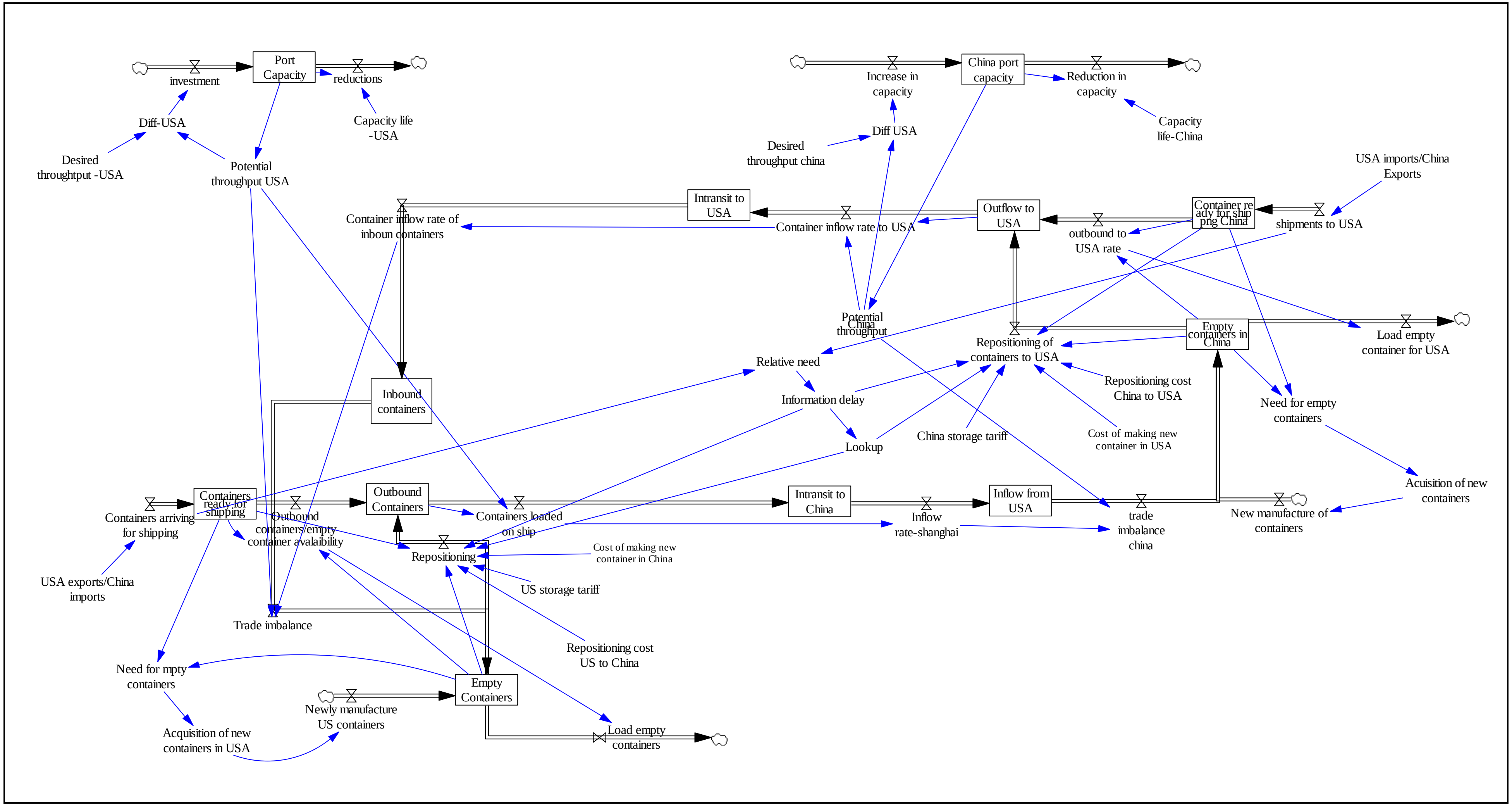

Figure 3: Proposed two port container flow system

4. DEMONSTRATION EXAMPLE AND RESULTS

The model is demonstrated using the Port of Los Angeles as an example. The Port of Los Angeles is a major port on the US west coast and has its major trading partners in Asia. For the sake of this example we assume that the Port of Los Angeles has a single trading partner in China. The TEU statistics for the port of Los Angesles have been obtained from (Port of Los Angeles, 2010). 'Inloaded' TEU are assumed to be the equivalent the import volume which corresponds to the export volume of the Chinese partner port. On similar lines the 'Outloaded' TEU are considered as export from Los Angeles and are assumed equivalent to the imports by the Chinese partner port. Both import and export volume in TEU are modeled as linear functions with the slope of the function equal to the difference between TEU volumes from 2000 to 2006 divided by the time span (2555 days). The numeration is displayed in Table 1. The second section of the piecewise linear function is calculated for the same parameter from 2006 to 2009 in the same manner as described above, and is shown in Table 2.

Table 1: Export/Import input for the model from 2000-2006

	In loaded-Import (TEU)	Out Loaded – Export (TEU)	Out Empty (TEU)
Jan-00	185913.65	73881.05	90174.35
Dec-06	359066.60	129467.75	217201.50
slope	67.77	21.76	49.72

Table 2: Export/Import input for the model from 2006-2009

	In loaded-Import (TEU)	Out Loaded-Export (TEU)	Out Empty (TEU)
Dec-06	359066.60	129467.75	217201.50
Dec-09	283364.40	153836.50	120142.40
slope	-69.13	22.25	-88.64

The resultant import and export input trends for the ten year period can be seen in Figures 4-5 below. The Y-axis represents volume in TEU/Year.

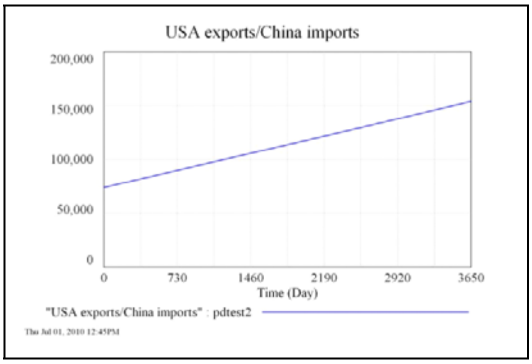

Figure 4: Export trend for port of Los Angeles (2000-2009)

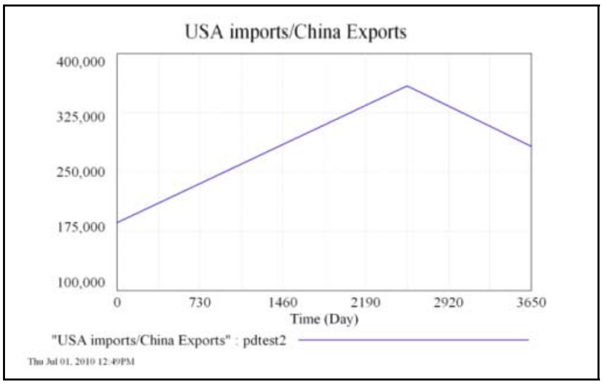

Figure 5: Import trend for port of Los Angeles (2000-2009)

The model as shown in Figure 3 is simulated for a period of ten years or 3650 days and the results are analyzed. For the sake of simplicity it is assumed that the repositioning cost is always less than the cost of making new containers. If no empty containers are available for shipment, they are bought new. Secondly the storage tariff is assumed equal at both the port locations. Also, it is assumed that sufficiently large capacity is available at both the port so that no active capacity constraints are imposed. The major points of interest here are the trends followed by the volume of repositioned containers from the US and the volumes of empty containers in the hypothetical Chinese port.
Figure 6-7 display the simulated and the average actual TEU of container repositioned (out empty) from the Port of Los Angeles from 2000 to 2009 per day. As can be observed the simulated and the actual figure follow similar trend and take comparable values, which provides validation for the proposed model. The second point of validation can be obtained by observing the increased accumulation of empty container on the Chinese (Asian region) port during the later part of the simulation, as displayed in Figure 8. This agrees with the observations of Bloomberg (2009) as far as the trend is concerned and can also be considered as a validation for the proposed model.
Although a more extensive experimentation and validation would be desirable, the validation provided above may be considered sufficient to establish the basic tenets of the proposed model and demonstrate the utility and usefulness of the undertaken exercise.

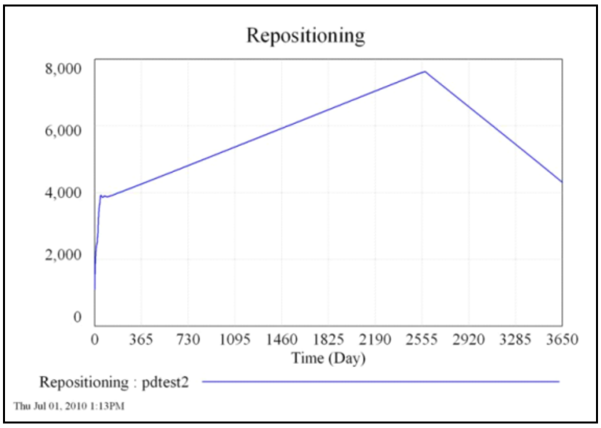

Figure 6: Volume of repositioned TEU for port of Los Angeles (Simulated)

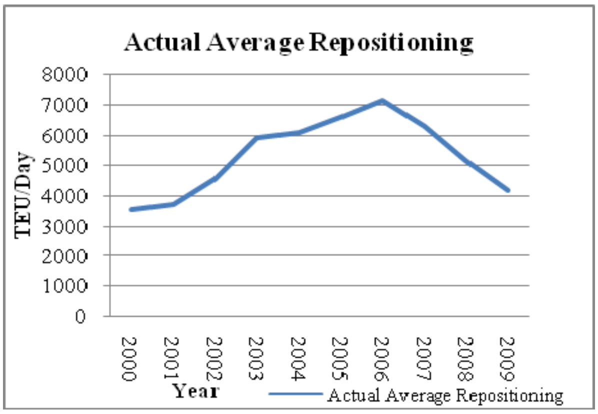

Figure 7: Average volume of repositioned TEU for port of Los (Actual)

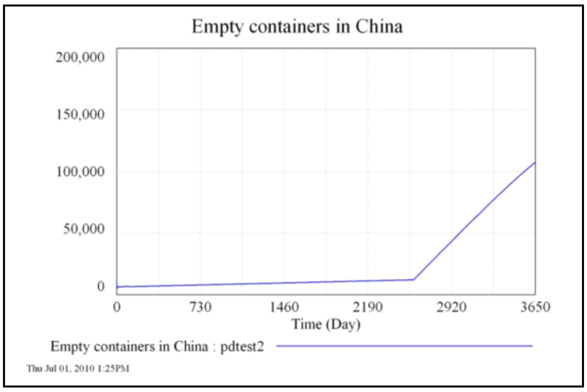

Figure 8: Simulated trend for empty container accumulation in the Chinese port (Y-axis- TEU)

CONCLUSIONS

The volume of containers in the logistics system is decided by the volume of the global trade. With the rapid increase in global trade with the advent of globalization the population of the container around the world has exploded. New containers are manufactured every year to meet the increasing demand for empty containers due to overall increase in volume. Also, due to a large geographical distance between exporting Asian countries and the importing Western countries there is a huge in-transit inventory of containers at various stages from ports and ships to intermodal transport and warehouses.

A slowdown in the global trade as has been observed during the recent recession years, demands a reduction in the inventory of the containers due to reduction in demand. However, unlike the goods they carry the containers are neither easily consumable in secondary markets nor economically disposable. Valuable resources need to be spent on the storage, handling, repositioning and maintenance of these containers. Such cost directly affects the profitability of the highly competitive shipping industry. Secondly, port authorities around the world need to make adequate space arrangements for storage of empty containers, so that the exporter's demand for the empty containers can be met. This is particularly challenging in view of rapid metropolitan development in the vicinity of major ports around the world, and the resulting shortage and high cost of space in the port vicinity. Under this scenario, studies aimed at gaining a better understanding of the dynamics behind container movements are warranted.

The analysis presented above can be termed as an attempt in such a direction. The authors have attempted to model and simulate the container flow for a two port system, by including the major factors that affect the container flow dynamics. The multiple interacting factors like tariffs, cost of manufacturing new container and cost of repositioning affect this system. System dynamics is a tool that provides the ability to model complex relationships and study the resultant system behavior. This capability makes system dynamics as an idea tool for modeling the container flow system.

A demonstration and validation of the model has been provided using the Port of Los Angeles as an example. This model can assist both the shipping companies and the port authorities in a more efficient decision making as far as the facility size, expansion planning, tariff structures and inventory management of containers is concerned. This would also help researchers to develop new approaches to handle this problem in a better and cost effective manner.

The present study can be significantly expanded to consider multi-port systems. In the present study we have assumed a fixed relationship between the cost of repositioning and the cost of manufacturing new container. However, this relationship changes depending on major drivers for these factors namely the cost of oil and the cost of steel respectively. It would be interesting to include such primary drivers in the analysis so as to make the model more generalized. Also the effect of different storage tariff structures on the accumulation of container may also be accessed. Lastly, the experimentation and validation provided in the present study can be fitting for demonstration purposes only, which is the intended purpose of this study. However, a more rigorous experimentation and validation of the expanded model would be desirable.

Lastly, the authors would like to acknowledge, that certain non scholarly sources of information such as news reports and articles have been referred in the present study as a basis of particular assertions. However, the authors believe that, the credibility of these sources and the expertise of the individuals reporting the facts, particular to this field, sufficiently satisfy the required validity of information as far as this study may require.

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