System Dynamics Modeling of Logistics Hub Capacity: the Dubai Logistics Corridor Case Study

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Abstract. This paper proposes a System Dynamics (SD) modeling and simulation-based approach to support decision making and policy actions to make appropriate and effective investment decisions about the planning of an intermodal air, sea and land logistics hub capacity. The Dubai Logistics Corridor (DLC) is used as a concrete case study. The model offers the necessary decision support that captures the complexity of managing the logistics hub along with overcoming the implicit policy resistance. The paper illustrates the case study model, application, and various case scenario simulations. The model can be used as a predictive tool to encourage decision making and detecting capacity bottlenecks to help in planning and scheduling the capacity investment of a logistics hub.

Keywords: Logistics, Transport hub, System Dynamics .

1 Introduction

Several reasons are positioning Dubai as one of the major logistics and transportation hubs in the world. Over the past decade the Emirate of Dubai has emerged as a leading transport and logistics center serving not only the Middle East and North Africa, but also Russia, Europe, Asia and the Far East (Thorpe and Mitra, 2011). This has been driven by concerted and farsighted government initiatives that since the mid-1970s have sought to diversify an economy underpinned by oil revenues, but with an otherwise limited domestic resource base. A succession of formal government plans have introduced incentives and inducements aimed at encouraging Free Zone based companies to set-up operations in the region with the aim of fast-tracking the establishment of a modern, service-based economy. The consequent phased development of Dubai's transport and logistics sector over the past several decades, has culminated in the establishment of a major regional multimodal commercial and transport hub, a so-called 'Transtropolis' that includes the Dubai Logistics corridor.
Dubai has arisen as a major international multi-modal commercial and logistics hub. This has been driven by bold government plans and incentives to encourage free-zone based companies to set-up operations and locate their logistics services (Thorpe and

Mitra, 2011). Although several development stages of the logistics hub are already in action, the project remains continuously under reinforcement and numerous strategies and policy actions are undertaken to face the increasing demand of logistics capacity. Some of these policies involve investment decisions to sustain the growth of airport and port capacity in response to significant increase in demand.

This paper is a contribution to support policy actions for the Dubai logistics hub project as to help public policy makers make appropriate and effective investment decisions about the planning of logistics capacity. This is done via using a System Dynamics (SD) modeling and simulation-based approach offering the necessary decision support that captures the complexity of managing the logistics hub along with overcoming the implicit policy resistance. While the use of SD to model and simulate logistics problems is not new, this work is believed to be unique in combining the three dimensions of air, sea and land logistics and using a concrete case study for simulations: the Dubai Logistics Corridor (DLC).

This paper is structured as follows. Firstly, we present the SD approach and list some pertinent works available in logistics and transportation. Secondly, we illustrate the Dubai hub case study model, application, and simulations. Then, we discuss the main results and give the implications. Finally, we draw the conclusions.

2 Literature Analysis: System Dynamics Approach in Logistics

SD is a modeling and computer-based simulation approach that helps understand complex systems. SD allows to graphically diagram a system of feedback-based causal loops between interrelated accumulation stocks, flow rates, and auxiliary variables, to define various linear and nonlinear mathematical relations, and to have commercial software packages do the discrete-step computational effort of solving the differential set of equations over a preset time frame (Sterman, 2000). As an output to computer simulation, the curve lines of all variables are plotted on a time axis. Model testing is based on historical data and sensitivity analyses. SD lets understand the dynamics of a system, the influence of the various variables to the problem at issue, to support decision making, and test policies through simulations of various case-scenarios.

Overall, the efforts for using SD in logistics is done around two main objectives: capacity simulation and policy making (Tako and Robinson, 2012). For capacity simulations, different variables can be predicted such as traffic flow rates, storage capacity, quality of service, efficiency, etc. From the policies perspective, the impact can be evaluated, and case-scenarios analyses made about, for instance, the location of new ports or the development of new paths for road transportation.

Specifically, some SD-based papers are available in the research area of port transportation that could be easily traced to this study about Dubai Logistics Corridor. For instance, Ruutu (2008) uses SD to forecast the Finnish sea transport national demand and associated capacity. A comparison between the SD approach and time series methodology or statistics tools like regression analysis is made to understand the accuracy of the different approaches. Briano et al. (2009) adopt SD decisions for the case of the Voltri terminal Europe located in Genoa, Italy. The purpose of is to design a model for

the port's performance metrics to improving the quality in ports by integration of six sigma and SD. Carlucci and Cira (2009) model through SD a plan for seaport investments. The authors focus on analyzing a small sized seaport. Its main advantage is the ability to linearly depict several relationships occurring amongst the different subjects involved, with increased advantages as opposite to more traditional approaches, like the "Costs-Benefits" mode, or the "Multi-criteria" techniques. Castillo et al. (2004) simulate the decision-making process of vessels carrying merchandise whose final destination is the province of Seville. A forecast is obtained for the port of Seville traffic, highlighting how public investment influences this entrance decision via improvements in the Port of Seville infrastructure and associated cost. De Marco and Rafele (2007) propose a simulation model as a strategic tool for policy making. In particular, the case of logistics and transportations in Piedmont is considered with reference to the localization decision for dry harbor of Genoa. Also, Sebo et al. (1995) develop a SD approach to design the intermodal port of Lewiston, Idaho, and to highlight leverage points, hidden assumptions, second order effects resulting from feedback loops, and system drivers. Intermodals are the interconnections among modes of transport like road, rail, water, and air. The development of an effective and efficient intermodal transportation system requires the identification of barriers to intermodal transportation and the investigation of the impact of proposed changes in infrastructure development, policies, regulations, and planning. A systems approach is necessary to adequately represent the interaction between the sometimes incompatible-concerns of all modes and stakeholders. Finally, dos Santos proposes an SD model to analyze investment policies for the port of Lisbon that could lead to an increase in throughput. Additional objectives include assessing port profits and investments associated with each management policy, as well as their implications to the regional economy. The impact of the port activity on regional employment, trade and GDP is used to measure the beneficial effects associated with each policy.
Most papers available in the literature have research objectives like those of this work, such as logistics demand forecast, optimization of port capacity and analysis of investment, which are linked to cost savings, profitability, and long-term competitive advantage. However, out study overcomes some literature gaps. First, it is the first case study reported for the Middle East region as most of the literature is related to European or US-located logistics and transport SD models. Second, unlike the studies already available in the literature, this paper does not focus on port operations only, but it attempts to study a complete logistics hub including both sea, air and land modes of transport.

3 The Dubai Logistics Corridor

Dubai Logistics Corridor has been implemented to drastically improve the trade process affecting the Dubai Logistics in its entirety, whether it involves land, air, or sea modes of transport. The Dubai Logistics Corridor is composed of three main parts: the Jabel Ali port (governed by an institution called DP World), the Al Maktoum airport (reporting to Dubai World Central – DWC), and the Jabel Ali Free Zone Area (JAFZA). In

the context of logistics management, when freight moves from one free zone to another it must undergo various long and expensive procedures of custom clearance and legal compliance. However, with the creation of the Dubai Logistics Corridor, goods moving within DP world, JAFZA and DWC, i.e., sea-road-air cargo route, need to go through customs only once at the first point of entry. After that, movement within the corridor will be relaxed as the shipment has complied with the stipulated regulations. This globally unique system has made it possible to process demands more quickly and
in a cost-effective manner than ever before. Its innovative policy initiatives spell out that initiating and doing business in Dubai is consistently straightforward and constantly monitored with the advice and guidance of the rulers.
Further, the time taken to unload shipment at DP World, clear the containers, and transport them to the Al Maktoum International Airport in DWC would just be a matter of a few hours (Kalli et al, 2013). Prior to the creation of the Dubai Logistics Corridor, a lot of documentation and customs work had to be finalized in a week-long period of time. Thus, The Dubai Logistics Corridor's business model would help companies reduce their lead times and be able to enjoy more responsive logistics, without compromising their operational efficiency. To create value added to this efficiency, it is crucial to forecast the proper amount of increased capacity investment and anticipate a development schedule. The present work tackles these problems and tries to find a solution.

4 Proposed Approach

The research was developed as follows. First, we worked on understanding, structuring, and analyzing how the logistics system works for both the port and airport. This was done through gathering information, freight traffic data, and interviews with local managers including the vice presidents and the logistics managers of both the port and airport operators. Second, we sketched a first-hand conceptual Causal Loop Diagram (CLD) based on system thinking (Forrester 1961). Third, a numerical SD model was-created using the Vensim software tool. In compliance with SD principles and practices, the case model was developed to include stock variables, flows, and feedback loops that tackle store inventory management, store labor utilization, and customer demand. The mathematical equations underpinning the stock & flow model, were then developed. After that, the model was tested through analysis of model sensitivity associated with random exogenous variables. After testing, many simulation runs were performed under several scenarios. Finally, we analyzed results and made recommendations.

4.1 Causal Loop Diagram representation of the model

Here we present the model via explaining some of the most important feedback loops of the model. Figure 1 gives the CLD representation of the seaport capacity demand section. One has to consider that both airport and land transport sections are the same of the seaport section.

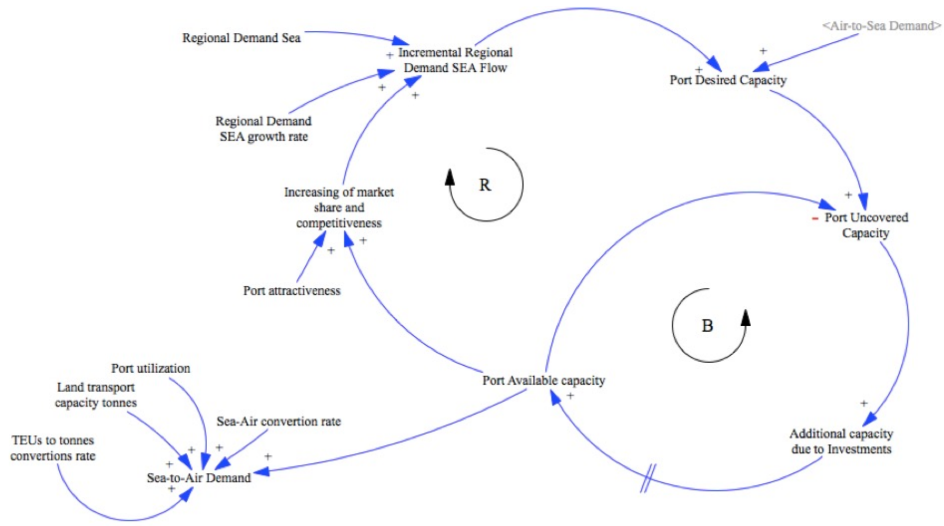


Fig. 1. Seaport capacity demand CLD

The CLD can be explained as follows. The Incremental Regional Demand SEA Flow, defined as the monthly increase in capacity demand increase as far as the Regional Demand grows. The incremental growth in capacity demand generates a shortfall in port capacity, called Port Uncovered Capacity. The uncovered capacity is the difference between desired capacity and available capacity. If positive it generates a stock out in the production area. If negative, then there will be excess capacity. As uncovered capacity increases, stakeholders will be encouraged to invest and consequently increase the 'Additional capacity due to investments' variable. In turn, the increase in available port capacity generates a reinforcing loop: it decreases Uncovered Capacity and increases the ‘Competitiveness and increased market share’ variable. When available capacity grows, the service offered by the port improves and so does its attractiveness and competitiveness.
The interaction between the two airport and seaport model subsections happens through the variables 'Sea to air demand' and 'Air to Sea demand', respectively. These variables correspond to key factors and assumptions that are fundamental in the model, that is the possibility of neglecting control and travel times between the port and airport using the Free area zones and according to the synergy existing between the seaport and dry port. Because of this synergy there is an increase in the demand for both because considered intertwined, that is, part of the demand for one transits also in the second one generating a greater need for capacity.

Figure 2 presents the reinforcing loop affecting the seaport logistics capacity. A positive change in the Incremental Regional Demand causes a variation in the port desired capacity, which is the capacity planned by stakeholders. Obviously, due to constraints, it does not always meet the available capacity target. Consequently, a shortfall of capacity, called Port Uncovered capacity, incurs. It grows with the growth of the Port Desired

Capacity. In turn, it increases the Additional Capacity variable through investments of additional capacity. Not all the discovered capacity is always transformed into additional capacity. Consequently, the additional capacity is added to the available capacity with a delay. A greater available capacity tends to make a higher level of service perceived and, therefore, increases the competitiveness, which is reflected in a further increase in regional demand, thanks to the greater market share taken and the market share of the port. Eventually, this further increases the desired capacity.

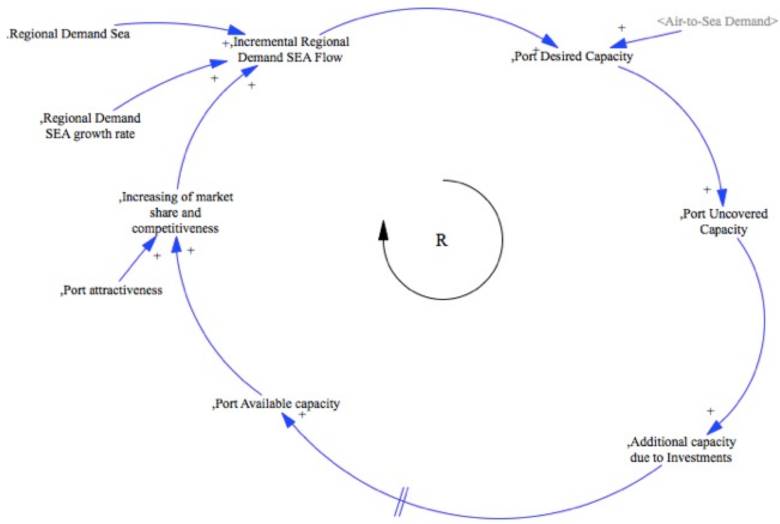


Fig. 2. Seaport capacity reinforcing CLD

The seaport logistics reinforcing loop given in Figure 3, is counteracted by the balancing loop of the Uncovered Capacity. Here the Uncovered Capacity positively influences the Additional Capacity due to investment variable (as capacity increases, the stakeholders will have more incentive to invest to fill this gap). In return, investment that generate capacity will increase Available Capacity, but it will increase with a delay since generating new production capacity is not an instant task and requires considerable time.

An increase in the available capacity will in turn decrease the Uncovered Capacity, and here we are back to the initial variable by closing this loop. It can therefore be said that the Uncovered Capacity influences itself, an increase of it determines with the delay a simultaneous decrease.

5 The SD Model and case-scenario analyses

The multiple reinforcing and balancing feedback loops were then converted into a complete SD model, which can be requested by contacting the authors of this work. As a sample, Figure 3 illustrates the seaport portion of the SD model.

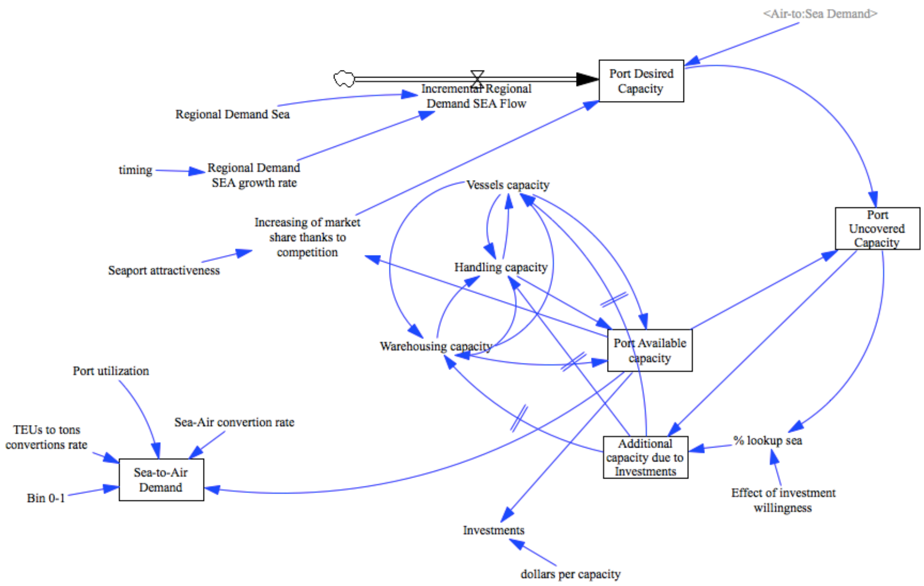


Fig. 3. Seaport section of the SD model used for the simulations

The complete model includes all equations. As an example, the Port Available Capacity is the minimum between the Warehousing, Handling and Vessels Capacity and the Port Uncovered Capacity is the difference between the desired capacity and the available capacity. When it is negative it indicates an excess of capacity.

Based on the complete SD model, we run multiple case-scenario analyses using real data collected via interviews and open data sources. In all the simulations, the time horizon is set as long as 96 months, corresponding to 8 years, being 2015 the first year in all simulations. Simulations consider either a cross-demand factor or no cross demand between the seaport or the airport. In other terms, scenarios can be tested under either dependent or independent logistics capacity between the port and the airport.

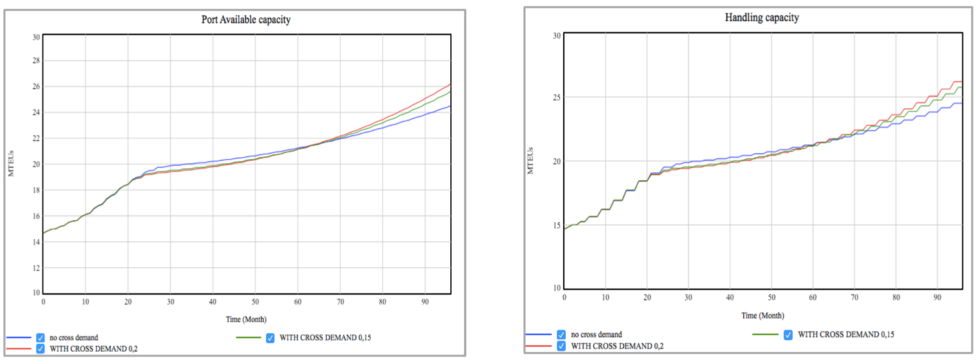


Fig. 4. Port available capacity simulations

The main results of simulation run for the Port Available capacity is that cross demand generates more demand for both vessels, warehousing and handling capacity than without cross demand. It can therefore be noted that the most expensive simulation (because it generates the greatest capacity) is the one with DEMAND equal to 0.2, which requires an outlay of about 6 billion dollars to generate a surplus of about 12 MTeus. Next, we find the CROSS DEMAND 0.15 and, finally, the 'no cross demand' that compared to the first one costs 1 Billion less to generate a capacity less than about 2Mteus (Figure 4). The main results of simulation run for the Airport Available capacity are shown in Figure 5.

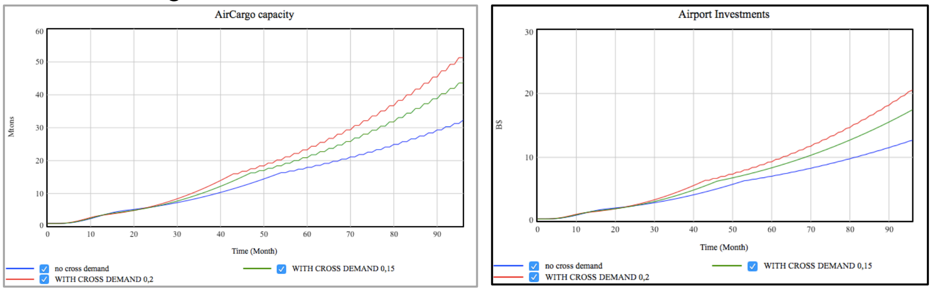
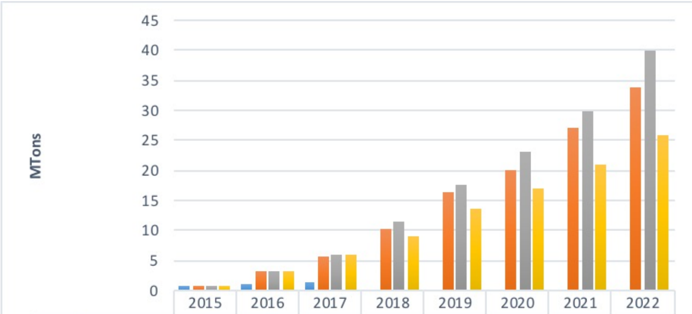


Fig. 5. Airport available capacity simulations

In this case the growth rate is important, in fact in the intermediate case of part in the month 0 from almost 1 million Tons and then reach 43 million Tons. The important growth is mainly since the airport is getting ready to meet an important level of capacity for the project is really ambitious. It is sufficient to think that the total of Air cargo's capacity that is now at the Dubai International Airport (DXB) will be totally transferred to the Al Maktoum Airport. Accordingly, the air cargo, warehousing and handling capacities that form the Available capacity behave in the same way. Warehousing capacity and Handling capacity start from much higher capacity; therefore they start to increase later. Also, in this case it is worth underlining how, once determined which of the three simulations behave more truthfully, it can be used as a policy making tool to evaluate how much and when to invest and above all where to go to act in order to balance the capacity in order to optimize the investments and returns generated by it. It is recalled that a Delay function is used in order to take into consideration the time between the investment expenditure and the actual availability of the related capacity. It can therefore be noted that the most expensive simulation (because it generates greater capacity) is that of the DEMAND 0.2 which requires an outlay of about 20 billion dollars to generate a surplus of about 50 MTons. CROSS DEMAND 0.15 instead is a slightly cheaper but less performing solution, with an outlay of 17 billion dollars to generate a capacity of 42 MTons.

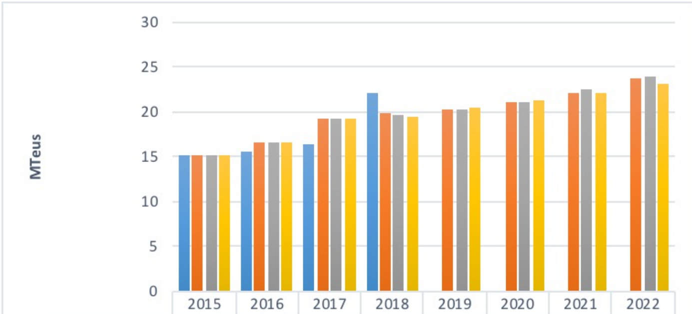
6 Validation

Figures 7 and 7 report the results obtained from the simulations and compare simulated capacity versus real logistics capacity for both the airport and port systems.



	2015	2016	2017	2018	2019	2020	2021	2022
real	0.89	0.96	1.3					
forecast 0,15	0.89	3.21	5.8	10.2	16.3	20	27	34
forecsat 0,20	0.89	3.25	6	11.5	17.5	23	30	40
forecast No Cross	0.89	3.1	5.9	9.2	13.5	17	21	26

Fig. 6. Airport available real capacity vs simulation forecast



	2015	2016	2017	2018	2019	2020	2021	2022
real	15.24	15.58	16.36	22.1				
forecast 0,15	15.24	16.58	19.23	19.9	20.3	21.15	22.2	23.7
forecsat 0,20	15.24	16.6	19.17	19.6	20.24	21.15	22.41	24
forecast No Cross	15.25	16.55	19.3	19.41	20.56	21.24	22.12	23.2

Fig. 7. Port available real capacity vs simulation forecast

As far as the Airport model is concerned, the validation seems to be consistent until 2016, after which the forecasts undergo an important increase that seems not to be followed by reality. In defense of the model, however, DWC has inferred that by 2020 the resulting capacity will reach 16 MTons. A large share of this increase in capacity is due to the acquisition of all the production capacity of Air Cargo at DXB airport, which will consequently become purely a passenger transport provider. It follows that it is not the model that seriously misrepresents the forecast but the airport that is lagging the Master Plan outlined. For this reason, it is difficult to compare the simulations and therefore, to assert which of these seems to be more coherent. For the Seaport simulations, we can see how all three simulations behave in a way that is coherent with respect to reality. More precisely, if we compare the data of 2018 that are the most current today, we can see that the most accurate prediction with the minor error is with CROSS DEMAND

0.15. Depending on this it is possible to state with due precaution that it seems to be a synergy between Airport and Seaport, something confirmed by several articles on the Re-Export of the Dubai Trade.

7 Implications, Limitations and Conclusion

This work has twofold implications. First, this model is proposed as a decision support tool to drive enhanced capacity investments in the Dubai Logistics Corridor. Through the proposed simulation model, it is possible to foresee the future seaport and airport capacities. Consequently, this is a predictive tool to encourage decision making.

Second, this model detects capacity bottlenecks and can help in capacity investment planning and scheduling. It is also affected by some limitations, such as the assumption of perpetual growth in the time horizon, minimum level of detail of the model, and capacity utilization assumed as an aggregate form of Import-Export and Re-Export. In addition, the model does not include the super-additive relationship between investments that may generate other investments. The work presented in this paper is a unique of its kind by targeting one of the major logistics hubs in the world: the Dubai Logistics Corridor. To allow decision makers sustain the Dubai Logistics Corridor growth, we developed a modeling and computerbased simulation approach based on SD to allow to capture the complexity of the logistics system at hand. Different experiments were carried out demonstrating not only the technical viability of the approach, but also its accuracy in term of predicting capacity growth. Future research is directed towards examining other aspects of the Dubai Logistics Corridor such as the appropriateness of connecting Jabel Free Zones to other free zones in the UAE using dedicated corridors.

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