Cross country co-operation in Emergency Situations

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Abstract

During last decade globalization has resulted in larger volumes of foreign trade and containerization of freight. Sea ports are an important part of international supply chains; e.g. in Finland over 75 percent of trade volumes flow through sea ports. Thus, the functionality of the ports and supporting infrastructure plays an important role in the national economy and security of supply. In addition to own import and export, the ports of Finland handle a great share of the Russian imports.

Although, sea is the main mode of transportation in the Gulf of Finland region, there is no study on how the maritime volumes could be handled, if the operational environment changes unexpectedly. The objective of this paper is to evaluate the functionality of the transportation system under selected risk scenarios by using system dynamics simulation. A special kind of risk in the region is connected to spillage of railway wagons, as a large amount of Russian oil and liquid bulk is transported on the Finnish railways.

Although the ability to reroute container flows is limited by the special handling equipment required, special arrangements providing security of supply could be found, given that platforms are available. Based on the simulation experiments, it takes a long time to return to normal situation in the chain after the local crisis, e.g. in the sea port is over. Based on our findings the functionality of sea ports should not be analyzed in isolation, but merely as a part of a wider transportation chain.

Keywords: Emergency situations, containerization, freight transportation, intermodal transportation, sea ports, efficiency, simulation.

1. Introduction

Sea ports are an important part of logistical supply networks as they integrated the inland logistics to international trade through the oceans. One very important part in the global supply chains are the containers. Containers allow the standardized operations in individual sea ports and the amount of containers has increased dramatically during the last 20 years [1]. According IMF forecasts, globalization will only increase this trend and the amount of container traffic will increase [1]

Security is an important is in maritime supply chain. It is not only an issue to individual companies, but overall to international trade as well [2]. According to Salter [3] more critical studies are required to analyze the impact of key infrastructure nodes including airports, sea ports, and border crossings in both national and international context. One way to conduct these critical studies is to use simulations to study, how the system interacts in a crisis situation. System dynamics has been used in supply chain risk management [4] and in this research work we analyze a national level crisis. This study is part of a larger study, where the cargo flows in the Gulf of Finland in emergency situations is studied (STOCA-project).

Transportation systems are a typical example of complex real-world systems, which cannot accurately be described by analytic methods. Ujvari and Hilmola [5] show in Automated Guided Vehicle context explicitly that minor system details, which can be incorporated in to a simulation model, but typically cannot be dealt with using other tools, can have major impact on system performance.

This paper is structured as follows: The second section provides a brief overview of seaborne transportation and the Gulf of Finland. The third section introduces simulation and its recent applications in the field of transportation system analysis. Specific focus is set on system dynamics, the methodology used in this paper. The fourth section is devoted to our simulation experiment regarding the functionality of intermodal transportation systems in emergency situations. The final section contains both the discussion about the simulation model and concludes this paper. We also provide further research objectives in this section.

2. Seaborne transportation and the Gulf of Finland

Sea ports play an important part in the Finnish foreign trade flows as over 75 percent of trade (in tons) happens through sea ports [6]. On a global scale the amount of trade through sea is enormous and trade using containers has increased to 142.9 million TEU a year [1]. As the world becomes even more connected through globalization, this growing trend will most likely continue.

Sea ports also play an important part in the competitiveness of the national infrastructure and thus have an indirect impact on the competitiveness of companies. Sea ports should be able to offer quick service for the ships in order to remain competitive. In addition to competitiveness of a nation, sea ports contribute to the overall wellbeing of a nation as most countries are heavily dependent on trade. For instance, in Finland the amount of exports and imports are 44.5 percent and 39.3 percent, respectively, from the GDP [6].

According to an earlier literature review conducted in the STOCA project on infrastructure of intermodal transportation [7], the functionality of a maritime transportation system is affected by the form cooperation and information exchange between the parties involved in the system. If the information exchange is disrupted for some reason, the overall efficiency of the system is reduced. Special risks identified for international ports include foreign containers and recreational vessels. Interruptions have typically been caused by labor or weather conditions.

The Gulf of Finland contains many large sea ports. These include Helsinki, Sköldvik, Kotka, Primorsk, St-Petersburg, Tallinn and Vysotsk. The amount of oil transportation will increase heavily in the future [8] and thus, an oil spillage might happen in the near future. This would have a large impact on the local economies and nature as the ecosystem in Gulf of Finland is relatively sensitive [9].

According to case study interviews [7] different ports and railway yards in the Gulf of Finland have differing risk profiles depending on the infrastructure and cargo handled. Sources of risk include energy supply, information systems, weather conditions and labor. A special risk in the region is connected to oil transportation.

3. Simulation

Naylor et al. [10] define simulation as the process of designing a mathematical or logical model of a real system and then conducting computer-based experiments with the model to describe, explain, and predict the behavior of the real system. Simulation analysis is a descriptive modeling technique. It does not provide explicit problem formulation and solution steps like linear programming.

Borschev and Filippov [11] distinguish between discrete-event system simulation, agent based simulation and system dynamics modeling. In agent-based modeling individual actors behavior is modeled; the dynamics of the system is derived from the interaction between the actors. Furthermore, in discrete-event simulation discrete units flow inside a system, while resources offer services to the units.

Simulation has been widely used in transport system analysis. Applications range from elevator planning and airport baggage handling system design [12], [13] to evaluating segregation strategies of genetic manipulated grain [14] and modeling of national freight systems [15]. Godwin et al. [16] use simulation for tactical locomotive fleet sizing for freight trains. Simulation has also been used for assessing different regulatory methods in congested transport systems [17]. Although simulation is often seen as an alternative to other analysis tools, it can also be used in combination with them. The Canadian Pacific Railway has used an optimal block-sequencing algorithm, a heuristic algorithm for block design, simulation, and time-space network algorithms for planning locomotive use and distributing empty cars when changing their service concept [18]. Cheng and Duran [19] report a decision support system for managing transportation and inventory in a world-wide crude oil supply chain. The tool is based on a discrete-event simulation model and dynamic programming.

Recently simulation has been used also in analyzing sea transportation. For example Engelen et al. [20] have used system dynamics for a strategic and tactical decision making model for ship owners in the dry bulk sector. Ottjes et al. [21] have investigated the future capacity needs of the Rotterdam port area. Their results include the requirements for deep-sea quay lengths, storage capacities, and equipment for interterminal transport. Further traffic flows on the terminal infrastructure are determined, and the consequences of applying security scanning of containers are evaluated. Douma et al. [22] have evaluated effect of information exchange in the Rotterdam port area on the waiting profiles. Tu and Chang [23] have analyzes operations of ditch wharfs and container yards in future mega-container terminals by using simulation. Grunow et al. [24] have analysed strategies for dispatching AGVs at automated sea port container terminals in single and dual-carrier mode.

SD was developed by Jay Forrester in the late 1950s. The first published work was “Industrial Dynamics” [25] and the simulation model consisted of a supply chain. SD is part of a larger school of thought, Systems thinking. Systems thinking studies dynamic complexity. In dynamic complexity is seen to arise from the non-linear and multi-loop feedbacks, while in detailed complexity the complexity derives from a wide array of possibilities [26].

SD uses only a couple of different kinds of elements to construct complex models. Nowadays almost all SD programs use a graphical interface where the model can be build by connecting different elements together and writing the actual equations inside the individual elements. The used elements are shown in Figure 1.

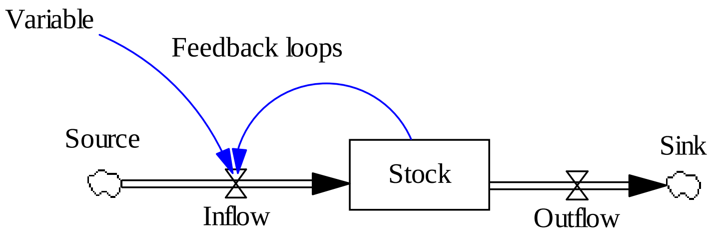

Figure 1. The basic elements in a system dynamic model.

Among the most important elements in a SD model are the stock and flows. The stocks are accumulations which are defined by the in- and out-flows of the model. Mathematically speaking the equations are simply integrals. The stocks play an important part as the model reaches equilibrium as the stocks regulate the feedbacks in the system. For instance, in the example of Figure 1, the stock impacts the values of the in- and outflows so the system reaches equilibrium in time. As the model needs to have fixed boundaries, sinks and sources are used to represent stocks with an infinite capacity. Final parts in SD are variables / parameters and feedbacks. Variables simply store information and / or conduct different calculations during the simulation. The feedbacks represent either a positive or negative feedback, e.g. it will either have a positive correlation between the elements or a negative one. [27]

SD has been used in a wide area of applications. These include ecology, economics, supply chain management, urban development, and even world development. SD has also been used earlier in studying sea ports. Munitic et al. [28] created a SD model where they studied the material flows in a whole port cargo system. The model was constructed on a micro-level and it contained individual fork-lift trucks, wagons, wharfs, etc. Sanders et al. [29], on the other hand, studied the investment dynamics in larger port systems including hinterland capacity. The model also contained the competition between the different sea ports. Lättilä [30] constructed a macro-level SD model where the focus was on the development of demand in different sea ports. The simulation model did not include competition between the different sea ports and the demand was imposed on individual sea ports using the historical values. Even thought the amount of publications regarding system dynamic simulations of sea ports are low, there should be no reasons why SD could not be a valid method in studying the development of sea ports.

4. Simulation Case Study

In this scenario Muuga seaport is going to be closed due to an oil spillage in the port. Twenty percent of the container traffic to Muuga (105 TEU per day) is transported via Helsinki seaport. From Helsinki containers will be transported to Paldiski on platforms with ro-ro ships. The amount of 20 percent of the containers is assumed to be sufficient in respect of security of supply. 80 percent of the containers will remain in the seaports in Central Europe. We analyze the effect of having different amounts of platforms available for the sea transport between Helsinki and Paldiski.

In Helsinki the handling capacity is annually 500 000 TEU. In year 2009 it handled about 350 000 TEU [31]. Helsinki has a fixed amount container storage at the seaport. In the simulation model the containers stay in the seaport for about 1-2 days on average. Muuga cargo handling devices are not moved, they remain in the port. Tallinn and Helsinki have at least two ro-ro connections daily [32]. As Muuga is closed the ferries from Helsinki visit Paldiski port. A standard platform is assumed to carry two TEUs. Empty platforms are transported back to Helsinki. The turnaround time for the platforms between Helsinki and Paldiski is assumed to be two days. Although the same platforms are not returned directly, the number of platforms dedicated to the transportation loop between Helsinki and Paldiski equals the number of daily containers. In different simulations, the number of dedicated platforms receives the values from 10 to 110 with an increment of 10. The duration of the malfunction is 60 days.

Results

During Muuga malfunction Helsinki is able to take 105 containers of Muuga seaport without any problem. Helsinki total demand increases momentarily on day 90 as the malfunction begins, but comes back to the average level as soon as the malfunction in Muuga is over on day number 150 (Figure 2). The effect on the amount of free storage in Helsinki is limited in all cases (Figure 3). Furthermore Figure 4 presents Helsinki free storage, if free container capacity in Muuga is also used in after the crisis for transporting the containers from Helsinki.

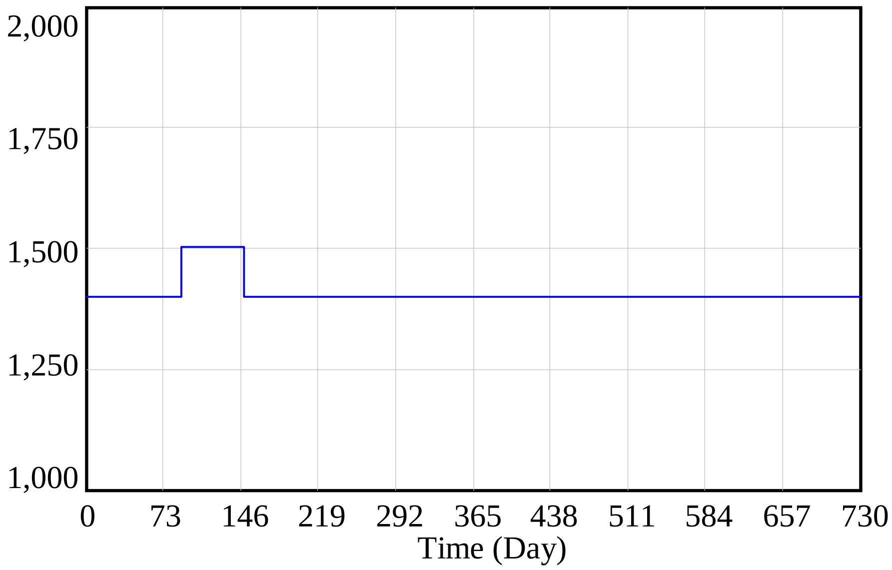

Figure 2. Total demand in the port of Helsinki.

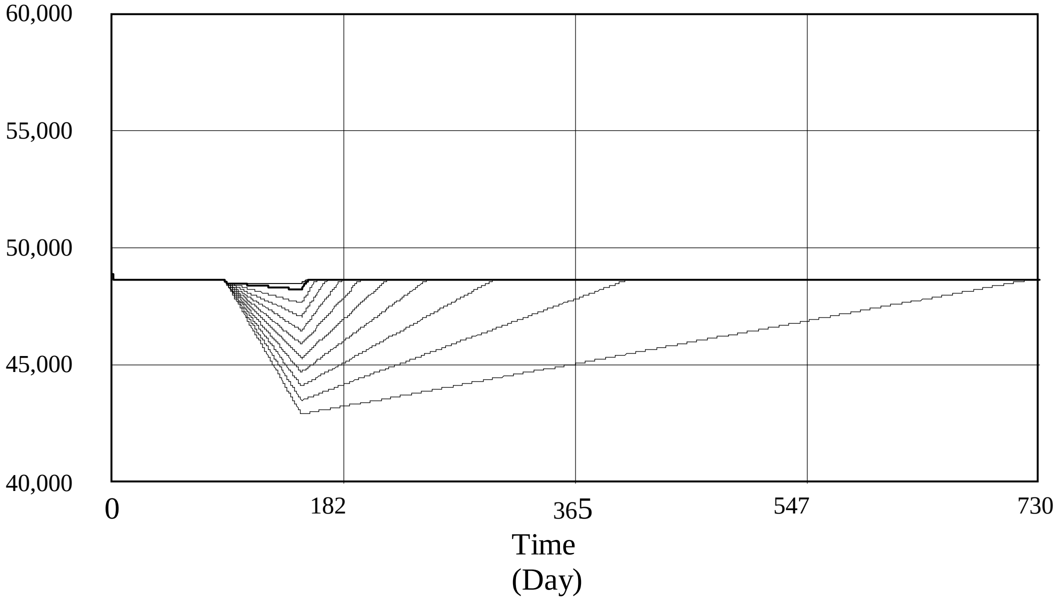

Figure 3. Free storage space in Helsinki

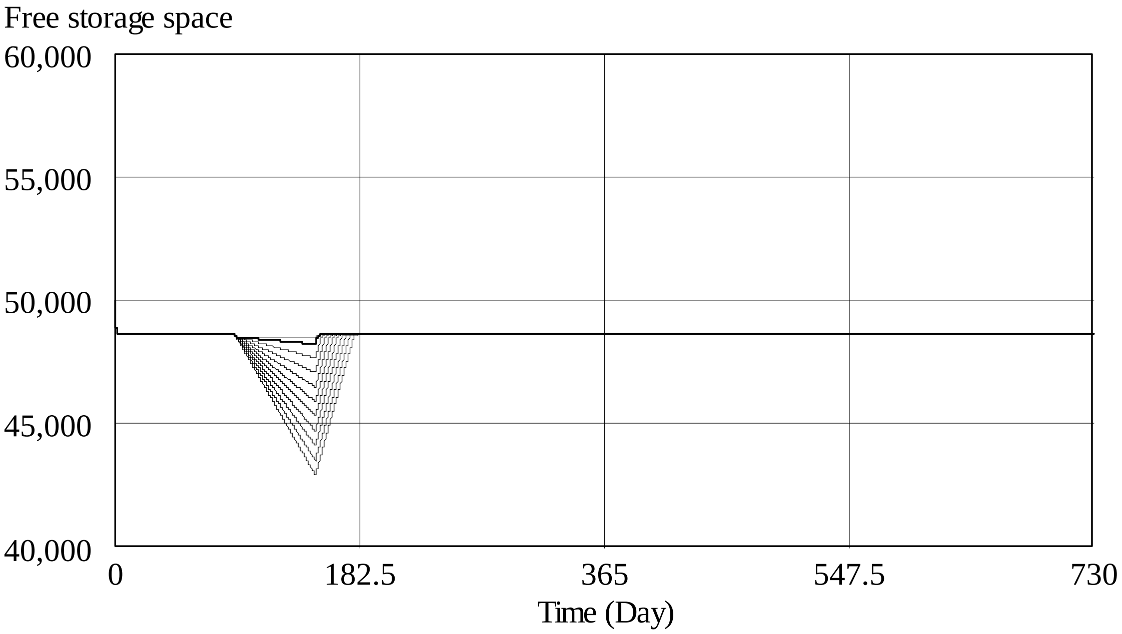

Figure 4. Free storage space in Helsinki, containers directed also to Muuga

However, in Estonian perspective Figures 3 and 4 have more dramatic consequences. If the amount of platforms is not sufficient, receiving the containers will take months. As container handling capacity in Estonia is concentrated in the port of Muuga, the system is vulnerable to local disturbances.

5. Discussion and Conclusions

In this research work we explored intermodal freight transportation performance in crisis situations with system dynamics simulation. A simulation model was build to analyze the impact of number of container platforms on the performance of a sea port. Although the ability to reroute container flows is limited by the special handling equipment required, special arrangements providing security of supply could be found, given that platforms are available. Based on the simulation experiments, it takes a long time to return to normal situation in the chain after the local crisis, e.g. in the sea port is over. Based on our findings the functionality of sea ports should not be analyzed in isolation, but merely as a part of a wider transportation chain.

Based on our study system dynamics works relatively well when crisis situations are analyzed. As long as the goods can be aggregated to categories, it is easy to construct a simulation model. However, larger networks are probably more easily explored by means of discrete-event simulations or agent-based modeling.

References

1. United Nations, 2007. *Regional shipping and port development, Container Traffic Forecast 2007 Update*, New York, USA.
2. Barnes, P., Olorontuba, R., 2005. Assurance of security in maritime supply chains: Conceptual issues of vulnerability and crisis management. *Journal of International Management*, 11 (4), 519–40.
3. Salter, M.B., 2008. Political science perspectives on transportation security. *Journal of Transportation Security* 1 (1), 29–35.

4. Kara, S., Kayis, N., 2008. Proactive logistics risk Management. *International Journal of Risk Assessment and Management*, 13 (3), 224–37.
5. Ujvari, S., Hilmola, O-P., 2006. Advanced manufacturing simulation – Minor system details can be major issues in the real world. *Industrial Management & Data Systems,* 106 (8), 1166-86.
6. Statistics Finland, 2007. *Statistical Yearbook of Finland 2007*. Tilastokeskus, Helsinki.
7. Saranen, J., Karttunen, J., 2009. Infrastructure in Intermodal Transportation in the Baltic Sea Region. In: Tapaninen, U., Hilmola O.-P., Hunt, T., (Eds.). *Study of Cargo Flows in The Gulf of Finland in Emergency Situations*. Tallinn, 27-35.
8. Kuronen, J., Helminen, R., Lehikoinen, A., Tapaninen, U., 2008. *Maritime transportation in the Gulf of Finland in 2007 and in 2015*. Publications from the centre for maritime studies – University of Turku - A45, Kouvola, Kopijyvä.
9. Hänninen, S., Rytkönen, J., 2004. *Oil transportation and terminal development in the Gulf of Finland*. Espoo: VTT Publications 547.
10. Naylor, T., Balintfy, J., Burdick, D., Kong, C., 1966. *Computer Simulation Techniques.* John Wiley, U.S.A.
11. Borshcev, A., Filippov, A., 2004. From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reason, Techniques, Tools. *The 22nd International Conference of the System Dynamics Society*, July 25 – 29, 2004, Oxford, England.
12. Tervonen, T., Hakonen, H., Lahdelma, R., 2008. *Elevator planning with stochastic multicriteria acceptability analysis.* Omega, 36 (3), 352-62.
13. Rijsenbrij, J. C., Ottjes, J. A., 2007. New Developments in Airport Baggage Handling Systems, *Transportation Planning and Technology,* 30 (4), 417–30.
14. Coleno., F. C., 2008. Simulation and evaluation of GM and non-GM segregation management strategies among European grain merchants. *Journal of Food Engineering,* 88 (3), 306-314.
15. De Jong, G., Ben-Akiwa, M., 2007. A micro-simulation model of shipment size and transport chain choice, *Transportation Research Part B,* 41 (9), 950-65.
16. Godwin, T. Gopalan, R., Narendran, T.T. (2008). Tactical locomotive fleet sizing for freight train operations. *Transportation Research Part E,* 44 (3), 440-454.
17. Kidokoro, Y, 2006. Regulatory reform and the congestion of urban railways. *Transportation Research Part A,* 40 (1), 52-73.
18. Ireland, P., Case, R., Fallis, J., Van Dyke, C., Kuehn, J., Meketon, M., 2004. The Canadian Pacific Railway transforms operations by using models to develop its operating plans. *Interfaces,* 34 (1), 5-14.
19. Cheng, L., Duran, M. A., 2004. Logistics for world-wide crude oil transportation using discrete event simulation and optimal control, *Computers & Chemical Engineering*, 28, (6-7), 897-911.
20. Engelen, S., Meersman, H., van de Voorde, E., 2006. Using system dynamics in maritime economics: an endogenous decision model for shipowners in the dry bulk sector, *Maritime Policy Management*, 33 (2), 141-58.
21. Ottjes, J. A, Veeke, H. P. M., Duinkerken, M. B., Rijsenbrij, J. C., Lodewijks, G., 2006. Simulation of a multiterminal system for container handling, *OR Spectrum*, 28 (4), 447-68.
22. Douma, A., Schutten, M., Schuur, P., 2009. Waiting profiles: An efficient protocol for enabling distributed planning of container barge rotations along terminals in the port of Rotterdam, *Transportation Research Part C*, 17 (2), 133-48.
23. Tu, Y-P., Chang, Y-F., 2006. Analyses of Operations of Ditch Container Wharf and Container Yard. *The Journal of American Academy of Business*, 9 (2), 139-46.
24. Grunow, M., Günther, H.-O., Lehmann, M., 2006. Strategies for dispatching AGVs at automated sea port container terminals, OR Spectrum, 28 (4), 587-610.

25. Forrester, J.W., 1958. Industrial Dynamics--A Major Breakthrough for Decision Makers. *Harvard Business Review*, 36 (4), 37-66.
26. Maani, K.E., Maharaj, V., 2004. Links between systems thinking and complex decision making. *System Dynamics Review.* 20 (1), 21–48.
27. Sterman, J.D., 2000, *Business Dynamics: systems thinking and modeling for a complex world.* United States: McGraw Hill.
28. Munitic, A., Simundig, S., Dvornik, J., 2003. System dynamics modelling of material flow of the port cargo system. In *Proceedings of the 21th International Conference of The System Dynamics Society*. July 20 – 24. New York City, USA.
29. Sanders, F., Verhaeghe, R.J., Dekker, S., 2007. Investment dynamics for a congested transport network with competition: application to port planning. In *Proceedings of the 23th International Conference of The System Dynamics Society*. July 17 – 21. Boston, USA.
30. Lättilä, L., 2009. *Combining advanced forecasting methods with system dynamics – the case of Finnish sea ports.* Research report 209, Lappeenranta University of Technology Faculty of Technology Management – Department of Industrial Management, Lappeenranta, Digipaino.
31. Port of Helsinki, 2010. Port of Helsinki. Available at URL: http://www.portofhelsinki.fi Retrieved: Sept. 2009.
32. Port of Tallinn, 2010. Regular Cargo Lines. Available at URL: http://www.portoftallinn.com/?k=3&p1=9&p2=146&t=regular+cargo+lines, Retrieved: May 2010.