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A GENERIC TERMINAL MACRO SIMULATION MODEL FOR MEASURING OPERATIONAL PERFORMANCE

Sonja M. Protic[(a)], Manfred Gronalt[(b)]

[(a),(b)]University of Natural Resources and Life Sciences Vienna, Institute of Production and Logistics, Feistmantelstr.4
1180 Vienna, Austria

[(a)]sonja.protic@boku.ac.at, [(b)]manfred.gronalt@boku.ac.at

ABSTRACT

Strategic decision making linked to the development of intermodal transport terminals is marked by high complexity. Terminal operators need to cope with uncertainties and potential cascading impacts of decisions which were taken a long time ago. The aim of this paper is to present a generic System Dynamics (SD) model of a terminal's operational performance. SD is used to capture a holistic view on a dynamic system, which is characterized by complex feedback structures, nonlinear processes, uncertainties and time delays. After introducing the qualitative Causal Loop Diagram (CLD), the underlying hypotheses are transposed into a quantitative Stock-and-Flow (S&F) model. The main components and its input data are explained. The generic model can be used as a decision support tool to bridge the gap from a detailed view to an understanding of long-term consequences. It offers multiple areas of application, which are briefly discussed.

Keywords: logistics, intermodal terminals, decision support tool, strategic management

1. INTRODUCTION

Intermodal transport is defined as the combination of at least two modes of transport in a single transport chain, without handling the goods themselves (United Nations 2001). The transshipment of a loading unit is organized at intermodal freight terminals. In the European Union are more than 800 freight terminals, ranked as terminals of high relevance (European Commission 2013). Intermodal transport is of a complex nature due to the use of multiple transport modes and the necessary consideration of various stakeholders (Caris, Macharis, and Janssens 2013). In this sense, to manage the operations of intermodal freight terminals and to take strategic decisions regarding a terminal's development are characterized by high complexity. Decision makers need to cope with uncertainties and potential nonlinear consequences. The present paper aims to introduce a basic model of a terminal's operational performance. The generic model can be used as a tool, e.g. for testing different policies or for estimating the long-term impact of investment decisions. Due to the complexity of the topic and the nonlinearity of interacting parameters SD is a well suited method. The model is implemented on a high level of abstraction to allow an understanding of the dynamics (Mella 2012). The remainder of this paper is organized as follows: Section 2 offers an overview of SD methodology. Section 3 presents the first step of the modelling process, the qualitative CLD, its underlying hypotheses and the system archetype growth and underinvestment. Section 4 explains the second step of the modelling process, the quantitative S&F model, its major components and input data. Finally, Section 5 lists the model's possible scenarios and its potential areas of application.

2. METHOD

Simulation methods are often used to model container operations at terminals. SD is a simulation methodology, which allows capturing especially complex systems from a macro perspective. It offers decision-makers the possibility to compare available options and to develop their skills in understanding interdependencies. Sterman (2000) describes SD modelling as discovering and presenting feedback processes, which define the dynamics of a system. Other simulation approaches than SD take a more detailed perspective on the operational performance of terminals. Discrete-event models, for instance, often model physical processes performed at the terminal, or traffic situations, which occur at the yard with a medium time horizon. The operational flows are modelled as a sequence of events. One can, e.g. identify potential bottlenecks or evaluate the performance of different vehicle-, equipment- or routing strategies (see e.g. Gronalt et al. 2012; Schroër et al. 2014; Kavakeb et al. 2015; Cimpeanu et al. 2017). For simulating the interaction of multiple agents at a terminal, one can use agent-based models. In general, these models apply a microscale and aim at describing the effect of different agent's behavior and decisions on the entire system. Examples are Garro et al. (2015) or Sharif and Huynh (2012). In addition, hybrid approaches, e.g. combining agent-based simulation and SD, exist (see, e.g. Swinerd and McNaught 2012).

On the contrary, SD is well suited to measure the impacts on the operational performance of a terminal with a view to strategic consequences on a long time horizon. The method consists of a qualitative and a quantitative process and uses two different types of feedback loops, i.e. self-reinforcing loops (R) and self-correcting loops (B). + and – signs at the arrowheads indicate if the effect related to the cause is positive or negative. In the qualitative process, a CLD portrays cause-and effect relationships (Morecroft 2015), thus, develop dynamic hypotheses (Shepherd, 2014). A well-known shortcoming of CLDs is their inability to capture stocks and flows (Sterman 2000). Stocks are accumulated values created by changes of its inflow and outflow over time. Valves control the flows and define the rules for the model's behavior in mathematical equations. Time delays between a decision and its actual impact on the system are rather common and in the model, they are marked by a double line "||".

In the transport sector, SD is most often used to address policy concerns or to model the uptake of alternate fuel vehicles (Shepherd, 2014). In addition, several terminal papers have been published, most of them dealing with seaports (Oztanriseven et al. 2014). Others address the capacity utilization and investment decisions (e.g. Randers and Göluke 2007; Ho, Ho, and Hui 2008).

In the present analysis, eight semi-structured interviews with respondents of five inland terminals in Belgium and Austria served as an input for the qualitative terminal model. Furthermore, the analysis uses data of detailed simulation models of inland container terminals. The simulation models map existing or planned infrastructure layouts and terminal operations and compare different settings with regard to a given scenario (Gronalt, Benna, and Posset 2006; Gronalt et al. 2011).

Then, the CLD was transposed into a quantitative S&F model, using the software Vensim 7.2. Iterative meetings with decision-makers allowed feedback during the modelling process and to integrate practical experiences, which is known to result in knowledge creation (Petty, Thomson, and Stew 2012).

3. QUALITATIVE TERMINAL MODEL

The qualitative CLD includes a handling loop (B1), a market power loop (R1), a cost loop (R2), an infrastructure investment loop (B2) and an energy loop (B3) (see Figure 1). The loops describe the basic model's behavior by guiding dynamic changes over time. The model includes several exogenous variables, which set the boundary and are input factors only: the total market demand, a perceived minimum infrastructure and equipment standard, a terminal's geographical position within the transportation network, and existing mergers and alliances, a growth limit due to space restrictions.

The handling loop describes the impact of a change in the number of incoming load units. An increase leads to a rising equipment utilization rate and longer lead times. Consequently, terminal reputation decreases, which has again an impact on the customer demand rate and the number of incoming load units. The market power loop visualizes the causalities between the costs of operation, the terminal's bargaining power and its reputation. In addition, the terminal's reputation is positively influenced by a terminal's growing energy efficiency, whilst a reduced energy consumption results in lower costs of operation (energy loop). Furthermore, if the equipment utilization rate increases, the costs of operation increase due to higher maintenance costs (costs loop). Finally, the investment loop compares the actual equipment utilization rate to a perceived standard and decides upon an investment, which, after a time delay, results in more capacity and, thus, a lower equipment utilization rate. As a measuring unit of load units, the model uses twenty-foot equivalent units (TEU). For a detailed description of the CLD the reader is referred to Gronalt, Vögl, and Protic (2018).

The terminal model contains the system archetype growth and underinvestment (Senge 2010). Archetypes are generic structures in dynamic systems. Once an archetype is identified, its impact on the behavior of a model can be analyzed.

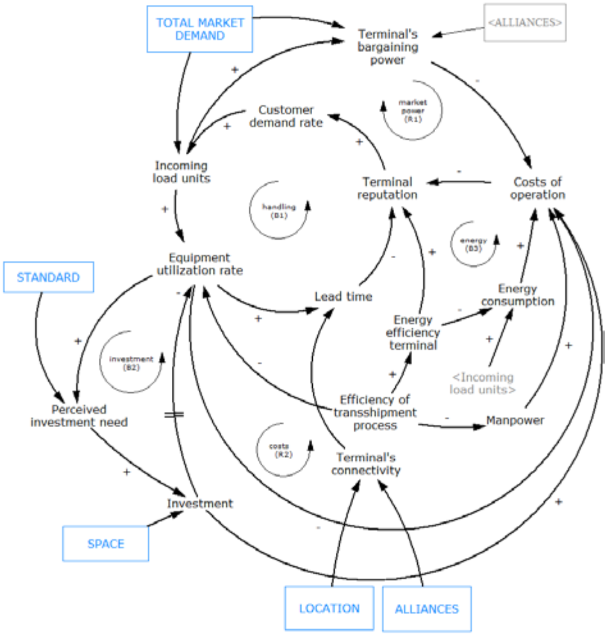


Figure 1: Qualitative Terminal Model.

The growth and underinvestment archetype consists of one reinforcing loop and two balancing loops, at present the handling loop (B1), the costs loop (R2) and the investment loop (B2). In theory, the archetype is often linked to a star-up's decision if and how much to invest in new production capacity. Due to the time lag in-between investment and an actual capacity increase, fast growing demand cannot be met. The backlog (negative performance) increases customer dissatisfaction, which lowers the new demand. As a result, the actual capacity is again sufficient. An oscillating effect of new demand and capacity may occur. We observe similar dynamics regarding terminal investment and an increase in lead times due to higher equipment utilization rates. Therefore, if decisions are made too late or too cautious, it is hard to anticipate a reduced demand. This is especially of high relevance in view to long construction periods. Figure 2 visualizes the basic dynamics of the archetype in a simple S&F model. The archetype's impact on the new demand and the capacity are exemplarily shown in Figure 3.

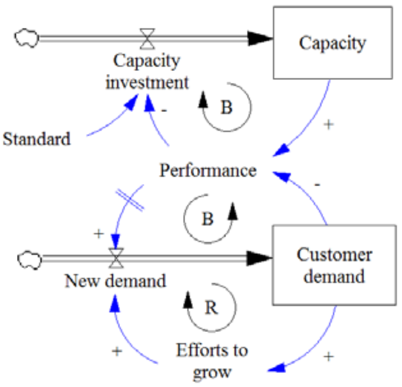


Figure 2: Archetype growth and underinvestment in a simple S&F model.

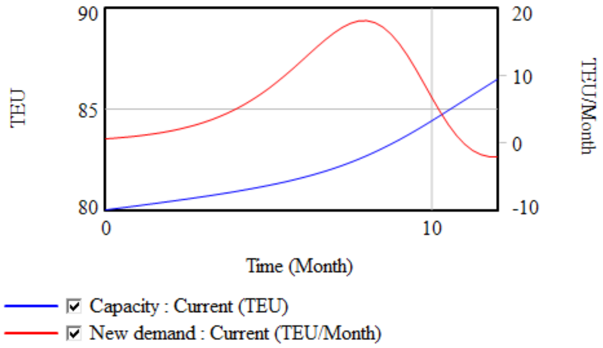


Figure 3: Dynamics of the archetype growth and underinvestment.

4. QUANTITATIVE STRATEGIC TERMINAL MODEL

The terminal model has a time horizon of 30 years, which seems an appropriate period to observe the model behavior and to link the origin and the effect of changes in the terminal performance. The length of the time horizon considers long-time construction projects and periods of depreciation for new infrastructure. The simulation applies monthly time steps.

The S&F model allows to choose several input parameters, some of which are the model's exogenous variables and, thus, time-independent and valid over the entire time horizon of a simulation, e.g. a terminal's geographic location. Others determine the initial situation of the terminal, e.g. a terminal's initial capacity. Correctly selected, the input parameters allow to adapt the generic essence of the model to reality. Table 1 and 2 list the main model variables and its definitions. Stocks are symbolized as rectangles (☐), in- and outflow processes are symbolized as circles (O), and valves, which control the flows, are symbolized as crossed out circles (⊗).

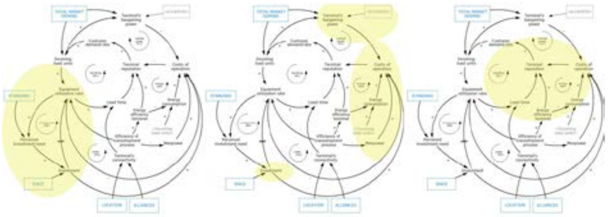
Table 1: Exogenous variables. User-defined input parameters are marked (*).

Exogenous variables		
☐	Geographic location (*)	The geographic location of a terminal refers to (i) its gateway role, thus, its position in the TEN-T network. Each direct link to a TEN-T corridor increases the potential market volume of a terminal, according to estimated volumes of European Commission's corridor studies (European Commission 2014a-i). (ii) Its Loco role, thus, the number of potential customers closer than 150km (Posset et al. 2014), and (iii) the number of potential customers in the terminal's surrounding area.
☐	Total market demand	The market demand is determined by a terminal's geographic location. Annual growth rates assume an increase of 2% until 2020, of 1.9% until 2030 and of 1.4% until 2050 (Enei 2010).
☐	Strength due to alliances (*)	This value stands for a terminal operator's bargaining power and its role in the transport network. It ranges between 0 and 2, depending on the number of terminals, the terminal's operator is controlling.
☐	Growth limit (*)	Maximum growth rate of the terminal capacity, compared to its capacity in the initial time step. The growth rate might be limited du to, e.g. space restrictions.
☐	Modal share (*)	Modal share of the terminal, including road and rail transport.
☐	Actual lifting factor (*)	This value can differ from the average value of 2.5, e.g. due to efficiency gains in a terminal's transhipment processes.
☐	Minimum infrastructure / equipment standard (*)	This value determines, if an operator will decide to invest or not. In the model, the investment decision is linked to a maximum equipment utilization rate, calculating with a forecast of the expected handling volume.
O	Financial data and terminal operation data	Lookup functions, e.g. maintenance costs, for investment costs, for staff costs (all three depending on the terminal size), and for lead times (depending on the equipment utilization rate) are used to equate the actual input with an impact factor. They are graphical functions, which are determined by linear interpolation between known input values.

Table 2: Endogenous variables

Endogenous variables		
□	Terminal reputation	The current level of the terminal's reputation, ranging between 0 and 1.
⊗	Reputational gains	Depending on the total reputation impact caused by the lead time - impact (O), the environmental image - impact (O), and the costs of operation - impact (O). A maximum increase is defined per time step.
⊗	Reputational losses	Depending on the total reputation impact caused by the lead time - impact (O), the environmental image - impact (O), and the costs of operation - impact (O). A maximum decrease is defined per time step.
O	Lead time - impact	Ranging between -1 and 1, depending on the dynamic change of the lead time compared to the initial year.
O	Costs of operation - impact	Ranging between -1 and 1, depending on the dynamic change of the costs compared to the initial year.
O	Environmental image - impact	Ranging between -1 and 1, depending on the dynamic change of the image compared to the initial year.
□	TEU at yard	Difference between incoming load units (TEU) and those leaving the yard.
⊗	New demand (TEU)	Depending on the terminal reputation and the volume handled in the previous time step. It is influenced by the actual backlog (thus, the negative performance) due to previously cancelled load units due to capacity constraints.
⊗	TEU leaving the yard	Depending on the actual transhipped volume, determined by the capacity and the lifting efficiency of a terminal.
□	Total terminal capacity	Stepwise increase in case of investments being made. Its value in time step 0 is required as an input parameter.
⊗	New equipment	Depending on the investment decision taken and considering the delay of the construction period.
O	Costs of operation	Consisting of investment costs (O), maintenance costs (O), staff costs (O) and energy expenses (O).
O	Equipment utilization rate	The rate depends on the current terminal capacity, the amount of outgoing load units (TEU) and the actual lifting efficiency of a terminal.

The computational model can be roughly structured in three major components: (i) investment decisions, (ii) costs of operation, and (iii) reputation building. Figure 4 explains the link between the three components in the S&F model and the qualitative CLD in Figure 1. To allow for a better understanding of the modelling process the three components and the input data will be explained one after the other.



(i) Investment decision (ii) Costs of operation (iii) Reputation building

Figure 4: Assignment of major components in the S&F model (see Figure 1), to the CLD.

4.1. Investment decision

In the S&F model the perceived investment need of the terminal depends on the forecasted equipment utilization rate, thus, it is a dynamic decision concerning the ratio of the forecasted handling volume and the actual capacity (Slack and Johnston 2010). If the equipment utilization rate is expected to exceed the set standard of 65 percent within the next year (t+12 time steps) and if the equipment utilization rate does not demonstrate a downward tendency, we assume that the terminal operators will invest in order to increase its capacity. The use of forecasts is a valid leveraging point to cope with a threatening decrease of new demand linked to the archetype growth and underinvestment. The total investment depends on the expected future handling volume. The decision pursues the objective of reducing the equipment utilization rate to a level of 50 percent, which is another leveraging point linked to the archetype growth and underinvestment (Mandl 2019).

In general, infrastructure construction periods last between two and seven years (Wiegmans and Behdani 2017). Nevertheless, smaller handling equipment or small-scale modifications in the terminal entrance area are realized more quickly. In the model, every decision to invest in an extension of terminal capacity is followed by a construction period, which delays the investment effect on the equipment utilization rate and pauses new investment plans. It is for this reason that the capacity in the S&F model increases stepwise. In literature, there is only little to be found about terminal capacity calculation. The present model refers to the design capacity of a terminal, defined as the maximum capacity at ideal conditions during actual operating times (Slack and Johnston 2010). The standard scenario assumes a lifting factor of 2.5, which means that each TEU is lifted 2.5 times at average (Gronalt et al. 2011). The equipment utilization rate calculates the actual output and takes into regard the difference between the assumed lifting factor (2.5) and its real value, which is an input variable. As the difference of the real lifting factor affects the equipment utilization rate, it also restricts the number of outgoing TEU, whilst the units, which can't be handled due to low capacity remain at the terminal yard and increase the backlog. A growth limit of the terminal, e.g. due to area restrictions, can be set in advance in the model's input.

4.2. Costs of operation

The costs of operation are a sum of fixed costs, including infrastructure and equipment investment, and variable costs, including maintenance costs, energy expenses and staff costs. Furthermore, the exogenous factor, a terminal's strategic alliances (e.g. if the terminal is controlled by an operator that controls several other terminals as well) has a moderate impact on the cost structure as the negotiating power is expected to allow an operator realizing price advantages. Other variable costs such as IT systems or taxes are not taken into account due to the high level of aggregation required in SD.

Wiegmans and Behdani (2017) describe the relatively low level of variable costs compared to investment costs. Furthermore, returns on scale are reflected in the S&F model, in which the operational costs decrease with an increase in the number of transshipped containers. Following the classification of five freight terminal types by Wiegmans, Masurel, and Nijkamp (1999) we use estimated terminal realization costs and the approximate number of employees as input (Wiegmans and Behdani 2017). Another input is the average gross salary for a full time employee assuming a 40/60 mix of workers and administrative staff. The maintenance costs account for approximately 15 percent of the total investment costs (Wiegmans and Behdani 2017). In general, the equipment of a terminal is fueled either by electricity or diesel. In the following, we assume that one third of the overall energy consumption is covered by electricity and two thirds by diesel (Green Efforts 2014), which is reflected in the composition of the energy costs in the S&F model (Eurostat 2017, Weekly Oil Bulletin 2018). For an approximation of a terminal's average energy consumption we use 12,83kWh/TEU (Hong et al. 2013). Efficiency gains in the transshipment process result in energy savings.

The importance of government subsidies and tax breaks for realizing a profit is recognized by various authors, even after a terminal's start-up phase (Wiegmans and Behdani 2017, Woodburn 2007). The S&F model applies a subsidy of 40 percent of total investment in a given time period, if the total investment costs exceed a given threshold, which is comparable with the purchase price of an average reach stacker. For the remaining investment stream we use a linear depreciation over a depreciation lifetime of a reinvestment duration of 18 years. The depreciation period of infrastructure investment ranges between 13 years (office furniture) and 21 years (gantry cranes) (Bundesministerium der Finanzen 2000).

Determined by linear interpolation between these known values, the maintenance costs, the staff costs and the energy expenses for any terminal can be estimated. It is important to consider that considerable differences in the characteristics of a terminal in terms of its staff number, the price of its equipment or the energy costs are possible. For this reason, the S&F model does not aim for realistic customer prices, but calculates the dynamic changes of the operational costs per loading unit (TEU) over time. Experiences from terminal operators validate the final composition of costs, which is close to the average composition as observed in practice, i.e. 55 percent staff costs, 25 percent maintenance costs, 15 percent investment costs (taking into regard the depreciation period), and 5 percent energy costs (WienCont 2018).

4.3. Reputation building

The reputation of a terminal, i.e. it's attractiveness from a customer's point of view, is expected to increase and decrease stepwise. We assume a terminal's initial reputation equal to 50 percent, while 0 and 100 percent denote its minimum and maximum level. While several authors underline that a customer choosing a terminal is influenced by various factors, due to the required high level of abstraction in SD, the focus lies on the most important ones only. Ng (2006) carries out a survey among shipping lines to determine, which factors have an impact on a port's attractiveness. Monetary aspects and time efficiency were rated beyond the most important factors. In the model, the determined scores are translated into impact factors on a terminal's reputation. Although the survey does not list environmental concerns, the present model takes it into regard due to an observed increase of environmental public interest and its expected implications for the future transport sector (Protic, Geerlings, and van Duin 2018). Therefore, the present model includes three influencing factors, namely (i) lead time, (ii) environmental image, and (iii) costs of operation.

- The lead time refers to the time a load unit (TEU) needs from the gate-in to the gate-out. Higher equipment utilization rates are expected to increase lead times. The model considers two different lead time lookup functions, one for rail-rail transshipments and one for road-road transshipments, both using data of a terminal simulation study (Gronalt et al. 2011). It is possible to determine a terminal's average mix of transport modes, which allows taking into regard rail-road and road-rail transshipments. The average lead time is calculated as an arithmetic mean of lead times for transshipments with lorry and train. The function describes a steep rise in lead times at occupancy levels above 80 percent, due to the fact that terminals often face problems in their daily operation when their utilization rate passes this threshold (Wiegmans and Behdani 2017, Gronalt et al. 2011). A terminal's position within the transportation network, i.e. TEN-T corridor position, and its role in existing mergers and alliances affect the total lead time, due to efficiency gains or losses (Lun and Cariou 2009).
- The impact of a terminal's environmental image on its reputation is set at a rather low level

compared to the ones of lead times and costs. Nevertheless, environmental sustainability is not only an operator's tool to decrease energy costs, but is increasingly becoming a matter of societal needs and beliefs. Worldwide best practices, e.g. wind or solar power at the terminal area, measures to reduce fine dust or noise, witness to the high degree of acceptance (Protic, Geerlings, and van Duin 2018).

- The terms costs of operation and customer costs per TEU (price for a transshipment) are used synonymously. We calculate the cost level's dynamic change over time. In general, the transshipment price of a container is fixed and includes all liftings needed to handle a container. If certain in advance that only one lifting, e.g. train-train, is needed a lower price can apply. For the sake of simplicity, this was left out in the model. Nevertheless, the more favorable the prices are compared to the initial level, the higher the more likely a customer will choose the terminal for a transshipment (Ng 2006).

The impact of all three factors is a matter of dynamic changes over time. An increase of lead times or costs will decrease the reputation level. On the contrary, an increase of the energy efficiency will increase the reputation. Clearly, countervailing effects can be observed, e.g. investments increase costs, but offer the chance to decrease lead times and environmental benefits.

5. POTENTIAL AREAS OF APPLICATION

The model allows to adapt various input factors to adopt the generic model to a terminal's specific characteristics (see Table 1). Furthermore, it is possible to choose different scenarios regarding the overall handling volume of the terminal and the development of energy prices over time. Whilst (in addition to the endogenous dynamic behavior of the model) in the CR_low scenario the customer demand rate decreases by 50 percent within the next 30 years, the CR_high scenario assumes that the handling order rate increases by 200 percent. The energy price scenarios (EP_low and EP_high) allow variations of -30 percent and +30 percent within the anticipated simulation period. The basic scenarios include moderate market and price developments (business-as-usual). The holistic view of the SD model and the fact that it describes only one terminal instead of an entire network, makes it interesting for the strategic terminal management. It allows to analyze the effect of investment decisions on a long-term and to think about its underlying parameters, e.g. the time of an investment, the need of correct volume forecasts, public subsidies or the maximum utilization rate that should trigger an investment. But it is not all about an expansion of equipment capacity. Also the overall impact of an innovation, which leads to an improved process efficiency, e.g. fast lanes for lorries, or of an ICT innovation that speeds up the exchange of information between terminal operators and customers, can be analyzed. Another interesting area of application is the reputation building of a terminal, e.g. to find out how a strong environmental awareness of terminal customers would change the overall performance of a terminal. The generic model offers multiple areas of application and allows to bridge the gap from a detailed view in decision making to a holistic understanding of potential cascading effects and long-term consequences on the terminal performance.

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REFERENCES

Bundesministerium der Finanzen, 2000. Afa Table. Available from: https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Steuern/Weitere_Steuerthemen/Betriebspruefung/AfA-Tabellen/Ergaenzende-AfA-Tabellen/AfA-Tabelle_AV.pdf?__blob=publicationFile&v=12 [Accessed April 2019].

Cimpeanu, R., Devine, M. T., and O'Brien, C., 2017. A simulation model for the management and expansion of extended port terminal operations. Transportation Research Part E: Logistics and Transportation Review 98: 105-131.

Enei R., 2010. Freight trends and forecasts. ISIS, paper produced as part of contract ENV.C.3/SER/2008/0053 between European Commission Directorate-General Environment and AEA Technology plc. Available from: www.eutransportghg2050.eu [Accessed April 2019].

European Commission, 2013. Regulation (EU) No 1315/2013 of the European Parliament and of the Council of 11 December 2013 on Union Guidelines for the Development of the Trans-European Transport Network and Repealing Decision No 661/2010/EU Text with EEA relevance. Official Journal of the European Union, Vol. 348, No. 1.

European Commission, 2014a. Mediterranean Core Network Corridor Study. Final report. Available from: https://ec.europa.eu/transport/themes/infrastructure/ten-t-guidelines/corridors/corridor-studies [Accessed February 2019]

European Commission, 2014b. Rhine-Danube Core Network Corridor Study. Final report. Available from: https://ec.europa.eu/transport/themes/infrastructure/ten-t-guidelines/corridors/corridor-studies [Accessed February 2019]

European Commission, 2014c. Scandinavian-Mediterranean Core Network Corridor Study. Final report. Available from: https://ec.europa.eu/transport/themes/infrastructure/ten-t-guidelines/corridors/corridor-studies [Accessed February 2019]

European Commission, 2014d. North Sea-Baltic Core Network Corridor Study. Final report. Available from: https://ec.europa.eu/transport/themes/infrastructure/ten-t-guidelines/corridors/corridor-studies [Accessed February 2019]

European Commission, 2014e. North Sea-Mediterranean Core Network Corridor Study. Final report. Available from: https://ec.europa.eu/transport/themes/infrastructure/ten-t-guidelines/corridors/corridor-studies [Accessed February 2019]

European Commission, 2014f. Baltic-Adriatic Core Network Corridor Study. Final report. Available from: https://ec.europa.eu/transport/themes/infrastructure/ten-t-guidelines/corridors/corridor-studies [Accessed February 2019]

European Commission, 2014g. Orient/East-Med Core Network Corridor Study. Final report. Available from: https://ec.europa.eu/transport/themes/infrastructure/ten-t-guidelines/corridors/corridor-studies [Accessed February 2019]

European Commission, 2014h. Rhine-Alpine Core Network Corridor Study. Final report. Available from: https://ec.europa.eu/transport/themes/infrastructure/ten-t-guidelines/corridors/corridor-studies [Accessed February 2019]

European Commission, 2014i. Atlantic Core Network Corridor Study. Final report. Available from: https://ec.europa.eu/transport/themes/infrastructure/ten-t-guidelines/corridors/corridor-studies [Accessed February 2019]

Eurostat, 2017. 2017/2H Eurostat database: Industry electricity prices. Available from: https://ec.europa.eu/eurostat/data/database [Accessed December 2018].

Caris A., Macharis C., and Janssens G. K., 2013. Decision support in intermodal transport: A new research agenda. Computers in Industry 64: 105–112.

Garro A., Monaco M.F., Russo W., Sammarra M., and Sorrentino G., 2015. Agent-based simulation for the evaluation of a new dispatching model for the straddle carrier pooling problem. Simulation 91(2):181–202.

Green Efforts, 2014. Deliverable 12.1. Recommendations Manual for Terminals. Seventh Framework Programme. Available from: https://cordis.europa.eu/docs/results/285/285687/final1--green-efforts-d12-1-final.pdf [Accessed April 2019].

Gronalt M., Benna T., and Posset M., 2006. SimConT Simulation of Hinterland Container Terminal Operations. In: Blecker, T., Kersten, W. eds. Complexity Management in Supply Chains - Concepts, Tools and Methods 2, Berlin: Ericht Schmidt Verlag: 227-246.

Gronalt M., Haeuselmayer H., Posset M., and Royas-Navas S., 2011. Simcont - theory and practice in simulation of binnenland container terminals. International Conference on Harbour, Maritime and Multimodal Logistics Modelling and Simulation 1: 155-160.

Gronalt M., Posset M., and Rojas-Navas S., 2012. Capacity evaluation of Inland Container terminals - the simulation based approach of SimConT. In: Guenther H.-O., Kim K. H., Kopfer H. (Eds.) LOGMS 2012, The 2012 International Conference on Logistics and Maritime Systems. University of Bremen, Bremen, 2012.

Gronalt M, Voegl J, and Protic S.M., 2018. Final Report HubHarmony. FFG, Bundesministerium für Verkehr, Innovation und Technologie, 14, 89.

Ho K.H., Ho M.W., and Hui C.M.E., 2008. Structural dynamics in the policy planning of large infrastructure investment under the competitive environment: Context of port throughput and capacity. Journal of Urban Planning and Development 134: 9-20.

Hong Z., Merk O., Nan Z., Li J., Mingying X., Wenqing X., Xufeng D., and Jinggai W., 2013. The Competitiveness of Global Port-Cities: the case of Shanghai – China. OECD Regional Development Working Papers: 2013/23.

Kavakeb, S., Nguyen, T. T., McGinley, K., Yang, Z., Jenkinson, I., and Murray, R., 2015. Green vehicle technology to enhance the performance of a European port: a simulation model with a cost-benefit approach. Transportation Research Part C: Emerging Technologies 60: 169-188.

Lun Y.H.V. and Cariou P., 2009. An analytical framework for managing container terminals. International Journal of Shipping and Transport Logistics 1: 419-436.

Mandl C.E., 2019. Managing complexity in social systems – Leverage points for policy and strategy. Vienna: Springer.

Mella P., 2012. Systems Thinking – Intelligence in Action. Heidelberg: Springer.

Morecroft J.D.W., 2015. Strategic Modelling and Business Dynamics. A Feed-back Systems Approach. John Wiley & Sons.

Ng K.Y.A., 2006. Assessing the Attractiveness of Ports in the North European Container Transhipment Market: An Agenda for Future Research in Port Competition. Maritime Economics and Logistics 8(3): 234-250.

Oztanriseven F., Lespier L.P., Long S., and Nachtmann H.L., 2014. A Review of System Dynamics in Maritime Transportation. Proceedings of the IIE

Annual Conference and Expo 2014, 2447-2456. May 2014. Montreal, Canada.

Petty N.J., Thomson O.P., and Stew G., 2012. Ready for a paradigm shift? Part1: introducing the philosophy of qualitative research. Manual Therapy 17: 167-274.

Posset M., Gierlinger D., Gronalt M., Peherstorfer H., Prip H., and Starkl F., 2014. Intermodaler Verkehr Europa: FH O Forschungs & Entwicklungs GmbH - Logistikum Steyr.

Protic S.M., Geerlings H., and van Duin R., 2018. Environmental sustainability of freight transportation terminals. In: Faulin J, Grasman S., Juan A. and Hirsch P. eds. Sustainable Transportation and Smart Logistics. Amsterdam: Elsevier, 233-260.

Randers J. and Göluke U., 2007. Forecasting Turning Points in Shipping Freight Rates: Lessons from 30 years of Practical Effort, System Dynamics Review 23: 253-284.

Schroër, H. J., Corman, F., Duinkerken, M. B., Negenborn, R. R., and Lodewijks, G., 2014. Evaluation of inter terminal transport configurations at Rotterdam Maasvlakte using discrete event simulation. In: Proceedings of the Winter Simulation Conference 2014: 1771-1782.

Senge P.M., 2010. The Fifth Discipline: The Art and Practice of the Learning Organization. Crown Publishing Group.

Sharif O., Huynh N., 2012. Yard crane scheduling at container terminals: a comparative study of centralized and decentralized approaches. Maritime Economics & Logistics 14(2):139–161.

Shepherd S., 2014. A Review of System Dynamics Models applied in Transportation. Transportmetrica B: Transport Dynamics 2:2: 83-105.

Slack S.C. and Johnston R. 2010. Operations management. Prentice Hall: Pearson Education.

Sterman J.D., 2000. Business Dynamics – Systems Thinking and Modeling for a Complex World. Boston MA: Irwin McGraw-Hill.

Swinerd, C., and McNaught, K.R., 2012. Design classes for hybrid simulations involving agent-based and system dynamics models. Simulation Modelling Practice and Theory 25: 118-133.

United Nations, 2001. Economic Commission for Europe - Terminology on Combined Transport. Available from: www.unece.org/fileadmin/DAM/trans/wp24/documents/term.pdf [Accessed March 2019].

Weekly Oil Bulletin, 2018. Available from: https://ec.europa.eu/energy/en/data-analysis/weekly-oil-bulletin/ [Accessed December 2018].

Wiegmans B.W., Masurel E., and Nijkamp P., 1999. Intermodal freight terminals: an analysis of the terminal market. Transportation Planning and Technology 23: 105-128.

Wiegmans B. and Behdani B., 2018. A review and analysis of the investment in, and cost structure of, intermodal rail terminals. Transport Reviews 38: 33-51.

WienCont, 2018. WienCont Container Terminal GmbH Personal interview with Waltraud Pamminger.

Woodburn A., 2007. Evaluation of rail freight facilities grant funding in Britain. Transport Reviews 27(3): 311-326.

AUTHORS BIOGRAPHY

Sonja M. Protic is a Researcher at the Institute of Production and Logistics at the University of Natural Resources and Life Sciences in Vienna. She finished her Master’s studies in Environmental Science and her Bachelor studies in Business Administration. She has several years of work experience in national and European research projects and in international project development for a multilateral organization. Her research interests include sustainable freight transport, innovation management, and living labs. She is enrolled as a doctoral student, writing her doctoral thesis in the field of innovation systems at multimodal inland terminals.

Manfred Gronalt is Professor at the University of Natural Resources and Life Sciences in Vienna and Head of the Institute of Production and Logistics. His expertise and research interests include computer-aided simulation, logistics and operations research and production management.