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Generic Simulation Model for Less-Than-Truckload Terminals Based on Requirements of SMEs

Generisches Simulationsmodell für Stückgutspeditionsanlagen auf Basis der Anforderungen von KMUs

Maximilian Mowe, Lasse Jurgeleit, Maximilian Kiefer,
Christin Schumacher, Uwe Clausen
Institute of Transport Logistics / TU Dortmund University, Dortmund (Germany),
maximilian.mowe@tu-dortmund.de, lasse.jurgeleit@tu-dortmund.de,
maximilian.kiefer@tu-dortmund.de,
christin.schumacher@tu-dortmund.de, uwe.clausen@tu-dortmund.de

Abstract: Simulation can be used to plan and optimize less-than-truckload (LTL) terminals. To develop simulation models, specific expertise in this field is needed, which often requires high financial investments for acquisition of this knowledge. Due to limited financial resources, SMEs are often incapable to get to this expertise. The objective of the paper is to develop a generic model for LTL terminal planning that can be used without simulation expertise and that can be adapted to individual SME layouts. Therefore, based on focus group interviews with SMEs, a catalog of requirements is developed, including input variables and design criteria. Key performance indicators (KPIs) are defined to evaluate the results. A feasibility study for implementing a generic model based on the identified requirements is then performed. The implementation is done by modeling the I-layout of an LTL terminal.

1 Introduction

Layout planning for new less-than-truckload (LTL) terminals is often structured as a sequential process based on factory planning techniques that do not take into account dynamics such as daily variations in shipment volume or daily variations in functional areas to analyze which layout and truck loading concepts should be selected (Schenk and Wirth, 2004). A simulation-based approach can capture these dynamics. By building multiple variants of simulation models with different layout variants of LTL terminals, it is possible to consider dynamics in the design process (Chmielewski, 2007). However, applying simulation techniques requires expertise often only acquired through financial investment. Because the investment exceeds their financial resources, small and medium-sized enterprises (SMEs) often cannot afford this expertise (Schenk and Wirth, 2004).

The paper's objective is to collect requirements from SMEs for developing a generic simulation tool for modeling processes in LTL terminals. It is understood to be a tool that automatically converts user input into an executable model. The generic tool should be usable without simulation expertise and fit individual SME layouts and other business conditions. In this paper, we build a generic simulation model for the I-layout including first selected requirements of our catalog.

Therefore, the approach is organized as follows. Section 2 overviews the research findings on simulation experiments in SMEs, LTL terminals, and first studies on generic simulation models. Section 3 presents and analyzes the focus group interviews conducted to find the influencing parameters for our generic model of an LTL terminal with an I-layout. A catalog of requirements is developed, including input variables and design criteria. Key performance indicators (KPIs) are defined to evaluate the results. Section 4 describes the simulation architecture and used modules of AnyLogic 8.8. A first simulation model is then created. This model will validate how a universal simulation tool can be developed based on the requirements. The section also presents a series of experiments to test our methodology and analyzes the results obtained. Finally, Section 5 summarizes the main findings of this study and outlines a future research perspective.

2 Literature Review

Wiese (2018) found that 85,56 % of SMEs had not used simulation experiments before. The implementation barrier due to initial resources and short-term costs are reasons analyzed. Reviewing the literature on simulation models for SMEs we identify papers that include value stream analysis and material flow simulations only for specific use cases in SMEs (Kumar et al., 2016; Suhadak et al., 2015; Teerasoponpong and Sopadang, 2021). These simulations were conducted in collaboration with external simulation service providers due to the lack of knowledge in SMEs. For example, Kumar et al. (2016) investigate a layout analysis in a manufacturing SME using simulation software. Also, Suhadak et al. (2015) analyze different layout variants using simulation and value stream analysis for a production system of an SME in the food industry.

In the field of LTL terminals, Poeting et al. (2017) and Clausen et al. (2017) present frameworks that combine heuristic algorithms and Mixed-Integer Programming models with discrete event simulation to provide robust solutions to the loading and unloading decision problems in parcel transshipment terminals. Detailed inferences on the real system behavior are analyzed by testing the mathematical solutions in simulation experiments. Clausen and Goedicke (2012) develop a simulation model to compare yard strategies in LTL terminals concerning their effects on performance aspects of internal sorting operations, which benefit from constantly high input rates. In the approaches presented so far, the simulation models for SMEs are built manually.

There are also initial approaches that automatically generate simulation models. Their focus is mainly on manufacturing. Aggogeri et al. (2015) propose a generic simulation model for modeling and evaluating SME manufacturing processes. Using a tree structure that exploits similarities between different categories of manufacturing systems, in the first step, they categorize the systems to realize a model adapted to the specific needs of the user's application cases. In the second step, they also support the data collection process for simulation by a web application. Mages et al. (2022) provide an approach for user-configurable simulation models for manufacturing processes. They define simulation building blocks such as storage towers and different types of machines as components. Using a graphical user interface (GUI), the number of storage towers and the number and types of machines can be adjusted, and the resulting model can be synthesized. In this way, multiple simulation models can be built using the GUI by varying the numbers, allowing layouts to be compared quickly. Mestiri et al. (2021) defined a generic model representing inbound transportation systems. All identified use cases differ from the objective mentioned above of developing a generic simulation model for the I-layout of LTL terminals.

3 Focus Group Interviews

This study used a focus group interview to gather data from SMEs regarding the attributes of a simulation tool that could assist SMEs in planning LTL terminals. Focus group interviews aim to explore the perspectives and experiences of a group of individuals who share a common characteristic (Calder, 1977). In this case, the focus group interview allows a deeper understanding of the essential needs of SMEs when developing a simulation tool. Within the focus group interviews, participants share their experiences and ideas. Emerging group dynamics enable individuals to build upon each other’s contributions in an interactive setting leading to detailed responses (Calder, 1977). These detailed insights are essential to understand the SMEs’ perspectives to develop a simulation tool tailored to their needs.

In 2022, a focus group interview was conducted with six participants representing four distinct industry areas. However, all participants work with LTL terminals. The discussion focused on the identification of values associated with three categories of LTL terminal planning, namely: (1) input parameters, (2) design criteria, and (3) key performance indicators (KPIs). Therefore, the semi-structured discussion was split into four rounds. In the first three rounds, relevant deemed attributes for each category were determined. Afterward, the participants engaged in a final round to discuss the assigned attributes and explore interdisciplinary linkages between the represented industry areas. The result is the classification with depending attributes all participants can agree on, shown in Table 1.

According to the results of the Focus Group Interviews, the requirements catalog is built. The framework of the catalog is divided into three main categories, which are mentioned above, and their corresponding attributes. The first criterion, input parameter, is mainly determined by given resources in the LTL terminals and includes parameters that can be individually set and modified by the user before model generation. Thus, these input parameters provide a fundamental basis for mapping and analyzing various planning scenarios. The second category, design criteria, is used to define those characteristics that describe the infrastructural design of general LTL terminals and indicate the main components of the yard. During the development of the simulation environment, it is essential to consider these criteria to ensure the realistic representation of such terminals and to provide an opportunity for validation. Although the values for the design criteria cannot be determined directly by the user, they are influenced indirectly by the specified input parameters. The third category of the requirements catalog contains relevant key performance indicators for evaluating the efficiency of LTL terminals. Thus, these parameters represent the main output of the simulation model and can be divided into various fields of content, such as utilization-related and economic indicators, as well as time-related and volume-related performance indicators. The complete catalog of requirements with the determined attributes of the three main categories is shown in Table 1.

Table 1: Requirements catalog for Simulation Models of LTL terminals

Input Parameters	Design Criteria	KPIs
• Loading strategy	• Capacity of yard area	• Carbon footprint
• Number of forklifts	• Layout-forms	• Cycle time of shipment
• Number of docks	• Material flow	• Cycle time of forklifts
• Number of workers	• Paths for vehicles	• Distance traveled
• Performance forklifts	• Pick-up-area	• Handling volume
• Processing time	• Storage area	• Sales volume
• Shipment volume		• System load
• Truck capacity		• Utilization: forklifts
		• Utilization: docks
		• Utilization: storage areas
		• Utilization workers

4 Simulation

The structure for a generic simulation tool derived from the requirements catalog is shown in Figure 1. In order to enable a low-threshold use of the simulation tool, two layers arise. The first layer of SMEs must meet the level of user knowledge. This layer influences the second layer, the simulation layer, directly. Simulation experts are omitted from the transfer between these levels. Thus, the simulation expert only affects the tool during development but not during use. Contrary to this, the expert connects the user and the simulation in classical simulation studies. The presented structure leads to a simulation layer, which must automatically adapt to user input while ensuring executability.

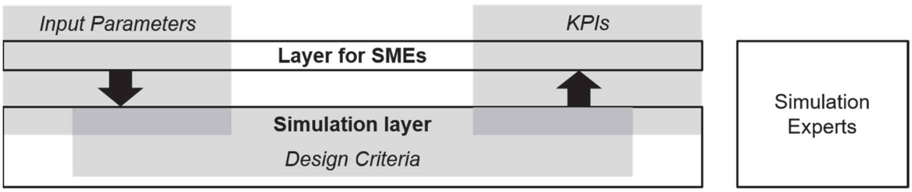

Figure 1: Structure for the generic simulation tool

The development of the generic simulation model for the I-layout of an LTL terminal is based on this structure, using the catalog of requirements defined above and the process model of VDI Guideline 3633 Sheet 1, because this approach has considerable relevance in the simulation of systems in materials handling, logistics and production in the German-speaking area. It defines the procedure of a simulation study with all relevant phases, starting with the target description, through verification and validation, and finally to the simulation results (Rabe et al., 2008; VDI 3633). The I-layout represents one of the basic shapes of LTL terminals and is characterized by a rectangular design that can easily extend its length by adding further docks. Thus, this type is one of the most preferred basic shapes in practice and will be investigated in this paper (Chmielewski, 2007). The structure of this layout type and the associated modification of the lengths is demonstrated in Figure 2.

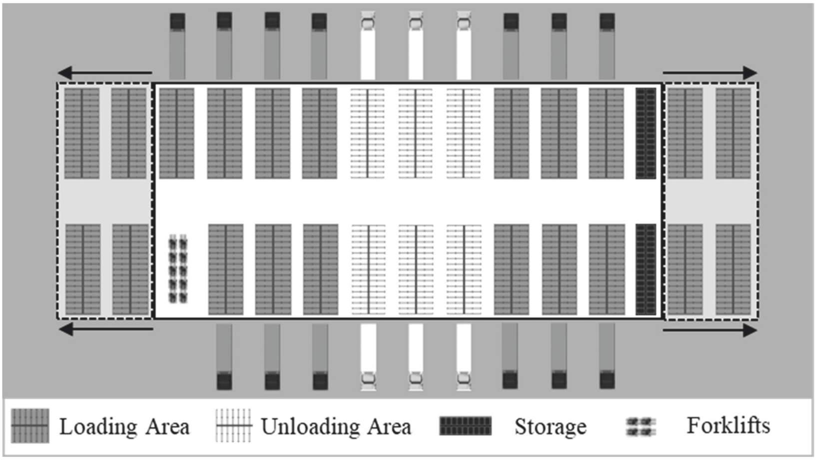

Figure 2: Structure of the I-Layout based on Anylogic

The software AnyLogic 8.8 is used to develop the simulation model, which combines three different modeling methods and examines various levels of abstraction in a single model. The developed simulation model uses discrete and agent-based modeling and includes several agents, which map the process of an LTL terminal by interaction with each other. In addition, the user-specific terminal design gets determined through an input before the simulation run. Using a graphical user interface (Figure 3), the user defines a selection of various input parameters from the requirements catalog. The framework of this simulation tool allows to configure the number of workers, respectively forklifts, the number of docks for loading and unloading, and processing times according to the user's needs. These parameters will be set using a slider or entering concrete values.

After setting the parameters, the simulation model will be generated automatically by considering all defined design criteria of the catalog to ensure the realistic representation of the LTL terminal. The central instance of the simulation model is the agent “Main”. The terminal is modeled and presented in two and three dimensions within the main agent based on the user input. Furthermore, the main agent contains the logical process flow defined by the simulation expert. The user cannot change the logic, which remains unchanged regardless of the terminal size. Lastly, the statistics of the simulation run are shown in the main agent. The selection of the statistics displayed corresponds to the KPIs of the requirements catalog. In addition to the main agent, five further agents will be generated and injected into the process flow, except for the docks. The agent Dock is only used to generate the terminal layout.

- Unloading Truck
- Loading Truck
- Forklift
- Dock
- Pallet

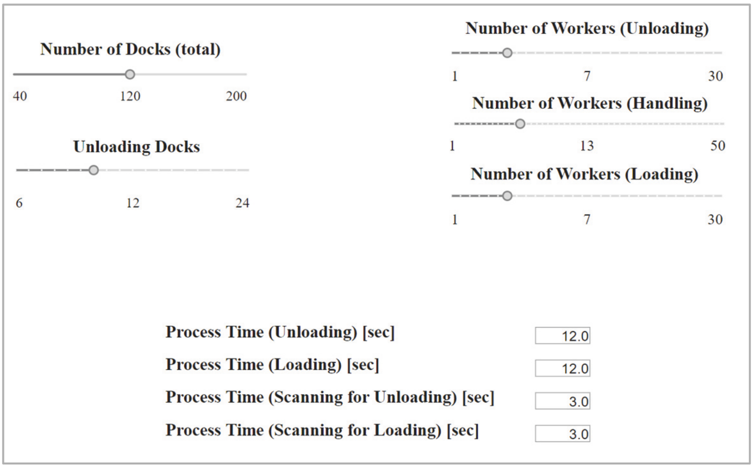

Figure 3: Input screen for defining the parameters

The simulation model's logic covers LTL terminal's entire handling processes. They are divided into various sub-processes, linked to each other directly or by using exit and enter blocks (Figure 4). These are represented in AnyLogic by the sequential order of particular blocks, which are passed through by the agents and perform defined actions. The system boundaries of the simulation model are defined by the arriving unloading trucks and the departing loading trucks.

The first part of the process flow includes the arrival and departure of the unloading trucks. For this purpose, the respective agents are injected into the simulation model according to a triangular distribution based on the vehicle arrival distribution at LTL terminals by Chmielewski (2007). In addition, the generated agents will be assigned to a corresponding unloading dock. The arrival procedure is linked to the sub-process "Unloading Process", where the agent "Pallet" is created and symbolizes the incoming shipments. In the next step, these pallets are transported to the unloading areas using the previously defined agent “Forklift”. Afterward, based on real shipment data of a forwarding company, a triangular distribution is used to determine the target loading area of the shipments and their transport is executed by a handling forklift. In case of an already occupied loading area or if the loading truck has no more available capacities, a case distinction is made, which results in storing the pallets in the intermediate storage. These processes are represented by the two sequences "Store Process (if no free slot in loading storage)" and "Store Process (if no loading capacity in truck)". Finally, the pallets stored in the loading area will be transferred to the

"Loading Truck" agent. This is mapped using the two directly connected sub-processes, "Loading process" and "Arrival and Departure Loading Truck". The Loading Truck agents are injected into the process flow based on a defined schedule and are allocated to a corresponding loading dock. After a successful load, the loading truck agents will leave the model via the defined sink. In this context, the transport processes of the pallets are performed by using the forklifts in combination with the available number of workers for loading defined at the beginning.

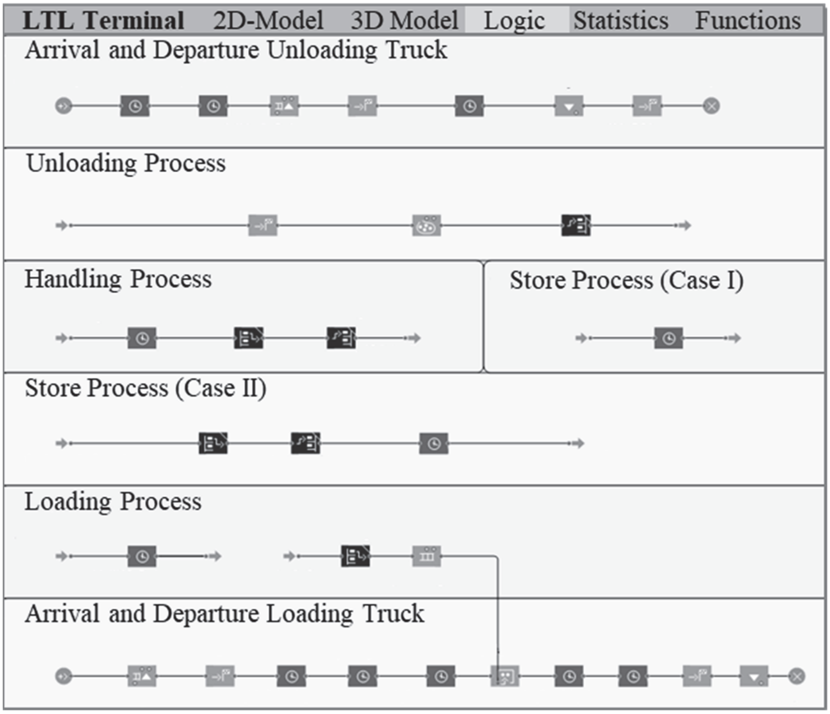

Figure 4: Process Flow of the Simulation Model

For validation of the generic simulation model, several simulation runs with different parameter configurations are performed. On the one hand, this will demonstrate the possibility of an individual configuration and investigation of the I-layout of an LTL terminal. On the other hand, it shows that the mapped processes correspond to practice and that the simulation model provides realistic results. To cover the entire possible setting range, the number of total docks is increased in steps of 40 up to the maximum value of 200 docks. The share of unloading docks is set at 10% continuously. In addition, the processing times for loading and unloading are set at 12 seconds, and the time for two scanning processes is defined as 3 seconds per shipment. The number of employees assigned to the corresponding sub-processes is determined based on previous investigations and can be taken from Table 2. Here, the number of employees must be at least enough to handle the volume of shipments until the end of the respective shifts and to ensure that the simulation run is not interrupted by capacity bottlenecks.

Table 2: Parameter configurations of the simulation runs

Variant	Number of Docks (total)	Unloading Docks	Number of Workers		
			Unloading	Handling	Loading
1	40	4	3	4	3
2	80	8	5	8	5
3	120	12	7	13	7
4	160	16	8	19	8
5	200	20	10	26	10

The first step to verify the possibility of a generic model is to determine if the shipments rise with the increased number of docks. For this purpose, the number of loading docks corresponds to the number of arriving trucks with shipments. In this context, the trucks are injected according to the distribution explained above and their capacity is defined based on real data of a forwarding company. The data preparation shows that all trucks in long-distance traffic have a capacity of about 32 spaces for euro pallets. However, in local traffic, only 33 percent of all trucks have these characteristics, leaving the remaining trucks with a capacity of up to 17 pallets, depending on the type of vehicle used (Deymann, 2011).

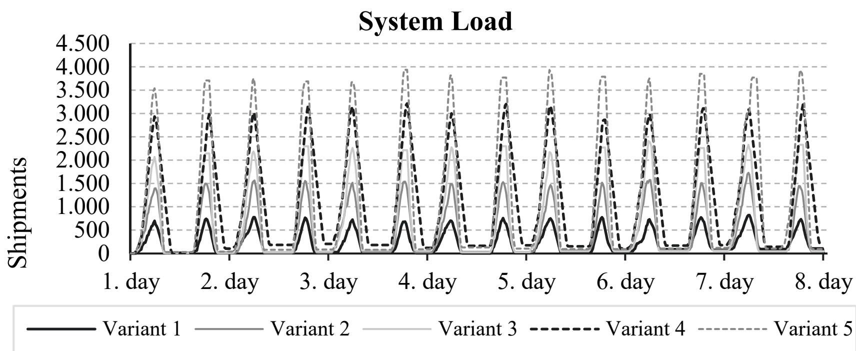

Figure 5: System Load of LTL terminals

Figure 5 shows the system load of the terminal depending on the number of docks and represents the absolute value of shipments per day. Further extensions of the model should include the user's specific adaption of shipment volume based on individual circumstances. In addition, the distance traveled was evaluated depending on the number of loading docks. Figure 6 shows that the distance the unloaders cover rises as the size of the LTL terminal increases. This progression occurs because unloaders drive exclusively to the middle docks for unloading the trucks. As the number of docks increases, more unloading trucks arrive at the docks leading to a rise in the distance traveled. Contrary, unloaders can drive directly to the next truck after completing the unloading process of another truck more often at this point. On the other hand, the distance traveled by loaders increases proportionally to the number of docks. In the loading process, the empty run, i.e., the distance to the truck to be loaded, becomes longer as the number of docks increases. However, at each dock, the distances for loading are independent of the number of docks since the worker only travels between the storage area and the truck. Since the loading and unloading processes are similar, the course of the distances in Figure 6 is also similar. This differs from the distance covered in the handling process. In this process, the employees must pick up a pallet from the unloading area in the middle of the plant, bring it to the respective loading gate, and drive back without a pallet. As the number of docks increases, the distance between these areas and the distance covered in the handling process rises disproportionately and significantly exceeds the traveled distance of the loading and unloading processes.

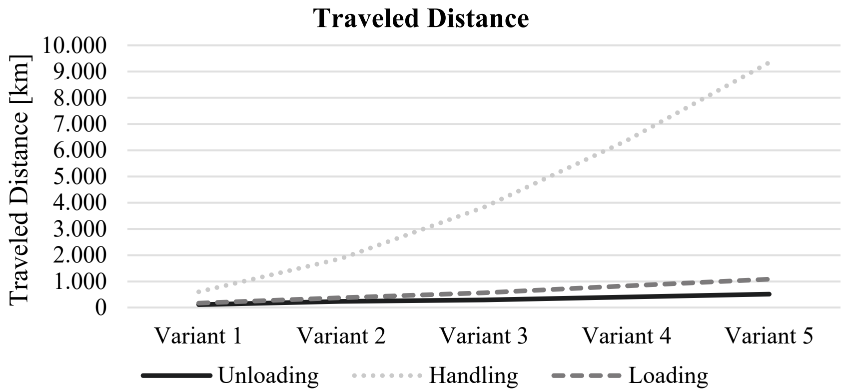

Figure 6: Mean value of traveled distance in km

In addition to the key performance indicators presented, the simulation model can determine the utilization of the forklifts, docks, storage areas, and workers. Moreover, the cycle times of forklifts and shipments can be identified, as well as handling volume. Based on this model, a large part of the requirements for a generic simulation model determined in the focus group interview can be fulfilled. Following this research, a tool that supports other forms besides the I-layout and determines all KPIs has to be developed in the next step.

5 Conclusion

In this paper, an automatic generation of discrete event simulation models for LTL terminals has been developed. We found that using a generic simulation tool can overcome the barriers of incorporating simulation into SME planning processes. With the help of focus group interviews, a catalog of requirements for SME planning processes was built and divided into input parameters, design criteria, and KPIs. For this feasibility study, a first generic model was realized with a selection of the input parameters for the I-layout of LTL terminals. The evaluations show that it can be helpful to compare different layouts with dynamic inputs, since, for example, distances traveled can vary considerably which can influence the efficiency and carbon footprint of the terminal. Further approaches should develop a generic tool covering the requirements catalog in its entirety and enabling the modeling of any terminal layout beyond the I-layout.

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