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AUTOMATIC MODEL GENERATION FOR DISCRETE EVENT SIMULATION OF LESS-THAN-TRUCKLOAD TERMINALS

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ABSTRACT

Planning and optimizing Less-Than-Truckload (LTL) terminals is challenging, particularly for small and medium-sized enterprises (SMEs) lacking simulation expertise. Despite simulation-based approaches' effectiveness, the required financial investments often prohibit SMEs from utilizing them. This paper introduces a tool combining automatic model generation and generic modeling for discrete event simulation in LTL terminal planning for all terminal shapes. Specifically designed to meet SMEs' needs, the tool generates simulation models customized to individual terminal requirements through user input, facilitating efficient layout planning and resource allocation. The approach ensures that SMEs can benefit from advanced planning techniques without substantial financial investments or specialized knowledge, thus fostering competitiveness and sustainability within the LTL sector. Validation demonstrates that the automatic model generation tool yields results comparable to manually built simulation models regarding the most efficient terminal shapes.

1 INTRODUCTION

The Less-Than-Truckload (LTL) sector, which is characterized by a few global forwarding companies and also, especially in Europe, by several cooperation networks of small and medium-sized enterprises (SMEs), is currently facing major challenges (Pflaum et al. 2020). To handle increased service requirements of customers and rising shipment volumes while operating costs simultaneously rise, cross-docking terminals and logistical processes need to be modified more efficiently. Remodeling terminals and choosing the most efficient shape is becoming increasingly important, with various forms being applied in the sector. Figure 1 illustrates the example of an I-Shape for LTL terminals and the main components of LTL terminals. Storage areas are placed in front of the unloading docks in the middle of the terminal. Furthermore, pickup areas are assigned to loading docks on both legs of the terminal. The forklifts handle the shipments.

Layout planning of these terminals or the dimensioning of functional areas and paths are often based on factory planning methods (Schenk and Wirth 2004). However, dynamics such as daily fluctuations in shipment volume or the variation of functional areas and other decision support needs could not be considered sufficiently. Simulation-based approaches have been used to map these dynamics and provide decision support (Mowe et al. 2023). Applying these techniques requires specific simulation knowledge, resulting in investments. Due to limited SMEs' financial resources, these companies cannot benefit from simulation methods (Schenk and Wirth 2004).

Hence, the objective of the paper is to develop a tool combining automatic model generation and generic modeling of discrete event simulation models for LTL terminal planning that is automatically generated based on the user's input. It will be designed to consider SME requirements especially and should be usable without simulation expertise. Therefore, the paper is divided into five sections. First, the main problem is identified, and from this, the objective of this study can be derived and defined. The second section offers an overview of current research on simulation in SMEs, LTL terminals, and automatic simulation model generation. The third section describes the development of the simulation approach. Here, the architecture

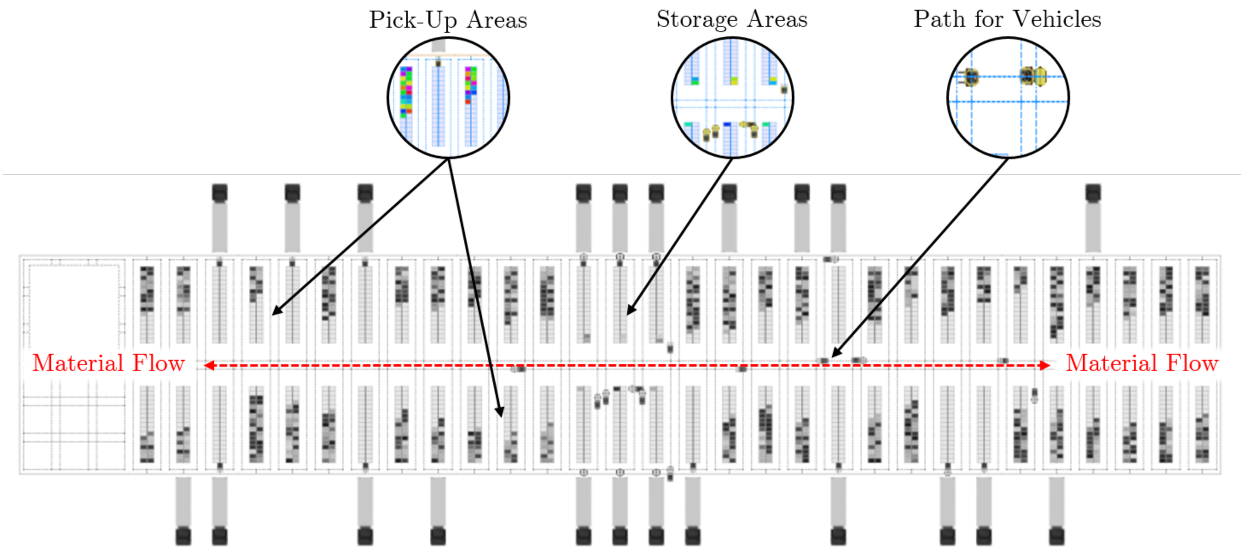

Figure 1: Infrastructural characteristics of simulation model in the I-Shape.

is presented. Section 4 is used to verify the developed model. This validation process is divided into two stages and includes the performance of experiments. The last section summarizes the main results of the applied study and outlines future research in this field.

2 LITERATURE REVIEW

2.1 Simulation in SME and in the LTL Sector

Wiese (2018) surveyed 1,420 production and logistics SMEs based in Germany. The approach discovered that 85.56 % of the SMEs had not previously utilized simulation experiments to analyze their business processes. Some barriers to usage stemming from time constraints and costs to use simulation models have been identified by those SMEs that already use simulation. These barriers are also determined in a study by Yu and Zheng (2021).

Reviewing the literature explicitly mentioning that simulation models were designed for SMEs, Kumar et al. (2016) applied a layout analysis within a manufacturing SME with discrete event simulation software. Similarly, Suhadak et al. (2015) investigated various layout variations and an additional value stream analysis using simulation within a food industry SME.

The use of modeling and simulation approaches in logistics is diverse. It ranges from a microscopic view, e.g., of the internal processes in a terminal, to the macroscopic modeling of a transport network. To investigate and evaluate the complex behavior of logistics systems, simulation is used to support planning and decision-making (Zouhaier et al. 2013; Clausen et al. 2017; de La Fuente et al. 2019; Clausen et al. 2019; VDI-Guideline 3633 Part 1 2014)

The simulation for logistic terminals is well-suited to modeling manual processes and routes of forklifts and automated guided vehicles on an agent-based and detailed basis and to simulating, e.g., arriving shipment volumes with their stochastic influences. Poeting et al. (2017) and Clausen et al. (2017) introduced frameworks using heuristic algorithms and Mixed-Integer Programming models with discrete event simulation to offer robust solutions for the assignment of loading and unloading trucks to docks in parcel transshipment terminals. The system behavior is analyzed by testing the mathematical solutions in simulation experiments. Clausen and Goedicke (2012) used a simulation model to compare yard strategies at LTL terminals concerning their impact on performance aspects of internal sorting operations. However, these logistic simulation models have been manually constructed.

2.2 Automatic Model Generation

The main challenge is to reduce the time and effort required to carry out simulation studies and to make them accessible to non-simulation experts. The automatic model generation provides a way to solve this problem (Fowler and Rose 2004). With automatic model generation, a model generator is used for several simulation studies, creating new program code for the simulation model for each study (Mathewson 1984). This is achieved using suitable algorithms and interfaces (Bergmann and Straßburger 2010; Wenzel et al. 2019).

Various technical approaches can be used to achieve automatic model generation. Often, these approaches lead to a semi-automatic modeling process rather than full automation (Bergmann and Straßburger 2010). The techniques are classified as parametric, structural, or hybrid-knowledge-based approaches (Bergmann and Straßburger 2010; Gmilkowsky et al. 1998). Beyond that, according to Bergmann and Straßburger (2010) and Wenzel et al. (2019), there is a strict separation between the planning and operational phases, focusing on the field of use. Vieira et al. (2018) add a further dimension and include the data input type for classifying the approaches. For this purpose, classification methods of Barlas and Heavey (2016) and Skoogh et al. (2012) are used. Those methods differentiate data input by the degree of automation. Additionally, Vieira et al. (2018) classify the application of those approaches according to the application sector. In their study, they found that 73 % of model generators address production systems.

The application of an automatic model generation is demonstrated in Gocev and Rabe (2010). They implement a graphical user interface for data input. They extend the Semantic Web Framework for modeling and simulation with a module for graphical layout planning assigned to manufacturing in early planning phases. Instead of layout data, Selke (2004) and Lugaresi and Matta (2021) use system data for automatic modeling. Selke (2004) automatically analyzes system data to derive strategies and rules and transfers them to decision tables. Lugaresi and Matta (2021) use system data as process data for automatically modeling digital twins in manufacturing. Automatic model generation is also used in Bessai (2019). He uses combinatorial logic for reusing and varying existing components of simulation models. Exemplary applications of this approach for intralogistics systems are Kallat et al. (2021) and Mages et al. (2022).

The research field that deals with automatic model generation is characterized by approaches for specific cases with no consistent methodological standard (Reinhardt et al. 2019; Wenzel et al. 2019). Efforts towards standardization are evident in developing data formats for data input rather than in the standardized application of the various approaches (Reinhardt et al. 2019). In addition, the transfer of specific approaches to other application areas is yet to be defined. This hinders the transfer to transport logistics, as the associated handling facilities are barely considered so far (Vieira et al. 2018).

Besides technical approaches and their transfer, V&V is a challenging aspect of automatic model generation. Considering the paper's use case of enabling non-simulation-experts to use the application, V&V gains importance. Due to the automatic or semi-automatic modeling, the classical application of V&V is only partially possible. Sarnow and Elbert (2022) discuss the application of V&V in generic models. They state that V&V activities should be shifted from model operation to the development phase wherever possible. This can also be applied to some extent to automatic model generation and semi-automation. Nevertheless, V&V is still needed for every instance. This requires automated techniques, which Langenbach and Rabe (2023) discuss.

In addition to the automatic model generation discussed above, generic models should be mentioned. Generic models are not limited to one scenario. The program code is defined once and tailored via variables. This also reduces development efforts. Likewise, non-experts can access a suitable user interface for data input (Pidd 1992). However, generic models are less flexible. Since this study requires a high degree of flexibility, automatic model generation is being considered alongside generic modeling.

2.3 Preliminary Work on Model Generation for LTL Terminals

Mowe et al. (2023) developed a generic simulation model for LTL terminals, designed to be accessible without simulation proficiency and customizable to fit unique SME I-Shapes of LTL terminals. To get insights into the SMEs' essential needs for LTL simulation model development, focus group interviews with SMEs were conducted to gather requirements. Focus group interviews delve into the perspectives and experiences of individuals who share a profession. Participants share experiences and ideas, and group dynamics enable individuals to build upon each other's contributions in an interactive setting (Calder 1977).

In Table 1, SME requirements such as input parameters, design criteria, and KPIs found by Mowe et al. (2023) are listed. The criteria are defined not only for I-Shapes of LTL terminals, but also for all other shapes. In this approach, users can individually set and modify input parameters before model generation. Design criteria describe infrastructural characteristics and yard components. KPIs evaluate LTL terminal efficiency for the given shape and procedures. All identified use cases differ from the paper's objective of developing a simulation tool for all LTL terminal shapes.

Table 1: Requirements catalog for simulation models of LTL terminals (Mowe et al. 2023).

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	Pickup area	Handling volume
Processing time	Storage area	Sales volume
Shipment volume		System load
Truck capacity		Utilization: forklifts
		Utilization: docks
		Utilization: storage areas
		Utilization workers

3 METHODOLOGY

3.1 Conceptional Design

This paper is based on the preliminary work of Mowe et al. (2023) and extends the scope to various terminal shapes besides the I-Shape. The layout-forms design criterion is addressed to develop a solution independent of the terminal shape. Automatic model generation is used to model the terminal shapes. The authors choose a parametric approach, as it allows high-level user input and is suitable for LTL terminals, which are similarly structured throughout the sector. For the processes within the terminal, generic modeling is applied using a combination of discrete simulation and agent-based modeling. The proposed concept is shown in Figure 2. First, user input is done with predefined building blocks that can be combined to form LTL terminals and with parameters for the generic components. Next, the data input gets transferred to the component for the automatic model generation. Afterward, an executable simulation model is generated in combination with predefined generic process models (e.g., unloading and loading) and agents (e.g., forklifts and shipments). Experiments can then be performed under the guidance of the user and are not handled automatically in this paper. Furthermore, Figure 2 shows a differentiation between users within the concept to ensure flexible usability. Therefore, the concept is divided into three layers, each representing a user group with a specific knowledge profile. A user of Layer 3 requires no simulation knowledge, but a deep understanding of the LTL terminals under consideration. In Layer 2, a broad understanding of LTL terminals without knowing a specific terminal is required. In addition, simulation knowledge is necessary to create and adapt the building blocks and perform generic modeling of the processes and agents. Moreover, it must be ensured that these layer components are in synchronization. For users of Layer 1, the knowledge of the processes in LTL terminals is optional. However, deep simulation know-how is necessary, especially for automatically generating simulation models within the application. Based on the concept of three layers, a wide range of users can utilize the solution.

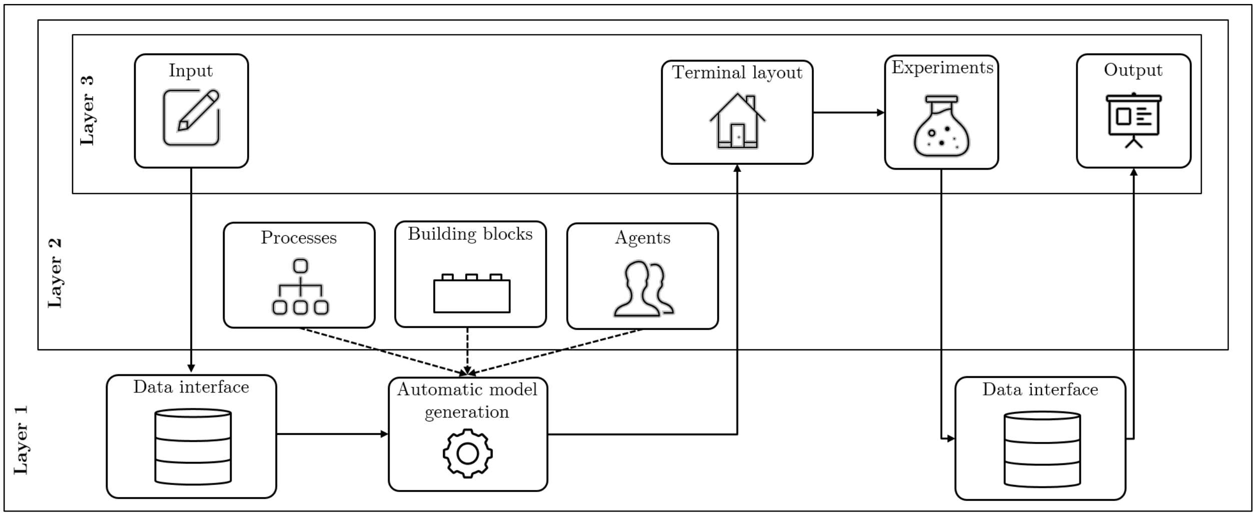

Figure 2: User assignment.

The shape is created using simulation building blocks using principles and base properties. The building blocks are squares with a side length of x, representing a three-dimensional object, and are a subset of a given terminal. Hence, a set of building blocks represents a terminal defined by a two-dimensional matrix with elements A_{ij}, where i is the row and j the column index, as shown in Figure 3. Each element is assigned a block (1) or not (0). $A_{ij} \in \{0,1\}$ does not define different building blocks. Neighboring blocks are connected by the edge both blocks share. Thus, there are two types of edges: connecting edges and free edges. Connecting edges must allow agents to move between the blocks. Free edges represent the outer wall of the terminal and can be used for docks.

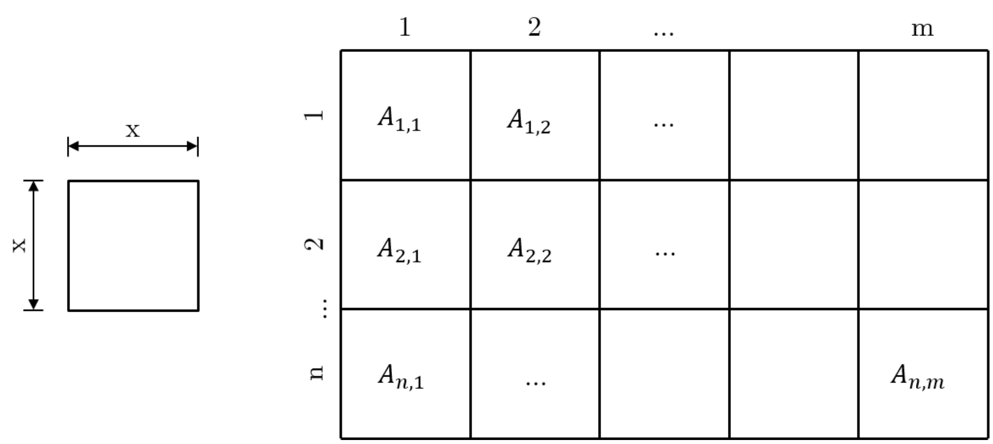

Figure 3: Matrix notation for the building blocks.

3.2 Definition of Building Blocks and Generic Process Modeling

The authors propose three building blocks. According to the concept, they are just an exemplary implementation and could be adapted by Layer 2 users without taking care of the automatic model generation in Layer 1. Figure 4 shows a block for docks, forklifts, and passages. LTL terminals consist mainly of docks and storage areas. Due to the geometric requirements of a square shape and the dimensioning of functional areas, each block contains three docks, resulting in a side length of 19.5 m. Each pickup area is assigned to a dock within the corresponding block and placed in front of it. Additionally, a pickup area has a capacity of 34 Euro pallets, corresponding to a full truckload. The dedicated path enables transportation with forklifts and is designed to allow pallet access at any time. Furthermore, paths are used to connect neighboring blocks via their connecting edge. The Dock block additionally features one predefined free edge where the docks are placed. The Forklift block represents a charging station for forklifts. It includes paths, but is not directly involved in the handling process. Passage blocks do not include functional areas and solely enable forklift crossing. Forklift and Passage blocks allow connection via any edge.

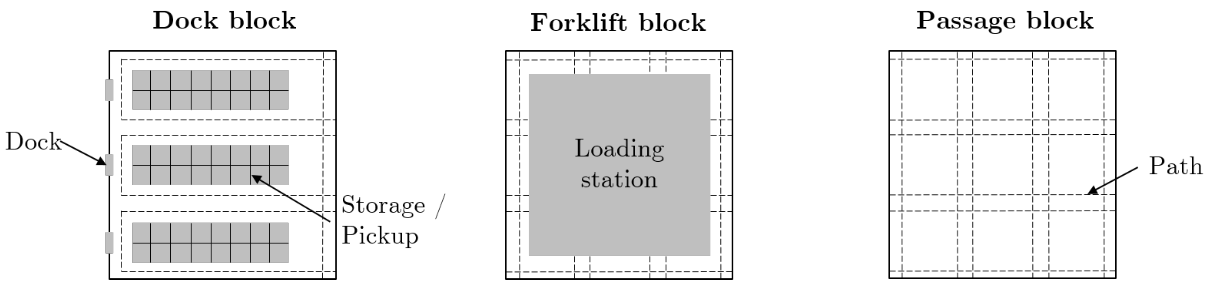

Figure 4: Predefined building blocks.

Expanding the matrix notation to types of building blocks, the matrix elements can be defined as $A_{ij} \in \{0, y\}$, where each is empty or refers to one of the y building blocks. Matrix A with n rows and m columns has $(y+1)^{n \cdot m}$ possible solutions. However, this upper bound can not be reached if duplications are excluded and conditions are used to ensure valid inputs. Two primary conditions are used for the input of terminals. An input must consist of two Dock blocks to ensure ingoing and outgoing material flows (1), and the entered shape must represent a contiguous building (2).

The generic process modeling is simplified, as the paper focuses on the automatic modeling of terminal shapes. The process modeling includes an unloading, handling, and loading process. Incoming trucks make the shipments available at the assigned dock for unloading, where forklifts pick up the shipments and store them in the unloading storage area. During the following handling process, forklifts transport the shipments to the designated destination pickup area. The loading process starts with the arrival of a truck at the destination dock. This triggers the loading process, during which the shipments from the assigned pickup area are transported to the truck. The process ends with loading the last assigned shipment into the truck.

3.3 Automatic Model Generation

With the predefined building blocks and matrix notation, an Entity-Relationship model (ERM) is developed to substantiate the automatic model generation. The ERM oriented by the notation of Chen (1976) is shown in Figure 5 and includes entities, relationships, and key attributes. The main entity *component* refers to a subset of a terminal. Its internal properties are defined via a specific underlying building block. The position of each component is determined by matrix A. According to its square shape, each component has exactly four edges. A connection to a neighboring component via all edges is possible, resulting in a maximum of four connections for each component. On the other side, each connection connects exactly two components via two edges (one edge for each component). Each edge is defined by the component it belongs to and its orientation.

The presented ERM is transferred to a database used during model generation. This automatic model generation process is structured as follows: First, predefined building blocks need to be generated.

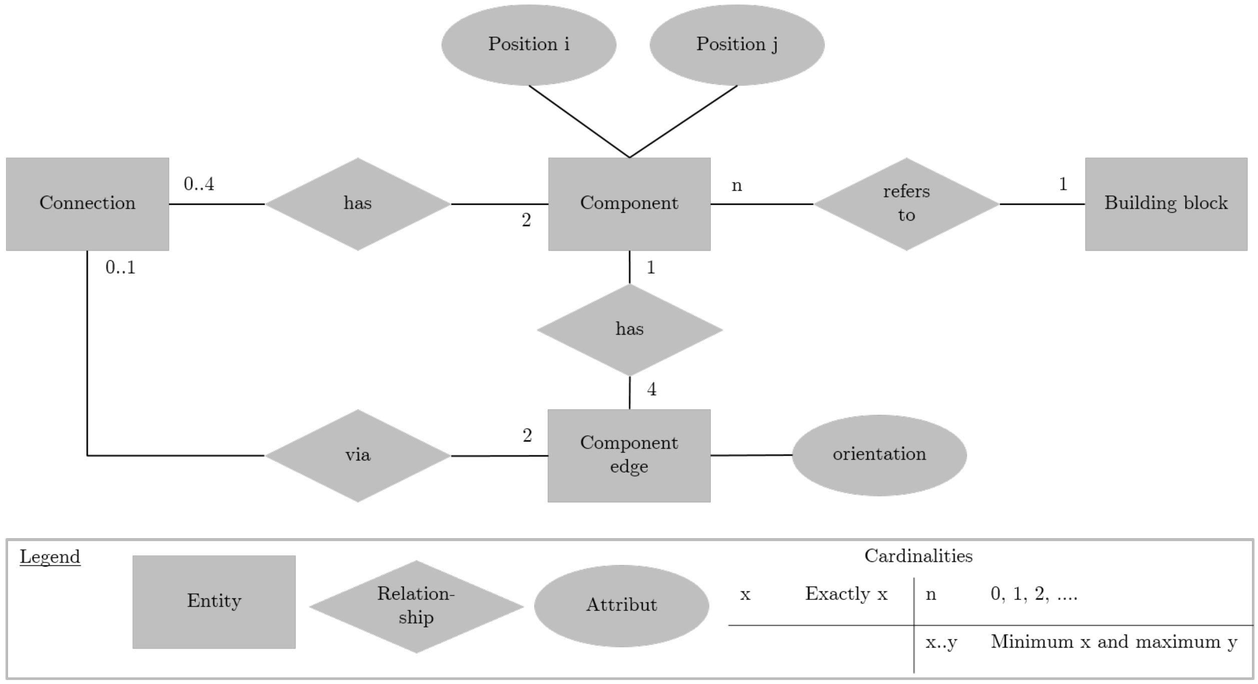

Figure 5: Entity-Relationship-Model for shape generation.

Therefore, the building blocks are divided into individual elements to make them reproducible. Here, it must be considered that some building blocks must be rotated. For example, docks can be placed on different edges of the Dock blocks depending on the input. In that case, Layer 2 must specify if rotation should be possible. For those building blocks, all elements are rotated around the center point and provided for the following steps. Subsequently, the terminal components are created automatically based on the user input. Each component's associated building block and all its elements are duplicated and relocated to the desired position. At this point, all terminal components are created but not connected. Connection paths between neighboring components are created for this purpose. Furthermore, walls will be created for free-moving vehicles. This is achieved by creating a wall element on top of every edge without a neighboring component. Finally, the generated elements are provided for the modeled processes. These include, for instance, the pickup and storage areas and paths.

3.4 Implementation in AnyLogic

Anylogic 8.8 is used to implement the concept described above, including automatic model generation, predefined building blocks, and process modeling. AnyLogic features integrated databases, provides GUIs in the form of web apps and allows the combination of discrete simulation with agent-based modeling. Moreover, it is based on Java, which is used to perform the automatic model generation. The building blocks and processes are implemented using agents and AnyLogic's libraries with additional Java functions (Borshchev 2013).

For data input, a pixel-based interface is created. The terminal is defined in three consecutive steps. In the first step, the user sets the available capacity of the yard (1). Based on this choice, the user defines the terminal shape (2). The user interface for this step is shown in Figure 6. In the last step, the positions of the docks must be determined (3). Furthermore, process parameters not pre-determined by the terminal (e.g., shipment volume) should be set in an additional step. These parameters are selected based on the input parameters described in Section 2.

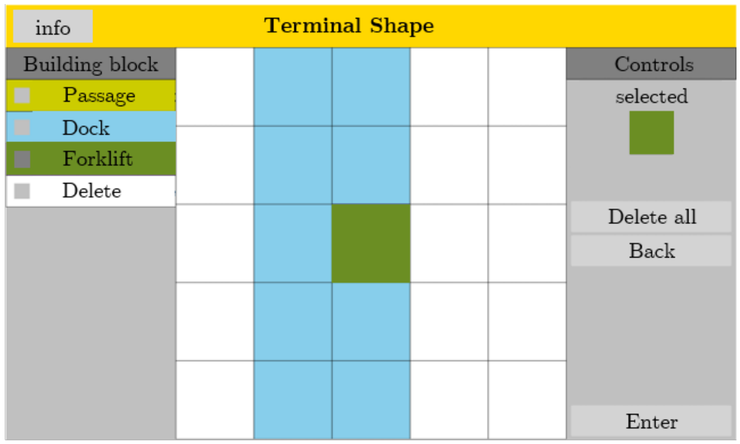

Figure 6: Step 2 of the GUI.

4 EXPERIMENT AND RESULTS

Validation of the previously developed simulation model is performed to ensure that the modeled processes correspond to practice and that this approach provides realistic results. Therefore, the validation process is divided into two phases. First, the simulation model is verified regarding its completeness of infrastructural characteristics. The second phase focuses on developing an experimental plan to evaluate whether the model can achieve realistic results.

The first part of the validation process is carried out according to the defined requirements catalog of Mowe et al. (2023) for developing LTL terminal simulation models. The category "Design Criteria" of Table 1 represents the main infrastructural components of the yard and includes the criteria "Capacity of Yard Area", "Layout-forms", "Material flow", "Paths of vehicles", "Pickup area", and "Storage area". All mentioned criteria must be considered in the modeling process to provide a realistic representation of a terminal. Therefore, Section 3 discussed the criterion "Capacity of Yard Area" for dimensioning the terminal. Moreover, the criterion "Layout-forms" can be confirmed, as the developed model can cover many shapes of LTL terminals because of this approach's structure. All further criteria are already illustrated in Figure 1 (Section 1), where the simulation environment for an I-shape of an LTL terminal generated by this simulation approach is shown. This illustrates the consideration of storage areas in front of the unloading docks. Furthermore, pickup areas are linked to loading docks. Paths for the movement of the forklifts are presented, and material flow between unloading and loading docks is mapped correctly, causing it to run from the center into the legs of the terminal.

The second part of the validation process focuses on evaluating if the simulation model provides realistic results. For this purpose, reference is made to Bartholdi and Gue (2004), who investigated the optimal shape of cross-docking terminals depending on the total number of docks. In this publication, the traveled distance of forklifts during the handling process is taken as a reference value for evaluation. Regarding this value, the study showed that with increasing terminal size, I-Shape, T-Shape, and X-Shape are most efficient (Bartholdi and Gue 2004). This hypothesis obtained by Bartholdi and Gue (2004) is used to verify and validate the model. Therefore, an experimental plan with specific model configurations is developed.

In total, the I-, T-, X-, L-, and H-shapes are investigated. Due to the dock width's different dimensioning in this paper, a conversion must be done to make the results for the traveled distance of forklifts comparable. Therefore, terminal sizes of the simulation model must equal the size of the study by Bartholdi and Gue (2004). Still, because the docks in the studies have different dimensions, the number of docks must be adjusted in this study. For this use case, it leads to the hypothesis that the I-Shape is best for terminals with less than 69 Docks and that the X-Shape is most efficient for terminals with more than 104 Docks.

Within this range, the T-Shape is best suited. Considering this hypothesis, the experimental plan, shown in Table 2, can be developed.

Table 2: Experimental plan.

	I-Shape	L-Shape	T-Shape	H-Shape	X-Shape
Variant 1	18 Dock blocks / 54 Docks				
Variant 2	20 Dock blocks / 60 Docks				
Variant 3	30 Dock blocks / 90 Docks				
Variant 4	38 Dock blocks / 114 Docks				
Variant 5	40 Dock blocks / 120 Docks				

Five terminal sizes with a different number of docks are analyzed for each shape. This enables the evaluation scenario to cover all three dock ranges while keeping the complexity manageable. A further requirement for determining the terminal size for the simulation runs is to ensure that an even number of blocks is used to guarantee that all shapes are possible to build.

Stochastic effects play a critical role in the simulation model, as each run is characterized by unique conditions influenced by manual logistics processes. Consequently, analyzing the required number of replications is essential to ensure stochastic reliability regarding the validity of the results. Therefore, the traveled distance of forklifts was recorded and analyzed with the help of confidence intervals based on the I-Shape with 54 docks. For this purpose, a sample size of 20 values was selected and a variance of 1 % from the expected value was considered acceptable. Analyzing the confidence interval shows that 20 replications are sufficient for a valid conclusion regarding the optimal shape. Furthermore, a transit phase is not considered, as it is assumed that terminals do not have any shipments at the start of each shift.

In addition to the dimensioning of the terminal, further settings are defined for the simulation runs. The share of unloading docks is set constantly at 10 %. Moreover, the shipment volume is distributed uniformly, with the freight of every inbound truck dispatched equally to every outbound truck. The number of used forklifts for the handling process is maximized to ensure the on-time handling of all shipments. In addition, since there is no impact on the evaluation, the number of used forklifts for loading and unloading processes corresponds exactly to the number of loading and unloading docks. Under consideration of the experimental plan and the defined settings, the results for the simulation scenarios are shown in Figure 7.

This diagram compares the traveled distances of the handling forklifts for each shape and terminal size relative to the I-shape. Thus, the values determined by the I-Shape experiments are plotted on the x-axis. If the traveled distance in the experiments of other shapes is shorter than this reference value, it is indicated below this axis. Greater distances are marked above. In addition, colored areas of the chart illustrate the three dock ranges mentioned by Bartholdi and Gue (2004) and recalculated for this use case regarding the most efficient shape type. The evaluation of the experiments confirms the hypothesis defined in this paper, since the results of the reference study can be reproduced with this simulation model. For terminals with a number of docks less than 69, the I-Shape has proven to be the most efficient. Intermediate terminals up to 104 docks fit most, as T-Shape and X-Shape are best suited for larger terminals. In the context of the experiments, further key performance indicators could be determined by applying the simulation approach. This includes utilization of forklifts, the terminal's system load, and the forklifts' cycle times.

5 CONCLUSION

Simulation-based approaches provide advantages for handling the major challenges in the LTL sector, which typically cannot be realized in an environment characterized by SMEs. The approach presented in this paper empowers users without simulation knowledge to obtain simulation experiments of their respective LTL terminals. The authors propose a solution that combines automatic model generation for modeling terminal shapes using a parametric approach with generic process modeling. The presented concept provides three user layers with different levels of simulation knowledge. The concept is exemplary implemented within the simulation software AnyLogic. The implemented tool generates any LTL terminal

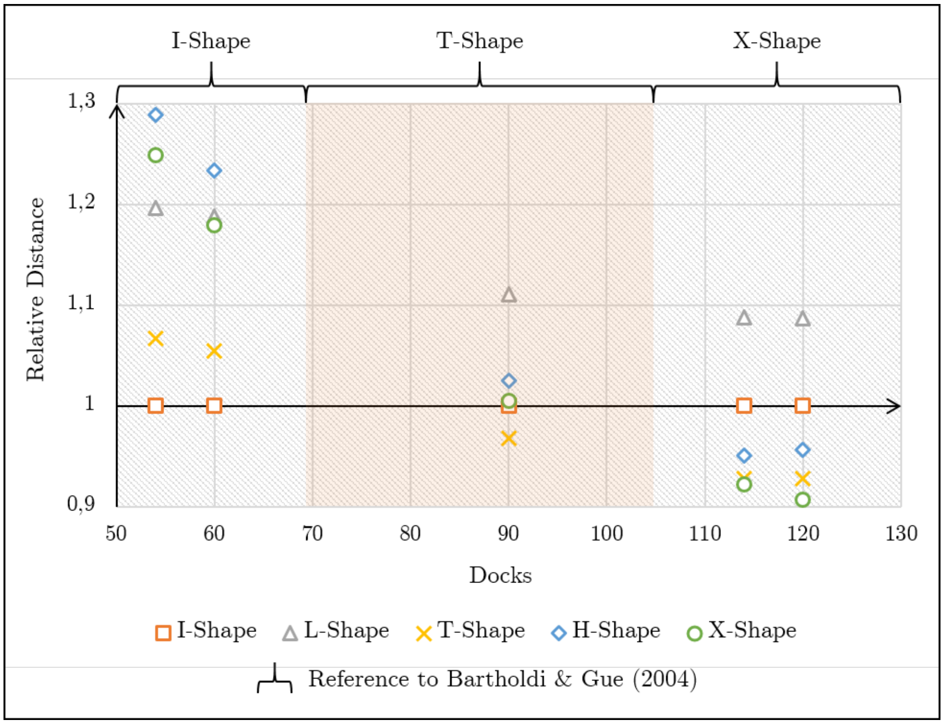

Figure 7: Results of the experiments.

shapes while producing realistic output compared with other studies analyzing LTL terminals. Predefined requirements for the simulations of LTL terminals are sufficiently fulfilled. With its libraries and the option of using them solely in Java code, AnyLogic helps implement the concept. Additionally, the combination of agent-based modeling and discrete event simulation can be realized. However, AnyLogic also imposes restrictions, which are noticeable in GUI development. Besides, license costs are incurred for creating standalone applications to provide the solution to the users. Although the current implementation is limited to AnyLogic, a standard for implementing the concept in other environments could be developed in the future. The paper presents an application-specific solution for LTL terminals. Further applications might be found in transport logistics and production planning. In principle, the systems should have recurring components that can be modeled in standard blocks, and layout variations should be considered to exploit the reduction in modeling effort.

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