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Simulation of Handling Operations in Marine Container Terminals for the Purposes of a Profession Simulator

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Abstract: Marine container terminals play an irreplaceable role in modern logistics. They ensure the functioning of material flows and supply chains. Optimal and efficient operations of terminals are increasingly based on full or partial automation. As a result, the expertise and skill prerequisites for service personnel and managers are increasing. This paper presents an original idea of creating a "profession simulator". Its principle is based on the application of a dynamic computer simulation method. The results represent a generally valid concept for a "profession simulator" that can be calibrated for any container terminal. Within this concept, the inputs, outputs, and processes that take place in the profession simulator are defined. The simulation model is created with the Tecnomatix Plant Simulation program. Mathematical models are implemented for all individual processes in the simulation model. A programming method using the SimTalk 2.0 language is used for their implementation. The obtained results point to the possibility of using the profession simulator to analyze and monitor selected indicators regarding handling techniques, the utilization of maritime terminals, information about the number of transported containers, or the implementation of handling activities.

Keywords: marine container; handling; training; analysis; profession simulator

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1. Introduction

Marine container terminals play an increasingly important role in global transport chains. As an intermodal hub between marine traffic flow and inland distribution, these terminals are significant for shipping routes [1].

The primary function of a container terminal, which can be overland or marine, is the handling and movement of containers. Direct transshipment between cargo ships or ships and road vehicles is impossible [2], due to the different arrival times of individual means of transport to the terminal. Therefore, containers must be temporarily stored in the terminal. Storage is necessary not only because of the different arrival times but also because of the substantially different volumes of shipment vessels compared to trains and trucks. Container terminals have a storage area where containers are stored for the necessary time. But terminals are not warehouses, and containers can only be stored for the shortest possible time. Many stored containers complicate other handling and logistical processes [3]. Terminal operators limit container storage times and request forwarders to resolve this issue with the means of transport for their containers. The standard storage time for a container without additional charges is two or three days [2].

The efficiency of a container terminal can be achieved by configuring the correct layout, which consists of the elements of the terminal and vehicles. This layout correctly connects transport and handling operations. Each container terminal has its specific layout, the basis of which is the same for the most modern container terminals, many of which are partially or fully automated [4].

The actual results of container terminal automatization often do not match the expectations of terminal operators [5]. Therefore, researchers have tried to develop different ways of simulating discrete cargo ship loading and unloading events for analysis using simulation models. These are recorded in the research of several authors. Ottjes et al. [6] (1994) developed a simulation model for container terminals in the Netherlands to evaluate system feasibility to reduce container transshipment time. Ambrosino and Tanfani [7] created a simulation model with the software Witness, which allowed them to analyze different scenarios regarding potential changes in the import/export of flows, handling techniques, other equipment and investment options, as well as additional operating rules for moorings and warehouses in a container terminal.

Lately, different simulation techniques [8–11] have been used to study the transport systems of container terminals. Simulation models have been developed to compare the performance of equipment such as cranes, vessels, and trucks in docks, using the analysis of equipment characteristics [12,13]. Liu et al. [14] performed a numerical simulation to compare the performance of four concepts of automatized container terminals: AGV, linear motor transport systems, elevated grid rail systems, and high-rise automated warehouses. Maione [10] analyzed the performance of a complex marine intermodal container terminal to propose changes in system resources or handling procedures to guarantee a better performance under disturbed conditions. Discrete event system simulation showed that under future conditions of increased traffic volumes and reduced available storage space, performance would be improved by more internal transport vehicles, appropriate planning and routing policies, or an advanced degree of automation. A similar problem was solved by Kulak et al. [15], Nawawi et al. [16], and Cho et al. [17], who developed simulation models for the evaluation of different operational rules to improve the performance of container terminals. Canonaco et al. [18] created an integrated simulation model for channel contention and berth management at a maritime container terminal. Their simulator calculates point and interval estimates for system performance measures. Statistical calculations are based on the problem of dosing elementary observations within the same cycle or in several processes. Cimpeanu et al. [19] investigated the storage and discharge of aluminum oxide in a refinery using a designed simulation model, which could effectively plan the maintenance of the material handling chain and predict and evaluate performance increases in the port system. Maruri et al. [20] investigated an automatic container system for transport management that connects a port terminal and an inland depot using a simulation model they created. This system received container transport orders from the host computer and calculated the route for the shuttle inside the terminal. Wang et al. [21] considered an automated container terminal's economic and ecological design. This design was based on the fixed length and width of the container terminal. Then, energy consumption during the operation cycle of various devices was verified with a simulation model, emphasizing the sustainable development of the port. The influence of human factors in the unloading/loading of containers in an intermodal maritime container terminal with a low level of automation was investigated by Maione et al. [22]. The authors proposed a new approach to the modeling, simulation, and management of container terminals that would reduce prediction errors and avoid the unnecessary costs of retrofitting. Grunow et al. [23] proposed heuristic dispatch rules in their simulation study, which used the ability of AGVs to transport one 40-foot container or two 20-foot containers simultaneously. Azab et al. [24] proposed an optimization approach based on the simulation of scheduling the visits of external trucks to container terminals, taking into account operations at yards and gates and their stochastic nature. Malyshev et al. [25] researched robotic automation in a warehouse terminal complex. Robotized automation is essential because of technological progress that leads to highly organized technical processes and the need for highly paid specialists.

The paper aims to present the research results comprising a general original concept for a “profession simulator” of a maritime container terminal. It was designed using dynamic simulation with the Tecnomatix Plant Simulation program (ver. 2201). Processes were programmed with the help of the additional programming method in the SimTalk 2.0 language. The proposed simulator concept has a generally valid character that can be calibrated for any specific maritime container terminal. The simulator can be used for training competencies and skills and for a detailed analysis of the processes taking place within the maritime terminal.

2. The Concept of Profession Simulators

Container terminals play a significant role in world economic trade as an essential node of land and sea logistics transport. With the continuous development of the world trade economy and the intensification of the competition of each port, the operators have begun to think about strengthening their position and achieving sustainable development from all aspects. Automated container terminals (ACTs) are a key direction in future port development and a revolution in the construction of new ports [14]. In 1992, the first ACT in the world was built, and these terminals were then built in the ports of Rotterdam, Singapore, Hamburg, Thamesport (in England), and Nagoya in Japan [26].

According to UNCTAD statistics, by 2017, more than 50 ACTs had been built worldwide due to their significant benefits and the cost savings in human resources in terminals, improving port capacity, reducing energy consumption in the facilities, and improving the image of ports. After more than 25 years of development and innovation, the current ACT technology has gradually matured and improved. With the development of science and technology, the growth demands of the shipping market, due to the increasing cost of port enterprises, the frequent occurrence of safety accidents, and personnel capacity, cannot meet the requirements of development and other factors; thus, more and more traditional ports are considering, preparing, or already building ACTs. The investment in ACTs is significant, and the initial cost of building them is high [26].

Managing individual activities within container terminals is not easy. It puts strains on the planning of handling operations and simultaneously requires prepared personnel with sufficient skills and competencies for their implementation. However, fulfilling these requirements is not easy, both from the point of view of time and from the point of view of preparation and realization. However, the stated criteria can be met by using an approach based on creating and using a profession simulator.

2.1. Profession Simulators

The profession simulator is a digital immersive system representing the natural environment while simulating its functionalities. Thanks to the profession simulator, it is possible to simulate various processes based on the actual conditions of engineering practice. The profession simulator offers a considerable descriptiveness of essential functions and situations.

The design of a profession simulator assumes the use of virtual reality methods, immersive display, and projection. Thanks to this, it comes closer to simulating the real environment and processes in the form of a digital copy. A profession simulator enables a more realistic presentation of information and a more plastic display, thus ensuring a more effective transfer.

To create a profession simulator, it is necessary to use a suitable software tool, such as the Tecnomatix Plant Simulation program or one similar. In any case, a powerful software tool must be used during its creation, one that meets the strict criteria connected primarily with immersiveness and descriptiveness for creating profession simulators. The software tool must enable the creation of interactive elements that, in connection with visualization using virtual reality, will provide and deliver a realistic view of the training process in the specific area. The profession simulator uses cognitive processes based on computer simulation primarily in connection with 3D visualization and the possible support of virtual reality.

The concept of a profession simulator is generally divided into two parts. The first part is a demonstration, the primary purpose of which is to provide theoretical knowledge. The demonstration part emphasizes static visualization with partial support for dynamic variability. Within it, individual processes, or their parts, are presented. The goal is to support understanding the issue on which the profession simulator is focused. The second part of the simulator is the training part. Its primary mission is creating different model situations. It is a concept that is very closely connected with the discussed issue and with reality. It thus enables the resolution of model situations that commonly occur in industrial practice. The concept of model situations is always chosen based on the overall concept and focus of the profession simulator. Overall, the idea of a profession simulator corresponds to the philosophy of Industry 4.0.

The simulation model plays a key role in the concept of a profession simulator. Based on the study of the available literature, mathematical models were selected for the correct functioning of the model, which were implemented in the simulation model for the control of specific processes. Mathematical models were chosen to cover the main areas within the simulation model—planning, transport, and handling. The mathematical models presented by Kozan and Preston [27] were used in the simulation model presented in this paper.

The first mathematical model focused on planning [27]. Specifically, it concerned minimizing the time that container ships spend in berth (1):

$$Minimise\ Max_{Mac} \sum\nolimits_{\{i|mac_i=mac\}} (travel_i + setup_i) \tag{1}$$

mac_i—The yard machine, container *i* is scheduled to be transferred.
$travel_i$—The time required to transport container *i* between the storage area, marshaling area, track area, and/or intermodal terminal.
$setup_i$—The time required to move the container(s) stored above the next scheduled container.

Another Equation (2) used in the simulation model ensures that each container always occupies only one position [27].

$$If\ x_i = x_{i'}\ and\ y_i = y_{i'}\ then\ z_{i,t} \neq x_{i',t} \tag{2}$$

x_i—The row of the storage area partition where container *i* is stored.
y_i—The column of the storage area partition where container *i* is stored.
$z_{i,t}$—The vertical storage position of container *i* stored at time t_i; this is measured as the number of containers stored on container *i*, which delays access by the handling equipment.

Equation (3) [27] was used for the restrictions connected with handling means and equipment.

$$If\ mac_i = mac_{i'},\ then\ t_i \neq t_{i'} \tag{3}$$

t_i—Time at which container *i* is scheduled for handling (movement).

Equation (4) [27] was applied to manage the connections among stored containers in storage positions and their stacking.

$$If\ x_i = x_{i'}\ and\ y_i = {y_i}'\ and\ z_{i,t} < z_{i',t}\ and\ t_i < t_{i'},\ then\ z_{i',t} = z_{i',t} - 1 \tag{4}$$

The last Equation (5) applied within the model was focused on the duration of the time window, which was defined in the simulation model for the realization of the loading and unloading of the container ship [27].

$$arrive^S + \sum\nolimits_{\{i|ship_i=s\}} (traveling\ time_i + set - up\ time_i) \leq depart^s \tag{5}$$

$arrive^S$—Arrival time of ship *s*.

traveling time$_i$—The time required to transport container *i* between the storage area, marshaling area, track area, and/or intermodal terminal.
set-up time$_i$—The time required to move the container(s) stored above the next scheduled container.

As part of the initial research phase on profession simulators for handling operations in maritime container terminals, verified mathematical models were used. Based on studies from other similarly oriented research (Arnone et al. [28], Moura et al. [29]), in the next phase, our own mathematical models will be derived, which will then be implemented in a profession simulator.

3. Applications

The base of the terminal is the equipment that performs the required operations connected with handling. In container terminals, handling devices are specific in terms of their parameters. For the transshipment of large quantities of containers, robust and reliable equipment and devices with corresponding dimensions are needed. Several types of handling equipment and devices are used in terminals, each suitable for a different handling activity.

3.1. Marine Container Terminal

It is possible to divide a marine container terminal into three parts. The first part is the seafront handling area, located at the water surface for container ships. This area is used to unload cargo ships and move them to the transshipment point. Quay cranes unload cargo ships, and then the containers are loaded by these cranes to AGVs. Quay cranes move on rails and need adequate space for movement. There is an area for the movement of AGVs below the cranes, which is used for the movement of AGVs to the point where the crane loads them. From this area, the loaded AGVs are moved to the temporary parking location. In this area, the vehicle waits for the release of another location to which AGVs move, which comprises several imaginary driving lanes [30]. By way of this area, the vehicle reaching it is unloaded by a gantry crane (Figure 1) [31].

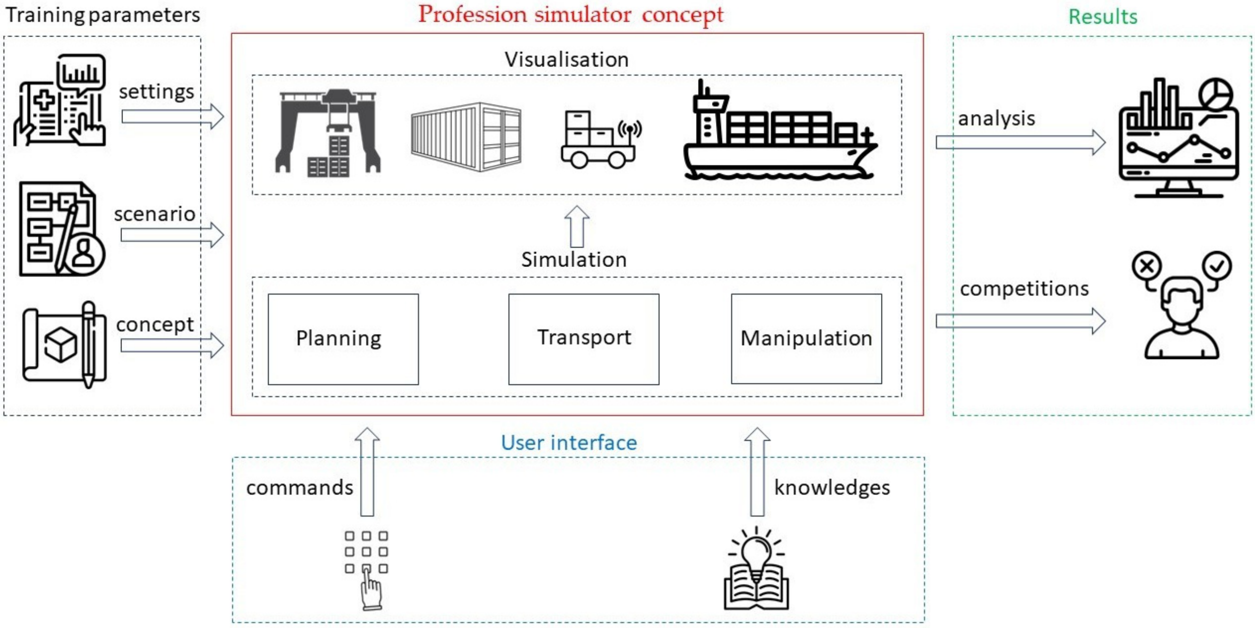


Figure 1. The concept of a profession simulator.

The second part of the terminal is the container store (Figure 2), which connects the quay and land handling area. This area comprises the center of the container terminal, and it has the most significant space. The capacity of a typical storage area is between 30,000 and 40,000 containers. Containers are stored in blocks that contain gantry cranes. In these blocks, the containers are stored in stacks; their height depends on the handling devices used. Using an automatic gantry, cranes can create a stack of five containers. However, this storage system makes containers at the bottom of the stack difficult to access. Therefore, it is necessary to leave free positions to move containers from the stack above the desired container [31].

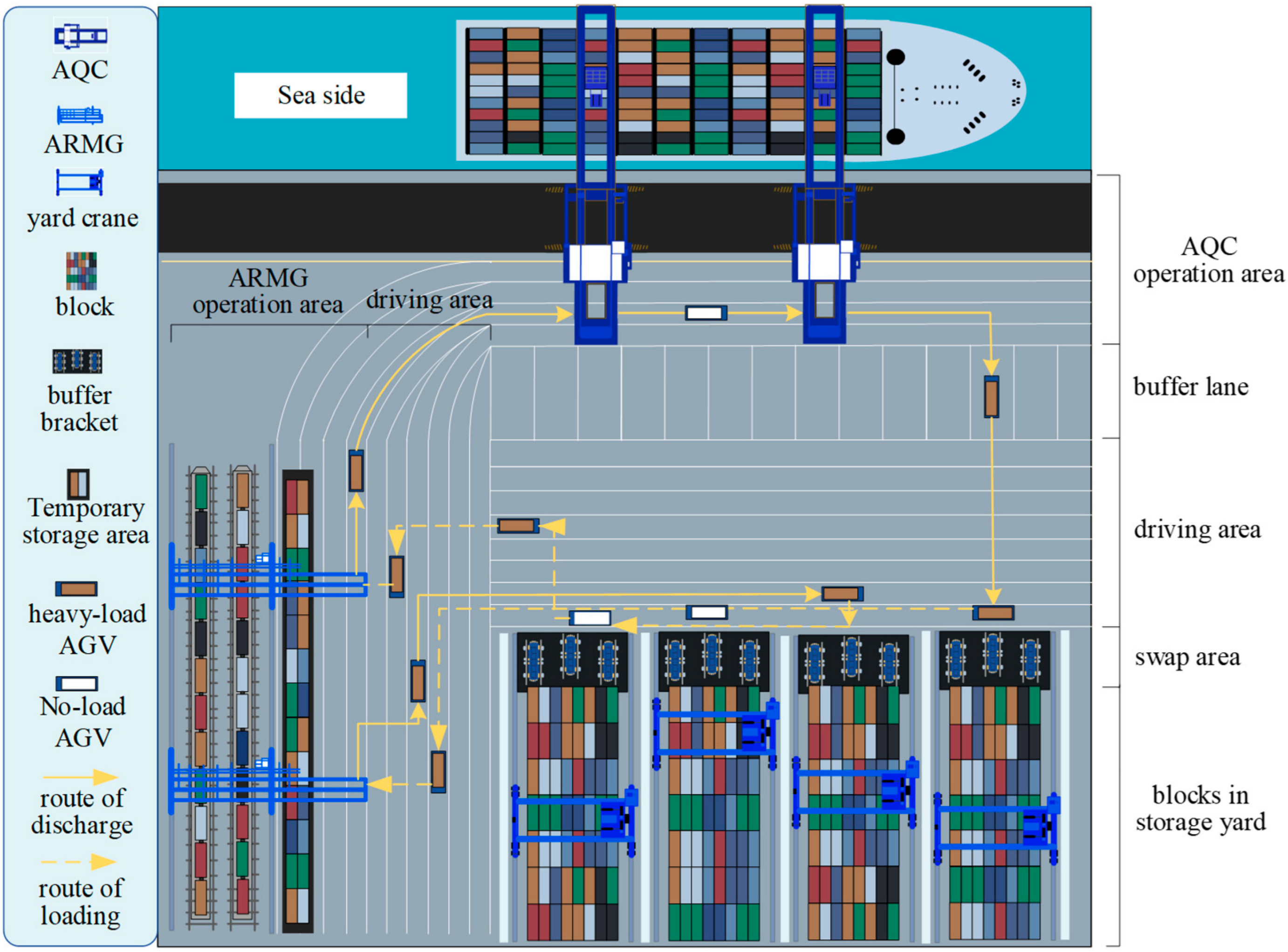


Figure 2. Example of a possible layout of the marine container terminal [31].

The third part of the terminal comprises a ground handling area that moves various types of transport, for example, road vehicles, trains, etc. This is the terminal's last part, where the material flow ends, and the loaded cars leave the terminal to travel inland. After the road vehicle arrives at the terminal, it moves along the designated lanes. The vehicle is transferred to the storage area, where a gantry crane loads it. The pre-required container from the storage area is loaded. After loading, the vehicle leaves the container terminal through the exit gate. By default, a road vehicle is loaded with only one container [21,32].

3.2. Handling Devices in Container Terminals

Each container terminal must use specific handling devices for its operation. The use of a particular type depends on the size of the terminal, its layout, and degree of automation.

The automation of handling devices belongs to the latest trend in this field and is suitable for handling many containers. The advantage is a reduction in labor costs and an increase in the efficiency of the entire terminal. On the other hand, there are high initial costs and a change in the whole terminal operation system. For efficient management of the handling technology in marine container terminals, an approach based on computer simulations and optimization is currently being used [32]. This was confirmed by the work of Kurniawan et al. [33]. Effective approaches in this area also include the use of heuristic/metaheuristic methods [34].

3.3. Automatically Driven Vehicles

This transport-handling technique is one of the most modern types currently used. The name comes from the English term for automatic guided vehicles—AGVs. They do not need human operation and move independently, navigated using computer systems. They can be powered by a diesel or electric engine or a combination thereof. Vehicles reach a speed of 6 $m.s^{-1}$ and in curves, 3 $m.s^{-1}$. During emergency braking with a load of 60 t, the stopping distance is 6 m. Due to its maximum length of around 15 m, the vehicle can carry one 40-foot or two 20-foot containers [35].

Vehicles moving along the seafront area have a predetermined route, reducing collision risk. In addition, the vehicles have sensors installed in the front and back, which stop the vehicle before it collides with another vehicle or an element in the terminal. The operator can see the movement of all vehicles on the screen, and in the event of a breakdown, the operator can redirect the vehicle to the parking area. Experiences in container terminals indicate that eight AGVs should be assigned to one quay crane. With six quay cranes, the AGVs number around 50 [35]. An example of the application of AGVs in marine terminals is in Figure 3.

Figure 3. Example of the application of AGVs in marine terminals [36].

The basis of the operation of AGVs is the precise determination of the position at the terminal surface. Several types of navigation are used for this. One is laser navigation, in which it is necessary to install reflective surfaces in the terminal environment, e.g., on the pillars. These reflective surfaces are used by a scanner mounted on the vehicle body, which uses the reflections to calculate the vehicle's position. This type of navigation is not used independently. It is combined with navigation through transponders assembled in the ground or under the surface of the seafront area. Another type of navigation is navigation via GPS, which is suitable for outdoor environments, i.e., terminals [37].

Increasing the productivity of AGVs is provided by a new technology called Lift AGV, or, lifting automatically controlled vehicles. These vehicles were created by the further development of AGVs, the benefits of which have been proven in terminals worldwide. Compared to classic AGVs (Figure 3), two lifting platforms are added, which are electronically controlled. These platforms allow the lifting of the container and its placement in the rack at the point where a gantry crane subsequently picks it up. This eliminates waiting for the gantry crane, and the vehicles work without unnecessary breaks. Compared to classic AGVs, their required total number is significantly lower. At the same time, some manufacturers report a reduction of up to 50%, which will reduce the total costs of operating and maintaining these vehicles [38]. Planning the operation of autonomous systems uses an optimization approach based primarily on the energy-saving point of view [39]. The optimization approach is also essential for the overall performance of the container terminal. This issue is described in detail by Hsu et al. [40]. Automatically driven vehicles can increase the productivity and performance of terminals and allow them to cope with the growing volume of the container trade [41].

4. Simulation Model and Results

The research was conducted based on the mentioned facts, the purpose of which was to create a profession simulator aimed at training activities and obtaining skills in managing transport and handling operations within the marine container terminal. The basis of the entire profession simulator was a simulation model.

The container terminal simulation model was created using the most modern technology, such as AGVs (automatic guided vehicles) and automated rail cranes. AGVs do not need human operation, and their independent movement is realized via navigation using computer systems.

A program from Siemens called Tecnomatix Plant Simulation created the simulation model. The program is primarily intended to simulate production flows and activities in enterprises. A wide spectrum of its elements can be used to simulate product storage, vehicle loading, cross-docking, or traffic intersections.

However, the program does not include activities used in maritime container terminals. Using the SimTalk 2.0 programming language, individual commands were easily modified based on precisely formulated requirements.

The concept of a profession simulator, shown in Figure 1, has a generally valid character. This concept must always be addressed and calibrated for a specific container terminal. It must consider all the basic parameters of the terminal, from its layout to the parameters of handling devices. The simulation model, which will be presented later in the paper, was created so that the calibration of the model was easily realizable using the programming language SimTalk 2.0. The report presents a simulation model developed by combining information to present the functions of a profession simulator. The goal of the simulation model is to present its final realization for the needs of a profession simulator. This profession simulator was also created to use as part of university education in logistics. The profession simulator will be calibrated for a container terminal in the following research phase. The results will be compared with the actual ongoing processes within the terminal.

4.1. Concept of the Simulation Model within the Profession Simulator

The layout of the maritime container terminal can be divided into sea and land. A cargo ship is anchored at sea, from which containers are unloaded. All handling operations associated with transshipment take place on land. Figure 1 presents the designed illustrative layout of the simulation model of the container terminal. It contains several different surfaces and devices. Unloading of the cargo ship in the upper part is ensured by four quay cranes, each of which is assigned its part of the ship's loading area from which it unloads containers. Cranes move along rails in an area with which other equipment does not interfere. The quay cranes simultaneously ensure the loading of docked AGVs. These vehicles have a sufficient separate area for their movement that is unobstructed.

The operator can see the movement of all vehicles on the screen, and in the event of a breakdown, they can redirect the vehicle to the parking area. The simulation model used the parameters and shape of the AGVs of the company HHLA [42]. The loaded AGV automatically takes the shortest possible route to the transshipment point, where the container is unloaded from the vehicle and moved to the free position in one of the 10 storage area blocks. Automated gantry cranes perform AGV unloading and handling containers within the block. The loading of containers from the block onto road trucks is realized through the addition to the transshipment point in the lower part of Figure 4 using the second gantry crane.

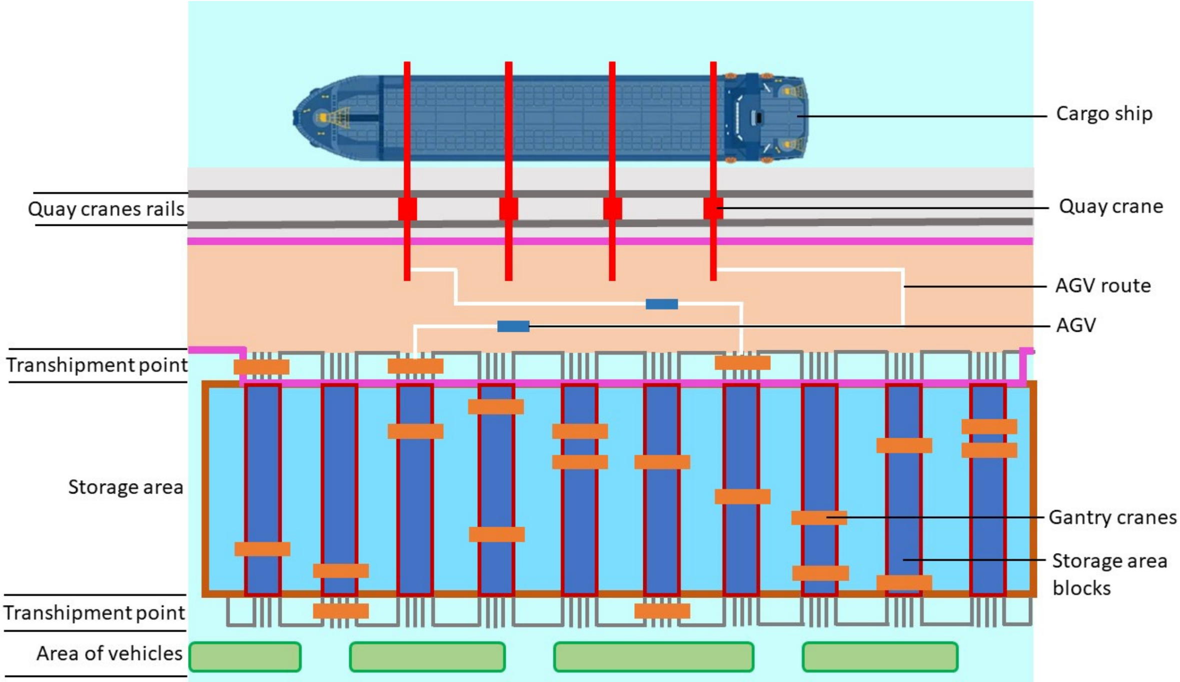


Figure 4. The proposed layout of the simulation model of the container terminal.

4.2. Parameters of the Simulation Model

The loading area of the ship in the simulation model is divided into four parts. Viewed from the ship's bow, there are 972 containers in the first and third sections and 810 in the second and fourth sections. The container stack is 9 containers high and 18 containers wide in each section. The capacity of the entire cargo ship is 3564 containers. Only 40-foot containers are used in the simulation model (Figure 5).

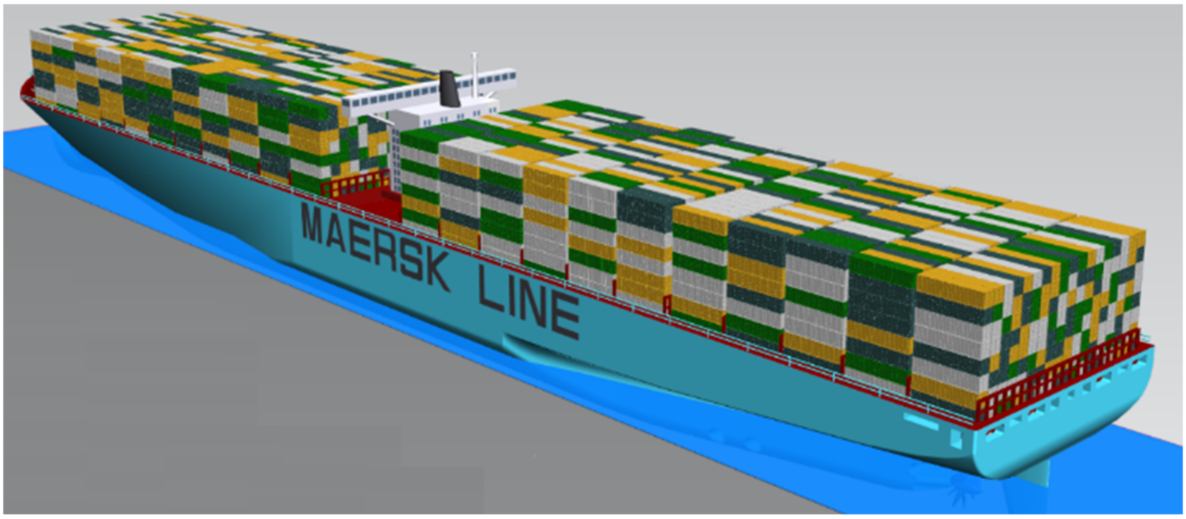


Figure 5. Visualization of the marine container ship in the simulation model.

Parameters of the cargo container ship and quay cranes

The speed of movement of the trolley of four quay cranes is 3 m.s^{-1}. The lifting speed of the spreader of four quay cranes (Figure 6) is 1.83 m.s^{-1}, and the maximum lifting height is 50 m. The spreader is lifted and lowered by the trolley using ropes.

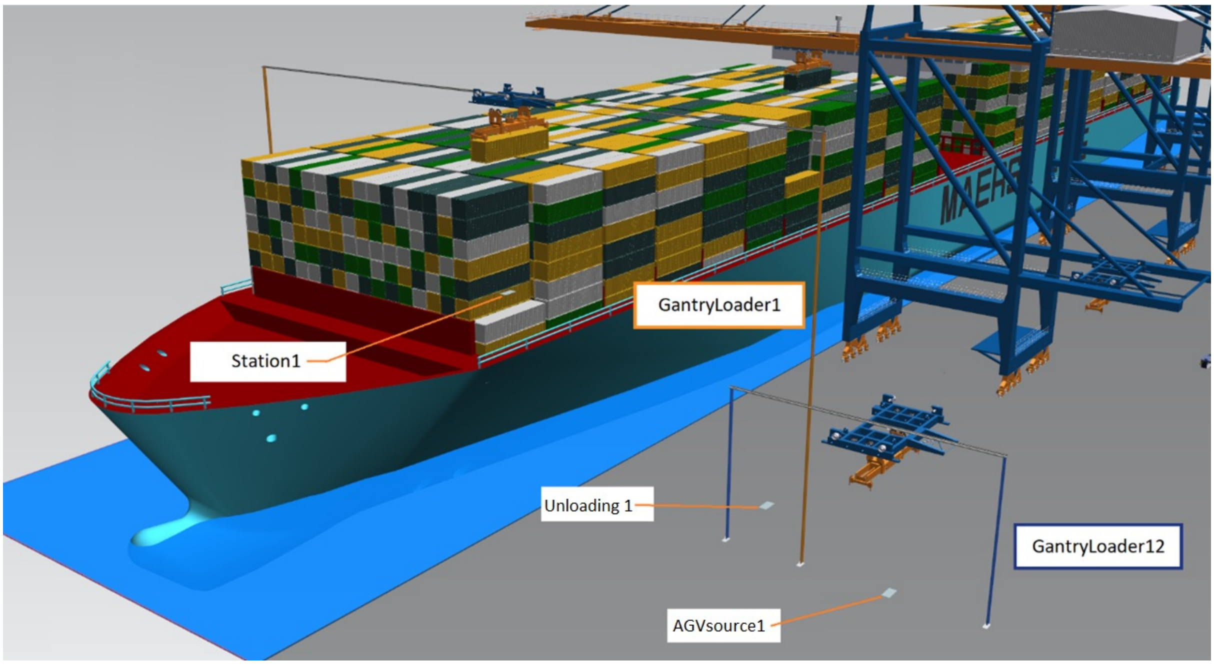


Figure 6. Process of the activity of a quay crane.

Parameters of AGVs

An electric motor powers the vehicles and must be recharged regularly. Vehicles moving along the quay area and predetermined route have collision sensors installed in the front and back, which will safely stop the vehicle before collision with another vehicle or element in the terminal (Figure 7). Their essential characteristics are an average speed of 6 m.s^{-1} and a speed on the curve of 3 m.s^{-1}. The simulated AGVs are 13.5 m × 2.8 m ×1.8 m. The braking distance during emergency braking (with a load of 60 t): 6 m. Load size: one 40 ft or two 20 ft containers, considering the maximum AGV length of 15 m.

Figure 7. Visualization of the AGV using the profession simulator.

Road network parameters for AGVs

In the simulation model, the first lane from the quay crane consists of four roads, each assigned to a single quay crane. The second lane consists of one road with a length of 370 m. The width of each of the roads is 3 m (Figure 8).

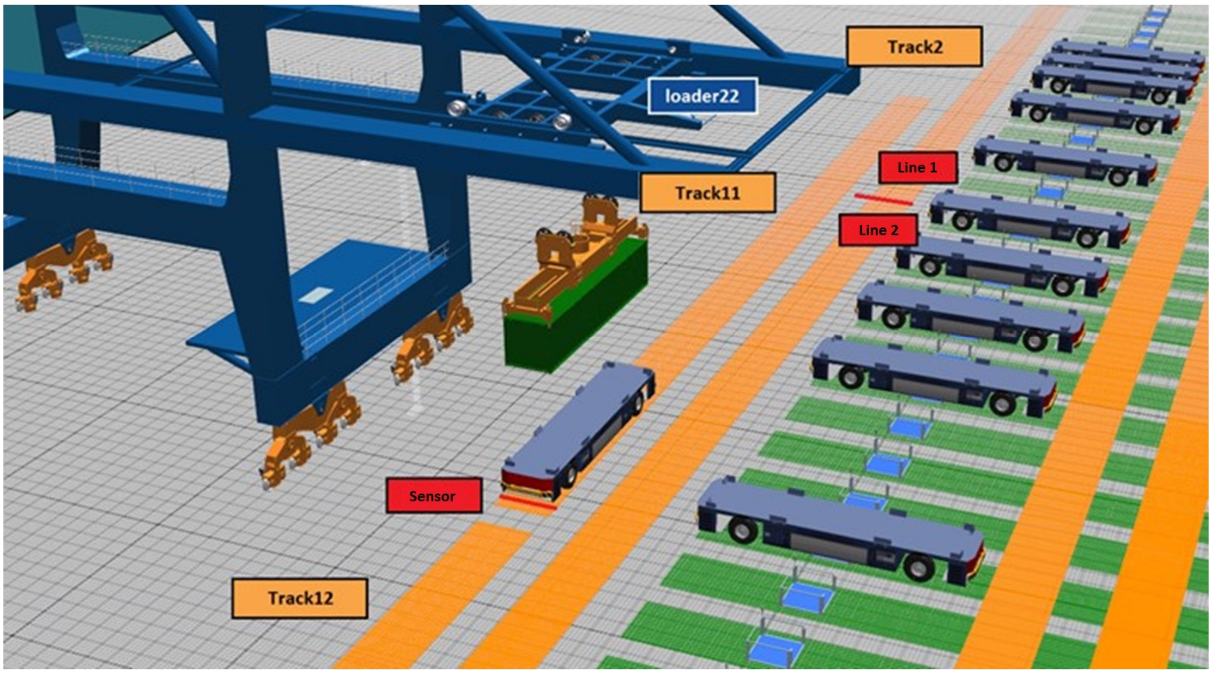


Figure 8. Two lanes under the crane.

Parameters of automated gantry cranes

Seven automated gantry cranes that move on rails stack containers in the terminal storage area. They are used to immediately unload AGVs into the containers after arrival at the transshipment point, then to move and store containers in a free position in the storage area, and to load external trucks. The length of the working area of the gantry crane: 178 m; the width of the gantry crane working surface: 27 m; the height of the crane portal: 20 m; the width of the crane portal: 13 m; the speed of the portal moving along the rails: 4 $m.s^{-1}$; the speed of the trolley in a horizontal direction: 3.5 $m.s^{-1}$. The speed of the spreader in a vertical direction is 0.8 $m.s^{-1}$.

Storage space parameters

The container storage area in the model consists of seven blocks with the same capacity (Figure 9). Each block can store 585 containers, and 4095 can be located in the storage area. In this simulation model, the capacity of the first six unloaded blocks is 508, and the last block is 516 containers. There are two gantry cranes on each block. There are 14 gantry cranes on rails in the entire simulation model.

4.3. Management of Processes within the Simulation Model

Several mathematical models were implemented in the simulation model for the proper functioning of the processes within the profession simulator, which were published in the previously mentioned scientific periodicals (Section 2.1). Their implementation aimed to ensure that the activity of the simulator was as close as possible to reality. The mentioned mathematical models were implemented in the simulation model using the SimTalk 2.0 language in the form of several sequences (Figure 10). In this way, the management of individual processes was ensured by the requirements for the operation of a profession simulator. At the same time, it was a way to calibrate the profession simulator for a specific container terminal.

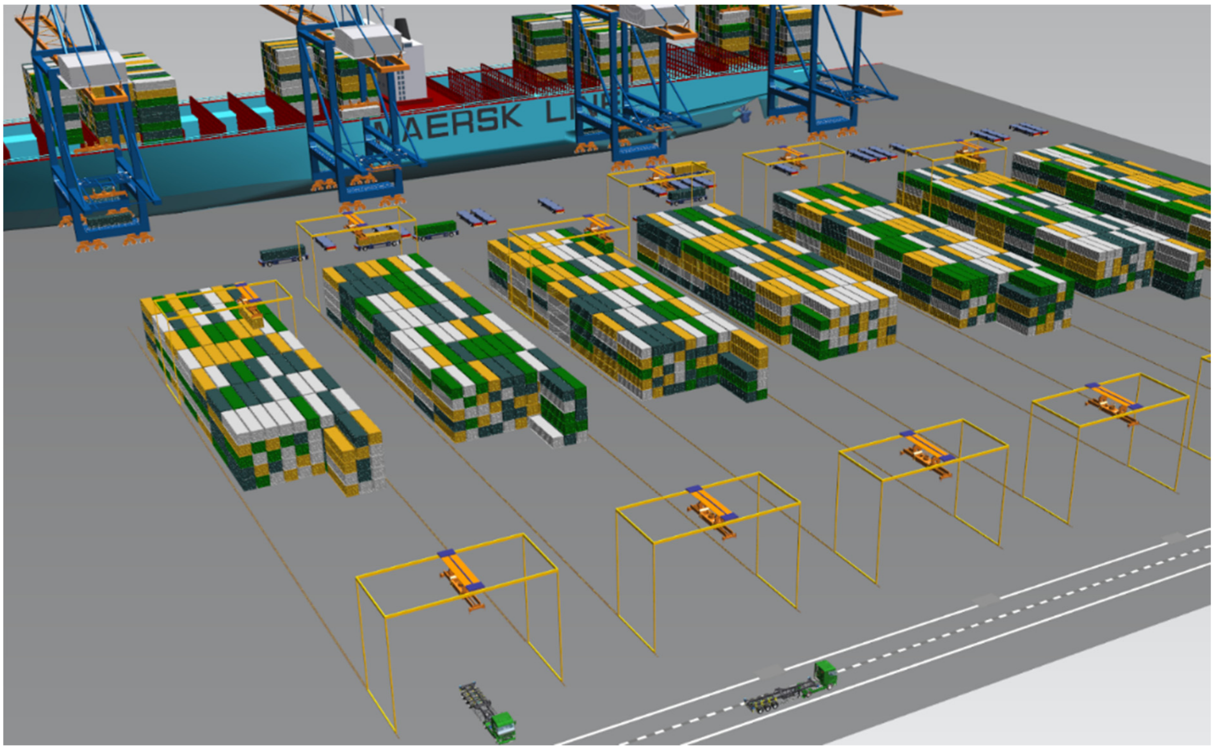
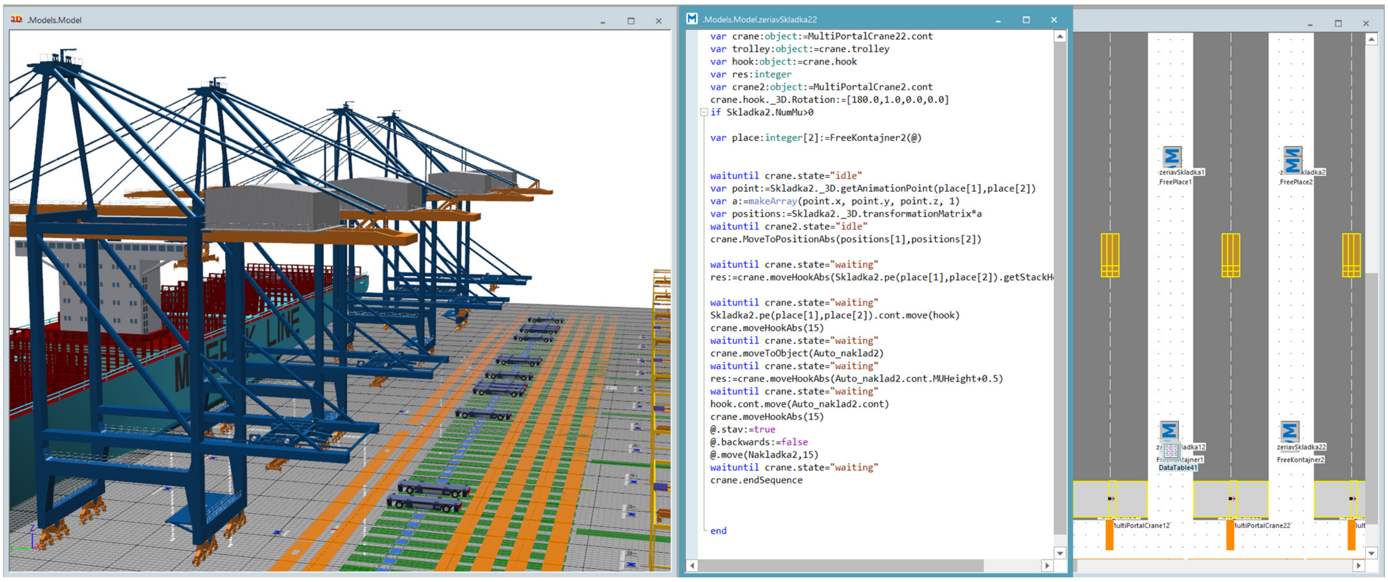


Figure 9. Graphic representation of the simulation model of the container terminal.



```
var crane:object:=MultiPortalCrane22.cont
var trolley:object:=crane.trolley
var hook:object:=crane.hook
var res:integer
var crane2:object:=MultiPortalCrane2.cont
crane.hook._3D.Rotation:=[180.0,1.0,0.0,0.0]
if Skladka2.NumMu>0

var place:integer[2]:=FreeKontajner2(@)


waituntil crane.state="idle"
var point:=Skladka2._3D.getAnimationPoint(place[1],place[2])
var a:=makeArray(point.x, point.y, point.z, 1)
var positions:=Skladka2._3D.transformationMatrix*a
waituntil crane2.state="idle"
crane.MoveToPositionAbs(positions[1],positions[2])

waituntil crane.state="waiting"
res:=crane.moveHookAbs(Skladka2.pe(place[1],place[2]).getStackH

waituntil crane.state="waiting"
Skladka2.pe(place[1],place[2]).cont.move(hook)
crane.moveHookAbs(15)
waituntil crane.state="waiting"
crane.moveToObject(Auto_naklad2)
waituntil crane.state="waiting"
res:=crane.moveHookAbs(Auto_naklad2.cont.MUHeight+0.5)
waituntil crane.state="waiting"
hook.cont.move(Auto_naklad2.cont)
crane.moveHookAbs(15)
@.stav:=true
@.backwards:=false
@.move(Nakladka2,15)
waituntil crane.state="waiting"
crane.endSequence



end
```

Figure 10. A demonstration of the transformation of a mathematical model in the language SimTalk 2.0.

SimTalk 2.0 is a simulation tool within the Tecnomatix Plant Simulation that allows for the programming of various conditions, activities, and functions so that the simulation model comes as close to reality as possible.

4.4. Use of the Profession Simulator

A profession simulator was created to allow a wide range of computer simulations with the aim of process analysis and the acquisition of skills and competencies for managing and handling activities within the container terminal.

In the realized simulation experiments, it is possible to monitor the following parameters:

- Use of quay cranes (percentage of working conditions of quay cranes) (Figure 11);
- Use of gantry cranes (percentage of working conditions of gantry cranes) (Figure 12);
- Time flow of the container numbers on the parts of the loading area of a cargo container ship (Figure 11);
- Occupancy of the parts of parking lots by empty AGVs (Figure 13);
- Occupancy of the transshipment point of AGVs before blocks of the storage area (Figure 14);
- Occupancy of the transshipment point of road vehicles before blocks of storage area;
- Use of the second lane for AGVs (percentage of a certain number of vehicles on the specific lane) (Figure 15);
- The actual loading time of AGVs;
- Total unloading time of the cargo container ship (Figure 16).

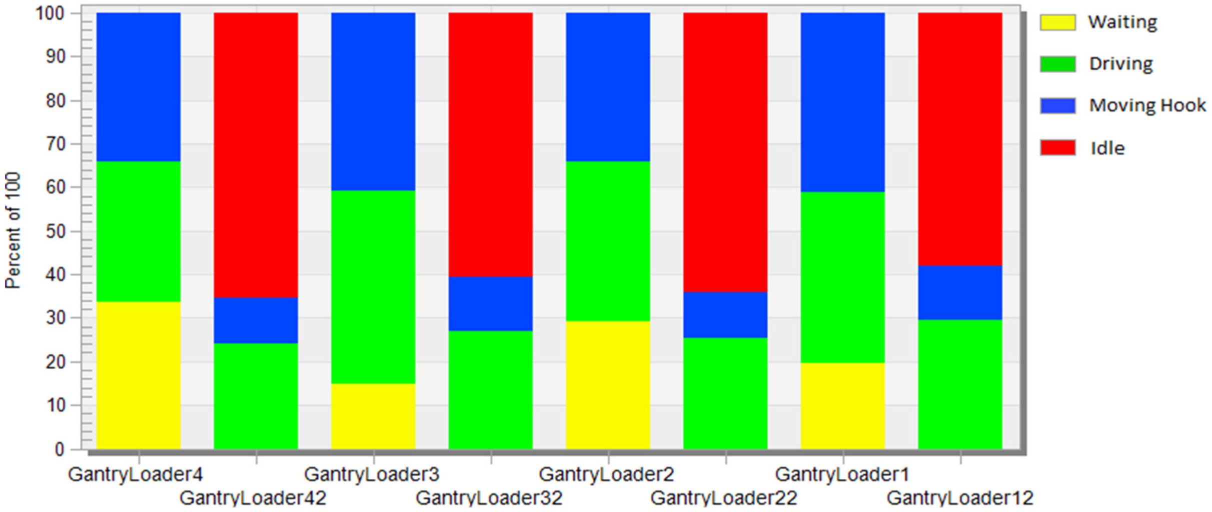


Figure 11. Representation of the use of quay cranes (percentage of working conditions of quay cranes).

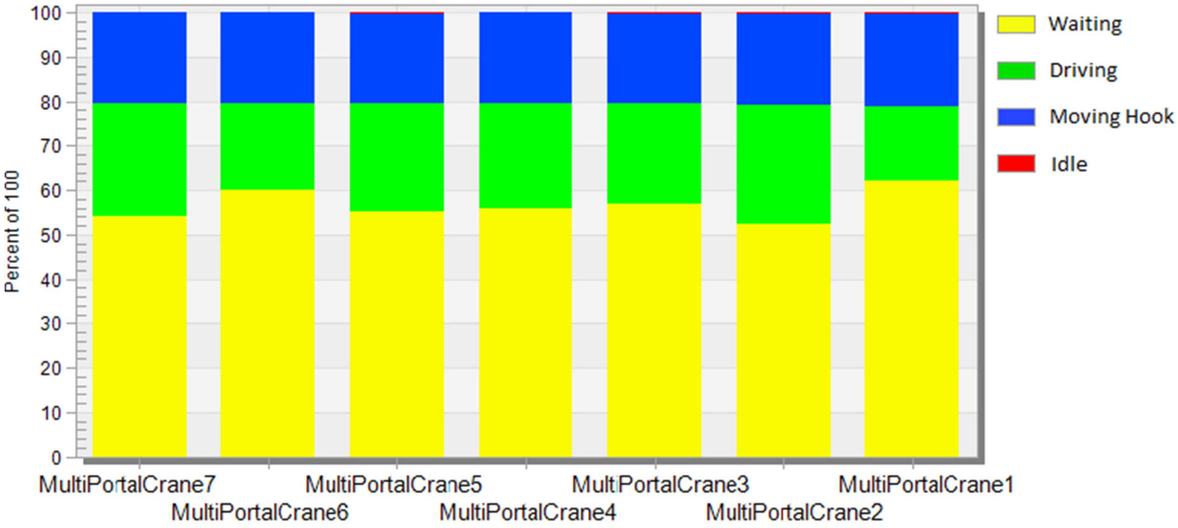


Figure 12. Representation of the use of gantry cranes (percentage of working conditions of gantry cranes).

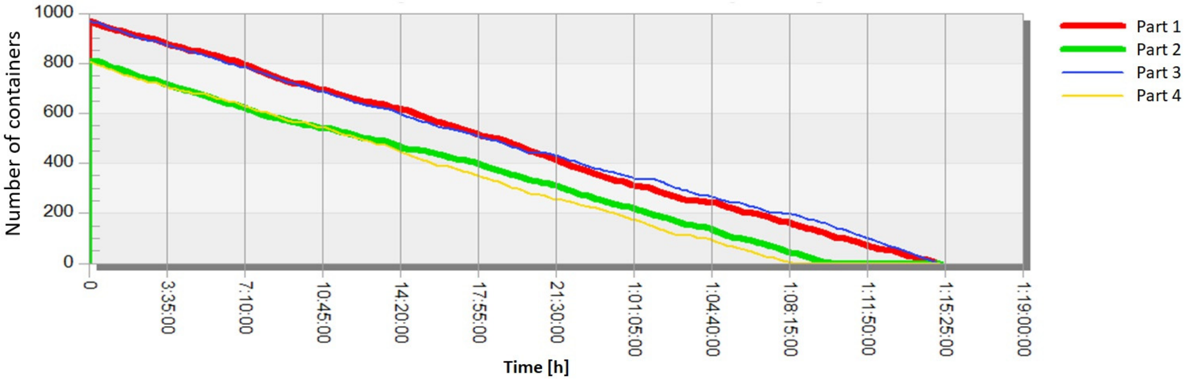


Figure 13. Time flow of the container numbers on the parts of the loading area of a cargo container ship.

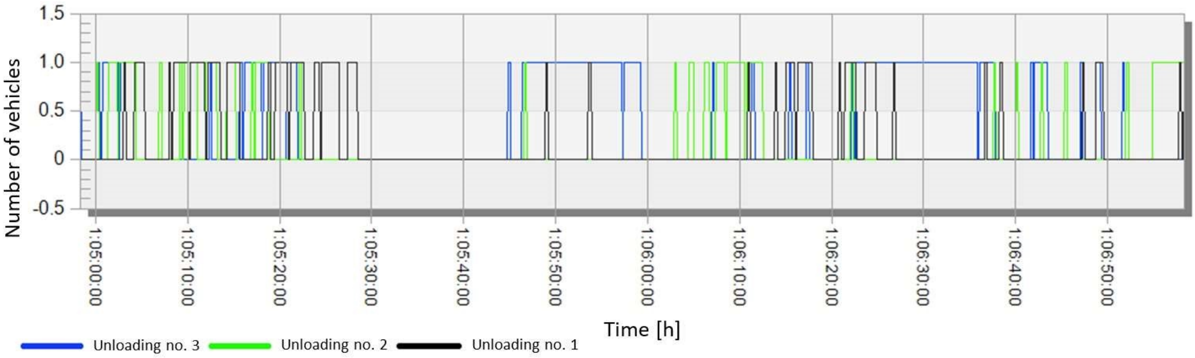


Figure 14. Representation of the occupancy of the transshipment point by AGVs in front of three blocks of storage area.

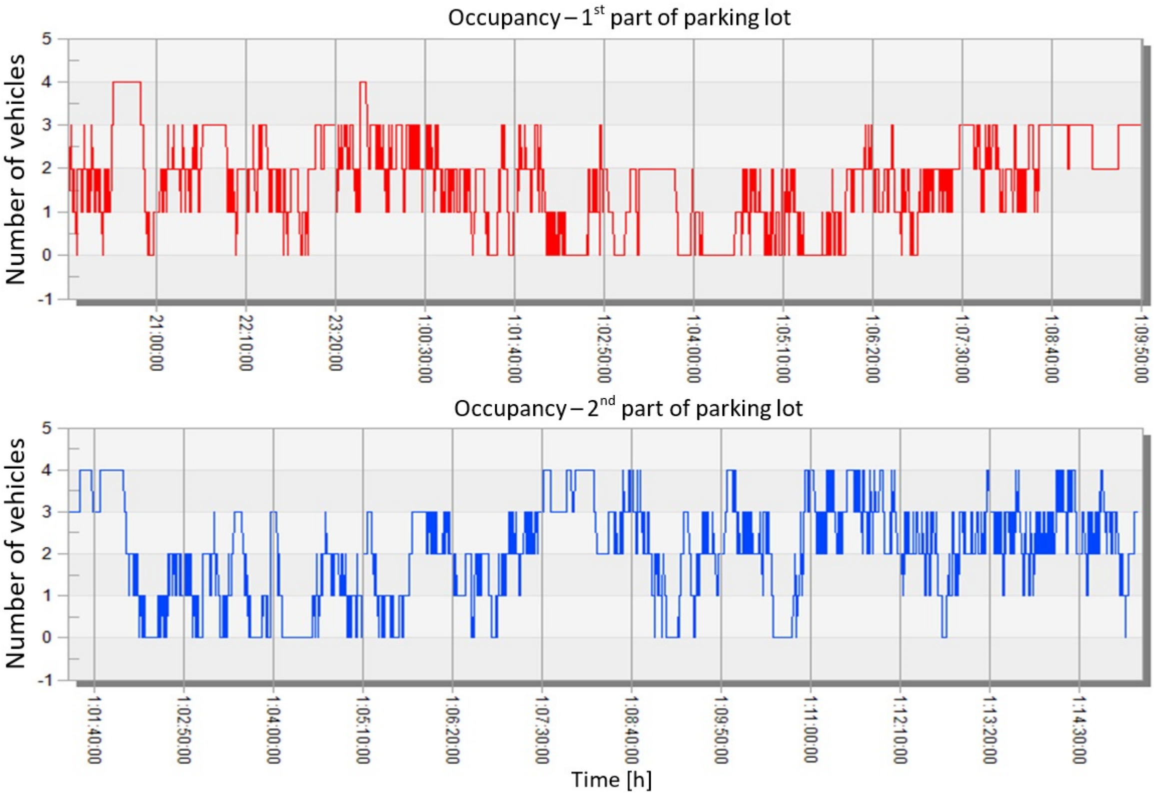


Figure 15. Time flow of the occupancy of two parts of the parking lot.

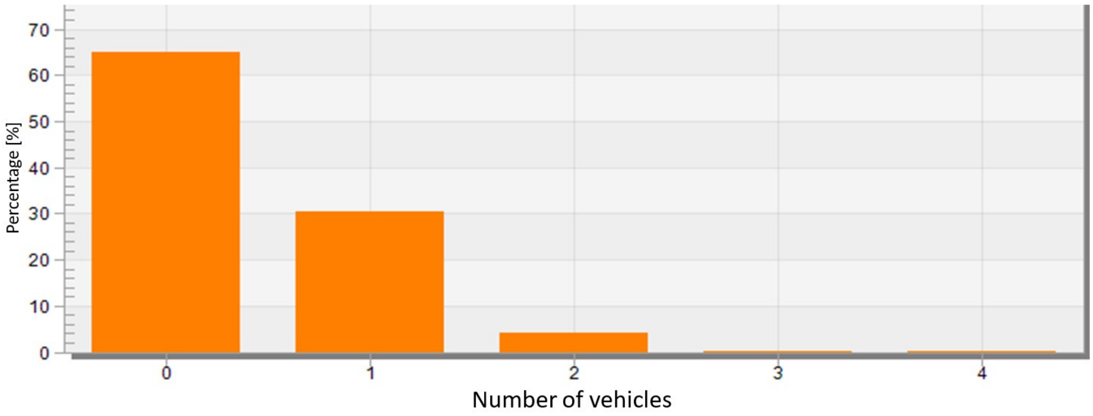


Figure 16. Use of the second lane for the AGVs.

All mentioned monitored parameters can be used to evaluate the correctness and efficiency of the realized processes. First, they represent information about the use of quay and gantry cranes. First, it is information about the use of quayside and gantry cranes. Due to their extent in the experiments, the next section of the paper presents only selected samples of monitored parameters.

A graph can monitor the use of quay cranes. In this graph, it is possible to see the percentage of individual job states. This graph includes all quay cranes and their two levels (Figure 11). Different colors in the chart represent their status. Each column of the graph represents one part of the quay crane. Yellow means the crane is waiting for work. Green is the percentage of the trolley's movement. Blue is the movement of the spreader, and red is the idleness of the second level.

The operation of gantry cranes can be visualized using a graph that shows their working states (Figure 12).

The impact of the failure rate of cranes on the number of transferred sea containers is possible to monitor with the help of experiments using the created simulation model. After defining the failure rate of all cranes, it is possible to monitor all relevant parameters and events until the completion of unloading the last container from the ship to the storage area.

Using a graph, the simulation model allows for the monitoring of the number of containers on parts of the cargo ship's deck. The development of the number of containers in the shipping area can be seen in the graph (Figure 13). In the initial state, the lines are straight and fall evenly downwards. The yellow and green lines overlap, as do the red and blue lines. The lines break differently according to the accumulation of the containers on parts of the deck during the duration of the simulation. The failures of the crane that unloads containers from a given part of the ship's area can be seen on the graph by slowing down the line, i.e., the number of containers. Thus, it is possible to see how the failure rate affected the unloading speed of the cargo ship.

Another essential aspect of the model is the occupancy of the transshipment point in front of the cranes. The graph (Figure 14) represents the accumulation of vehicles at the unloading site. In this graph, it is possible to monitor the unloading in front of the gantry cranes and to determine when the crane was out of order and the vehicles were awaiting their unloading. During this period, for example, the vehicle waits in front of the gantry crane for its unloading due to crane failure.

Another parameter monitored by the simulation model used in the profession simulator is the occupancy of the parts of the parking lot with empty vehicles (Figure 15). This value and its development during the simulation is significant for the functioning of the simulation model, i.e., the container terminal. If this part of the parking lot is empty for a long time, no vehicle is available for loading by the quay crane, which causes an interruption of the material flow in the terminal. It creates downtime because the crane must wait for the AGV and cannot unload the cargo ship.

Another parameter the profession simulator enables is tracking the lanes along which the quay cranes move. Figure 16 presents a graph where the columns show different numbers of vehicles. The height of the column represents the percentage of time when a specific number of vehicles were in that lane. It is possible to determine the time when the lane was empty.

4.5. The Accuracy of a Profession Simulator

The creation of the concept of a "profession simulator" was based on whether this simulator would use a physical or digital model to realize simulation experiments. The decision was based on the requirement that, if a profession simulator is to be effective, the simulation experiments must provide the most accurate results that correlate with reality. At the same time, it was necessary that the profession simulator enable variability during the simulation of different operational situations and the calibration of the specific conditions of the marine terminal. Based on the mentioned criteria, the concept of the profession simulator was built using a discrete simulation model.

The accuracy of the simulation model is very important. This is an issue that is closely dependent on the complexity of the simulation model. Based on a study of the available literature focused on the accuracy of simulation models, it was possible to determine that the complexity and level of detail of the simulation model led to higher accuracy of the results (Figure 17) [43].

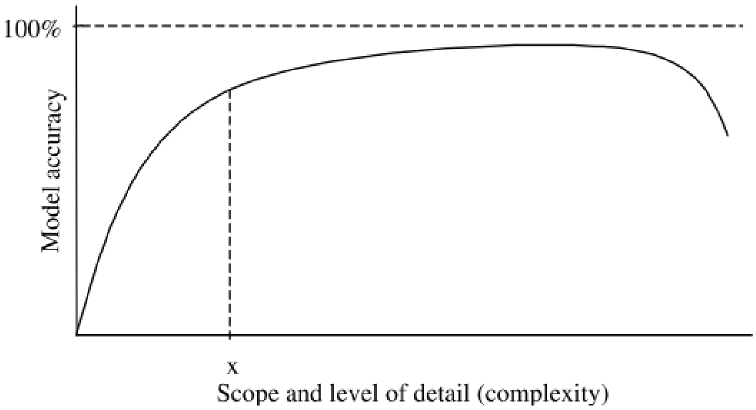


Figure 17. Simulation model complexity and accuracy [43].

Robinson [44] tested this hypothesis and concluded that the statement about the relationship between accuracy and complexity is incorrect. However, it remains a useful heuristic to guide modelers in considering the scope and level of detail with which to model a system.

The creation of a simulation model for the needs of a profession simulator was realized based on the mentioned facts.

Although the concept of the simulation model is developed in general and needs to be calibrated for the needs of a specific container terminal, several simulation experiments were realized to determine the accuracy of a profession simulator, and the total unloading time of a container ship was used as an evaluation criterion. Within these experiments, random numbers of shipping containers were generated as inputs. The obtained results (Figure 18) were compared with the available data in [45,46].

The data in Figure 18 indicate that the median time for unloading containers from a ship is 1.25 days, while in [46] the duration of unloading is in the range of 1 to 3 days. By comparing the results of the dynamic simulation with the random generation of inputs, it is psossible to determine a match of the results of simulation experiments and generally available data. However, it should be emphasized that the simulation model needs to be calibrated for each marine terminal.

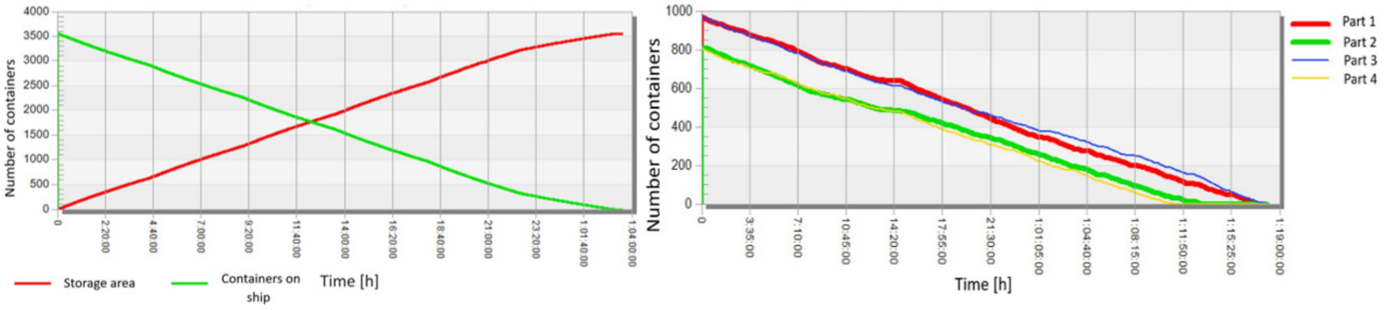


Figure 18. Simulation of container ship unloading.

5. Conclusions

Marine container terminals play a significant role in the operation of different types of logistics chains. With the increasing quantity and volume requirements of transported container units, the demands of the handling operations within individual transshipment points have also grown proportionally. This fact is reflected in the increasing automation of handling operations.

However, adequately trained service personnel must be prepared to manage and implement individual handling processes correctly and efficiently. With the current utilization of maritime terminals, there is not enough time or space to train service personnel.

One of the options that makes it possible to this problem is the use of profession simulators. A profession simulator will enable a more realistic presentation of information and a more plastic display, thus ensuring a more effective transfer. At the same time, it offers an interactive way of obtaining new skills and learning to resolve different types of situations. This research presents an approach to creating and using a profession simulator based on dynamic simulation. At the same time, we proposed the concept of this simulator. The environment of the Tecnomatix Plant Simulation program was used to create the profession simulator. It is a powerful software tool that meets the criteria for creating profession simulators. It allows for the creation of interactive elements that, in connection with virtual reality visualization, provide new and, until now, unused approaches to the training process in managing maritime container terminals. The profession simulator was created considering the requirements of Industry 4.0. The research team created an innovative training and educational tool that will support and develop the instruction process in managing the handling activities of maritime container terminals in an understandable, illustrative, and immersive form.

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