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SIMULATION-BASED APPROACH TO A MORE EFFICIENT HANDLING STRATEGY FOR A CONTAINER TERMINAL STORAGE YARD: CASE STUDY OF THE BALTIC HUB CONTAINER TERMINAL

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ABSTRACT

The primary objective of this research was to implement a more efficient handling strategy in the container terminal storage yard at the Baltic Hub Container Terminal (BHCT). Following an analysis of the current logistics system associated with starboard-side mooring, an attempt was made to shift the mooring to the port side. Two routing strategies corresponding to the analysed mooring operations were tested using a developed model. Simulations were conducted to enable a comparison of various handling strategies that were suitable for the mooring arrangements and equipment under investigation. This analysis was based on reliable information obtained from a real process. Evaluative criteria for examining the impact of changing the handling strategy of internal movement vehicles (IMVs) in the terminal storage yard in terms of process efficiency included the total time and distance of container transportation and the truck utilisation level. A new route for IMVs was developed to accommodate the changed mooring operation. This adjustment aimed to enhance the discharge process and to reduce the distance travelled, resulting in a reduction in fuel consumption. The shorter travel distance also positively impacted productivity, and contributed to a reduction in operating costs. The changes to the mooring arrangement directly resulted in a 10% increase in the quay crane gross productivity, measured in moves per hour (mph). Given that many ports do not pay attention to how ships are moored, the case study and analysis presented here can help staff quickly improve their handling strategy and productivity, thus increasing the port's competitiveness.

Keywords: container terminals, container handling, container transportation, simulation modelling, quantitative analysis.

INTRODUCTION

Container ports have become an essential element of the global economy and a key factor in the supply chain, as they enable the efficient and economical movement of goods over long distances. The terminal serves as an intermediary between sea and land transport, and operations can be divided into quayside operations, transfer operations, and operations in the storage yard, as illustrated in Fig. 1 [1,2].

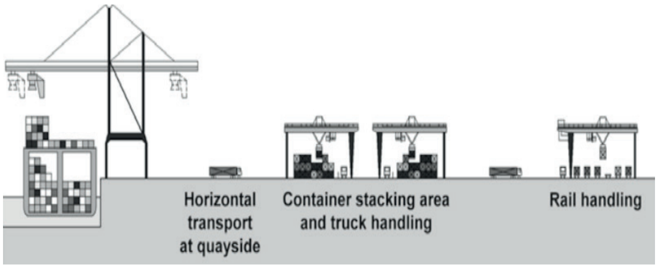

Fig. 1. Main areas of a container terminal [2]

Quayside operations focus on discharging incoming containers or loading outgoing containers onto ships using ship-to-shore quay cranes (QCs). It is very important to coordinate the scheduling of vessel berthing with the loading and discharge operations. Transfer operations in the container terminal focus on moving containers from the quay to the storage yard using various types of vehicles. In the Baltic Hub Container Terminal (BHCT) in Gdańsk, Poland, formerly known as the Deepwater Container Terminal (DCT), container transportation is performed by internal movement vehicles (IMVs). An efficient planning and routing system for vehicles moving around the yard is essential to maximise the efficiency of the port.

Container storage is the final operation in the handling strategy. The storage yards of container terminals are essential for storing and distributing goods, and their efficiency has a direct impact on the entire supply chain. Yard planning involves the proper arrangement of imported, exported, or transhipped containers. The arrangement of cargo should facilitate further handling and transportation, as this allows for optimal use of the container yard space in the port [3]. Many factors influence the performance indices of a container terminal. According to Chen et al. [4], port operators focus on two aspects in order to maximise these indicators: minimising the vessel turnaround time, and maximising the throughput of the terminal. However, achieving satisfactory performance depends on many factors, and cargo handling plays a significant role in these processes. Proper planning of transportation activities between a ship and the storage yard is crucial in terms of minimising the turnaround time.

Climate change and environmental pollution are among the most urgent problems that need to be faced and resolved. Container terminals strive to achieve a healthy ecological environment with rational use of resources, low energy consumption and minimal pollution. The most significant proportion of the total carbon emissions inside a terminal container comes from ships, which account for 81.7%, followed by QCs (8.0%), yard cranes (5.5%) and trucks (4.8%). Increasing the efficiency of port equipment can effectively reduce the auxiliary time for ship berthing, thereby contributing significantly to a decrease in CO_2 emissions [5]. The ship handling time, which represents the average duration taken by the terminal to unload and load a vessel, offers the most important performance measure for a shipping line when assessing a terminal. From the customer's perspective, minimising this measure is essential, as it is directly correlated with costs [6]. Hence, a growing number of research papers have been dedicated to optimising all of the operations within container terminals. As discussed in [6], simulations of ship handling can aid in decision-making in regard to selecting the shortest and safest routes for vehicles within the yard. They can also assist in optimising the number of vehicles required for discharge, thereby minimising interruptions.

The optimised operations implemented in container terminals are typically supported by simulations, which form an integral part of the research and development conducted in this field. The sizes of objects and the complexity of the equipment used pose challenges when predicting how the terminal will operate under specific configurations and layouts. The dynamic behaviour of the terminal hardware is difficult to analyse and compare, and necessitates the development of a tool that is capable of replicating the behaviour of a real terminal and predicting the outcomes after introducing modifications [7]. The purpose of this paper is to examine the impact of changing the handling strategy for IMVs at the BHCT storage yard in terms of process efficiency, the use of vehicles and cranes, and overall improvements in the terminal's operation for specific mooring arrangements and equipment.

The remainder of this paper is structured as follows. The next section, entitled "Literature Overview" discusses relevant studies. In the following section, "Overview of the Problem", we describe the mooring arrangements that influence the IMVs' routes in this case. The proposed research methodology is presented in the section entitled "Simulation Case Study of Quayside and Storage Yard Transportation". The following section, "Simulation Results and Discussion", presents our results, which are validated against real values for QC productivity. Finally, the authors' approach and the contributions of this work are summarised in the "Conclusion" section.

LITERATURE OVERVIEW

The challenges associated with planning container terminal operations are frequently examined in the research literature, and numerous simulations have been developed to optimise terminal productivity and to minimise vessel handling times. The efficiency of container terminal operations is influenced by many processes that occur during the handling process, with a crucial aspect being the choice of optimal storage strategies. When analysing transportation operations within a container terminal, three primary decision problems are typically distinguished: the first involves the selection of the type of vehicle to be used within the port; the second entails determining the required number of these vehicles; and the third focuses on the designation of the routes along which they will operate. Each of these elements influences the operational time and the efficiency of cargo handling, as reported in [8]. Enhancing ship productivity does not hinge solely on expanding the number or speed of the transport vehicles in the port, since the likelihood of congestion around the cranes and within the yard increases more than proportionally to the number of vehicles or their speed. Hence, the development of an optimisation system must also consider the minimisation of traffic congestion, as described in [9,10], as this contributes a major proportion of the pollutant emissions in terminals [11]. Moreover, various means of transportation and strategies for allocating vehicles to cranes are used in the port.

A topic that has been frequently analysed by researchers and practitioners is the selection of single- and double-cycle strategies. In the single-cycle mode, vehicles serve only one crane. Depending on the crane's cycle, these vehicles either transport discharged (import) containers from the quay to the yard, or loaded (export) containers from the yard to the crane. In the double-cycle mode, vehicles serve multiple cranes undertaking loading or discharge cycles, effectively combining the effort of two QCs that are loading and discharging as a single unit during the transportation of export and import containers [12]. The dual-cycle strategy for terminal operations is considered to be a cost-effective approach to increase the efficiency of container terminal processing [13]. The results of numerical experiments presented in [14] demonstrated that a dual cycle for internal trucks in the yard area can reduce the transportation distance of containers, and that the space allocation method based on this strategy was more effective than traditional methods. The simulations conducted in [15] confirmed a notable improvement in regard to maximising productivity and minimising hourly and unit costs; however, the higher usage of QCs has been found to contribute to an increase in their highest observed peak power demand, leading to higher energy-related costs, as discussed in [16].

A mixed storage strategy involves storing incoming and outgoing containers in the same block, thereby reducing the number of container handling steps. The authors of [17] showed that by implementing a mixed storage strategy, the distance travelled by a truck could be reduced, and the number of trucks required and the working time of the QC could be reduced by 16% and 26%, respectively. Mixed storage and dual-cycle strategies can also improve the overall handling system in container terminals, as shown in [18].

Developers of container terminals often struggle with the problem of choosing suitable ratios between QCs, yard cranes and transportation equipment inside the terminal in an integrated container handling system. These are key aspects of terminal design and operation. In particular, optimal proportions need to be found between QCs, rubber-tyred gantry cranes (RTGs) and IMVs. According to previous analyses, a reasonable range for the QC-IMV ratio is between 1:5 and 1:6.3, while a reasonable range for the QC-RTG ratio is between 1:2.4 and 1:2.8. The final determination of these indicators hinges on factors such as the capacity of the container terminal, equipment utilisation rates, and the likelihood of bottlenecks for QCs, IMVs and RTGs [19].

Another aspect that is frequently addressed in research articles is the challenge of dynamically controlling the waiting positions for inactive IMVs, in order to optimise the overall system performance. Performance, which is assessed in terms of service levels, IMV requirements, and empty travel distances, is evaluated through simulations. Notably, look-ahead rules have been found to yield superior performance compared to a simple first-come-first-served rule [20]. Whenever an IMV returns empty from the storage yard to the quay, it should be assigned to the QC with the smallest number of IMVs and the shortest queue among all the QCs involved in discharge at that time. A minimum of two yard cranes should be assigned to each working QC, to ensure that each container group is distributed across at least two yard crane working regions. Studies have indicated that even greater dispersion, with each container group having one or a small number of stacks in each block, can prove to be beneficial [21].

Before introducing logistic concepts, decision rules, and optimisation algorithms into real systems, it is crucial to compare them through simulation. This approach helps mitigate unnecessary errors or excessive costs associated with the implemented optimisations [22]. Simulations conducted by Deja et al. [23] enabled the minimisation of the turnaround time for vessel discharge at a specific berth location, using a defined number of IMVs.

Mooring and anchoring operations are among the most critical and hazardous tasks routinely carried out on ships in a port. The mooring arrangement, equipment requirements, and local weather conditions vary from one port to another, and careful preplanning is therefore essential before any mooring operation [24,25]. In [26], an analysis was conducted to assess the impact of dynamic wind and passing-ship conditions on the mooring system, with the aim of preventing adverse effects on ports and marine terminals. Furthermore, the emission of greenhouse gases is determined by sailing speeds and mooring times, and the range of variation is influenced by arrival and berth times at terminals [27]. The installation of automatic mooring systems using vacuum suction cups offers the potential to substantially decrease the emission of greenhouse gases produced by ships during navigation and manoeuvring in ports [28].

In view of this, and recognising the critical importance of mooring aspects for safety, greenhouse gas emissions, and handling efficiency, simulations were conducted in this study to compare different handling strategies suitable for specific mooring arrangements, on both the starboard and port sides, and using equipment available at BHCT Gdańsk.

OVERVIEW OF THE PROBLEM

Since the commencement of cargo operations at BHCT Gdańsk in 2007, ships have been consistently moored on the starboard side, as illustrated in Fig. 2. The layout of the terminal storage yard, with container doors facing north, was designed to streamline cargo operations for ships moored on the starboard side.

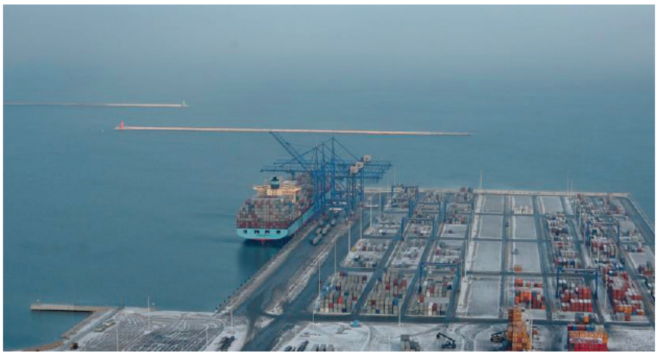

Fig. 2. The Maersk Taikung, moored on the starboard side at BHCT Gdańsk

Due to continuous development and increases in container volumes, the dimensions of ships have risen. Ships of large sizes cannot call at ports that do not have the required technical parameters. The emergence of mega-containerships has revealed the infrastructure constraints of many ports. Due to the need to transport larger amounts of cargo, the draft of ships has also increased, imposing a further limitation caused by the depth of the water. The depth of the sea channel must be sufficient to safely accommodate ships with the deepest draft. Furthermore, the waiting time for mega-ships to secure an appropriate berth in the port has been extended. To effectively reduce waiting times, each terminal should formulate a comprehensive berthing plan that takes into consideration factors such as the size of the ship, the length of stay, and the cargo handling priority. Another challenge has been the limited reach of QCs, which may impede the loading and discharge operations of mega-ships [29].

To meet the servicing needs of large vessels at BHCT Gdańsk, the berthing configuration was altered in 2012. An arriving ship is now positioned with its bow facing towards the shore, and ships moor on the port side, as illustrated in Fig. 3. Many ports do not pay attention to how ships are moored; however, the case study and analysis presented here demonstrate that this kind of easy-to-implement change can enhance the handling strategy, consequently increasing the productivity and competitiveness of the port.

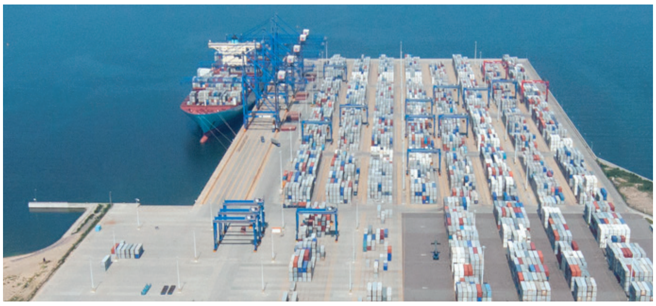

Fig. 3. The Maersk Eleonora, moored on the port side at BHCT Gdańsk

After adopting the revised mooring method illustrated in Fig. 3, the positioning of the ship with the bow towards the land led to a different arrangement of containers in relation to the terminal, and it became necessary to rotate the containers during their transport to the storage yard. This adjustment resulted in significant alterations to the routes taken by IMVs, as depicted in Figs. 4 and 5.

Modifications to IMV routes directly affect the duration and distance covered by these trucks during the delivery or receipt of containers. Extended routes and the resulting increase in time exert a significant influence on vessel operations, leading to heightened environmental pollution through elevated CO_2 emissions from vessels moored for longer periods and the prolonged operation of port equipment.

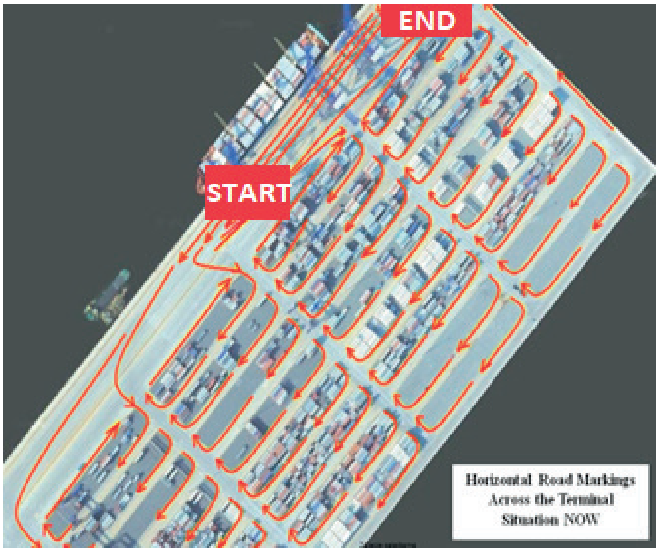

Fig. 4. Terminal workflow for a vessel moored on the port side

Fig. 5. Transportation route of a container by an IMV for a vessel moored on the port side

To enhance the productivity and utilisation of the container terminal, simulation studies have been planned to help analyse the problem under investigation. Computer simulation has made meaningful progress over the past decades, and its impetus in the area of port and terminal research has strengthened, despite the increasing use of other modelling techniques. Simulations have become important as a quick and reliable decision-making tool for port developers [30]. This methodology is also employed in the current research, in which we study the handling process at BHCT Gdańsk, with a specific focus on whether the mooring arrangement is on the starboard or port side.

SIMULATION CASE STUDY OF QUAYSIDE AND STORAGE YARD TRANSPORTATION

Our simulations concentrate on container transport within both the ship and the terminal storage yard. The ship is moored at the terminal quayside, and is handled by two QCs. Containers are taken from the ship by the QC and loaded onto IMV trucks, which are tasked with transporting cargo within the terminal. The trucks move along predefined routes, transporting containers to assigned locations within the storage yard. They travel along predetermined paths at a speed of 20 km/h (333 m/min) when loaded, or 25 km/h (420 m/min) without a load. In the storage yard, the container is picked up by a yard crane and placed in a dedicated location. Each yard crane operates in two storage areas. In this article, we focus on analysing two primary scenarios: Routing Strategy 1, which involves the need for container rotation with starboard side mooring, and Routing Strategy 2, which is characterised by the absence of unnecessary turns of the IMVs with port side mooring.

Under Routing Strategy 1, containers are arranged in a manner that means they need to be rotated before they are positioned beneath the gantry crane in the storage yard. After picking up the load from beneath the QC, the IMV proceeds along the port, making its first turn leading to the rotation of the container (point P1 in Figure 6). The truck then executes a series of additional turns, manoeuvring around the selected storage area and heading to the transfer location where the gate crane is located. When the transfer is complete, the IMV proceeds to the end of the yard and then returns to the starting point to pick up another container. Visual representations of this workflow within the terminal are shown in Figs. 4 and 5, while the layout considered in the simulation model, featuring three exemplary discharge routes, is shown in Fig. 6.

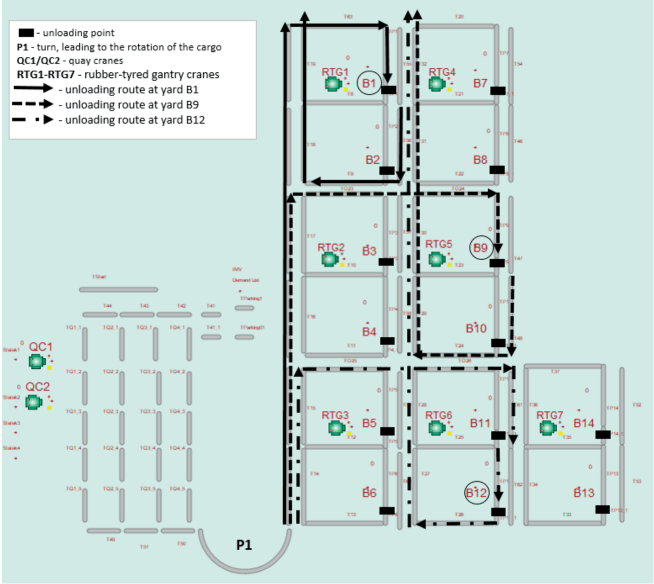

Fig. 6. Layout of the seaport terminal, showing three exemplary discharge routes considered in the simulations under Routing Strategy

Routing Strategy 2 is depicted in Fig. 7, and involves a transport route with the container doors facing south (container swing). The containers are positioned in such a way that they need not be rotated before being placed under the gantry crane in the storage yard, meaning that the IMV no longer needs to makes extraneous turns in the storage area before heading to the end of the yard.

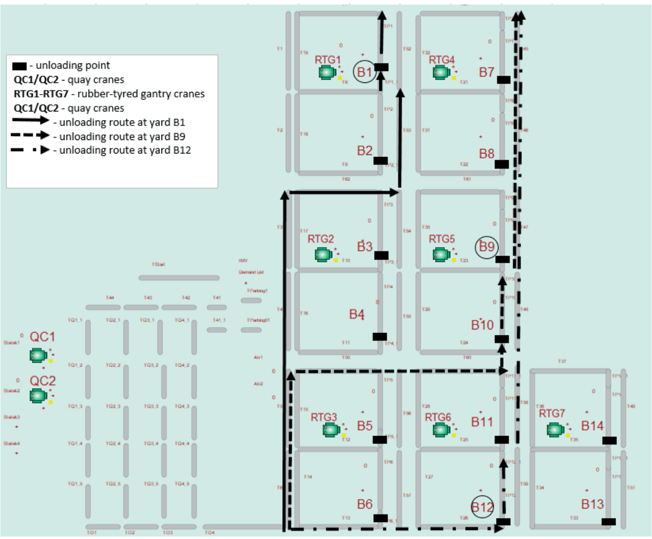

Fig. 7. Layout of the seaport terminal, showing three exemplary discharge routes considered in the simulations under Routing Strategy 2

In the simulation project, discharge operations are modelled at the quay, and are performed on a medium-sized vessel with containers of various types as an illustrative case study. Containers A and B, with lengths of 20' and 40' respectively, are placed in the designated storage area (block numbers from B1 to B12), while containers of type C, carrying dangerous or oversized goods, are placed on specially dedicated blocks (B13 and B14). The layout of the entire storage area, before and after the proposed changes, is shown in Figs. 6 and 7, respectively.

To determine the optimal design solution, alternative scenarios were thoroughly examined in this quantitative study. The basic attributes of the terminal equipment used in the simulations and their operational characteristics are provided in Table 1. For the QCs and RTGs, uniform distributions of the cycle time were assumed, with an equal probability of obtaining a given value in the specified range, i.e. from a minimum value of 1 min to a maximum value of 2 min. The simulations reported in [23] used the same distribution, except that they employed larger values for both the minimum and maximum cycle times. The assumption of shorter cycle times in this article is more closely aligned with real container terminal practices, which use higher operating speeds. A simplified flowchart of the container terminal operation at the quay under analysis is shown in Figure 8.

Tab. 1. Types of terminal equipment and their operating characteristics based on the container terminal practice

Type of equipment [units]	Value used in the simulations
Number of quay cranes	2
Cycle time for quay cranes [min]	Uniform (1.0,2.0)
Number of rubber-tyred gantry cranes	7
Cycle time for rubber-tyred gantry cranes [min]	Uniform (1.0,2.0)
Number of IMV multipurpose vehicles	6, 7, 8
IMV speed [m/min]	420 (unloaded) 333 (loaded)

The following assumptions were made in the simulations:

I. The number of IMVs was equal to the number of QC cranes multiplied by three, (i.e. six IMVs were used);
II. The number of IMVs was increased by one and was equal to the number of RTG cranes serving the storage yard area (i.e. seven IMVs were used);
III. The number of IMVs was again increased by one to explore its impact on the ship discharge time and on the continuity of the QC's working cycle (i.e. eight IMVs were used).

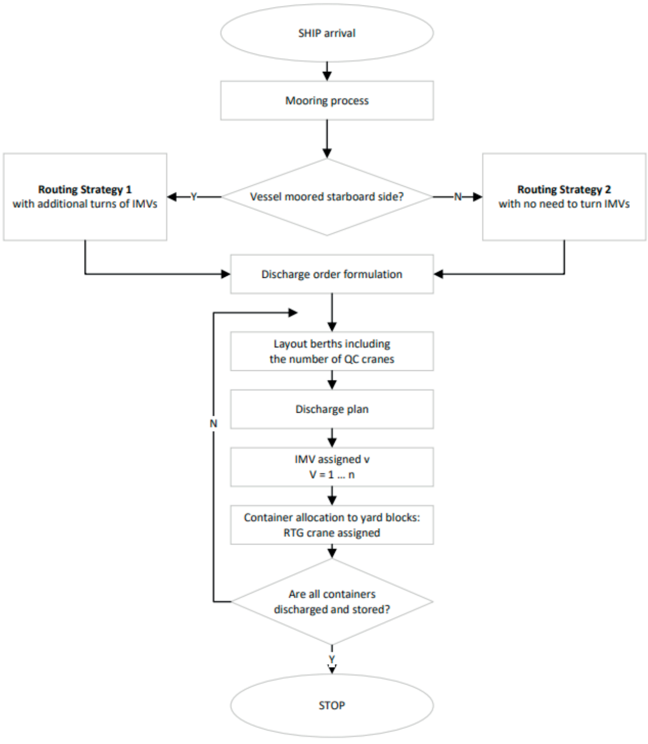

Fig. 8. Simplified flowchart for container terminal operation at the quayside of BHCT Gdańsk

As part of the simulation analysis, three scenarios were adopted, corresponding to the established number of transport resources operating in the storage yard area, with six, seven, and eight IMVs. Process simulation studies were conducted in the environment of the Witness interactive software package [31], using programmable models representing the actual operating characteristics of the seaport container terminal. The sequences used for stowing containers in the storage area for the scenarios analysed here are depicted in Fig. 9, using a graph model where shaded nodes denote the starting block locations. The blocks are unloaded sequentially, starting simultaneously with blocks B1 and B11. Containers in blocks B13 and B14 were unloaded alternately after completing one full cycle.

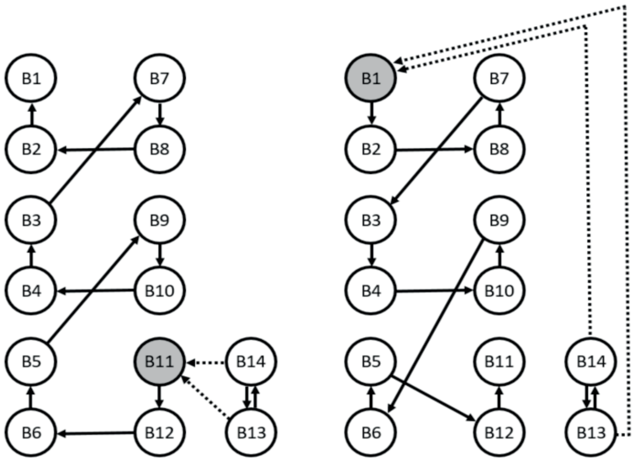

Fig. 9. Directed graph models showing the sequence used to stow containers in the storage area.

SIMULATION RESULTS AND DISCUSSION

The data gathered from our simulations allowed for an in-depth analysis of how the change in the IMVs' route through the storage yard affected the loading time and the usage of the quay and yard cranes. The differences in the data obtained depending on the number of IMVs were also analysed.

When we compare the total times for the discharge process, as outlined in Table 2, noticeable differences are evident not only between the routing strategies but also contingent upon the number of available vehicles. Routing Strategy 1 corresponds to the situation before the implemented changes, while Routing Strategy 2 reflects the current situation after introducing the changes. When six IMVs are used, there is a time difference of 32% between the analysed routing strategies (before and after the changes). The percentage decreases to 6% with an increase in the number of vehicles, due to their greater availability.

Tab. 2. Total simulation cycle times for the discharge process under different routing strategies and numbers of IMVs

Number of IMVs	Routing strategy	Discharge time [min]	Difference between Routing Strategies 1 and 2 [min]	Percentage difference between Routing Strategies 1 and 2
6	1	3,260.45	781.2	32%
	2	2,479.26		
7	1	2,811.87	431.9	18%
	2	2,379.98		
8	1	2,506.01	144.1	6%
	2	2,361.94		

Table 3 shows the percentage vehicle utilisation time. For each number of IMVs considered under Routing Strategy 1, the average load percentage was 50%, accounting for half of the total process time. This means that the IMVs loaded time comparing to Routing Strategy 2 was longer while transporting cargo in the yard. In contrast, Routing Strategy 2 yielded an average load percentage of 38%, meaning that the change in route resulted in a faster flow of vehicles in the storage yard.

The idle level is the time during which IMVs are waiting for a container and are not utilised. Vehicles in Routing Strategy 2 had a higher percentage idle time, confirming that they covered their routes in the yard faster and therefore waited longer for the next container. The demand level refers to the time during which the IMVs are in demand, i.e. traveling in order to respond to a call action. The demand percentage is at a comparable level for both routing strategies, as can be seen from Table 3. The transfer level refers to the time spent by the IMVs in loading and discharging. The demand, transfer and loaded levels refer to the IMVs' busy times, and the idle level refers to the period in which the IMV equipment is not used.

As shown in Table 3, there are no notable differences with the usage of six, seven or eight IMVs for Routing Strategy 1, with the average percentages of the idle time in relation to the demand, transfer and loaded times remaining at comparable levels. Distinct differences are observable in Routing Strategy 2, with an increase in the idle percentages when seven and eight IMVs are considered. The demand, transfer, and loaded times also exhibit a decrease when seven or eight IMVs are used.

Tab. 3. Vehicle utilisation time during the discharge process for different routing strategies and numbers of IMVs

No. of IMVs	Parameters	Idle (%)		Demand (%)		Transfer (%)		Loaded (%)	
		Routing Strategy 1	Routing Strategy 2	Routing Strategy 1	Routing Strategy 2	Routing Strategy 1	Routing Strategy 2	Routing Strategy 1	Routing Strategy 2
6	Min	41.25	48.97	6.29	9.61	0.12	1.64	49.75	42.95
	Max	46.08	51.60	8.73	9.91	0.44	2.38	54.24	43.73
	Avg	43.86	50.54	7.51	9.80	0.23	1.92	51.55	43.23
	Med	44.11	50.82	7.51	9.81	0.20	1.76	51.37	43.19
7	Min	42.63	63.66	7.38	8.57	0.99	2.27	50.12	38.24
	Max	44.20	66.18	7.50	8.91	1.60	2.69	51.14	39.19
	Avg	43.38	65.03	7.45	8.71	1.24	2.42	50.64	38.73
	Med	43.54	65.17	7.46	8.68	1.25	2.37	50.69	38.79
8	Min	44.41	80.42	7.16	7.54	0.86	1.47	49.70	33.35
	Max	46.46	82.30	7.39	7.81	1.45	2.24	50.94	35.02
	Avg	45.68	81.22	7.28	7.67	1.21	2.01	50.34	34.20
	Med	45.82	81.20	7.28	7.64	1.30	2.13	50.30	34.32

Tab. 4. Total distances travelled by IMVs during the discharge process for different routing strategies and numbers of IMVs

No. of IMVs	Parameters	Distance [m]		Difference between Routing Strategy 1 and Routing Strategy 2 [m]	Percentage difference between Routing Strategy 1 and Routing Strategy 2
		Routing Strategy 1	Routing Strategy 2		
6	Min	1,033,223	831,095	202,128	19.6%
	Max	1,047,122	836,700	210,422	20.1%
	Avg	1,040,140	833,640	206,500	19.9%
	Med	1,040,121	833,227	206,894	19.9%
7	Min	888,305	709,030	179,275	20.2%
	Max	894,987	718,469	176,518	19.7%
	Avg	891,551	714,551	177,000	19.9%
	Med	891,471	715,021	176,450	19.8%
8	Min	777,851	621,500	156,351	20.1%
	Max	782,568	629,120	153,448	19.6%
	Avg	780,110	625,235	154,875	19.9%
	Med	779,982	626,095	153,887	19.7%

Based on the findings outlined in Table 3, six IMVs emerges as the optimal choice for discharge operations, as this gives a lower idling level in comparison to the operation of seven or eight IMVs. Minimising the equipment idling time remains a top priority for equipment operation.

Table 4 contains data on the distances travelled by the vehicles. Significant differences in the lengths of the routes taken by IMVs were observed in the simulation studies. The change of route in the simulations resulted in a 20% reduction in the distance covered by the vehicles, corresponding to approximately 180 km.

Data from simulations of the use of RTG and QC cranes were also analysed, as shown in Table 5. Although the idle state percentage corresponds to the equipment not being used, it has two components, idling and blocking, which are both related to the vehicle waiting for a container to be loaded. The busy state percentage includes the demand, transfer and loaded times for the equipment. The busy state percentage in Routing Strategy 2 for RTGs reaches higher values for all scenarios when six, seven and eight IMVs are used. As can be seen in Table 5, the QCs achieved a noticeably higher percentage of busy times under Routing Strategy 2. This means that the containers arrived much faster, due to the reduction in their routes, and hence cranes were used more often. The most notable differences in the busy stage were evident when employing six IMVs for all RTG and QC operations. This finding can be considered further confirmation that six is an appropriate number of vehicles, in a similar way to the analysis of the vehicle utilisation time during the discharge process (Table 3), where the idling level was lower compared to the operation of seven or eight IMVs.

Tab. 5. Utilisation of RTGs and QCs during the discharge process for different routing strategies and numbers of IMVs

Equipment		**% Idle**		**% Busy**		**% Busy difference**
		Routing Strategy 1	**Routing Strategy 2**	**Routing Strategy 1**	**Routing Strategy 2**	
6 IMVs	RTG4	84.98	80.25	15.02	19.75	4.73
	RTG5	84.87	80.10	15.13	19.90	4.77
	RTG6	84.90	80.15	15.10	19.85	4.75
	RTG7	93.14	90.97	6.87	9.03	2.16
	RTG1	85.23	80.57	14.77	19.43	4.66
	RTG2	85.25	80.60	14.75	19.40	4.65
	RTG3	84.84	80.06	15.16	19.94	4.78
	QC1	49.58	33.70	50.42	66.30	15.88
	QC2	53.82	39.27	46.18	60.73	14.55
7 IMVs	RTG4	82.59	79.43	17.41	20.57	3.16
	RTG5	82.46	79.27	17.54	20.73	3.19
	RTG6	82.50	79.32	17.50	20.68	3.18
	RTG7	92.04	90.60	7.96	9.40	1.44
	RTG1	82.87	79.76	17.13	20.24	3.11
	RTG2	82.90	79.79	17.10	20.21	3.11
	RTG3	82.42	79.23	17.58	20.77	3.19
	QC1	41.55	30.93	58.46	69.07	10.61
	QC2	46.46	36.74	53.55	63.26	9.71
8 IMVs	RTG4	80.46	79.27	19.54	20.73	1.19
	RTG5	80.32	79.12	19.68	20.89	1.21
	RTG6	80.36	79.16	19.64	20.84	1.2
	RTG7	91.07	90.52	8.93	9.48	0.55
	RTG1	80.78	79.61	19.22	20.39	1.17
	RTG2	80.81	79.64	19.19	20.36	1.17
	RTG3	80.28	79.07	19.73	20.93	1.2
	QC1	34.40	30.41	65.60	69.60	4
	QC2	39.92	36.26	60.08	63.74	3.66

Changes in the yard traffic pattern were made according to the simulation results. All of the containers in the BHCT Gdańsk storage yard were rotated, and the container traffic patterns for internal and external trucks were adapted. A new IMV route was developed to optimise the discharge process and to reduce the distance travelled, which in turn led to a reduction in fuel consumption. The shorter travel distance may also have had a positive impact on productivity and reductions in operating costs. Figs. 10 and 11 show the changes made at the terminal.

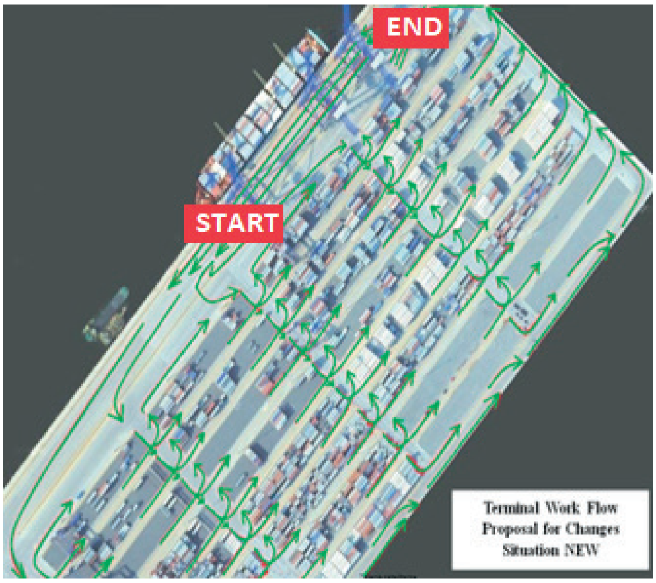

Fig. 10. Terminal workflow after rotating the containers in the yard

Fig. 11. Transportation route for a container by an IMV after the changes

Due to the continuous demand for greater efficiency and productivity of the BHCT Gdańsk operations, certain changes were proposed that concerned the paths of the IMVs during the entire cycle of container transport, i.e. picking up containers under the QC and transporting them to the storage yard and vice versa. To conduct a detailed analysis, a simulation of the terminal quayside together with the storage yard was continuously developed and adapted to the specific situations under analysis.

The results of the simulations were compared with the real data in Table 6, which represent the QC gross productivity (moves per hour) achieved for mainliner ships, before and after implementation of the traffic pattern changes.

The yearly average QC gross productivity in the year before the changes was at the level of 27.1 mph. In the first half of the subsequent year, from January to July, before the implementation of the changes, the average productivity was at the level of 28.5 mph, as shown in Table 6.

All operational changes were implemented between July and August, and positive results of the changes were seen from the first call of a mainliner ship. In the second half of the year, from August to December, after implementing the changes, the average productivity was at the level of 30.5 mph, representing a 10% increase in QC gross productivity (mph). The yearly average results for the following year, after the modifications, were at the level of 31.0 mph.

CONCLUSION

In this study, our objective of determining a quayside and yard transportation strategy based on the usage of IMVs was met, and a comparison of the QC productivity at BHCT Gdańsk indicated good results. A new IMV route was developed as a consequence of the mooring change, which reduced the distance travelled and in turn led to a reduction in fuel consumption. The shorter travel distance had a positive impact in terms of reductions in all operating costs. BHCT Gdańsk confirmed that the results of the simulations presented here were suitable for the mooring arrangement used, i.e. the port side, and the equipment available in the terminal. The simulations allowed for the determination of the optimal number of IMVs during discharge operations in terms of their idling levels and busy periods. Reducing equipment idling time is one of the highest priorities of the terminals during equipment operation.

The operational changes implemented as a result of this study had positive effects, which were already visible during the first call of a mainliner ship. After implementing the changes, the average QC gross productivity (mph) increased by 10%. The yearly average results for the next years were also characterised by a continuous increase, which was made possible by further simulations using a model adapted to the real conditions and situations at the container terminal of

Tab. 6. Quay crane gross productivity results (mph) (blue – before changes, green – after changes)

Quay Crane Productivity (mph)	January	February	March	April	May	June	July	August	September	October	November	December	Average
Year 1 - Before Changes Implemented	26.9	28.0	30.8	29.8	28.0	27.3	26.3	25.6	25.1	25.9	27.8	26.7	27.1
Year 2 - Changes Implemented from August	24.1	27.1	26.9	28.5	29.5	28.1	28.1	30.1	30.6	30.7	30.5	30.3	28.5
Year 3 - After Changes Implemented	29.0	30.3	32.0	31.3	31.0	31.9	30.3	31.7	30.2	30.7	31.3	32.1	31.0

BHCT Gdańsk, representing a highly dynamic and stochastic logistic system. Without the simulations, this system did not allow for pre-planning of detailed transportation, and was insufficient for a proper analysis and quantitative evaluation. In many ports, no attention is paid to how ships are moored, and the case study and analysis presented here can therefore help to quickly improve handling strategies and productivity, thus increasing their competitiveness.

The main limitations of this research are related to the parallel storage yard area considered in the simulations. The yard blocks at terminals may have multiple shapes and various dimensions, i.e. length and width, which limit the selection of container handling equipment and may be determined by existing devices and surroundings.

Further research will aim to use a simulation-based approach to implement a more efficient handling strategy in a container terminal with a perpendicular storage yard or a mix of parallel and perpendicular storage yards.

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