Optimizing Port Operations: Synchronization, Collision Avoidance, and Efficient Loading and Unloading Processes

Sakhi Fatima ezzahra, Bellat Abdelouahad, Mansouri Khalifa, Qbadou Mohammed
Signals, Distributed Systems and Artificial Intelligence (SSDIA), ENSET Mohammedia,
Hassan II University, Casablanca, Morocco

***Abstract*—This study focuses on optimizing the loading and unloading processes in a port environment by employing synchronization techniques and collision avoidance mechanisms. The objective function of this research aims to minimize the time required for these tasks while ensuring efficient coordination and safety. The obtained results are compared with previous studies, demonstrating significant improvements in overall performance. The synchronized handling systems, including gantries and cranes, along with speed control measures, facilitate streamlined operations, reduced delays, and enhanced productivity. By integrating these strategies, the port achieves better results in terms of task completion time compared to previous methodologies, thereby validating the effectiveness of the proposed approach.**

Keywords—Optimizing; synchronization; collision; efficient; time

I. Introduction

Productive and non-productive times play a crucial role when it comes to optimizing the loading and unloading of containers from ships in a port. Many of the common problems associated with optimizing these aspects which are firstly, Inefficient planning which leads to poor coordination and planning of ship arrivals, berth allocation and crane operations can lead to significant delays and inefficiencies. Vessels may have to wait for a berth, resulting in downtime and reduced productivity. Additionally, if container handling equipment, such as cranes, are not allocated efficiently, it can lead to downtime and reduced throughput.

In addition, insufficient or obsolete equipment can slow down the loading and unloading process [1]. Equipment failures and maintenance issues can cause unexpected delays and increase non-productive time [2]. Regular maintenance and prompt repairs are essential to minimize downtime and ensure optimal equipment performance. Ineffective coordination between ship's crew, port operators and logistics personnel can lead to inefficiencies. Lack of clear communication and collaboration can lead to delays, errors in documentation, and increased downtime [3]. Efficient cargo handling operations require effective communication channels and streamlined processes. By relying on manual processes, such as paper documentation, delays and errors can occur. Manual data entry, inspections, and customs clearance procedures may consume valuable time. Implementing digital solutions, such as electronic data interchange (EDI) systems and automated workflows, can significantly improve efficiency and reduce non-productive time. Customs regulations are essential but can also slow down operations [4]. Rigorous security checks, customs inspections and document verification processes can cause delays and increase non-productive time. Port authorities and operators must strike a balance between security measures and operational efficiency.

Various mathematical models and optimization techniques have been developed to solve planning and resource allocation problems in container terminals. These models aim to minimize vessel waiting times, dock occupancy and equipment, among the solutions cited in the literature first: *Automation and robotics*: Automation technologies, such as robotic systems and automated guided vehicles (AGVs) [5], are increasingly being used to improve the efficiency of container handling. *Simulation and optimization studies*: Simulation models and optimization algorithms are often used to evaluate different strategies and scenarios in container terminal operations. These studies analyze factors such as layout design, equipment utilization and resource allocation. *Digitalization and data-driven approaches*: The use of digital technologies, data analysis and real-time information has a significant impact on time optimization in port operations [6]. *Lean Process Improvement and Methodologies*: Lean principles and process improvement methodologies, such as Six Sigma, are relevant to improving operational efficiency and reducing non-productive time.

Previous studies [7] have answered the question of optimizing productive and non-productive times when loading and unloading containers in ports, it is crucial to implement the following strategies: Improve coordination and communication: Improve coordination between port authorities, shipping companies, terminal operators and logistics providers. Real-time information sharing and advanced communication systems can enable better planning and resource allocation. Optimize berth and equipment allocation: Develop effective berth allocation systems that take into account vessel size, cargo type and expected volume. Implement intelligent asset management systems to allocate cranes and material handling equipment based on real-time demand [8]. Improve infrastructure and layout planning: Invest in port infrastructure expansion and optimize layout plans to accommodate growing container volumes. Designate dedicated storage areas for efficient container handling and reduce congestion. Embrace automation and digitalization: Deploy automation technologies, such as automated overhead cranes and robotic container handling systems, to improve efficiency. Implement digital solutions to document, track and automate workflows to reduce manual processes and improve accuracy. Streamline customs and security processes: Collaborate with customs authorities to streamline inspection and clearance procedures. Implement technologies such as secure trading platforms and electronic seals to speed up security checks while ensuring compliance. Invest in training and skills development: Provide regular training and skills development programs to port workers and staff. Well-trained staff can complete tasks more efficiently and handle contingencies effectively, reducing non-productive time. By addressing these issues and implementing these strategies, ports can optimize productive and non-productive times during container loading and unloading operations, resulting in increased efficiency and overall productivity.

Congestion and limited space this can induce limited space in ports and can lead to congestion, making it difficult to manage containers efficiently. Lack of designated storage areas and inefficient layout planning can lead to delays in loading and unloading operations [9]. This problem becomes more pronounced when several ships arrive simultaneously or when there is a high volume of containers to handle.

II. Interference Problems and Unproductive Movements

A. Interference Problem between Gates

The interference problem is well related to the problem of planning multiple yard gates in a seaport since these gates share the traffic lane in the yard and the movement of one can block the movement of the other. In this context, Ng (2005) considered the interference between yard gates when planning the movements of this type of equipment. This phenomenon is defined as a physical blockage that must be considered when planning yard gates [10]. According to Ng, the courtyard inter-portal interference problem is a complicated problem and it requires the development of an efficient method for solving the planning problem.

Interference between yard gantries can affect the planning of quay gantries. In this context, [11-12] sheds light on the relationship between quay gantry planning and the timing of yard gantry operations. Their work is aimed at minimizing the turnaround time of ships and is aimed at scheduling quay gantries taking into account the progression of handling operations at the yard level. Indeed, any delay in the operations of the yard gantries affects the operations of the quay gantries.

Zhong, M.S. et al [13] proposed a model for planning yard gates while taking into account some constraints related to interference between yard gates, fixed separation distances between these gates and simultaneous container storage/retrieval operations. The model aims to minimize a linear combination of early collections, storage and late collections. The problem of interference between courtyard gates is developed within the constraints of the mathematical formulation.

Chen, J et al. [14] treated the interference problem implicitly. The work addresses the problem of scheduling multiple yard gantries during container loading operations. The objective of this work is to improve the processing efficiency of containers intended for export by the yard gates. The authors have taken into account the potential interferences that may occur. Indeed, they integrated this phenomenon into the gate planning problem. An interference hypothesis is developed in the mathematical model [15-16]. This hypothesis takes into consideration two types of interference which are “collision” and “crossover”. The first type of interference occurs when two-yard gates in the same block try to pick up containers stored in adjacent bays. According to Chen and Langevin, a minimum distance of five bays must be respected to avoid a potential collision between two courtyard gates. The second type is the crossing which occurs when the next container to be processed by a given yard gate is located on the other side of another yard gate. In order to avoid any possible interference, the authors developed several constraints in the mathematical formulation.

The work of [17-18] studied the operation of several yard gantries when loading/unloading containers. According to the authors, the yard gates must leave a safe distance to avoid accidents. Indeed, in the same block, several courtyard gates can work simultaneously; in this situation there may be a risk of collision between the yard gates and even between the trucks. In Fig. 1, yard gate 2 (YC2) wants to move to bay 01 after processing a container located in bay 07 but is blocked by yard gate 1 (YC1) which is processing a container located in bay 03. So yard gate 2 must wait until yard gate 1 completes its task.

B. Problem of Non-productive “Rehandle” Movements

In a previous study [19-20], an author proposed a methodology for estimating the anticipated quantity of non-productive moves required to pick up a container, as well as the overall count of non-productive container moves within a bay with an initial stacking arrangement [21]. The author highlights the significance of the rack's height and width in determining the average rehandling count and the design of the storage configuration. To estimate the expected number of non-productive moves for the next pickup, the author examined multiple container stack configurations and derived an approximate formula for estimating the total expected count of non-productive moves [22].

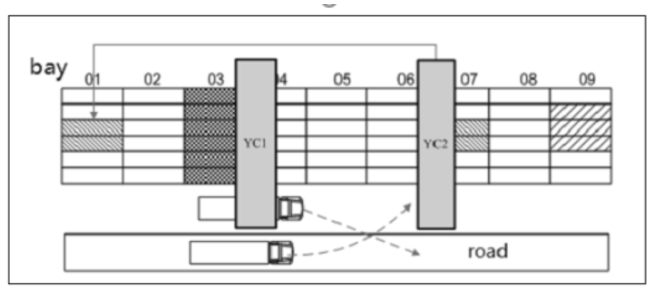

Fig. 1. The collision caused by the courtyard gates.

A study conducted in [23-24] focused on addressing the issue of non-productive crane movements during container loading and unloading activities at a seaport. The researchers aimed to ensure the stability of containers stored on a ship while minimizing the number of non-productive movements within container blocks. To tackle this problem, a multi-objective integer program was formulated. The authors utilized a weighting method to obtain non-dominated solutions, drawing inspiration from the works of [25-26]. They incorporated the consideration of non-productive moves by estimating their count and introduced the concept of probability to study this estimation. However, accurately calculating the number of non-productive moves relies on a predefined loading sequence, which introduces challenges due to the random recovery of containers [27-28]. To solve both the container loading problem on the ship and the rehandling problem, the researchers employed a genetic algorithm.

III. Mathematical Modeling of Container Movements

A. Model Assumptions

When developing a mathematical model, a number of assumptions must be taken into account. These will be integrated in one way or another in the model. Our assumptions are as follows:

- We limit ourselves to the loading operations of export containers (outbound).
- Location of containers is given.
- A courtyard is made up of several adjacent blocks.
- There are up to two court gates in a block.
- Court gate moves between blocks are possible, maximum one move.
- For each container, we know its destination on the quay (the quay gantry).
- We consider the simultaneous movements of the yard gantries and the trucks.
- All containers in a bay are destined for the same vessel.
- The possibility of interference from courtyard gates in the same block is taken into account.
- Containers are classified into groups with an order and priority in the handling of each group. The order is known in advance.
- Non-productive movements of containers (Rehandle) are taken into account.

B. Modeling and Constraint

We will consider that p_i is the processing time of container i through a yard gate which includes the time to pick up the container h_1 and the time to remove and return the containers so p_i can be expressed by the formula below:

$$p_i = h_1 + \sum_{\substack{j \in C \\ a_{i=aj} \\ r_{i=rj} \\ e_i < e_j}} h_2 \times V_{ij} \tag{1}$$

Where:

$$\sum_{\substack{j \in C \\ a_{i=aj} \\ r_{i=rj} \\ e_i < e_j}} h_2 \times V_{ij}$$

is the non-productive time of the yard gates (rehandle).

V_{ij} : if the processing of container j begins after the processing of container i by a yard gantry has finished.

h_1: Container handling time.

h_2: Handling time of a container to pick it up and put it back in its place (rehandle); we assume that h_2= 2 h_1.

P: Set of pairs of containers with a precedence relationship. We are talking here about an order of priority of containers that must be respected during the handling process by the quay gantries.

The variable pi can be divided into two parts pi1 and pi2 which are respectively the handling time of container i and its loading on the truck and the time to return the container(s) that have been removed to its (their) seat(s).

$$p_i = p_i^1 + p_i^2 \tag{2}$$

p_i^1 and p_i^2 are expressed as a function of h_1 and V_{ij} by the following formula:

$$p_i^1 = h_1 + \sum_{\substack{j \in C \\ a_i = a_j \\ r_i = r_j \\ e_i < e_j}} h_1 \times V_{ij}; i \in C \tag{3}$$

$$p_i^2 = \sum_{\substack{j \in C \\ a_i = a_j \\ r_i = r_j \\ e_i < e_j}} h_1 \times V_{ij}; i \in C \tag{4}$$

$$d_j^{Yc}, d_j^{YT}, p_i^1, p_i^2 \geq 0 \tag{5}$$

Indeed, to guarantee that the decision variables are positive and binary a constraint is expressed by the equation (5) is necessary for our approach.

It is also reported that in our study that constraints have been imposed which guarantee that the equipment which are respectively the trucks do not leave the starting point only once and they ensure flow conservation for each material handling equipment.

Other constraints that must be included in our model is first of all the constraint which defines the handling time of the container i and its loading on the truck the constraint which defines the time of reinstallation of the containers already removed this last is expressed by the equation (4).

$$d_j^{Yc} \geq d_i^{YC} + (p_i^1 + p_i^2) + k_{ij} + T(X_{ijm} - 1); \tag{6}$$

Where

$d_{i,j}^{YC}$: Start time of picking of container i, j by a yard gantry

T: Great value.

k_{ij}: Travel time of a yard gantry from container i to container j whatever

$X_{ijm} = 1$, if yard gate m processes container j just after container i; 0 otherwise.

The constraint that ensures the order in which containers are processed by each sorting gate is expressed in equation (6). This means that if a sorting gate m processes container j just after container i, then gate m will take the travel time kij to pick up the next container j.

Constraint (7) makes it possible to present the order in which the containers are processed by each yard gate according to the departure time of the trucks transporting the containers. Constraint (12) means that when containers i and j form a pair of containers with a priority relationship then container i is processed before container j as soon as it arrives at the dock.

$$d_j^{YC} \geq d_i^{YT} + \mathrm{k_{ij}} + T\left(X_{ijm} - 1\right); i \in C, j \in C, m \in M \quad (7)$$

Where:

d_i^{YT}: Departure time of a truck carrying container

IV. Methodology

A. Objective Function

In the objective function (8), we seek to minimize the production time (makespan). We also take into account that each container is assigned to a single parking gantry and a single truck.

The FOBJ objective function is calculated as follows:

$$\begin{cases} Min\left\{\operatorname*{Max}_{i} d_i^{YT}\right\} & (8) \\ d_j^{YC} \geq d_i^{YT} + \mathrm{k_{ij}} + T\left(X_{ijm} - 1\right); i \in C, j \in C, m \in M & (7) \end{cases}$$

the main objective is to optimize the flow of unloading containers and trucks in ports, avoiding collisions and promoting synchronization between handling systems, especially gantries

B. Optimization Algorithm

To optimize our objective function, we must take into consideration that containers i and j form a pair of containers with a priority relation, so container i is processed before container j as soon as it arrives at the dock. The container processing sequence is an essential parameter that must also be introduced into our optimization algorithm.

Due to the challenges associated with optimization, constructing a new model to optimize container management during loading and unloading at the port, particularly for autonomous ships, makes the use of deterministic methods arduous and resource-intensive. Hence, heuristic methods are chosen as the most suitable approach to tackle such optimization problems. Furthermore, in the presented work, genetic algorithms have been selected to optimize the transfer time of containers.

The decision to employ genetic algorithms stems from the fact that these algorithms are regarded as:

- A flexible and configurable method.
- Efficient in their ability to overcome the pitfalls of local optima while exploring the design search space to converge towards the global optimum.

The flowchart in Fig. 2 shows the optimization steps adopted to optimize a wind farm. In the Python© software, we have entered the data and the models established in the previous part, the optimization process begins to search for an optimal solution. GA research techniques include the following main steps:

In Step 1, we randomly generate specific paths while ensuring compliance with the constraints of the problem at hand.

Step 2 involves evaluating the layouts of the objective function being studied by utilizing the objective function itself.

In Step 3, individuals are selected to contribute to the population of the next generation. The selection probability in the current generation ensures the selection of high-quality individuals. The crossover operator is employed to modify two pairs of genes (positions) and generate further optimization. As a crossover function, gene modification at another position is accomplished through the random activation of mutation with a predetermined probability.

Step 4 involves producing a new course flow through the genetic algorithm (GA), which modifies the previous population. These steps are iterated until the maximum number of iterations is reached. The data parameters of our algorithm can be found in Table I.

TABLE I. Parameters OG Genetic Algorithm

GA Parameter	Value
Size of initial poulation	1000
Selection pressure	3
crossover probability	0.75
Mutation probability	0.25
Iteration number	4000

C. Case Study

We will apply our model to the Port of Tangier Med which is one of the largest ports in Africa and the Mediterranean, strategically located on the Strait of Gibraltar. It has modern infrastructure, including several terminals for containers, passengers and general cargo. With a large container and passenger handling capacity, the port serves as a key transshipment hub, facilitating trade between Europe, Africa and Asia. It has had a significant economic impact, attracted investment and generated employment opportunities. Continuous expansions and developments have been undertaken to meet the increasing demands of international trade. Overall, the Port of Tangier Med plays a crucial role in global trade and connectivity in the region.

In our case, we propose three distinct mathematical models. The initial model focuses mainly on the optimization of truck routes, with the objective of minimizing the distance traveled by each vehicle. The second model involves assigning tasks to trucks, which results in a schedule of container task assignments based on the input data comprising the set of container tasks. Finally, the third model is designed to avoid collisions between trucks and gantries, ensuring a safe operating environment.

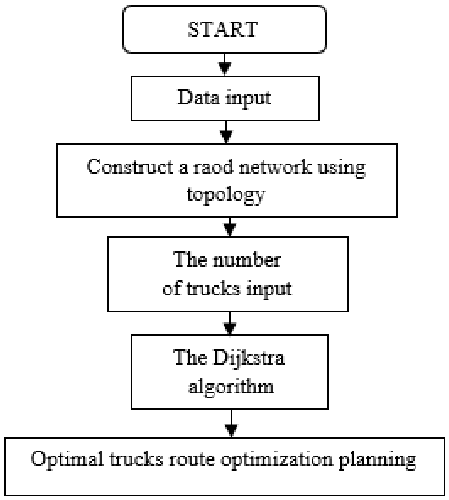

Fig. 2. Road planning trucks.

Our approach offers a hybrid solution by integrating simulations and algorithms to address modeling challenges. Essentially, truck route design can be simplified as a "shortest path problem". To solve this problem, we use the widely recognized method of Dijkstra, which has a long reputation for finding the shortest path. Model 1 in Fig. 2 uses Dijkstra's method. We can solve the model efficiently and determine the optimal route planning strategy for trucks (Fig. 4).

As illustrated in Table II, the truck scheduling model started with 1000 container tasks created at random. When the evolutionary algorithm was employed to solve the task assignment to trucks, the original population was 200, as shown in Fig. 3. If the crossover coefficient is set too low, the performance of our method suffers. If the mutation probability is sufficiently high, the genetic algorithm will reach the local optimum. As a result, the mutation probability and crossover probability were both set to 0.75.

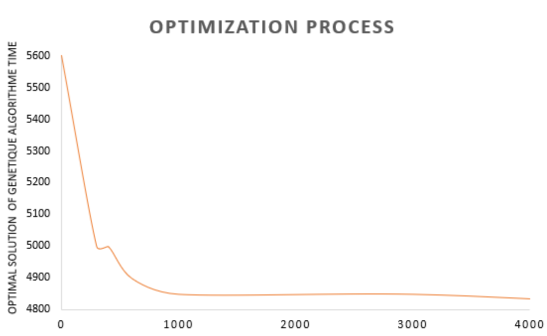

Fig. 3. Genetic algorithm's convergence diagram.

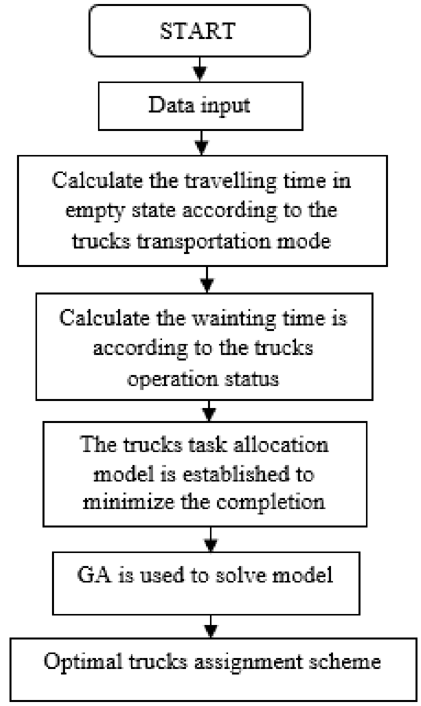

Fig. 4. Allocation of truck assignments.

TABLE II. SCHEDULING OF CONTAINER TASKS

Task Number	***Starting position quay cranes (QC)***	***Target position Yard (y)***
1	QC1	Y1
2	QC2	Y3
3	QC3	Y4
. . 999	. QC1	. . Y5
1000	QC3	Y6

The model shown in Fig. 5 and Fig. 6 focuses on optimizing truck task assignment, determining their routes, and managing their speeds to avoid collisions. It involves an intelligent system that uses advanced algorithms to solve this complex problem.

First, the model must take into account the different tasks to be performed by trucks, such as delivering goods to specific destinations, picking up materials, or performing specific services. These tasks are usually accompanied by specific constraints, such as delivery times, priorities or required resources.

The model must analyze the constraints and available resources, as well as the characteristics of the trucks, such as their load capacity, maximum speed, fuel consumption and mechanical constraints. Based on this information, the model can determine the best assignment of tasks to trucks, optimizing criteria such as total distance traveled, delivery time or operational costs.

Once the task assignment is determined, the model must plan the routes for each truck to avoid collisions. It must take into account various factors, such as distances between destinations, traffic conditions, traffic restrictions (such as toll roads or no-truck zones) and specific preferences, such as shorter routes or faster.

To avoid collisions, the model can use path planning techniques that take into account the movements of other vehicles on the road. This can be achieved through the use of sensors, global positioning systems (GPS), digital maps and obstacle detection algorithms. The model can also use communication techniques between the trucks to exchange information about their position and intention, which helps coordinate their movements and avoid potential conflicts.

Finally, the model can control truck speeds based on various factors, such as road conditions, speed limits, safety constraints and operator preferences. This can be achieved by using automatic cruise controls or by providing speed recommendations to drivers.

Overall, the model shown in Fig. 5 is designed to optimize truck task assignment, determine their routes, and control their speeds to minimize collisions, maximize operation efficiency, and ensure safety on the road. It is an approach based on artificial intelligence and optimization that requires precise data on tasks, trucks, constraints and road conditions to make informed and effective decisions.

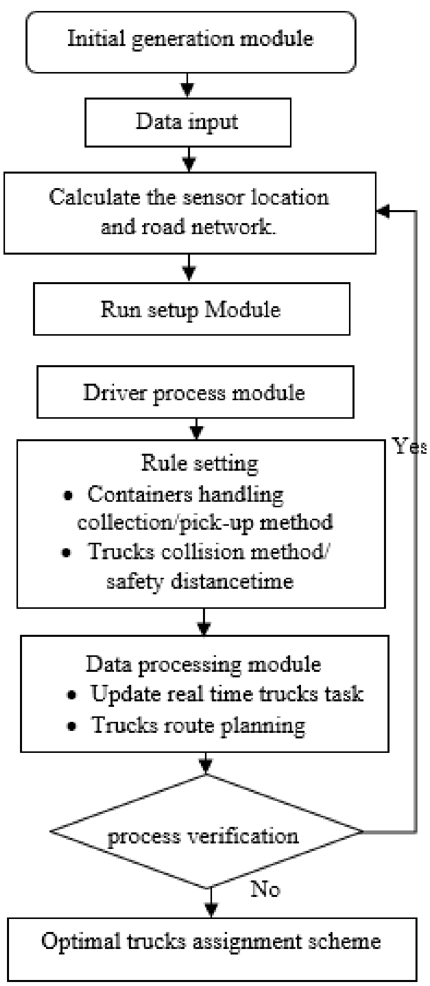

Fig. 5. Truck collision.

V. Results and Discussion

The truck task assignment model produced assignment outcomes and path outcomes for trucks, which were then incorporated into our model of our collision avoidance gait. In addition, the speed control strategy has been applied. Collision avoidance strategies were evaluated for different numbers of container tasks, and the results are shown in Fig. 7 and 8.

Fig. 6 shows that regardless of the number of trucks, trucks operating under the speed control strategy exhibited significantly shorter operating times compared to those under conventional scheduling. This result stems from the ability of speed-controlled trucks to effectively avoid conflicts. In contrast, route planning under conventional planning often encounters conflicts, leading to truck stalls and subsequent delays in completion time. These results confirm that the speed control strategy can effectively mitigate conflicts.

Fig. 7 provides a more detailed analysis that further solidifies the benefits derived from employing the speed control strategy. One notable advantage is the substantial reduction in the total wait time compared to conventional scheduling. By implementing the speed control strategy, conflicts in truck route planning are effectively minimized, allowing for smoother and more efficient transportation operations.

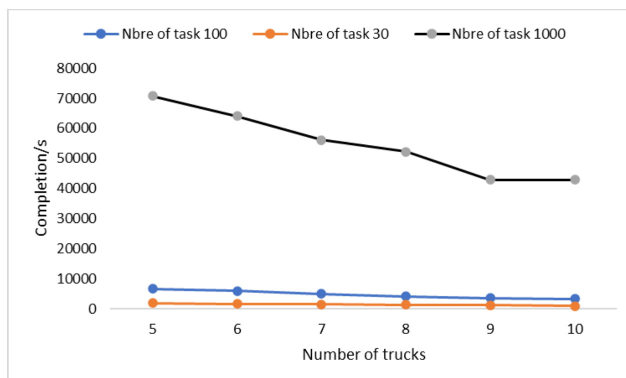

Fig. 6. Outcomes of various container tasks and diverse truck quantities upon completion.

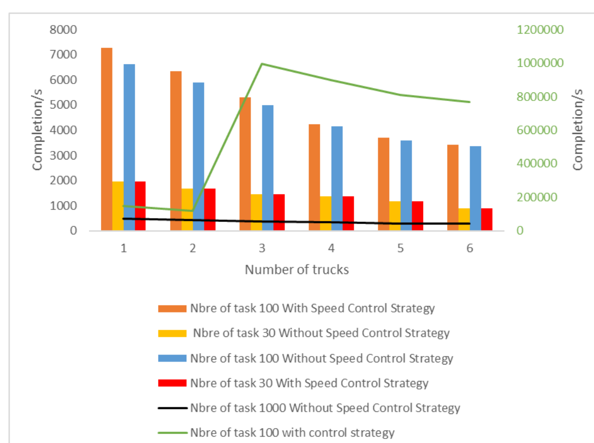

Fig. 7. Achievement outcomes of distinct container tasks and varying truck quantities through the implementation of a speed control strategy.

The reduced wait time is of paramount importance as it directly translates to improved transportation efficiency. With fewer conflicts and delays, vehicles can complete their assigned routes in a timelier manner, resulting in enhanced overall productivity and customer satisfaction. The speed control strategy ensures that vehicles can navigate through the road network more effectively, optimizing their travel paths and minimizing potential bottlenecks or congestion points.

The positive impact of the speed control strategy on transportation efficiency reinforces the significance of conflict resolution in road planning. By addressing conflicts through the three-step optimization algorithm proposed in this paper, the overall performance of the transportation system is greatly improved. The algorithm takes into account various factors such as traffic patterns, delivery schedules, and vehicle capacities to optimize route planning and minimize conflicts.

The findings presented in Fig. 7 confirm that the integration of the speed control strategy, along with the proposed three-step optimization algorithm, leads to substantial improvements in conflict resolution and overall transportation effectiveness. This provides valuable insights for decision-makers and stakeholders in the field of logistics and transportation management, emphasizing the importance of implementing intelligent strategies to enhance operational efficiency and customer service.

The curves in Fig. 8 illustrating a reduction in task execution time for trucks in a studied port due to the synchronization of handling systems, gantries, cranes and speed control to avoid collisions indicate the positive impact of these measures on operational efficiency. By coordinating the various components involved in port operations and implementing collision avoidance mechanisms, the port can streamline its processes and improve its productivity.

Reduced execution time means that tasks are executed faster and more efficiently. Synchronizing material handling systems, such as gantries and cranes, ensures a smooth flow of operations by minimizing delays and bottlenecks. This coordination allows the port to optimize resource allocation and effectively prioritize tasks.

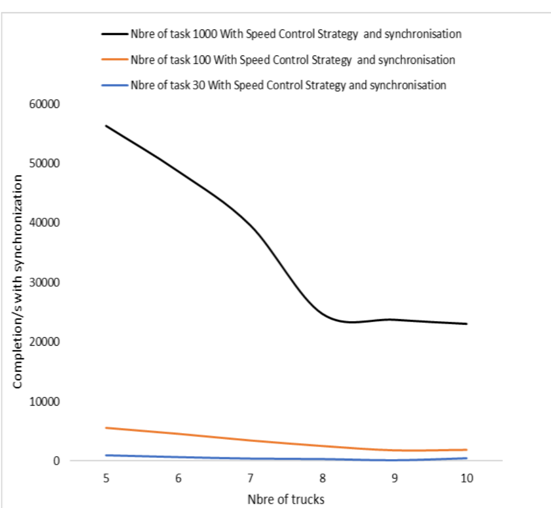

Fig. 8. Results completions by speed and synchronization control strategy.

Incorporating speed control mechanisms to prevent collisions is crucial to maintaining safety while maximizing productivity. By regulating the movement of trucks and equipment, potential accidents and disruptions are mitigated, leading to uninterrupted operations and improved overall performance.

It should be noted that the effectiveness of these measures is influenced by the number of tasks performed and their duration. As the number of tasks increases, the benefits of timing and speed control become more pronounced, resulting in greater time savings. The relationship between the number of tasks and the proportional reduction in time implies that the impact of these measures scales accordingly, leading to increased efficiency across different workloads.

Overall, the curves showing a reduction in lead time demonstrate the positive results achieved by synchronizing handling systems and implementing speed control measures. These improvements result in increased productivity, minimized delays, increased security and optimized allocation of resources in the studied port.

VI. Conclusion

As a sophisticated and information-intensive logistics system for loading and unloading operations, the developed port terminal at Tangier Med relies extensively on efficient truck transportation to establish seamless connections between the seaside loading and unloading area and the landside storage zone. The overall operational efficiency of the terminal greatly hinges upon effective time management and synchronized coordination between the transportation and handling systems. In light of this, we propose a three-stage model that tackles the truck route planning predicament by considering task allocation and integrating a speed control strategy to ensure collision avoidance during truck movement. The model is solved through the utilization of a heuristic algorithm, and its efficacy is exemplified through a comprehensive large-scale numerical demonstration, culminating in substantial enhancements to the operational efficiency of the Tangier Med port terminal. Nevertheless, practical circumstances necessitate the consideration of additional factors, such as the impact of truck charging on their movements. Therefore, future research endeavors focusing on devising collision avoidance routes for trucks while taking their load into account emerge as pivotal directions to explore for the further development of the Tangier Med port and its terminal.

References

[1] Review of Maritime Transport 2021 | UNCTAD. Available online: https://unctad.org/webflyer/review-maritime-transport-2021 (accessed on 23 October 2022).

[2] Liang, C.J.; Huang, Y.F.; Yang, Y. A quay crane dynamic scheduling problem by hybrid evolutionary algorithm for berth allocation planning. Comput. Ind. Eng. 2009, 56, 1021–1028.

[3] Zhang, Y.; Liang, C.J.; Shi, J.; Lim, G.; Wu, Y.W. Optimal Port Microgrid Scheduling Incorporating Onshore Power Supply and Berth Allocation Under Uncertainty. Appl. Energy, 2022, 313, 118856.

[4] Qiu, L.; Hsu, W.J.; Huang, S.; Wang, H. Scheduling and routing algorithms for AGVs: A survey. Int. J. Prod. Res. 1999, 40, 745– 760.

[5] Chen, X.C.; He, S.W.; Zhang, Y.X.; Tong, L.; Shang, P.; Zhou, X.S. Yard crane and AGV scheduling in automated container terminal: A

multi-robot task allocation framework. Transp. Res. Part C Emerg. Technol. 2020, 114, 241–271.

[6] Kim, K.H.; Bae, J.W. A Look-Ahead Dispatching Method for Automated Guided Vehicles in Automated Port Container Terminals. Transp. Sci. 2004, 38, 224–234.

[7] Xin, J.B.; Negenborn, R.R.; Lodewijks, G. Rescheduling of interacting machines in automated container terminals. IFAC Proc. 2014, 47, 1698–1704.

[8] Confessore, G.; Fabiano, M.; Liotta, G. A network flow based heuristic approach for optimising AGV movements. J. Intell. Manuf. 2013, 24, 405–419.

[9] Errico, F.; Desaulniers, G.; Gendreau, M.; Rei, W.; Rousseau, L. A priori optimization with recourse for the vehicle routing problem with hard time windows and stochastic service times. Eur. J. Oper. Res. 2016, 249, 55–66.

[10] Wu, W.M.; Xing, Z.C.; Chen, X.Y.; Zhang, T.Q.; Niu, H.Y. A neural network based multi-state scheduling algorithm for multi- AGV system in FMS. J. Manuf. Syst. 2022, 64, 344–355.

[11] Li, J.X.; Cheng, W.J.; Lai, K.K.; Ram, B. Multi-AGV Flexible Manufacturing Cell Scheduling Considering Charging. Mathematics 2022, 10, 2227–7390.

[12] Liu, J.E.; Zhang, S.; Liu, H. Research on AGV Path Planning under “Parts-to-Picker” Mode. Open J. Soc. Sci. 2019, 7, 1–14.

[13] Zhong, M.S.; Yang, Y.S.; Dessouky, Y.; Postolache, O. Multi-AGV scheduling for conflict-free path planning in automated container terminals. Comput. Ind. Eng. 2020, 142, 106371.

[14] Chen, J.; Zhang, X.; Peng, X.; Xu, D.; Peng, J. Efficient routing for multi-AGV based on optimized Ant-agent. Comput. Ind. Eng. 2022, 167, 108042.

[15] Xing, L.; Liu, Y.; Li, H.; Wu, C.-C.; Lin, W.-C.; Chen, X. A Novel Tabu Search Algorithm for Multi-AGV Routing Problem. Mathematics 2020, 8, 279.

[16] Homayouni, S.M.; Tang, S.H.; Ismail, N.; Ariffin, M.K.A.M.; Samin, R. A hybrid genetic-heuristic algorithm for scheduling of automated guided vehicles and quay cranes in automated container terminals. In Proceedings of the 2009 International Conference on Computers & Industrial Engineering, Troyes, France, 6–9 July 2009; pp. 96–101.

[17] Homayouni, S.M.; Tang, S.H.; Ismail, N.; Ariffin, M.K.A. Using simulated annealing algorithm for optimization of quay cranes and automated guided vehicles scheduling. Int. J. Phys. Sci. 2011, 27, 6286–6294.

[18] Jerzy, Z.; Waldemar, M.; Structural online control policy for collision and deadlock resolution in multi-AGV systems. J. Manuf. Syst. 2021, 60, 80–92.

[19] Liu, Y.; Luo, Z.; Liu, Z.; Shi, J.; Cheng, G. Cooperative routing problem for ground vehicle and unmanned aerial vehicle: The application on intelligence, surveillance, and reconnaissance missions. IEEE Access, 2019, 7, 63504–63518.

[20] Umar, A.; Ariffin, M.K.A.; Ismail, N.; Tang, S.H. Hybrid multiobjective genetic algorithms for integrated dynamic scheduling and routing of jobs and automated-guided vehicle (AGV) in flexible manufacturing systems (FMS) environment. Int. J. Adv. Manuf. Technol. 2015, 50, 1–15.

[21] Dimitri, A.; Loiseau, J.J.; Rosa, A. A Temporized Conflict-Free Routing Policy for AGVs. IFAC-Papers Online 2017, 50, 11169– 11174.

[22] Akbar, M. R. (2018). Dinamika Aktor dalam Perumusan Peraturan tentang Tata Ruang dan Tata Wilayah di Kota Makassar. The POLITICS: Jurnal Magister Ilmu Politik Universitas Hasanuddin, 4(1).

[23] ALDaghlas, H., Duffield, C., & Hui, F. K. P. (2018). The importance of environmental sustainability to obtain finance for port developments in Australia and Indonesia. 42nd AUBEA Conference 2018: Educating Building Professionals for the Future in the Globalised World, 156–165.

[24] Amran, A. (2020). Analisis Kebutuhan Fasilitas Penanganan Petikemas di Terminal Petikemas Makassar New Port. In Repository Unhas. (Doctoral dissertation, Universitas Hasanuddin).

[25] Arahman, A., Afifuddin, M., & Yusuf, S. (2018). Studi konservasi bangunan cagar budaya di dalam kawasan rencana pengembangan pelabuhan bebas Sabang. Jurnal Arsip Rekayasa Sipil Dan Perencanaan, 1(1), 43-52.

[26] Arianto, D. (2014). Kebutuhan Pengembangan Dermaga Petikemas (Studi Kasus: Pelabuhan Biak). Jurnal Penelitian Transportasi Laut, 16(3), 103-118.

[27] Ariyanto, D. (2017). Evaluasi Pengembangan Pelabuhan Sibolga. Jurnal Penelitian Transportasi Laut. Jurnal Penelitian Transportasi Laut, 19(1), 1–13.

[28] Beresford, A., Pettit, S., Xu, Q., & Williams, S. (2012). A study of dry port development in China. Maritime Economics & Logistics, 14(1), 73-98.