A Zero-blockage based Scheduling for Import Containers Pickup Operations at Container Terminal Yards

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Abstract: In container terminals (CTs), containers are stacked above each other due to the limited yard area space used for storing the containers. External trucks usually submit appointment requests to pick up their import containers from the CT. However, some containers are not on the top stack and are blocked by other containers when trucks arrive at the terminal yard. Resolving this blockage requires relocating all containers above the targeted container. This non-value-added operation reduces the yard crane utilization and increases the service of external trucks. This paper studies the appointment scheduling for picking up containers, considering the container stacking sequence in the yard. We propose a scheduling method for container pickup appointments to avoid container blockages. An IP model is developed to minimize shifting appointment times for picking up import containers from its preferable pickup time windows. The performance of the developed model is investigated by solving some numerical instances. In addition, further analyses are performed to study the effect of container blocking on appointment scheduling.

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1 INTRODUCTION

The Global seaborne trade acts as the key player in the global supply chain. According to the United Nations Conference on Trade and Development, It has been reported that about 80% of the global cargo is transported by sea (UNCTAD 2020). Using containers in cargo shipping is very cost-efficient with added supply chain values. Containers are transported between different parties in the supply chain, involve manufacturers producing goods for global use, freight forwarders, shipping lines, transfer facilities, and finally, customers(Günther and Kim 2006). As essential nodes in the maritime supply chain, container terminals (CTs) play an indispensable role in the container's transportation and cargo handling efficiency.

As a response to the container shipping growth, container ports always strive to increase their throughput by investing the infrastructure and designing more efficient operations. Figure 1 shows the growth in container terminal throughput at ports worldwide from 2012 to 2020, with a forecast for 2021 until 2024. CTs are faced with increasing numbers of containers to be handled at a low cost and in a short time (Stahlbock and Voß 2008). Therefore, CTs always try to enlarge their handling capacities and strive to achieve higher productivity without losing competitiveness.

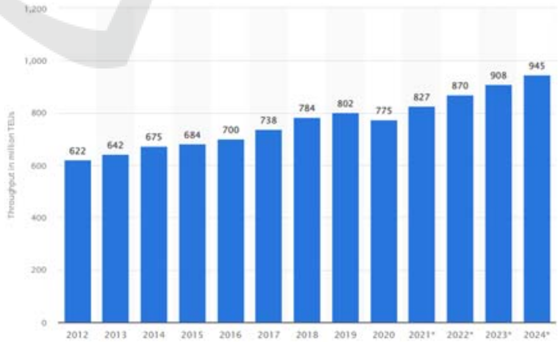

Figure 1: Container throughput at ports worldwide from 2012 to 2020 with a forecast for 2021 until 2024) (source: Statista 2021).

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Typically, CTs consist of three main areas:

Landside: In this area, export containers are received from outside the terminal by external trucks or trains, and import containers are picked up by the same transportation means.

Seaside: In this area, export containers are loaded to vessels to deliver to another CT. In contrast, import containers are unloaded from vessels to be picked up by road transportation or another vessel.

Yard Area: containers received from the seaside and landside are temporarily stored in the yard. Typically, containers are stacked above each other's due to limited yard area space and transported between seaside and yard using internal trucks or automated guided vehicles. A stack is a vertical column of containers and several stacks from a two-dimensional bay configuration, as shown in Figure 2.

Each area inside the container terminal has operations that interrelate with different processes inside and outside the terminal. For instance, the container unloading sequence from the vessels impacts the container handling and stacking operations at the yard area. The arrival times of the external truck at the terminal to deliver or pick up containers also affect the yard operations. Therefore, decision-making in this complex system is highly dependent, so that the integration of operational planning is essential.

This paper focuses on managing the arrival of the external trucks at the landside while considering the container stacking sequence in the yard. At landside, the external trucks arrive at the terminal at a pre-decided time window to deliver export and (or pickup import containers). The decided arrival times are usually obtained from Truck Appointment System (TAS). TAS is typically applied in a CT to control the terminal congestion and smooth the arrival peaks (Huynh, Smith, and Harder 2016). In addition, it is widely implemented in many terminals to coordinate the truck arrival process between trucking companies and container terminals.

Once the truck's arrival time (appointment time) is decided, trucking companies dispatch their trucks to the terminals. At the landside gates, pre-entry processes are performed, such as scanning the export container, checking the container customs, and revising the container and driver-related documents. Once the gate operations are finished, trucks are directed to the yard area, where containers are stored in separate yard blocks. A yard crane is used at a particular yard block to load the import containers to the external trucks or unload the export container from the truck to the container stack (See Figure 2). If the terminal adopts TAS, the yard crane stacks/unstacks the containers based on a prepared plan to achieve the best operational performance considering containers arrival or departure time, yard block configuration, and other spatial constraints.

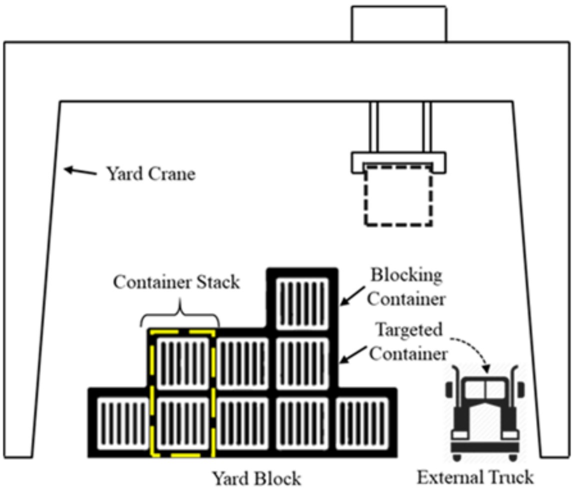

Figure 2: Container Bay Configuration showing the blockage.

A typical situation in CT occurs when an external truck is given an appointment to pick up an import container, but this targeted container is not on the top of the stack (see Figure 2). In this case, the yard crane must remove (relocate) all containers above the targeted container, resulting in more truck waiting time and extra container movements performed by the yard crane.

The container Relocation Problem (CRP) is typically solved to determine the optimum relocation sequence (de Melo da Silva et al. 2018) and resolve the container blockage. The truck arrival information is usually obtained from the TAS and used as an input to the CRP. The arrival time of each truck will determine the pickup sequence of the containers from the yard. The truck appointment scheduling problem is solved, usually independent from the CRP. In most cases, TAS is designed to tackle the congestion problems in CT regardless of some root causes of congestion inside the terminal and long truck waiting times. One of the hidden causes of such truck delay issues is the time consumed for resolving container blockage when picking up import containers from the yard.

This paper introduces a scheduling approach for truck appointments considering the container blockage in the yard. Unlike the previous studies, we consider the container stacking sequence in the yard when deciding final truck appointments to avoid container blockage during import container pickup operations. Considering container stacking sequence will enable the terminal operators to prevent or control the blockage and resolve one of the congestion root causes: container relocations.

The remainder of the paper is organized as follows; section 2 discusses some related work. In section 3, the problem description is introduced. The proposed mathematical model is explained in section 4. Section 5 discusses the numerical experiments and results. Conclusions and future work are discussed in section 6.

2 RELATED WORKS

TAS and CRP are extensively studied in the literature. In this section, some recent studies are presented. In Zeng, Feng, and Yang (2019), the impact of partial truck arrival information on the number of container relocations in yard areas is studied. An optimization model is developed, and five heuristic algorithms are introduced to solve the model. Results illustrated how the proposed algorithms could help CT operators to reduce container rehandling. To minimize the expected number of container relocations, Ku and Arthanari (2016) used the departure time windows for containers revealed by TAS. A stochastic dynamic programming model is developed, and a heuristic algorithm is proposed to beat the computational complexity of the exact method. Yi, Gui, and Kim (2018) used the real-time arrival information of the external trucks to improve the carry-out operations of the import containers. They showed how the expected arrival time of the trucks obtained by GPS in drivers' smartphones could help in reducing container relocation operations.

Truck appointment scheduling is also studied from the perspective of reducing terminal congestion. Torkjazi, Huynh, and Shiri (2018) formulated a mixed-integer nonlinear programming model to minimize both waiting time and the cost of external trucks. To study the effect of appointments on truck waiting times, Yi et al. (2019) developed a mathematical model and a heuristic algorithm to solve the problem within a reasonable computational time. In this context, Azab, Karam, and Eltawil (2020) also proposed a simulation-based optimization approach to minimize the truck congestion at terminal gates and in yard blocks for multiple trucking companies. Their approach illustrated the benefits of using TAS in managing truck arrival and reducing truck turnaround times.

Zhang, Zeng, and Yang (2019) proposed a mathematical optimization model to minimize the waiting time of external trucks and internal trucks used to transport containers inside the terminal. Their proposed queuing model reduced terminal operating costs and provided a more accurate estimation of the truck waiting times. More recently, Abdelmagid, Gheith, and Eltawil (2020) proposed an IP model to minimize the external truck delays under several truck arrival scenarios. Their results showed that the truck delays could be reduced while considering service time limitation and yard capacity. For a more comprehensive survey on TAS, interested readers can refer to Abdelmagid, Gheith, and Eltawil (2021).

From the surveyed studies in this section and more studies in the literature, it is noted that considering the container stacking sequence in scheduling the truck appointments is still undercovered. Moreover, studying the import container operations received less interest than export containers since the latter are prioritized to reduce the vessel operational time than trucking companies' operational times. So that, this paper introduces a preliminary design of the appointment scheduling system, which considers container stacking orders from the container terminal side and the preferable container pickup time from trucking companies' side.

3 PROBLEM DESCRIPTION

For a truck to access the CT for picking up an import container, an appointment request shall be submitted one day before heading to the terminal. The submitted request represents the preferred arrival time window for the truck to pick a predefined container. However, arriving truck at the terminal at the desired time window can experience a long service time since other containers may be blocking the targeted container (Figure 2). The blocking occurs when the truck arrives to pick up its targeted container before the container above it. On the other hand, terminal operators want to avoid container blockage as much as possible to increase the yard crane productivity. The more blocking containers the bay has, the more container relocations the yard crane will perform.

Changing the arrival time of trucks such that trucks with the topmost containers in the bay arrive before the trucks with the bottom containers can reduce the blockage scenarios. However, matching truck appointment times with container stacking sequence to prevent blocking may shift the trucks from their preferable arrival time. This paper proposes a new IP model to minimize shifting the appointment from the preferable container pickup time window while keeping container blockage under control.

It is worth mentioning that the proposed approach only considers the static blockage in the initial stack configuration. The initial stack configuration describes the stacking order of import containers in each stack before trucks arrive at the yard. However, considering the future relocations resulting from this blockage is not considered, and it requires considering the change of stack configuration as the containers pickup is progressing. Minimizing the number of relocations accordingly with appointment scheduling is recently considered by Azab and Morita (2022). The authors developed an IP model that considered a limited tolerance for container appointment shift while keeping relocations at a minimum.

In this paper, the container blockage describes the number of blocked containers in the initial stack configuration. For example, in Figure 3, the last highlighted stack in the initial bay configuration (right-hand side of the figure) shows that there is a blocking container if the trucks arrive according to their preferred times. However, our approach introduces a *pre-processing scheduling method* to schedule the truck appointments to control the blockage or avoid it when trucks arrive according to the scheduled times. This can be seen on the left-hand side of Figure 3. Assuming that attached times to the containers (highlighted in grey) will be the actual (newly scheduled) container pickup times. This leads to fewer blockages in the initial stack configuration.

According to Zhu et al. (2012), the number of blocking containers in the initial configuration of the stacks is considered the lower bound for the total number of containers relocations required to retrieve all containers from the bay. This lower bound contributes to determining the maximum number of relocations or the upper bound (Zehendner et al. 2015). Reducing the number of blocking containers in the initial stacks' configuration and accordingly bay configuration can reduce the total number of container relocations. Let LB_t is the number of blocking containers (lower bound for container relocations) at time window t. Then the overall minimum number of container relocations (LB) can be obtained as follows:

$$LB = LB_0 + LB_1 + \cdots + LB_{T-1}$$

T: Latest time window to pick up an import container from the bay.

Reducing the number of blocking containers in the initial bay (LB_0) can reduce the number of future relocations, which is our paper's primary motivation. We make this reduction by scheduling the pickup time of containers. This can be seen clearly in the illustrative example in Figure 3. Now you can see that the last highlighted stack does not contain any blocking just by changing the pickup time of the containers one or two time windows.

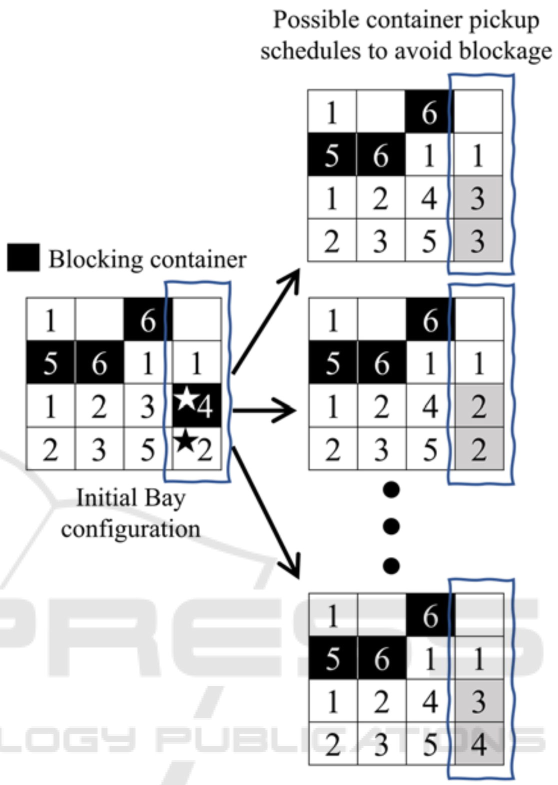

Figure 3: Illustration of the proposed appointment scheduling approach and the resultant stack configuration.

In our approach, the planning horizon is discretized in several time widows; each time window is assumed to be one-hour length. Each container is given a unique index corresponding to one truck in the truck appointment system. Since we don't study the dynamic version of the problem that deals with the change of stacks configuration with time, we solve the optimization problem of truck appointment scheduling for containers located in each vertical stack. This adds an advantage to our approach since we can solve the problem for a large number of stacks regardless of the location of this stack in the yard.

We also consider the number of trucks that can be received at the terminal yard during a particular time window. This is expressed as the yard capacity in the developed mathematical model. For instance, the number of appointment requests exceeds the yard capacity; some trucks will be scheduled to less congested time windows. In the proposed scheduling approach, the number of allowed blockings is typically assumed to be zero. This means that no relocations will be required in the future if the trucks arrive according to the developed schedule. However, terminal operators shall be aware that avoiding all blockings might require shifting many trucks away from their preferred arrival times, leading to less satisfaction for truckers. Therefore, we further analyze the impact of the number of acceptable container blockings on the appointment shifting. In the next section, we introduce the mathematical formulation for the described problem in this section.

4 PROBLEM FORMULATION

Indices:

i Container index.

s Stack index.

t Time window index, $t \in \{1, .., T\}$.

Parameters:

p_{is} Preferable container pickup time of container i located at stack s. $p_{is} \in \{1, .., T\}$

h_s Stack s height (number of containers in stack s).

m Number of stacks.

C Yard capacity (truck arrival quota) per time window.

T Latest possible container pickup time window.

k Number of allowable container blockings in the initial stack configuration.

Decision Variables:

Integer variables:

x_{is} The pickup time window of the container i located at stack s.

Derived binary variables:

y_{ijs} A binary variable represents the state of container i if it has pickup time later than the container j below it: $j = 1, \dots, h_s - 1, i = j + 1, \dots, h_s$. In other words, whether container i is blocking container j.

z_{ist} A binary variable represents if container i will be picked up from the stack s at time window t.

Objective Function:

$$Min \sum_{i=1}^{h_s} \sum_{s=1}^{m} |x_{is} - p_{is}| \qquad (1)$$

Subjected to:

$$y_{ijs} = \begin{cases} 1, & if\ x_{is} > x_{js} \\ 0, & otherwise \end{cases}, \quad \forall j \in \{1, \dots h_s - 1\}, i \in \{j + 1, \dots, h_s\} \qquad (2)$$

$$\sum_{i=1}^{h_s - 1} \sum_{j=i+1}^{h_s} y_{ijs} \le k, \qquad \forall s \in \{1, \dots, m\} \qquad (3)$$

$$z_{ist} = \begin{cases} 1, & if\ x_{is} = t \\ 0, & otherwise \end{cases}, \qquad \forall t \in \{1, \dots, T\} \qquad (4)$$

$$\sum_{i=1}^{h_s} \sum_{s=1}^{m} z_{ist} \le C, \qquad \forall t \in \{1, \dots, T\} \qquad (5)$$

$$0 \le x_{is} \le T, \forall i \in \{1, \dots, h_s\}, \forall s \in \{1, \dots, m\} \qquad (6)$$

The objective function (1) is to minimize the total shift of the final appointments from the preferred appointments. Constraint (2) defines the derived binary variable y_{ijs} . $y_{ijs} = 1$, if container i is blocking a container j below it. The container indexing i in each stack is ascending from the bottom to the top (See Figure 4). The model avoids/controls container blockage by defining the constraint (3). This constraint specifies the number of allowed blockings in the initial stack configuration using the parameter k. One "blocking" is counted if a container i has a later pickup time than a container j below it. Figure 4 shows two illustrative examples of blocking modeling in constraints (2) and (3). Typically, we use k equals 0 and called constraint (3) non-blocking constraint. The k values are further changed to investigate the effect of increasing the number of allowed blockings on appointments, as explained in section 5.

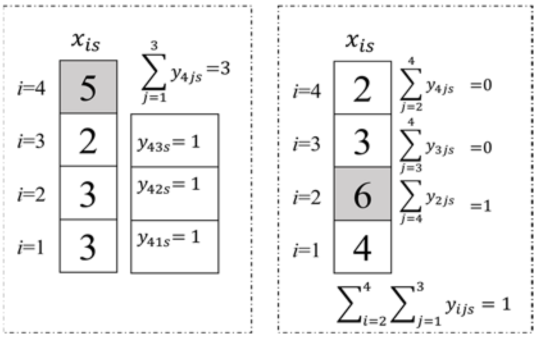

Figure 4: Illustrative examples for the constraints (2) and (3).

Practically, CTs have limited resources capacity to accept all appointments and handle containers demand. Constraint (4) defines the derived binary variable z_{ist} . The variable z_{ist} is used later in constraint (5) to determine and restrict the number of containers picked up during a specific time window t. For modeling simplicity, constraints (2) and (4) are formulated in such binary condition form since many commercial solvers can handle the definition of binary conditions without the need for "Big M" notations. In constraint (6), picking up containers are not allowed after the last working time window in the terminal. This constraint also defines the discrete domain of the decision variable x_{is}. The domain of the binary decision variables y_{ijs} and z_{ist} is inherently defined in constraints (2) and (4).

5 NUMERICAL EXPERIMENTS AND RESULTS

A number of 10 randomly generated instances with different sizes are synthesized to investigate the performance of the developed model. An instance size is determined by the number of stacks (m) and the planning horizon (T). A total number of 525 stacks are solved. Practically, the maximum number of containers in each stack is 5 or 6, where the yard crane can move above the stacks freely without collision. In this paper, we used the maximum height of the container stack (h_s) to be five, and all stacks are full. All containers are assumed to be picked up in time windows (p_{is}) between 1 and T. Finally, the number of allowable container blockings in the initial stack configuration is assumed to be zero; constraint (3) will be $\sum_{i=1}^{h_s-1}\sum_{j=i+1}^{h_s} y_{ijs} \leq 0,\ \forall s \in \{1, \dots, m\}$.

To solve the generated instances, CPLEX Studio IDE 12.9.0 is used. Table 1 illustrates the input parameters of the generated instances and computational results. The optimal objective values that determine the total appointment shift (in time windows) are obtained. The average appointment shift for each container is also obtained. Results show that all instances are solved to the optamilty in a reasonable time; however, the solution time is long for larger instances. It is noticed that each container can be shifted from its preferable pickup time by an average range from 1.4 to 2.5-time window. Therefore, a truck may face delaying or advancing its preferred appointment to avoid the container blockage in the initial stack configuration.

As more illustration, instance (1) solution is shown in Figure 5. In this instance, Figure 5 (a) shows the submitted preferable pickup time (p_{is}) corresponding to each container. In Figure 5 (b), the decided pickup times (x_{is}) obtained by solving the IP model are shown. It can be noted that in the stack $(s = 2)$, the first container on the top of the stack is preferred to be picked up by truck at time window 5, and the container below it $(i = 2)$ has an earlier preferred pick up at time window of 1. As a result, the topmost container is shifted to be picked up in time window 1 to avoid blocking the container below it. Results show that every container in the first instance will be shifted by 1.8 time windows on average from its preferable pickup time.

Table 1: Instances and results.

Inst.	*m*	*T*	*C*	*Optimal Obj. value*	*Optimal Obj. value /stack*	*Avg. shift/container*	*CPU time sec.*
1	5	10	4	45	9.0	1.8	0.33
2	10	10	6	93	9.3	1.86	9.51
3	15	10	8	119	7.9	1.58	137.19
4	20	10	12	145	7.25	1.45	55.22
5	25	10	14	183	7.32	1.46	69.06
6	30	10	17	208	6.39	1.39	59.63
7	40	10	22	288	7.2	1.44	151
8	80	16	30	921	11.5	2.3	378.89
9	100	18	32	1,261	12.61	2.5	113.03
10	200	32	40	4,470	22.35	4.47	1,195.39

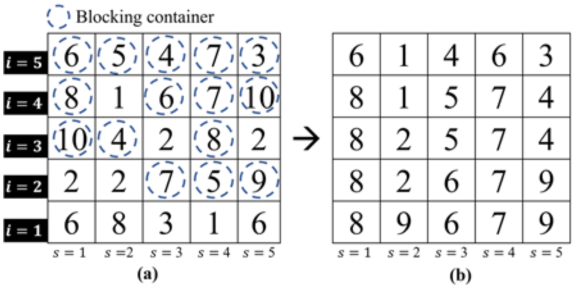

Figure 5: Instance 1 solution (a) stacks configuration with preferable appointment times (p_{is}), (b) the same stacks configuration with optimal appointment times (x_{is}).

The number of allowed blockings (k) and their impact on the objective values are also studied. We solved instance number 4, with the 20 stacks and planning horizon of 10 time windows length, under different k values. Results in Figure 6 show that the more the number of blockings is allowed, the less the container will be shifted from their preferable pickup time. This result is reasonable since the terminal operator may accept more blocking containers in the initial configuration of the stack to achieve higher satisfaction for trucking companies. However, it's worth mentioning that the non-blocking scenario guarantees less service time for external trucks since fewer non-value-added container relocations will be avoided and hence higher productivity for yard cranes.

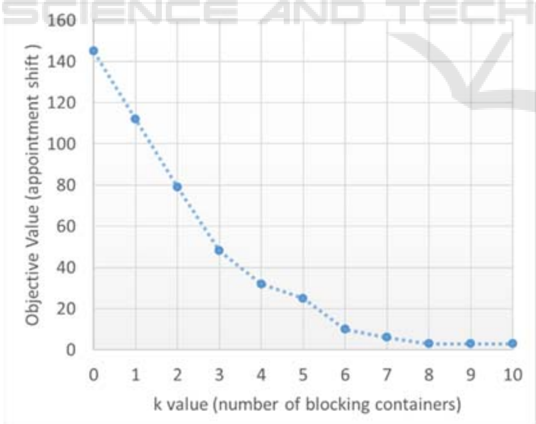

Figure 6: Effect of parameter k on objective values.

5 CONCLUSIONS AND FUTURE WORK

This paper proposes a preliminary design for an appointment scheduling system for picking up import containers by external trucks in CTs considering containers stacking sequence. Results showed that the non-blocking could be achieved while minimizing the appointment shifting from the desired pickup time windows. The developed IP model also considers the terminal capacity and appointment at the latest available time.

This work will be extended in the future by integrating truck appointment scheduling problems with container relocation problems (TAS-CRP). The primary motivation behind the integration is that most TASs are designed to alleviate the terminal congestion without considering the number of relocations that may confront the container retrieval process. Since the container stacking sequence is almost well known at the time of appointment submission, considering the number of relocations and terminal congestion issues is expected to improve the solution of both problems. The main goal is to match truck arrival times with container stacking sequence to minimize relocations, not only the blocking containers in the static stacks configurations, and maximize trucking companies' satisfaction.

However, some issues may arise due to integrating TAS with CRP, such as the problem of hardness. CRP alone has been proven to be an $\mathcal{NP}$-hard problem. In this case, exact or heuristic algorithms may be developed to solve the integrated problem. Another issue is the uncertainty of truck arrival times and container stacking sequence. Considering the number of relocations and preferable truck arrival times may not guarantee the system's efficiency. As a result, a real-time recovery system to recover the distrusted plans supported by reliable response strategies might be interesting to study.

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