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Truck Appointment System for Cooperation between the Transport Companies and the Terminal Operator at Container Terminals

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Abstract: Despite the number of sailings canceled in the past few months, as demand has increased, the utilization of ships has become very high, resulting in sudden peaks of activity at the import container terminals. Ship-to-ship operations and yard activity at the container terminals are at their peak and starting to affect land operations on truck arrivals and departures. In response, a Truck Appointment System (TAS) has been developed to mitigate truck congestion that occurs between the gate and the yard of the container terminal. The vehicle booking system is developed and operated in-house at large-scale container terminals, but efficiency is low due to frequent truck schedule changes by the transport companies (forwarders). In this paper, we propose a new form of TAS in which the transport companies and the terminal operator cooperate. Numerical experiments show that the efficiency of the cooperation model is better by comparing the case where the transport company (forwarder) and the terminal operator make their own decision and the case where they cooperate. The cooperation model shows higher efficiency as there are more competing transport companies (forwarders) and more segmented tasks a truck can reserve.

Keywords: truck congestion problem; truck appointment system; cooperation model; scheduling of truck arrivals

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1. Introduction

The global cargo operations, which had been steadily increasing every year since the global financial crisis in 2008, have been hit hard by COVID-19. Sea transportation regulations such as temporary suspension and cancellation of operations occurred, and 11% of ship operations were canceled for six months since December 2019 when the first case of COVID-19 appeared [1]. For example, 120 out of 126 countries have had restrictions on crew rotation, 92 of these countries have banned crew rotation, and 28 of these countries have allowed crew rotation through the search and approval of the authorities [2]. These restrictions will prevent ships from entering the container terminal until it confirms that the crew has not been infected with the virus (mostly 14 days), impeding the smooth operation of maritime transport.

According to the International Association of Ports and Harbors' Port Economic Impact Barometer report [3], major container terminals in Europe and North America need more moves per ship than ever due to the wave of blank sailings. Despite the number of sailings canceled in the past few months, as demand has increased, the utilization of ships has become very high, resulting in sudden peaks of activity at the import container terminals. As a result, ship-to-ship operations and yard activity at the container terminals are at their peak, especially starting to affect land operations on truck arrivals and departures. With several days off duty, the pressure on the workforce in some ports has increased. Increasing levels of congestion at port access roads exacerbates these issues. Therefore, it is necessary to discuss the truck congestion problem that occurs between the gate and the yard of the container terminal (see Figure 1).

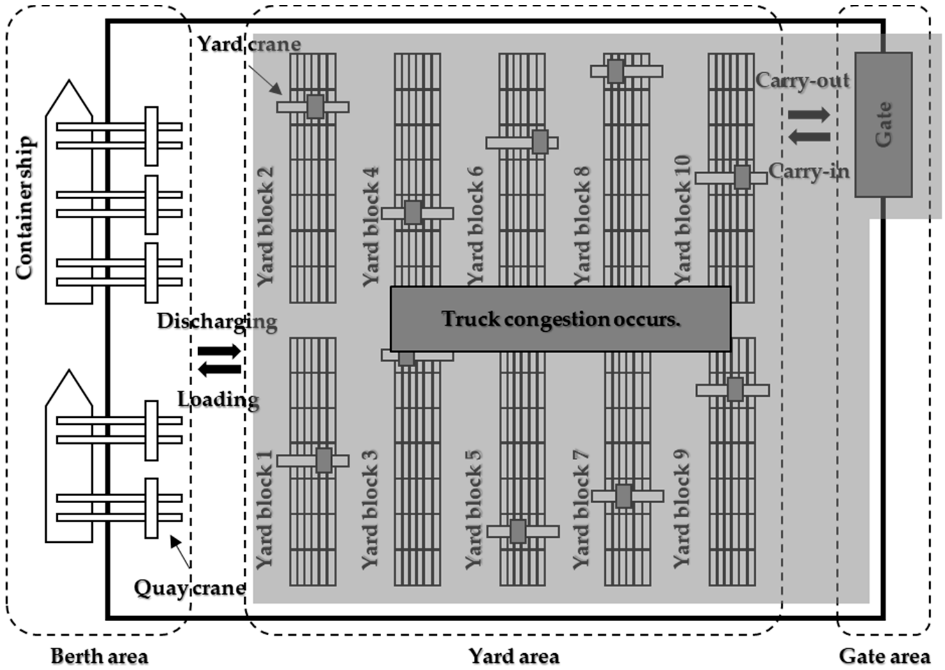

Figure 1. Truck congestion at the container terminal.

The truck congestion between the gate and the yard of a container terminal is the main topic of discussion in large-scale import and export container terminals around the world as it causes many trucks to wait and emit more CO_2 than usual [4]. The reasons for congestion of trucks between the gate and the yard vary, and are mainly due to uncertainty in the truck arrivals, an increase in container ship size, an increase in container volume, failure of logistics equipment or IT systems, and changes in work rules. The basic strategy for mitigating the truck congestion between the gate and the yard is to expand yard spaces and gate spaces. However, space expansion requires a lot of time and cost, and we cannot apply a space expansion strategy in a narrow area where it is impossible to secure additional space. Therefore, it is necessary to solve the truck congestion problem not only for the profitability of stakeholders but also for the reduction of CO_2 emissions.

If the terminal operator can predict the truck arrivals a few hours in advance, they can adjust the yard volume accordingly. The vehicle booking system is developed and operated in-house at large-scale container terminals. However, the efficiency of the system is low due to frequent truck schedule changes by the transport companies (forwarders). Therefore, it is possible to solve the truck congestion problem by developing a Truck Appointment System (TAS) that allows the transport companies (forwarders) and the terminal operator to cooperate to achieve their goals.

The TAS is a practical way for the transport company (forwarder) and the terminal operator to communicate. Some container terminals such as Los Angeles, Long Beach, Hong Kong, Jebel Ali, Antwerp Gateway, and Southampton are applying a TAS [5,6].

In a traditional TAS, the terminal operator pre-sets the maximum number of trucks that can arrive at the gate for each time window, and the transport company (forwarder) books appropriately so as not to exceed the maximum number of trucks per time window. The terminal operator then rejects reservations for trucks from transport companies (forwarders) that exceed the maximum number of trucks per time window [4]. The traditional TAS allows the terminal operator to control the truck congestion between the gate and the yard by limiting the maximum number of truck arrivals. However, transport companies (forwarders) have difficulty meeting the different situations and the transport requirements of individual containers.

In this paper, we propose a new TAS that helps improve the profitability of stakeholders by considering the positions of the transport companies (forwarders) and the terminal operator, respectively, and comparing them with cooperation cases. To this end, we develop a mathematical model from the perspective of (1) the transport company (forwarder), (2) the terminal operator, and (3) cooperation between the transport companies (forwarders) and the terminal operator.

The new TAS reflects each stakeholder's penalties as the objective function of the mathematical model. We define these penalties in terms of collectively expressing the time, number, and capacity that should be optimized to reduce truck congestion. In a mathematical model for the transport company (forwarder), the penalties are the waiting time for the truck and the number of rehandling for carry-out containers. In a mathematical model for the terminal operator, the penalties are the unassigned and unreserved slot capacity (the tasks a truck can reserve).

Figure 2 shows a framework of the new truck appointment system. From the perspective of the transport company (forwarder), it is necessary to reduce the truck turnaround time. The turnaround time consists of a fixed service time, a variable waiting time, and a variable rehandling time. Therefore, the transport companies (forwarders) aim to reduce the truck waiting time and the container rehandling time. From the perspective of the terminal operator, it is necessary to balance the workload of the yard crane. The more tasks that can be reserved and booked, the better the productivity of the container terminal. Therefore, the terminal operator aims to increase the number of slots that can be reserved. From the perspective of cooperation between the transport companies (forwarders) and the terminal operator, it is necessary to consider the purpose of the transport company (forwarder) and the terminal operator at the same time. We multiply each objective function by its weight and add them. Weight refers to the position of the stakeholders in cooperation. In this study, the transport company (forwarder) and the terminal operator have the same weight (transport company's weight = terminal operator's weight = 1).

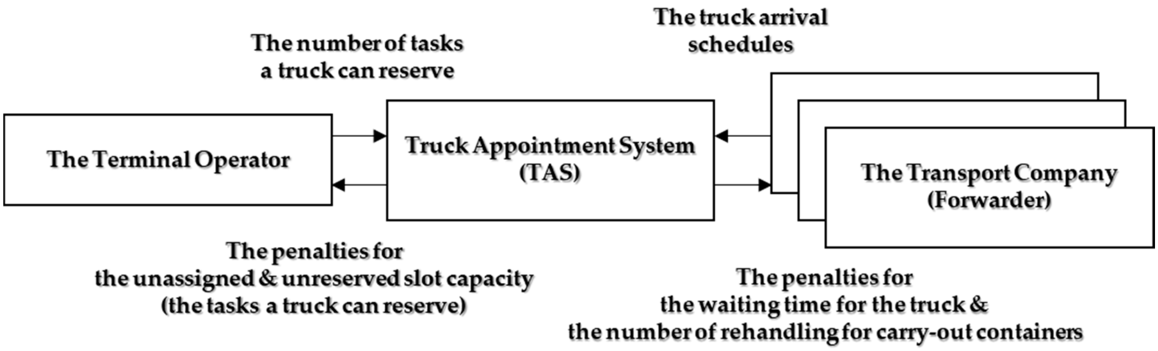

Figure 2. A framework of the new Truck Appointment System (TAS).

By comparing the results of numerical experiments for cases where transport companies (forwarders) and terminal operator make their own decisions and cooperate, we propose a model that is beneficial to all stakeholders.

The rest of this paper consists of the following topics. Section 2 discusses the literature related to this paper. Section 3 defines the TAS problem and proposes a mathematical model for the perspective of the transport company (forwarder), the terminal operator, and cooperation between the transport companies (forwarders) and the terminal operator. Section 4 shows the results of numerical experiments on the mathematical model in three cases. Section 5 provides conclusions and implications for all stakeholders.

2. Literature Review

The transmission of COVID-19 has destroyed the economy and immediate action is required. A study proposes the implementation of new green infrastructure along with the maintenance of the existing infrastructure for economic growth while protecting the environment [7]. However, this approach incurs additional costs because it requires rebuilding the existing infrastructure. In this paper, we improve the productivity of the container terminal by adjusting the work schedule through TAS while using only the existing facilities.

There have been several optimization studies that apply a TAS to the container terminal. One study developed a model that supports the decision making of transport companies (forwarders). A truck schedule was assigned to each time window to mitigate congestion occurring at the container terminal [8]. However, this study considered only export containers, not import containers arriving at the container terminal during peak times when truck congestion mainly occurs. This study also distributed the workload during peak times to each yard block but did not account for the increased waiting times for trucks at other times. Other studies developed a model that assigns truck schedules to each time window and optimized the time window by estimating the queue length [9,10]. However, these studies only considered the waiting time when calculating the truck turnaround time and did not take into account other factors (e.g., the number of rehandling).

Similar to general TAS, which considers the gate and the yard at the same time, there are studies conducted separately in the gate system and the yard system. A study in the gate system minimized the truck waiting cost and the gate operating cost in the queuing problem reflecting truck arrivals and gate processing [11]. Another study in the yard system calculated the expected number of rehandlings through a simulation of the yard crane handling import containers and applied it to the truck queuing model to improve the crane productivity and minimize the truck transaction time [12]. Also, there is a study that managed truck arrivals based on the truck-vessel service relationship in the congestion of the container terminal [13]. This study shows that the congestion of the container terminal is also affected by berth operations.

A study that solved the congestion of the container terminal by simulation determines the container arrival sequence through the gate simulation model reflecting the truck arrival distribution and calculates the container rehandling efficiency according to the heuristic procedure [14]. However, the system that includes both a gate system and a yard system has too many considerations, so it is more difficult to implement in one simulation. Likewise, in this study, only the gate system (not the entire system) was implemented as a simulation. Some studies improved the traditional TAS and developed a new TAS through a negotiation process that considers the needs of both the transport companies (forwarders) and the terminal operator [4,15]. When the transport companies (forwarders) inform the terminal operator of the truck arrivals, the terminal operator calculates an estimated turnaround time for each time window and provides it to the transport companies (forwarders). Then the transport companies (forwarders) reschedule truck arrivals according to the estimated turnaround time per time window. This sequential decision making process has a problem that requires a lot of procedures and time.

One of the methodologies to support the decision making process is to use cluster analysis that takes into account numerical or categorical data. Clustering means dividing data into meaningful groups, and one study reviewed cluster analysis techniques that support the decision-making process [16]. In particular, it provided technical details for cluster analysis dealing with mixed data consisting of numerical and categorical attributes. Meanwhile, in this paper, we propose an integrated decision making process that shares information (e.g., the purpose of each stakeholder) through cooperation between stakeholders and benefits all stakeholders.

In the broad context of competition between transport chains, a dry port is an extended version of a seaport [17,18]. In particular, since ports affect the competitive advantage of the hinterland [19], inland distribution is an important factor [20]. The dry ports are far from typical borders but have access to major metropolitan areas, highways, and labor bases [21]. From a functional perspective, the dry ports consist of close, mid-range, and distant dry ports [18]. Therefore, the TAS of this paper is available to a dry port as well as a seaport.

Most previous studies have focused only on strategies for determining truck schedules that can reduce the turnaround time from the perspective of the transport company (forwarder). From the perspective of the terminal operator, they have focused only on strategies for determining yard crane operations that can improve the productivity of the container terminal.

This paper differs from previous studies in the following aspects:

1. As a factor in reducing truck turnaround time from the perspective of the transport company (forwarder), most of the previous studies only considered truck waiting time, which did not reflect container rehandling time. However, this paper covers not only truck waiting time but container rehandling time as well. In this way, this paper can express truck turnaround time in more detail.
2. As a factor for improving terminal productivity from the perspective of the terminal operator, most previous studies only considered workload balancing and distribution containers to each yard block. However, this paper not only considers workload balancing but also reduces the waste of resources by increasing the number of available and reserved slots together. In this way, this paper can more directly express terminal productivity.
3. Previous studies of the negotiation process between the transport companies (forwarders) and the terminal operator required a sequential decision making process of exchanging their own decisions. However, in this paper we develop a mathematical model for integrated decision making that considers the transport companies (forwarders) and the terminal operator at the same time. Furthermore, it compares the results of numerical experiments for cases where transport companies (forwarders) and terminal operator make their own decisions and cooperate. Then we propose a model that benefits all stakeholders.

For example, we suppose there are one-yard block and two-time windows (t_1 and t_2) for two transport companies (forwarders).

In the sequential decision making process, each company allocates trucks by time window without information from each other. (Company A: five trucks for time window; Company B: four trucks for time window t_1 and two trucks for time window t_2). There are nine trucks for time window t_1 and two trucks for time window t_2. Then, the terminal operator informs each company that congestion will occur due to a longer turnaround time in time window t_1. Therefore, each company decides to move the two trucks from the time window t_1 to time window t_2. (Company A: three trucks for time window t_1 and two trucks for time window t_2; Company B: two trucks for time window t_1 and four trucks for time window t_2). Finally, the terminal operator informs each company that congestion is unlikely to occur.

On the other hand, the integrated decision making process proposed in this study considers cooperation between transport companies (forwarders) and the terminal operator so they share their information. Company A should allocate trucks to time window t_1 as much as possible, and company B does not have a problem with either time window t_1 or time window t_2. Therefore, through a mathematical model provided by the terminal operator, company A moves only one truck to time window t_2, and company B moves two trucks to time window t_2. (Company A: four trucks for time window t_1 and one truck for time window t_2; Company B: two trucks for time window t_1 and four trucks for time window t_2).

In summary, compared to the sequential decision making process, the integrated decision making process can make decisions in a short time, and company A can reduce the cost of changing work by moving only one truck.

3. Model Description and Formulation

3.1. Definition of a New Truck Appointment System(TAS)

In this paper, we consider a new TAS between the transport companies (forwarders) and the terminal operator at the gate and the yard of the container terminal. There is variability in truck arrivals due to the operational complexity of the container terminal and the uncertainty of inland flows [12]. The terminal operating system assigns tasks continuously, but to reduce the complexity of the continuity problem, the TAS is expressed in a discrete form (see Figure 3).

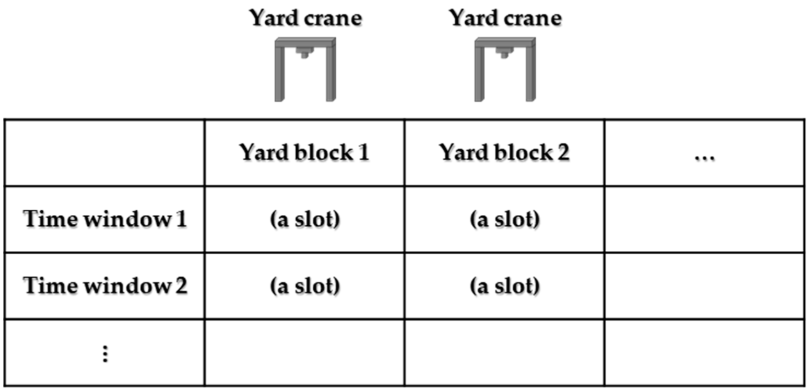

Figure 3. The Truck Appointment System (TAS) expressed in a discrete form.

The TAS consists of yard blocks (space concept, see Figure 4) and time windows (time concept) in a two-dimensional matrix, and each area is called a slot, and the slot capacity refers to the workload of the yard crane. The terminal operator determines the number of tasks a truck can reserve per slot, and the transport companies (forwarders) assign trucks per slot. Then, the yard crane assigned to each block performs the reserved tasks.

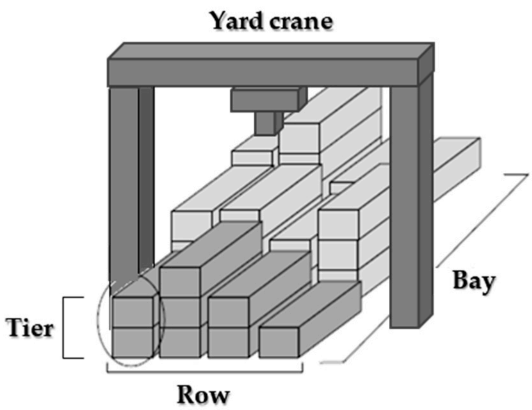

Figure 4. The configuration of the yard block.

From the perspective of the transport company (forwarder), the mathematical model assigns a truck schedule to the slots that can be reserved and set by the terminal operator for each yard block and time window. To do this, we minimize the waiting time for the truck and the number of rehandling for carry-out containers. From the perspective of the terminal operator, the mathematical model optimizes the number of tasks a truck can reserve according to the truck allocations set by the transport companies (forwarders) for each yard block and time window. To do this, we consider whether there is unassigned slot capacity other than the number of tasks a truck can reserve and whether there is unreserved slot capacity. From the perspective of cooperation between the transport companies (forwarders) and the terminal operator, the mathematical model simultaneously determines the number of tasks a truck can reserve and the truck allocations.

We consider the following assumptions to formulate a mathematical model:

1. The container handling process only includes loading/discharging, carry-in/out, and rehandling, not re-marshaling.
2. The priority of loading/discharging is highest and carry-in/out proceeds when there is no loading/discharging. (The truck arrives at the yard block according to the carry-in/out schedule).
3. All export containers arrive at the yard before loading, all import containers leave the container terminal after discharging, and we do not consider other exceptions.
4. We consider rehandling for carry-out, but not rehandling for loading.
5. We apply different stacking rules according to the task type of the container. (In the case of import containers, the carry-out times are different, so they are spread low to reduce rehandling. In the case of export containers, the loading times are similar, so they are stacked high with a small number of rows to facilitate shipment).
6. Carry-in/out or rehandling operations belonging to the same yard block and time window start with the truck that arrives first.

3.2. A Mathematical Formulation for the New Truck Appointment System

We use the following notations to formulate a mathematical model:

Indices and parameters

i Index for a task type, $i \in \{out(bound), in(bound)\}$
j Index for a yard block, $j = 1, 2, \cdots, J$
k Index for a time window, $k = 1, 2, \cdots, K$
n Index for a transport company (forwarder), $n = 1, 2, \cdots, N$
r^n The rehandling rate required during inbound operations by the transport company (forwarder) n, $0 \leq r^n \leq 1$
t The tier where an inbound container is stored
T Maximum number of storage tiers of a yard block
w_{ij}^n The number of tasks for the transport company (forwarder) n of task type i assigned to the yard block j
v_k^n The number of trucks from the transport company (forwarder) n available in the time window k
B_{jk} Maximum number of tasks for a yard crane (TC) in the yard block j and the time window k
s_{ijk} The number of loading/discharging operations of a container of task type i assigned to the yard block j and the time window k
g_k Maximum number of trucks that can pass through the gate in time window k
α Transport company's weight
β Terminal operator's weight

Decision variables

X_{ijk}^n The number of trucks of task type i assigned by the transport company (forwarder) n to the yard block j and the time window k (from the perspective of the terminal operator we apply this variable as a parameter.)
Y_{jk} The number of tasks a truck can reserve allocated by the terminal operator for the yard block j and the time window k (from the perspective of the transport company (forwarder), we apply this variable as a parameter).

3.2.1. A Mathematical Model from the Perspective of the Transport Company (Forwarder)

The mathematical model (Model 1) for the transport company (forwarder) takes into account the penalties for the waiting time for the truck and the number of rehandling for carry-out containers.

$$\text{Minimize } \sum_n \sum_j \sum_k \left\{ \frac{\sum_n \sum_i X_{ijk}^n - 1}{2} \sum_i X_{ijk}^n + r^n \frac{T+1}{2} \sum_{i \in \{in\}} X_{ijk}^n \right\}. \quad (1)$$

Subject to,

$$\sum_k X^n_{ijk} \geq w^n_{ij} \text{ for all } i,\ \ j,\ \text{and } n; \quad (2)$$

$$\sum_i \sum_j X^n_{ijk} \leq v^n_k \text{ for all } k \text{ and } n; \quad (3)$$

$$\sum_n \sum_i X^n_{ijk} \leq Y_{jk} \text{ for all } j \text{ and } k; \quad (4)$$

$$X^n_{ijk} \geq \ 0 \text{ for all } i,\ \ j,\ \ k, \text{and } n. \quad (5)$$

Equation (1) is an objective function that minimizes the sum of the penalties for each transport company's truck waiting and rehandling of carry-out containers. Equation (2) is a constraint, and the number of trucks of task type assigned by the transport company (forwarder) to the yard block must satisfy the number of tasks for the transport company (forwarder) of task type assigned to the yard block. Equation (3) is a constraint, and the number of trucks from the transport company (forwarder) available in time window must be satisfied. Equation (4) is a constraint, and the number of tasks a truck can reserve allocated by the terminal operator for the yard block and the time window must be satisfied. Equation (5) represents the non-negative condition of the decision variable X^n_{ijk}. In the mathematical model from the perspective of the transport company (forwarder), we apply Y_{jk} as a parameter.

The penalty for the waiting time for the truck is the value calculated by multiplying the number of trucks assigned to the same yard block and time window by the expected time waiting for the task to start. We calculate the expected time waiting for the operation to begin like (6)–(8). P_1 is the probability that a truck arrives at the yard block j and the time window k. W is the number of tasks for trucks arriving earlier (the waiting time of the target truck), and λ the sequence in which the trucks arrived in the same yard block and time window. E_1 is the expected time waiting for the operation to begin.

$$P_1 = 1/\sum_n \sum_i X^n_{ijk}, \quad (6)$$

$$W \ = \ \lambda - 1,\ for\ \lambda \ = \ 1, 2, \ldots, \sum_n \sum_i X^n_{ijk}, \quad (7)$$

$$E_1 \ = \ \sum_{\lambda} W \times P_1 \ = \ \sum_{\lambda\,=\,1}^{\sum_n \sum_i X^n_{ijk}} (\lambda - 1)/\sum_n \sum_i X^n_{ijk} = \left(\sum_n \sum_i X^n_{ijk} - 1 \right)/2. \quad (8)$$

The penalty for the number of rehandling for carry-out containers is the value calculated by multiplying the number of carry-out tasks, the expected number of rehandlings required to take out one, and the rate that requires rehandling during the carry-out operation. We calculate the expected number of rehandlings to take out one container like (9)–(11) [22]. P_2 is the probability of taking a container out of tier t. R is the number of rehandlings required to take it out of a specific location. E_2 is the expected number of rehandlings to take a container out of a bay.

$$P_2 = 1/T; \quad (9)$$

$$R \ = \ T \ - \ t \ + \ 1,\ for\ 1 \ \leq \ t \ \leq \ T; \quad (10)$$

$$E_2 = \ \sum_t R \times P_2 = \sum_{t\,=\,1}^{T} (T \ - \ t \ + \ 1)/T = (T \ + \ 1)/2. \quad (11)$$

3.2.2. A Mathematical Model from the Perspective of the Terminal Operator

The mathematical model (Model 2) for the terminal operator takes into account the penalties for the unassigned and unreserved slot capacity (the tasks a truck can reserve).

$$\text{Minimize } \sum_j \sum_k \left\{ \frac{B_{jk}}{\sum_j \sum_k B_{jk}} \left(B_{jk} - \ \sum_i s_{ijk} - Y_{jk} \right) + \left(Y_{jk} - \sum_n \sum_i X^n_{ijk} \right) \right\}. \quad (12)$$

Subject to,

$$\sum_n \sum_i X^n_{ijk} \leq Y_{jk} \text{ for all } j \text{ and } k; \quad (13)$$

$$Y_{jk} \leq B_{jk} - \sum_i s_{ijk} \text{ for all } j \text{ and } k; \quad (14)$$

$$\sum_j Y_{jk} \leq g_k \text{ for all } k; \quad (15)$$

$$Y_{jk} \geq 0 \text{ for all } j \text{ and } k. \quad (16)$$

Equation (12) is an objective function that minimizes the sum of the penalties for the unassigned and unreserved slot capacity (the tasks a truck can reserve). The unassigned slot penalty is proportional to the maximum number of tasks for a yard crane (TC) in each yard block and time window. Equation (13) and Equation (14) are constraints, and each equation means a limit on the number of tasks a truck can reserve allocated by the terminal operator and the number of unassigned slots for the yard block and the time window. Equation (15) is a constraint, and the maximum number of trucks that can pass through the gate in each time window must be satisfied. Equation (16) represents the non-negative condition of the decision variable Y_{jk}. In the mathematical model from the perspective of the terminal operator, we apply X^n_{ijk} as a parameter.

3.2.3. A Mathematical Model from the Perspective of Cooperation between the Transport Companies (Forwarders) and the Terminal Operator

The mathematical model (Model 3) for cooperation between the transport companies (forwarders) and the terminal operator is considered simultaneously by combining their respective models.

$$\text{Minimize } \sum_j \sum_k \left[\begin{array}{c} \alpha \sum_n \left\{ \frac{\sum_n \sum_i X^n_{ijk} - 1}{2} \sum_i X^n_{ijk} + r^n \frac{T+1}{2} \sum_{i \in \{in\}} X^n_{ijk} \right\} \\ +\beta \left\{ \frac{B_{jk}}{\sum_j \sum_k B_{jk}} \left(B_{jk} - \sum_i s_{ijk} - Y_{jk} \right) + \left(Y_{jk} - \sum_n \sum_i X^n_{ijk} \right) \right\} \end{array} \right]. \quad (17)$$

Subject to,

$$\sum_k X^n_{ijk} \geq w^n_{ij} \text{ for all } i, \ j, \text{ and } n, \quad (18)$$

$$\sum_i \sum_j X^n_{ijk} \leq v^n_k \text{ for all } k \text{ and } n, \quad (19)$$

$$\sum_n \sum_i X^n_{ijk} \leq Y_{jk} \text{ for all } j \text{ and } k, \quad (20)$$

$$Y_{jk} \leq B_{jk} - \sum_i s_{ijk} \text{ for all } j \text{ and } k, \quad (21)$$

$$\sum_j Y_{jk} \leq g_k \text{ for all } k, \quad (22)$$

$$X^n_{ijk}, Y_{jk} \geq 0 \text{ for all } i, \ j, \ k, \text{ and } n. \quad (23)$$

Equation (17) is an objective function and reflects the weighted sum of the perspectives of the transport company (forwarder) (Equation (1)) and the terminal operator (Equation (12)). Equation (18) is a constraint, and the number of trucks of task type assigned by the transport company (forwarder) to the yard block must satisfy the number of tasks for the transport company (forwarder) of task type assigned to the yard block. Equation (19) is a constraint, and the number of trucks from the transport company (forwarder) available in time window must be satisfied. Equation (20) and Equation (21) are constraints, and each equation means a limit on the number of tasks a truck can reserve allocated by the terminal operator and the number of unassigned slots for the yard block and the time window. Equation (22) is a constraint, and the maximum number of trucks that can pass through the gate in each time window must be satisfied. Equation (23) represents the non-negative condition of the decision variable X^n_{ijk} and Y_{jk}.

3.3. Analysis Procedure for the New Truck Appointment System

We carry out numerical experiments according to the following analysis procedure to propose a model that is beneficial to all stakeholders and draw implications. For numerical experiments, we apply the Monte Carlo approximation, a method of approximating the expected value using sampling. The greater the number of samples extracted by the Monte Carlo approximation, the higher the accuracy of the approximate expected value. This method utilizes the central limit theorem, which states that if you have a population with mean μ and standard deviation σ and take sufficiently large random samples from the population, then the distribution of the sample means will be approximately normally distributed. Therefore, in this paper, the expected value is approximated by sampling more than 100 times.

Step 1-1: Solve the mathematical model from the perspective of the transport company (forwarder) (Section 3.2.1). We reflect an arbitrary Y_{jk} value that follows a uniform distribution as an input variable and find the decision variable X^{n}_{ijk}. We derive the average of X^{n}_{ijk} by sampling more than 100 times and reflect it as an input variable in step 1-2.

Step 1-2: Solve the mathematical model from the perspective of the terminal operator (Section 3.2.2). We reflect the average of X^{n}_{ijk} derived in step 1-1 as an input variable and find the decision variable Y_{jk}. We derive the average of Y_{jk} by sampling more than 100 times.

Step 2: Solve the mathematical model from the perspective of cooperation between the transport companies (forwarders) and the terminal operator (Section 3.2.3). We derive the averages of the decision variable X^{n}_{ijk} and Y_{jk} by sampling more than 100 times.

Step 3: Compare the objective values derived in step 1-1 and step 1-2 with the value derived in step 2. We compare the mathematical model solved by the transport companies (forwarders) and the terminal operator from their respective perspectives and the one that reflects their goals at the same time. We propose a model that benefits all stakeholders.

4. Numerical Experiments and Results

We conducted numerical experiments using IBM ILOG CPLEX 12.8, and we used a personal laptop with Intel ® Core ™ i7-9750H CPU and 16GB memory specification.

The mathematical model in this paper considers task type, yard block, time window, and transport company (forwarder) as indices. Excluding the task type, the remaining three factors affect the objective function of both the transport company (forwarder) and the terminal operator. Therefore, the numerical experiments consider three factors of yard block, time window, and transport company (forwarder).

Through the sensitivity analysis, we examined the change of the objective value according to the change in these three factors. Since the yard block and time window are common elements constituting the two-dimensional matrix of TAS, they are considered together in the sensitivity analysis.

We first conducted a sensitivity analysis according to the change in the number of yard blocks and time windows under the control of the number of transport companies (forwarders). Next, we conducted a sensitivity analysis according to the change in the number of transport companies (forwarders) under the control of the number of yard blocks and time windows. Finally, we analyzed how the changes in these three factors affect the objective value of the mathematical model.

4.1. The Change in the Number of Yard Blocks and Time Windows

As shown in Table 1, we experimented with three cases of yard blocks and time windows based on two transport companies (forwarders). The input parameters for each case reflect random values generated according to the uniform distribution (as shown in Table 2). Table 3 and Figure 5 show the experimental results for the three mathematical models.

Table 1. Cases for the change in the number of yard blocks and time windows.

Cases	No. of Transport Companies (Forwarders)	No. of Yard Blocks	No. of Time Windows
Case 1	2	2	2
Case 2	2	3	3
Case 3	2	4	4

Table 2. Input parameters for the change in the number of yard blocks and time windows.

Input Parameters	Values
r^n	u (0,1.0)
w^n_{ij}	u (0,10)
v^n_k	u (10,30)
B_{jk}	u (20,40)
s_{ijk}	u (0,5)
g_k	u (40,60)
Y_{jk}	u (5,15)

Table 3. The experimental results for the change in the number of yard blocks and time windows.

Cases	The Objective Value of Model 1 (A)	The Objective Value of Model 2 (B)	The Objective Value of Model 3 (C)	Gap (%) ((A+B) − (C))/(C)
Case 1	210.19	16.56	225.19	0.69
Case 2	229.41	19.40	244.79	1.64
Case 3	251.78	21.59	266.80	2.46

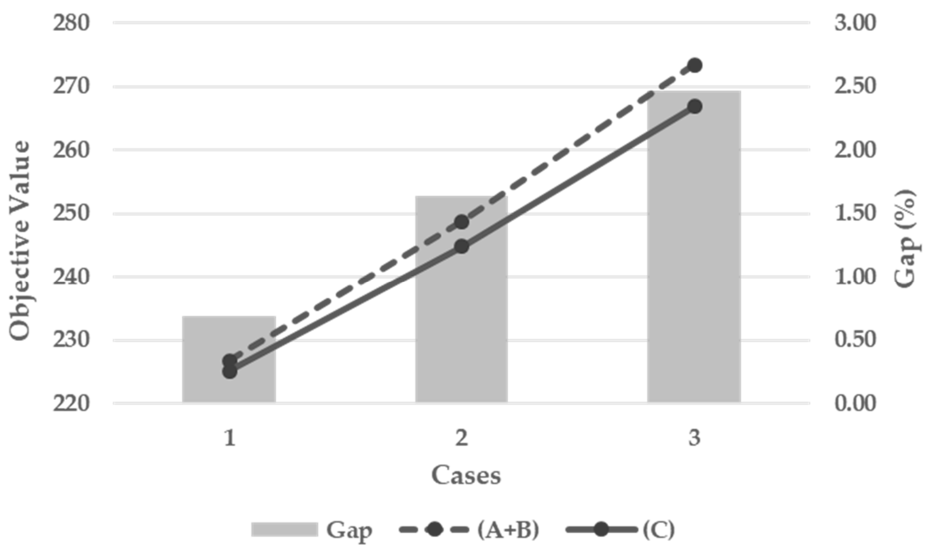

Figure 5. Comparison of experimental results for the change in the number of yard blocks and time windows.

According to the experimental results, in all cases, the objective value when the transport companies (forwarders) and the terminal operator cooperated was lower than when the transport company (forwarder) and the terminal operator decided independently. As the number of yard blocks and time windows increased, the gap in the objective value gradually increased.

4.2. The Change in the Number of Transport Companies (Forwarders)

As shown in Table 4, we experimented with three cases of transport companies (forwarders) based on two-yard blocks and two-time windows. The input parameters for each case reflect random values generated according to the uniform distribution (as shown in Table 5). Compared with the input parameters in Table 2, since the number of transport companies (forwarders) is large, the range of Y_{jk} is higher, but other input parameters are the same. Table 6 and Figure 6 show the experimental results for the three mathematical models.

Table 4. Cases for the change in the number of transport companies (forwarders).

Cases	No. of Transport Companies (Forwarders)	No. of Yard Blocks	No. of Time Windows
Case 1	2	2	2
Case 2	3	2	2
Case 3	4	2	2

Table 5. Input parameters for the change in the number of transport companies (forwarders).

Input Parameters	Values
r^n	u (0,1.0)
w_{ij}^n	u (0,10)
v_k^n	u (10,30)
B_{jk}	u (20,40)
s_{ijk}	u (0,5)
g_k	u (40,60)
Y_{jk}	u (10,25)

Table 6. The experimental results for the change in the number of transport companies (forwarders).

Cases	The Objective Value of Model 1 (A)	The Objective Value of Model 2 (B)	The Objective Value of Model 3 (C)	Gap (%) ((A+B) − (C))/(C)
case 1	210.19	16.56	225.19	0.69
case 2	407.26	12.39	397.15	5.67
case 3	770.86	8.84	697.22	11.83

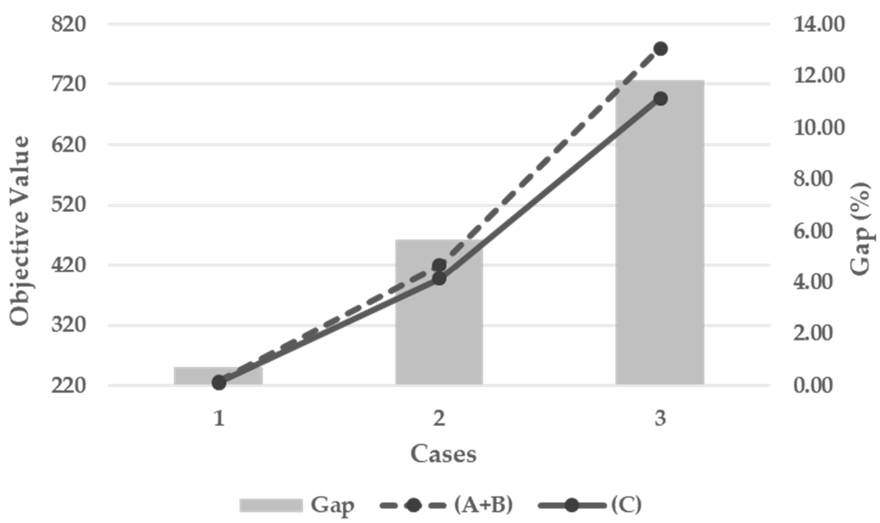

Figure 6. Comparison of experimental results for the change in the number of transport companies (forwarders).

According to the experimental results, in all cases, the objective value when the transport companies (forwarders) and the terminal operator cooperated was lower than when the transport company (forwarder) and the terminal operator decided independently. Also, as the number of transport companies (forwarders) increased, the gap in the objective value increased rapidly.

4.3. Analysis of the Results from the Perspective of Each Transport Company (Forwarder) and Terminal Operator

Based on the results of the sensitivity analysis performed in Sections 4.1 and 4.2, we analyzed how the changes in the number of yard blocks, time windows, and transport companies (forwarders) affected each transport company (forwarder) and terminal operator. Figure 7 shows the experimental results of the impact of the three factors on the transport company (forwarder). Figure 8 shows the experimental results of the effect of these changes on the terminal operator.

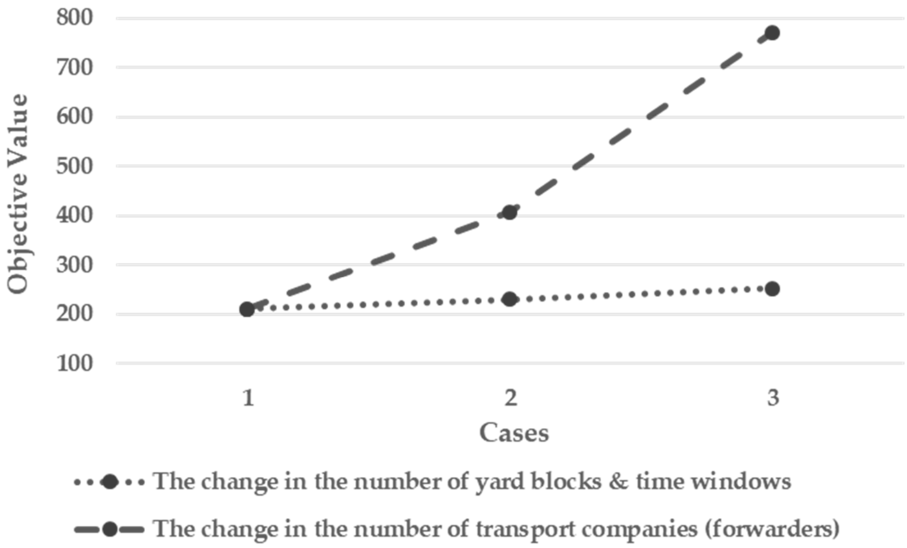

Figure 7. The relationship between the transport company (forwarder) and the change in the number of yard blocks, time windows, and transport companies (forwarders).

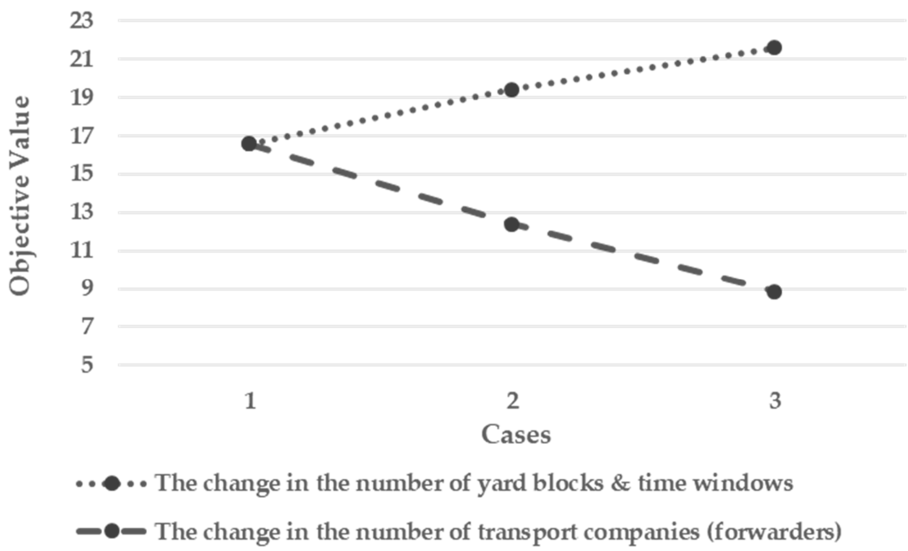

Figure 8. The relationship between the terminal operator and the change in the number of yard blocks, time windows, and transport companies (forwarders).

Both the number of yard blocks and time windows and the number of transport companies (forwarders) have a positive effect on the transport company (forwarder). In other words, as the number of yard blocks and time windows and the number of transport companies (forwarders) increased, the objective value of the transport company (forwarder) increased.

The terminal operator has a positive relationship with the number of yard blocks and time windows. However, it has the opposite relationship to the number of transport companies (forwarders). In other words, as the number of yard blocks and time windows increased, the terminal operator's objective value increased. On the other hand, as the number of transport companies (forwarders) increased, the terminal operator's value decreased.

5. Discussion

The results of the sensitivity analysis on the number of yard blocks, time windows, and transport companies (forwarders) clearly show the impact of maximizing the benefits of stakeholders.

When looking at the case of cooperation, the efficiency of the cooperation model was higher as the number of yard blocks and time windows increased. In case 3, the cooperation model showed an efficiency (gap) of 2.46%. This means that the more segmented tasks a truck can reserve, the more cooperation is required. The more detailed the reservation, the easier it is to plan the gate and the yard operations. As the number of transport companies (forwarders) increased, the efficiency of the cooperation model rapidly increased. In case 3, the cooperation model showed an efficiency (gap) of 11.83%. This proves that cooperation is necessary as the competitive relationship intensifies. Transport company (forwarder) can share information with other transport companies (forwarders) beyond communication with the terminal operator, enabling efficient truck allocation.

Looking at the perspective of the transport company (forwarder), the penalty of the transport company (forwarder) proportionally increased as the number of yard blocks, time windows, and transport companies (forwarders) increased. The increase in the number of tasks a truck can reserve has a minor impact on the transport company (forwarder). However, increasing the number of transport companies (forwarders) means increasing competitors, so the penalty for each transport company (forwarder) increases dramatically.

From the perspective of the terminal operator, results were quite different from those of the transport company (forwarder). The terminal operator's penalty is proportional to the number of yard blocks and time windows. However, as the number of transport companies (forwarders) increased, the terminal operator's penalty decreased in inverse proportion. The fact that a small number of transport companies (forwarders) participate in the TAS means that the management efficiency of the terminal operator is low. It is because one transport company's allocation schedule is a big part of it. On the other hand, as the number of participating transport companies (forwarders) increases, the terminal operator's management efficiency increases. This is because as the number of transport companies (forwarders) increases, the number of unreserved slots decreases.

6. Conclusions

Despite the number of sailings canceled in the past few months, as demand has increased, the utilization of ships has become very high. As a result, ship-to-ship operations and yard activity at the container terminals are at their peak, especially starting to affect land operations on truck arrivals and departures. The truck congestion causes many trucks to wait and emit more CO_2 than usual. Therefore, we solved the truck congestion problem by developing a new TAS that allows the transport companies (forwarders) and the terminal operator to cooperate to achieve their goals. The TAS in this paper helps reduce the truck congestion by considering the positions of the transport companies (forwarders) and the terminal operator, respectively, and comparing them with cooperation cases. To this end, we developed a mathematical model from the perspective of (1) the transport company (forwarder), (2) the terminal operator, and (3) cooperation between the transport companies (forwarders) and the terminal operator.

We reflected each stakeholder's penalties as the objective function of the mathematical model. In a mathematical model for the transport company (forwarder), the penalties are the waiting time for the truck and the number of rehandling for carry-out containers. In a mathematical model for the terminal operator, the penalties are the unassigned and unreserved slot capacity (the tasks a truck can reserve). From the perspective of cooperation between the transport companies (forwarders) and the terminal operator, we multiplied each objective function by its weight and added them. The transport company (forwarder) and the terminal operator have the same weight (transport company's weight = terminal operator's weight = 1).

For numerical experiments, we applied the Monte Carlo approximation, a method of approximating the expected value using sampling. The greater the number of samples extracted by the Monte Carlo approximation, the higher the accuracy of the approximate expected value. We sampled more than 100 times to approximate the expected value. Through the sensitivity analysis, we examined the change of the objective value according to the change in three factors of yard block, time window, and transport company (forwarder). Since the yard block and time window are common elements constituting the two-dimensional matrix of TAS, they are considered together in the sensitivity analysis.

As a result of the experiments, the cooperation model shows higher efficiency as the number of competing transport companies (forwarders) increases. Also, the more segmented tasks a truck can reserve in TAS, the easier it is to plan the gate and the yard operations. From the perspectives of the transport company (forwarder) and the terminal operator, a large number of yard blocks and time windows benefits both the transport company (forwarder) and the terminal operator. On the other hand, as the number of competitors increases, the penalty of the transport company (forwarder) increases, whereas the management efficiency of the terminal operator tends to improve.

This study attempted to see the efficiency of the cooperation model from the assumption that the transport companies (forwarders) and the terminal operator cooperate equally. However, in reality, each container terminal has a subordinate relationship between stakeholders and there is a limit that cannot reflect this legal and political environment.

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