

Article

A Stochastic Model for Shipping Container Terminal Storage Management

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Abstract: A good port terminal is not only a major economic multiplier for the nation's prosperity by being a gateway for trading, but is also an attractor for other commercial infrastructure development such as banks, logistics agencies, and manufacturing and trading investments. A measurement of the efficiency of a terminal is the duration-of-stay of visiting vessels. A quick and efficient loading/unloading process can increase productivity and thus reduce the waiting time for a vessel. In this study, we address the space allocation for stacking export containers. If the storage layout and the loading plan work well together, the productivity of the terminal can be increased and the duration-of-stay needed for each visiting vessel is reduced. In this paper, we propose a hybrid storage policy combining class-dedicated and sharing strategies, and construct a stochastic programming model using the concept of recourse.

Keywords: port logistics; port management; container management; allocation strategy; stochastic programming



Citation: Xu, Y.; Wang, M.; Lai, K.K.; Ram, B. A Stochastic Model for Shipping Container Terminal Storage Management. *J. Mar. Sci. Eng.* **2022**, *10*, 1429. <https://doi.org/10.3390/jmse10101429>

Academic Editors: Hsuan-Shih Lee and Po-Hsing Tseng

Received: 7 September 2022

Accepted: 26 September 2022

Published: 4 October 2022

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1. Introduction

Since the 1960s, containerization of cargo transportation has been the norm in global logistics services. Owing to standardized structure and sizes, containers offer obvious advantages of rationalization of shipment, of security, of handling facility and procedures and of multi-modal transportation. Containers are now playing a key role in the globalization of business. To handle a huge volume of containers through the terminals, the management of terminal operations therefore becomes an important area to study. Owing to competition among the ports in any given geographical zone, the efficiency of a port terminal becomes extremely important. A good port terminal is not only a major economic multiplier for the nation's prosperity by being the gateway of trading, but it is also an attractor for other commercial infrastructure developments such as banks, logistics agencies, manufacturing and trading investments. A measurement of the efficiency of a terminal is the duration-of-stay of visiting vessels. The duration-of-stay is mainly affected by berthing schedules and the loading/unloading processes. To shorten the waiting time for berthing, one can increase the number of berths (i.e., increase the number of servers). However, this is a long-term investment and involves a huge amount of financial capital. Alternatively, a quick and efficient loading/unloading process (i.e., a decrease in serving time) can increase the productivity and thus reduce the waiting time of a vessel. This requires the application of better planning, skilled labor and fast data-processing systems. In this study, we address the space allocation for stacking export containers. A good space allocation and storage layout of container stacks reduce the workload of both manpower and handling equipment. If the storage layout and the loading plan work well together, the productivity of the terminal can be increased and the duration-of-stay of vessels can be reduced. Additionally, other important factors such as skilled labor, loading/unloading

and berthing scheduling procedures are responsible for boosting productivity and cutting down on time. Our objective in this paper is to propose a novel storage strategy so as to retain the advantages of two traditional storage policies.

The organization of this paper is as follows: In Section 2, we briefly introduce the problem of layout planning for export containers in a terminal yard. Literature related to the problem is reviewed. We also highlight difficulties and solution to the problems. We propose a hybrid storage strategy combining class-dedicated and shared storage policy in Section 3. A stochastic linear model of the concept of recourse is formulated. Numerical examples are presented in Section 4. Concluding remarks are provided in Section 5.

2. Backgrounds to the Problem

A seaport container terminal is a very complicated system consisting of several important sub-systems. First, we elaborate on procedures for handling export containers. When an outside truck with an export container arrives at the port, the truck has to pass through the terminal gatehouse for document submission and inspection. After inspection, the truck has to wait in a parking area to receive the instructions from a port planner to unload the container. When the port planner decides the best location for the container, then the truck leaves the parking area to unload the container. A handling machine such as straddle carrier helps to pick up the container. The outside truck can then leave while the container is placed in the terminal waiting area for exportation. When a vessel arrives, a berth allocation process is carried out to schedule the berthing and anchoring in order to ship the container from one location to another. A loading plan is formulated taking into account the next port of destination. After unloading all import containers from the ship, the stowage and loading process are carried out for those imported containers. The straddle and internal trucks transfer the containers from the storage stacks placed in the terminal yard to the bay-side, where the containers are loaded into the ship by gantry cranes. After loading all containers, the vessel leaves for the exportation purpose.

As the link between the waterside and landside transport chains, the yard storage system is particularly significant because it serves as more than just a place to store containers. The majority of terminal operations either start or end in the container yard. A growing amount of storage space is also needed in the ports to accommodate the rising container volume. Storage systems for containers are generally categorized into two types—chassis system and stacking system. The chassis system is a storage container located on a tractor, which makes the movement of containers simple. However, for accommodating this kind of system, the port should have ample space. Due to a sharp rise in trade volume, ports nowadays usually have limited space. A typical storage system in most yards is therefore usually of the second type—stacking system (see Figure 1). However, a drawback of stacking systems is that the retrieval of a container may require multiple container handling (i.e., moving away the containers on top if one wants to retrieve a container that is at the bottom). These re-handling moves are generally unproductive moves and time-consuming.

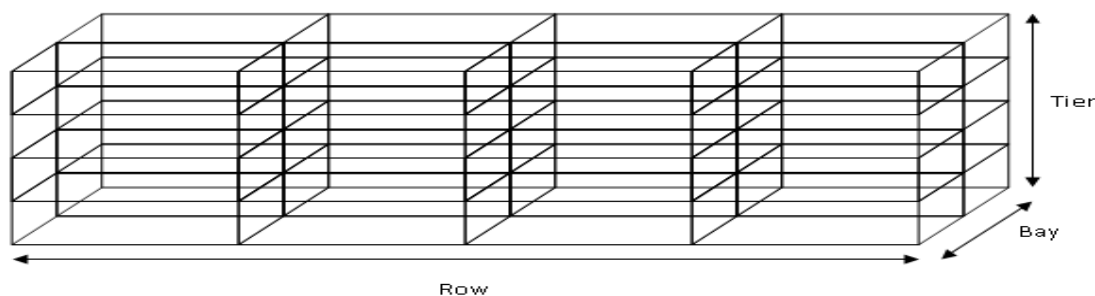


Figure 1. A stacking storage system for containers.

In the layout of container terminals, the containers in a stacking system are usually divided into three different stack zones such as for importation, for exportation and empty

container stacks for storage management purposes. A typical layout of a container terminal is shown in Figure 2. Generally, export containers are stacked near the bay side while import containers are stored near the gatehouse. This arrangement ensures better traffic control within the port and reduces the handling time for importing and exporting the containers.

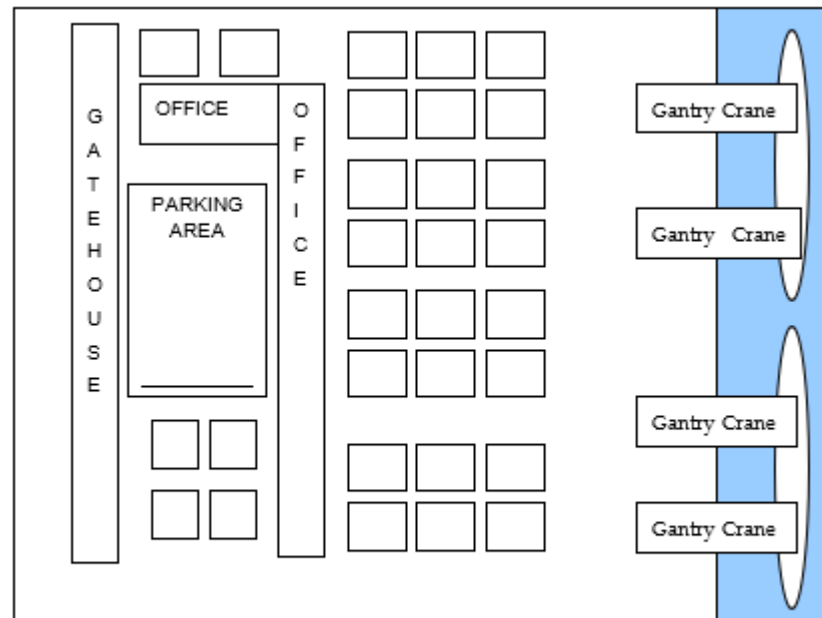


Figure 2. A Layout of a Container Terminal Port.

A vessel usually visits several ports for unloading containers. The space on the ship becomes free for loading new containers. Containers are categorized into different groups and placed on the container ship. These groups are made based on the planning of discharge ports. Some other considerations are also taken care of such as weight balance, containers loaded with dangerous goods and other criteria, etc. Unlike the import containers that arrive in a counted batch, the export containers arrive one by one randomly. Another unforeseeable consideration is that the quantities of different groups of containers are not known until the cut-off day as the volume of exportation to different countries changes so fast, and the task of space allocation in such an uncertain environment is challenging to a port planner.

3. Literature Review

Since the 1970s, many scholars and experts have analyzed the storage-space allocation problem from different aspects and applied various methods to solve practical problems. A brief discussion of storage strategies for export containers can be found in [1]. Chen [2] studied the ports in Taiwan, Hong Kong, Korea and UK. Two strategies have been summarized, namely the “pre-marshalling” and “sort-and-store” strategies. The pros and cons of the two strategies are pin-pointed. However, no quantitative models were reported. Koza and Preston [3] studied and analyzed the storage strategy of containers in the yard, and concluded that the storage near the berth is better than random storage. Preston and Kozan [4] established the container-stack allocation model with the optimal goal of minimizing the turnaround time of all ships, and solved it using a genetic algorithm. In terms of improving the utilization rate of storage space, Kim and Park [5] discussed the problem of the allocation of export containers in the container terminal. The entire planning period was divided into multiple stages. The number of containers arriving at each stage, the ship they belonged to, the maximum number of containers occupied by each ship and the maximum number of stacks in each area were known: a mixed integer-programming model was established with the goal of minimizing the shipping distance of the containers, and two solutions were proposed. However, the model makes certain assumptions about many

important parameters, and does not consider the departure of the containers. Holguín-Veras and Jara-Díaz [6] discussed the optimal-container allocation and optimal-pricing strategy of the container port system, fixed the arrival of imported containers randomly, and considered the container's presence time. Lee et al. [7] proposed a storage-space allocation method to reduce the number of re-handling rates, and used a load balancing method to reduce traffic congestion. Zhen [8] used the method of "shared storage space" to solve the problem of storage space allocation under conditions of uncertainty, and thereby improved the utilization rate of the storage space. Jin et al. [9] allocated containers to the ships in different areas based on their transportation costs.

In terms of storage-space operation and transportation distance balance, Zhang [10] proposed a rolling scheduling method for HIT container terminals in Hong Kong that adopted a site planning strategy and continuously adjusted the exceeded time to solve the storage/space allocation problem. In this case, loading and unloading operations were evenly distributed to different areas so that the throughput profit could be maximized and the ship berthing time minimized. Kim et al. [11] analyzed the number of storage allocations of containers in the horizontal and vertical shoreline directions based on the average travel distance of the trucks and the number of cranes under different layouts. Bazzazi [12] aimed to balance the operation volume of different areas and reduced the re-handling rate of the yard. Based on different types of container classification stacking zones, a genetic algorithm was used to solve the problem of storage space allocation. Kim et al. [13] studied the storage-space allocation problem of large-scale steel raw materials and found out where to store materials to determine the optimum efficiency of transportation distance and terminal operation. Lee and Kim [14] optimized the size of the storage area and estimated the operating time of the cranes using different models. Park et al. [15] utilized the rolling planning cycle to simulate the planning cycle of the yard operation. The objective function proposed in this case was to minimize the imbalance of the workload between each area of the planning cycle, and an integer-programming model was established to allocate storage space. Zhen et al. [16] aimed to reduce the cost of moving containers in the yard by establishing an integer-programming model. In this case, the traffic congestion inside the yard was taken into consideration, and the storage location of the containers was optimized during multiple periods.

Mi et al. [17] proposed target planning for the allocation of export container and established a rolling planning model to reduce the horizontal transportation distance from storage zones to berth zones. Additionally, the proposed hybrid algorithm improved the overall horizontal transportation distance in order to reduce the imbalance between areas. Chen and Lu [18] conducted a detailed study on the storage and distribution strategy of export containers by using a two-stage method. The obtained results successfully reduced the blocking of cars and cranes during the loading operation. Zhang et al. [19] constructed a two-stage model and identified a priority to characterize the location of the export containers that improved the storage quality and reduced the invalid operation of export containers. Chang and Zhu [20] put forth a storage space allocation problem in an effort to find a point of symmetry between two interactive aspects: the unbalanced allocations and reallocation operations of inbound containers in the railway operation area, and the efficiency and effectiveness of rail-water intermodal container terminals. Žulj et al. [21] combined the storage location, size, shape and operation sequence, and designed a path to collect containers and verified the influence of the parameters in the model. Zhang et al. [22] studied the impact of the mixed storage of import and export containers and proposed the principle of reducing the storage time to maximize the number of simultaneous loading and unloading operations. Gharehgozli and Zaerpour [23] studied the problem of stacking of export containers with the goal of reducing the re-handling rate, and proposed a way to allow mixed storage of different types of containers. We note that most of these research studies focused on the re-arrangement of containers where containers for different destinations are stacked in a mixed manner. The observations can be summarized as follows:

1. The total capacity of export containers assigned to different container groups on board a ship is assumed to be fixed, although containers arrive randomly.
2. Containers are first collected and their ordering is un-sorted. Re-marshalling or buffer space is then utilized for sorting before loading the containers onto the ship.

However, the nature of international trading is now changing fast owing to the advances in digital technologies and manufacturing systems. A demand for output to a particular area may change suddenly. Therefore, the quantity required to be exported to a destination port may change all the time. The adaptation of a “sharing” storage policy may be advantageous due to simplification in operations. These operations improve the profitability of the container terminals by sharing logistics resources among multiple terminal operators. Further, the cost of the operations is distributed among several transported containers. These containers shared the space that can be thought of as an internet-based platform that involves more than one container sharing storage space to receive and send the goods in the containers. Although there have been instances of sharing storage space between specific neighboring container terminals, the application is limited because many terminals do not adhere to common rules or procedures for sharing the storage space. In addition, the uncertainty in the arrival patterns of the containers can be ignored at the first planning stage, but great effort and time is needed for re-handling to marshal the containers. Logically, if the arrival patterns are known to be fixed in advance, a “class-dedicated” storage policy (i.e., the sort-and-store strategy) will lead to a smoother loading process because containers will be stacked in a yard in the expected loading sequence and so remove any requirement for sorting (or re-marshalling) and re-handling. Another advantage of a class-dedicated storage policy is that less re-handling of containers, also reduces damage to goods and containers. However, a difficulty is that a large storage space is always required in the yard.

In an uncertainty environment, the actual quantities of export containers are not defined until these have been finalized on the last cut-off day. Moreover, as reported by Chen [2], it happens from time to time that the shippers want to change the loading vessel (COV) and change the port of discharge (COD). To cope with the uncertainties in decision-making, there are at least two possible approaches, namely simulation and stochastic programming. Simulation has been the classical approach in the literature for modeling the operations of container terminals. However, the shortcoming of using simulation is that the model is usually case-orientated. A simulation model is usually built to investigate a particular container terminal. Therefore, to overcome this setting, in this study, we focus on the mathematical programming formulation so that the model is helpful for solving problems that are more general.

4. Proposed Hybrid Dedicated-Sharing Storage System

In this paper, we consider the advantages of the two developed storage strategies (dedicated and sharing). The proposed idea uses the combination of random access and rack storage to automate the position of containers in the warehousing system. We divide the storage area into two divisions—a dedicated zone and a shared zone. Inbound and outbound containers are temporarily stored in the shared yard at container terminals. A combination of container demand increase and dedicated storage scarcity creates complex operational challenges for yard managers. Therefore, yard managers require that the dedicated zone face these challenges. In the dedicated zones, all containers are of the same category, therefore containers can be loaded in a sequence with no ill-effects of re-handling, reducing the workload and increasing the productivity of the port terminal. A shared zone is utilized for collecting all containers if the dedicated zones are full. The arrival of any additional containers is stored in the shared zone. The containers from the shared zone are mixed up but need to be loaded into different areas on board ship; therefore, re-handling may be needed. An obvious research problem arises: how large is the optimal space to be reserved in the dedicated zones for collecting the arrival containers so that total time and costs can be minimized in re-handling the containers. The design of our hybrid dedicated–

shared storage policy is well suited to a two-stage stochastic programming framework. The re-handling in the shared zone can be considered as recourse for a dedicated zone.

4.1. Notations and Assumptions

For simplification, we consider the stochastic nature for the arrival of export containers in a scenario representation. The demands for each class are assumed to be discretized into some independent scenarios with a single figure that represents a particular demand level. The total capacity for a given storage area is assumed to be adequate to fulfill the demands under all scenarios. If capacity is full, the customer request is either rejected or handled by other means that are not considered in the proposed model. We apply the two-stage stochastic programming framework to the two-stage storage planning for export container stacking systems as shown in Figure 3. In Stage 1, yard managers sort the containers in a mixed-up system, increasing the need for additional handling and for speeding up operations. A container should be handled twice: once when being moved to or from the dedicated zone and then again when being moved to or from the shared zone. Anything beyond that is likely to indicate inefficiency.

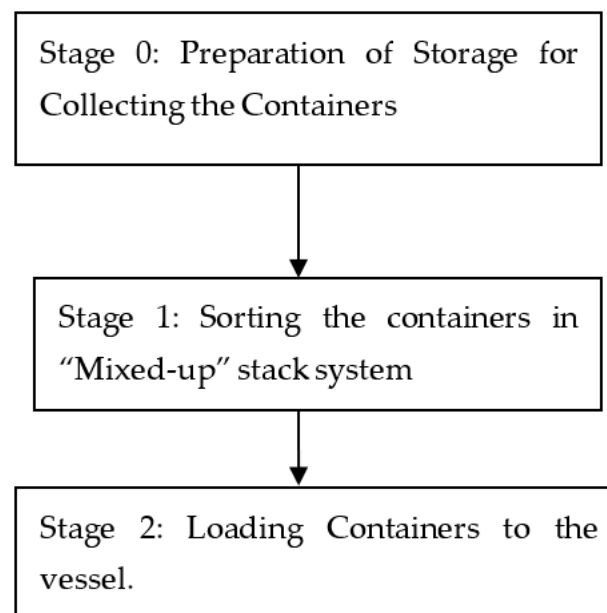


Figure 3. Storage Planning for Export Container Stacking System.

We denote the following notations for our model.

n : Index for group ($n = 1, 2, \dots, N$)

x_n : Dedicated space of group expressed as number of containers (firststage decision variables)

k : Index for different scenarios for demands ($k = 1, 2, \dots, K$)

p_k : Probability of scenario k ($p_k \geq 0, k = 1, 2, \dots, K; \sum_{k=1}^K p_k = 1$)

d_n^k : Realization of demand quantity of container to class under scenario k

y_n^k : Number of containers of group in shared zone (second-stage decision variables) under scenario k

R : Maximum number of rows for any given space area

B : Maximum number of bays for any given space area

H : Maximum number of tiers of stacking

4.2. Estimation of Cost Coefficients

The handling costs in the “shared” zone and “dedicated” zone play an important role in the proposed model. We use the following notation in our framework.

α : Average unit cost for the movement of a container in a dedicated zone.

This includes lifting a container, and putting it on a trailer or internal truck, and transporting it to the bay-side. To get an estimate cost, management uses this operational cost for the empty containers also, as the empty container is treated as an identical good during transportation. The movement of empty containers is similar to the movement of non-empty containers in a dedicated zone.

β : Average unit cost for the movement of a container in a shared zone.

This includes searching for and re-handling a container, lifting it, and putting it on a trailer or internal truck and transporting it to the bay-side. Most of the terminals use an estimated “All-sharing” cost, one quick estimation of which is their total throughput per year divided by the annual cost related to the re-handling and transferring of the container from storage to yard-side.

4.3. Two-Stage Recourse Model

We formulate the following two-stage stochastic model for the proposed dedicated–shared model.

$$\text{Minimize}_{x, y^k \{k=1,2,\dots,K\}} \alpha^T x + \sum_{k=1}^K p_k [\beta e^T y^k] \quad (1)$$

$$\text{Subject to } e^T x + e^T y^k \leq M \text{ for } k = 1, 2, 3, \dots, K \quad (2)$$

$$x + y^k \geq d^k \text{ for } k = 1, 2, 3, \dots, K \quad (3)$$

$$x, y^k \geq 0 \text{ and integer for } k = 1, 2, 3, \dots, K \quad (4)$$

where $\alpha^T = [\alpha_1 \ \alpha_2 \ \dots \ \alpha_N]$, $e^T = [1 \ 1 \ \dots \ 1]$, $(d^k)^T = [d_1^k \ d_2^k \ \dots \ d_N^k]$, $x^T = [x_1 \ x_2 \ \dots \ x_N]$, $(y^k)^T = [y_1^k \ y_2^k \ \dots \ y_N^k]$, and M is the total available capacity that can be expressed as:

$$M = R \times B \times H - (H - 1) \quad (5)$$

The last term $(H - 1)$ denotes the number of empty free spaces required for handling containers on top in order to retrieve those underneath. As the storage zone has two parts—shared zone and dedicated zone—the last term indicates the available free zone where the yard managers can accommodate containers. The first part of the objective function (1) is the cost for the dedicated zone, while the second part is the expected cost for the shared zone. For planning purposes, managers charge a cost based on the capacity of the container rather than on utilization. The reasons are as follows: (i) the utilization is not available at stage 0 as the collection of containers is not yet started at this stage; (ii) when management decides to store a container according to capacity M , there is an opportunity cost if the storage spaces are empty in either dedicated zones or shared zones. We assume the opportunity cost is close to the cost of the container because the cost of labor and equipment at a terminal is almost certain even if no service is performed. The variable cost (relating to the fuel or gas used for lifting and trucking if the space is occupied) is relatively small. In other words, we simply use an average cost for each zone. Constraint (2) ensures the capacity that should not be exceeded. Hence, the total available capacity is $R \times B \times H - (H - 1)$. We assume the capacity cannot be easily expanded. Although, in some situations, some late coming containers may have to be located somewhere temporarily, we also assume no additional charge should be made for these special handling events. In our model, we do not consider these special cases. Constraint (3) is to ensure the demands are fulfilled. We assume the capacity has to handle all demands under different scenarios. Although the model is in an integer programming setting, a prominent feature of the model is that the deterministic equivalent form can be solved by a linear programming technique that can handle a large-scale model. We show

below that the coefficient matrix in the constraints guarantees generating integer solutions. The constraints can be expressed as in the following:

$$\Gamma \begin{bmatrix} x \\ y^k \end{bmatrix} \leq \begin{bmatrix} M \\ -d^k \end{bmatrix},$$

$$\text{where } \Gamma = \begin{bmatrix} e^T & e^T \\ I & I \end{bmatrix}.$$

The coefficient matrix Γ can be proved to be uni-modular by reference to [24] and the uni-modular property of a matrix. Indeed, we readily find that when any column in Γ is divided into two sets, the row sum of one set minus the row sum of the other set is either ± 1 or 0. With the property of uni-modularity, the linear programming (LP) solution to the model can always guarantee to have integral values. Therefore, the model can be solved by LP-relaxation.

5. Numerical Examples

Consider export container stacking for a vessel visiting 10 discharge ports. The total land space available in the yard is 10 rows within 4 bays. Since the maximum height for stacking is 6 tiers, and saving 5 free spaces for re-handling, the maximum number of containers that can be accommodated is 2395. A yard storage planner estimate for the demands will be outlined in the 5 different scenarios. The demand quantities and likelihood of each scenario is summarized in the following Table 1.

Table 1. Data for Numerical Illustration.

Scenario	Port of Discharge										Likelihood
	1	2	3	4	5	6	7	8	9	10	
1	200	150	270	200	240	220	180	150	160	140	0.1
2	220	250	300	100	120	150	180	160	240	250	0.3
3	200	250	160	245	280	180	180	120	250	240	0.3
4	240	180	270	240	260	250	180	200	250	210	0.1
5	300	100	250	260	240	230	200	240	270	260	0.2

To investigate more deeply, we consider a more complicated problem. For simplicity, we assume the cost of loading a container in dedicated areas is 1 unit while the cost for loading a container in a shared zone is 3.5 units. The results of space allocation are in the Table 2. Here, there is no dedicated space allocated, all containers will be mixed in a shared zone. We can then calculate the cost without the dedicated-sharing storage policy. Compared with the traditional sharing strategy, the average saving is 63.43% in cost.

Table 2. Space Allocation using Proposed Dedicated-Shared Strategy.

	Port of Discharge									
	1	2	3	4	5	6	7	8	9	10
Dedicated Zone	240	145	250	245	240	230	180	200	250	250
Shared Zone										
Scenario 1	0	0	20	0	0	0	0	0	0	20
Scenario 2	0	105	50	0	0	0	0	0	0	10
Scenario 3	0	105	0	0	40	0	0	0	0	0
Scenario 4	0	35	20	0	20	20	0	0	0	0
Scenario 5	60	0	0	15	0	0	20	40	20	0

6. Conclusions

We propose a hybrid between dedicated and shared storage policy strategies to reduce the transportation cost of containers and increase the revenue to the shipping companies. The concept of recourse with a stochastic programming model yielded a better approach for allocating space for containers. Numerical results show that the proposed framework can generate significant savings in cost policy. It has also been argued the standard stochastic programming technique considers the expected cost without considering the risk attitude of the decision maker. In a future study, we may include such approaches into the model. A well-known approach called robust optimization is under investigation by our team for container-terminal yard management. One of the difficulties for robust optimization is that the second stage creates large-scale non-linear problems. An iterative parametric scheme embedding with non-separable parameters is helpful to solve such challenging problems.

Author Contributions: Conceptualization, Y.X., M.W. and K.K.L.; methodology, Y.X., M.W. and K.K.L.; software, Y.X., M.W., K.K.L. and B.R.; validation, B.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the General research project on major theoretical and practical issues in philosophy and social sciences of Shaanxi Province, China, grant number [2022ND0185].

Conflicts of Interest: The authors declare no conflict of interest.

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