A Simulation Study of a Storage Policy for a Container Terminal

Henokh Yernias Fibrianto[1], Bonggwon Kang[1], Bosung Kim[1],
Annika Marbach[2], Tobias Buer[3], Hans-Dietrich Haasis[2],
Soondo Hong[1](✉), and Kap Hwan Kim[1]

[1] Pusan National University, Geumjeong-gu, Busan 46241, Korea
joelhenokh@gmail.com, bonggwon.kang@gmail.com,
ksung505@gmail.com, {soondo.hong, kapkim}@pusan.ac.kr
[2] University of Bremen, Bibliothekstraße 1, 28359 Bremen, Germany
{annika.marbach, haasis}@uni-bremen.de
[3] German University of Technology in Oman, Halban, Muscat, Germany
tobias.buer@gutech.edu.om

Abstract. This paper proposes a storage policy for container terminals that handle large numbers of vessels and containers. The storage policy considers the estimated workload at a certain area in a given period; the partition of a storage block into subblocks; the proximities between containers belonging to the same group; the segregation between different groups of containers; and the stack heights of containers. We develop a framework for simulating container repositioning and vehicle congestion and use it to evaluate the yard crane productivity rate, amount of repositioning, and service time of a real-world port terminal. The preliminary result shows that the container terminal operates more efficiently under the storage policy with a bay as a subblock setting.

Keywords: Storage policy · Simulation · Container terminal

1 Introduction

The increasing use of container ships has encouraged container terminals to improve their ability to handle larger numbers of ships and containers more efficiently, and global competition has incentivized container terminal operators to improve their services (shorter vessel turnaround times, faster container unloading, etc.) [1]. One option that promises significant improvement in container terminal operations, according to studies, is that having a management strategy in place can reduce vessel turnaround time [2] and container retrieval time [3], and improve land productivity [4] and overall container terminal productivity [5].

Developing and implementing the most effective strategy, however, may be challenging. The challenges mostly come from the assumptions, such as negligible repositioning operation, negligible truck congestion, and known demand, that are difficult to achieve in practice.

In this paper, we propose a policy-based storage management strategy (hereafter storage policy), which is both practical and effective for determining each container's

M. Freitag et al. (Eds.): LDIC 2020, LNLO, pp. 62–69, 2020.
https://doi.org/10.1007/978-3-030-44783-0_6

location. The proposed storage policy considers the estimated workload at a certain area in a given period of time, the partition of a storage block into subblocks, the proximities between containers belonging to the same group, the segregation between different groups of containers, and the stack heights of containers. We develop a framework to measure the policy's key performance indicators: yard crane productivity rate, amount of container repositioning, and service time.

2 Literature Review

We briefly review the relevant literature on storage management strategies. These studies identify four specific parameters that affect a storage management strategy: the workload at a particular storage area, vehicle congestion, stack height, and shared space. Jeong, Kim, Woo and Seo [2], who proposed a workload-based yard planning method, showed that considering the workload at each storage block reduces the turnaround times of vessels. Petering [6] presented a storage location assignment system considering the distance between the berth and storage location, yard template, truck congestion, and stack height. Jiang, Lee, Chew, Han and Tan [4] proposed a two-step solution consisting of a template generation which allocates the subblocks for each vessel, and a space allocation and workload assignment which regulates the sharing space between neighboring subblocks. Zhen [7] considered the uncertainty in the number of containers and the amount of truck congestion when allocating subblocks for each vessel. He and Tan [8] investigated a resilient yard template that minimizes the risk of assigning slots that are unavailable because of fluctuations in storage demand. Tan, He and Wang [9] addressed a flexible yard template, considering yard allocation and yard crane deployment, to minimize the total cost of container transportation and YC movement. Jin, Lee and Hu [10] studied a berth and yard template design to balance quay-side workloads caused by vehicle congestion, considering transshipment demand. Li [11] studied the sizes and locations of export container groups, considering peak workloads in yard storage.

3 Storage Policy for a Container Terminal

We design a storage policy to define the storage location of an incoming container by sequentially determining the block, subblock, and row location. When deciding the block location, the storage policy considers the workload at each block in the time period when the container is expected to be stored and then selects the block with the least workload to balance the workload among the blocks.

After the block has been selected, the storage policy selects the subblock based on the segregation enforcement level and expected proximities. The segregation enforcement level is a parameter with an integer value which limits the number of container groups that may be stored in a subblock. We assume that the segregation enforcement level regulates the amount of repositioning and space utilization. The expected proximity, which is a parameter with a real value ranging from 0 to 1, represents the importance of concentrating containers in a subblock by placing the containers close to other containers in the same group. We also assume that the expected proximity influences the rail-mounted gantry crane (RMGC) movement cost, which affects the time to store/retrieve a container. The selection of the subblock is also dictated by the partition resolution; here, we use a bay as a subblock, a half-bay as a subblock, and a slot as a subblock. The partition resolution complements the segregation enforcement level by regulating the amount of repositioning and space utilization. During the selection of the subblock, the policy uses and updates the reservation data of the groups of containers that occupy each subblock.

Finally, the storage policy selects the row location within the subblock. This step is omitted when we use a slot as a subblock. Otherwise, the storage policy selects the row based on the flatness parameter, which is a parameter with an integer value representing the maximum height gap between the highest and lowest stacks in the subblock. A flatness parameter of 1 means that the height in all slots in the subblock must be as equal as possible, and a flatness parameter of 2 or more means that the storage policy will stack containers until the height difference of the highest stack and lowest stack is equal to 2 before the policy selects the lower stack. The policy uses the inventory data of the containers within each slot to determine the selection of rows. Figure 1 illustrates the storage policy flowchart.

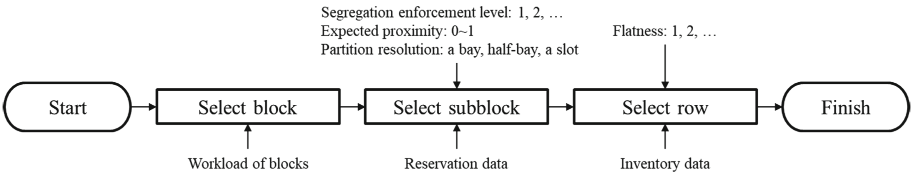

Fig. 1. Storage policy flowchart.

In Fig. 2(a), the integers in the blocks are the number of expected containers to be stored in a time period. The block in the first row of the second column should be selected for input containers because it has the least workload. Figure 2(b) shows that the size of the subblock is fixed as a bay, a half-bay, and a slot. Figure 2(c) shows the number of container groups stacked when the size of the subblock is a bay. Figure 2(d) shows the maximum difference between the tiers in a bay according to the flatness level.

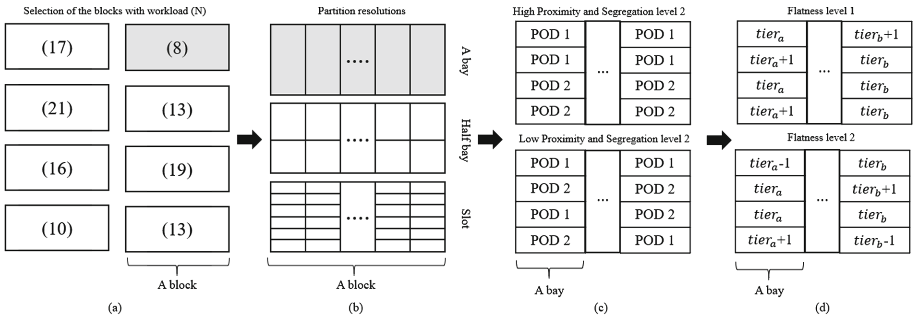

Fig. 2. Yard configurations under various parameters.

4 Simulation Design

We use a simulation to evaluate the storage policy of a real container terminal. The simulation ensures that the container storage and retrieval operations comply with real physical constraints. For instance, each container must be stacked on the ground or on another container, and a container can be retrieved only if there is no container on top of it. Our simulation also considers the congestion between trucks.

The simulation framework consists of the simulation system, supervisory system, and database system illustrated in Fig. 3. The supervisory system represents the operating system responsible for managing the terminal's equipment, infrastructure, and storage, i.e., rail-mounted gantry crane (RMGC), internal and external trucks, truck lanes and intersections, container slots, gates, and quay crane (QC) transfer point. The supervisory system manages the RMGC jobs, internal truck jobs, and container storage locations. The database system records the starting times, starting locations, completion times, and completion locations of RMGC and truck jobs, vessel berthing and leaving times, and tracks all jobs and inventory. We use the three systems to evaluate the container terminal's performance and to understand how the parameters in the storage policy affect the key performance indicators.

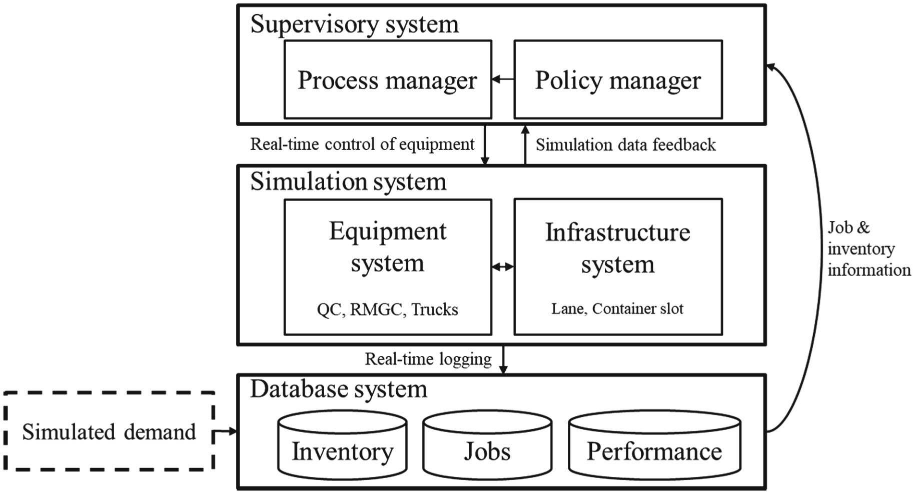

Fig. 3. Simulation framework.

5 Experiment Design and Discussion

We base our experiment on an area served by RMGCs in the Busan Port Terminal (BPT) in Korea. As shown in Fig. 4, the area consists of 4 × 2 blocks with two sets of 4 horizontal blocks parallel to the quay line. Each block has 34/17 bays for storing 20/40 ft containers. For simplicity, we only consider the 40 ft containers; hence, each block has 17 bays and 9 container slots (rows) for each bay. At each slot, containers can be stacked up to 7 tiers. We assume there are 20 internal trucks and 8 QCs, and that one RMGC serves each block. We set the equipment specification similar to the real-world container terminal.

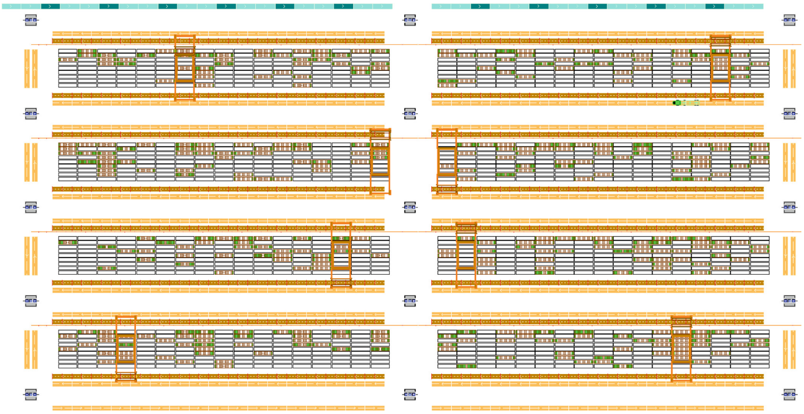

Fig. 4. BPT simulation layout.

We consider a demand pattern with mostly transshipment containers ($\sim 75\%$ of all incoming/outgoing containers), where 2 to 5 vessels arrive per day; the number of containers unloaded and loaded from and to each vessel ranges from 50 to 525 containers; and 2 vessels can berth simultaneously. We run the experiment for 30 days.

We use the simulation to measure RMGC productivity rate, service time, and the amount of repositioning. We measure the amount of repositioning when processing both loading and import jobs. The RMGC productivity rate affects the container terminal's overall productivity rate. We measure the average of RMGC productivity rate as the number of containers (cntr.) being stored and retrieved per yard crane per hour. The service time represents the container terminal's service level from the perspective of the vessel and external truck. We quantify the times required to retrieve a container to the internal truck (loading), store a container from the internal truck (unloading), retrieve a container to the external truck (import), and store a container from the external truck (export). The amount of repositioning represents the inefficiency that is substantially influenced by the storage management strategy.

We conduct experiments by changing one variance at a time to investigate the trade-offs between the different parameters. Table 1 summarizes their effects on the container terminal's performance. For instance, defining a bay as a subblock reduces the need to reposition the YC, i.e., saves time and cost. A comparison of our proposed storage policy with Zhen [7] shows improved performance in the container terminal's loading, export times, and total numbers of repositioning for loading.

Table 1. Workload balancing storage policy under different parameters.

	Partition resolution	Segregation	Proximity	Flatness	Productivity (Ctrl./ RMGC/hour)	Loading Time (s)	Unloading Time (s)	Import Time (s)	Export Time (s)	Total repositioning for loading (cntr.)	Total repositioning for import (cntr.)
Proposed approach	Slot	1	0.5	1	11.39	397.06	253.59	788.31	322.98	43569	17808
	Half-bay	1	0.5	1	11.41	398.38	262.36	811.95	324.32	36770	20459
	Bay	1	0.5	1	11.40	399.19	262.03	803.32	322.01	33903	20498
	Bay	1	0.5	3	11.41	391.36	261.63	798.65	317.72	33201	20235
	Bay	1	0.5	5	11.40	400.99	265.18	818.23	321.33	37658	20808
	Bay	2	0.5	1	11.39	388.62	256.44	791.06	306.83	35404	18897
	Bay	3	0.5	1	11.41	388.53	254.50	780.33	318.50	37223	17428
	Bay	1	0.3	1	11.41	394.69	260.41	801.66	313.16	33777	20668
	Bay	1	0.7	1	11.40	399.64	261.75	798.07	314.14	33932	20156
Consignment strategy (modified from Zhen [7])					11.37	407.32	251.01	792.70	332.76	49768	17015

6 Conclusion

This paper described a storage policy to improve the performance of large container terminals. The storage policy defined the storage location of an incoming container by sequentially determining the block, subblock, and row location. Four parameters were used to consider the workload of each block. The segregation enforcement level regulated the number of container groups that could share a subblock. The expected proximity controlled the concentration of containers in a group within a certain location. The partition resolution defined the size of a subblock. The flatness dictated how to stack containers in a subblock. A realistic simulation consisting of a simulation system, supervisory system, and database system was used to evaluate the storage policy. Yard crane productivity rate, amount of repositioning, and service time were used as the key performance measures. The result suggested that the container terminal operates more efficiently under the storage policy with a bay as a subblock setting.

Future research will develop a parameter tuning guideline for the proposed storage policy. We also will apply the proposed storage policy to different management systems (yard crane dispatching, truck pooling, etc.), measure the improvements in container terminal service, and analyze throughput across the systems.

Acknowledgment. This research was supported under the framework of the International Cooperation Program managed by the National Research Foundation of Korea (Project Number: NRF-2016K1A3A1A48954044).

References

1. Lee, C.-Y., Song, D.-P.: Ocean container transport in global supply chains: overview and research opportunities. Transp. Res. Part B: Methodol. **95**, 442–474 (2017)
2. Jeong, Y.-H., Kim, K.-H., Woo, Y.-J., Seo, B.-H.: A simulation study on a workload-based operation planning method in container terminals. Ind. Eng. Manag. Syst. **11**, 103–113 (2012)
3. Gharehgozli, A., Zaerpour, N.: Stacking outbound barge containers in an automated deep-sea terminal. Eur. J. Oper. Res. **267**, 977–995 (2018)
4. Jiang, X., Lee, L.H., Chew, E.P., Han, Y., Tan, K.C.: A container yard storage strategy for improving land utilization and operation efficiency in a transshipment hub port. Eur. J. Oper. Res. **221**, 64–73 (2012)
5. Petering, M.E., Wu, Y., Li, W., Goh, M., de Souza, R., Murty, K.G.: Real-time container storage location assignment at a seaport container transshipment terminal: dispersion levels, yard templates, and sensitivity analyses. Flex. Serv. Manuf. J. **29**, 369–402 (2017)
6. Petering, M.E.: Real-time container storage location assignment at an RTG-based seaport container transshipment terminal: problem description, control system, simulation model, and penalty scheme experimentation. Flex. Serv. Manuf. J. **27**, 351–381 (2015)
7. Zhen, L.: Container yard template planning under uncertain maritime market. Transp. Res. Part E: Logist. Transp. Rev. **69**, 199–217 (2014)
8. He, J., Tan, C.J.E.O.: Modelling a resilient yard template under storage demand fluctuations in a container terminal. Eng. Optim. **51**, 1547–1566 (2019)

9. Tan, C., He, J., Wang, Y.J.A.E.I.: Storage yard management based on flexible yard template in container terminal. Adv. Eng. Inform. **34**, 101–113 (2017)
10. Jin, J.G., Lee, D.-H., Hu, H.: Tactical berth and yard template design at container transshipment terminals: a column generation based approach. Transp. Res. Part E: Logist. **73**, 168–184 (2015)
11. Li, M.-K.J.E.J.o.I.E.: A method for effective yard template design in container terminals. Eur. J. Ind. Eng. **8**, 1–21 (2014)