An analysis of integrative AGV and ASC dispatching by means of simulation

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In designing container terminals, the terminal management has to consider the choice for interrelated AGV and ASC dispatching rules. In this paper, we therefore examine the joint decision problem of dispatching containers to AGVs and selecting ASCs. Savings of approximately 20 per cent in the number of AGVs are achievable, if we apply the nearest-AGV-first rule in combination with the cyclic ASC rule. Twin-load AGVs can also be used to obtain significant savings in unloading times and number of AGVs required.

Introduction

The most critical planning and control problems arise at the deep-sea side to ensure short berth times of the ships. In this paper, we study the interrelated planning and control problems of dispatching unloaded containers to automated guided vehicles (AGVs) and the dispatching of these containers to automated stacking cranes (ASCs) operating in the stack. We perform a simulation study and use several performance criteria such as the unloading times of the ship, the number of automated guided vehicles required and the utilization of these vehicles to examine dispatching rules. The input data used in this simulation study are obtained from interviews with logistics managers of Europe Combined Terminals at the port of Rotterdam and Vis and Harika [1].

Dispatching rules

We consider an automated container terminal in which the quay cranes (QCs) and ASCs are connected by a multiple lane loop layout. This loop is a fixed sequence of pick-up and delivery points at QCs and ASCs. AGVs travel over these fixed guide paths to handle all transportation requests. The moment an QC starts unloading a container, an AGV is selected from the parking area, according to a certain dispatching rule.

In this study, we will compare the performance of the following QC-initiated dispatching rules (i.e. an AGV is selected by an QC from a set of idle AGVs to transport a container – see [2]):

- *Nearest-vehicle-first*: A free AGV at the smallest distance is dispatched to the QC needing an AGV.
- *Farthest-vehicle-first*: A free AGV at the farthest distance is dispatched to the new QC.
- *Random vehicle rule*: The new pick-up container is randomly dispatched to any available AGV regardless the location of the AGV and the QC.
- Cyclic rule: Select the first available AGV beginning with the successor of the last AGV selected (to balance the workload among all AGVs in the system).
- *Preferred order rule*: Select the available AGV with the lowest unit number to transport the container.

The assigned AGV travels to the QC and waits for the container. The QC positions the container on the AGV. It might also occur that the crane needs to wait for an AGV to arrive. In that case, the QC needs to wait before it can unload a new container. After receiving the container, the AGV starts transporting the container to the stack. A variable number of AGVs is available to transport containers from the ship to the stack. The number of vehicles required to minimize the unloading times of the ship will be used as a performance measure in the experiments.

The AGV with its container will already be dispatched to an ASC with empty storage locations. In this way, we avoid the possibility that the AGV might have to travel to an ASC with no free space for a container. In this paper, we will study the performance of the following ASC selection rules:

- *Cyclic rule*: Select the first available ASC with empty space beginning with the successor of the last ASC selected (to balance the workload among all ASCs in the system.)
- *Random rule*: Randomly select an ASC with empty space.
- *Farthest/nearest ASC first*: Select the ASC (with empty space) at the farthest/smallest distance and with no more than v AGVs on their way to this ASC. The optimal value of v will be determined in the various experiments.

After arrival at the stack, the container needs to be stored in the stack. If the ASC is still handling another container, the AGV needs to wait. The ASC lifts the container off the AGV and the empty AGV travels back to the parking area at the QCs. After arrival of the AGV at the pick-up and delivery point of the assigned block, the ASC lifts the container and stores it in the stack.

First, we select one of the rows in the block according to a uniform distribution, in which each row has an equal probability to be chosen. Thereafter, a storage location is randomly selected from the empty locations in the selected row. Figure 1 summarizes the conceptual model. All processes have been implemented in Arena Rockwell Software.

Results

We will compare the dispatching rules with the following performance measures:

- *Total cycle time* required to unload all containers off the ship and store them in the stack
- *Minimum number* of AGVs required to achieve a minimal total cycle time
- *Average utilization* of the AGVs

We generate 100 replications of each experiment to obtain a high level of accuracy (relative error smaller than two per cent with a probability of 95 per cent) in the results.

In the simulation study, we assume that 2,500 containers need to be unloaded off the ship by four QCs. Due to space restrictions at both sides of the ship, containers are not equally distributed over the ship. Usually, 15 per cent of the containers are designated for the leftmost QC, 35 per cent for each of the two QCs in the middle and 15 per cent for the rightmost QC.

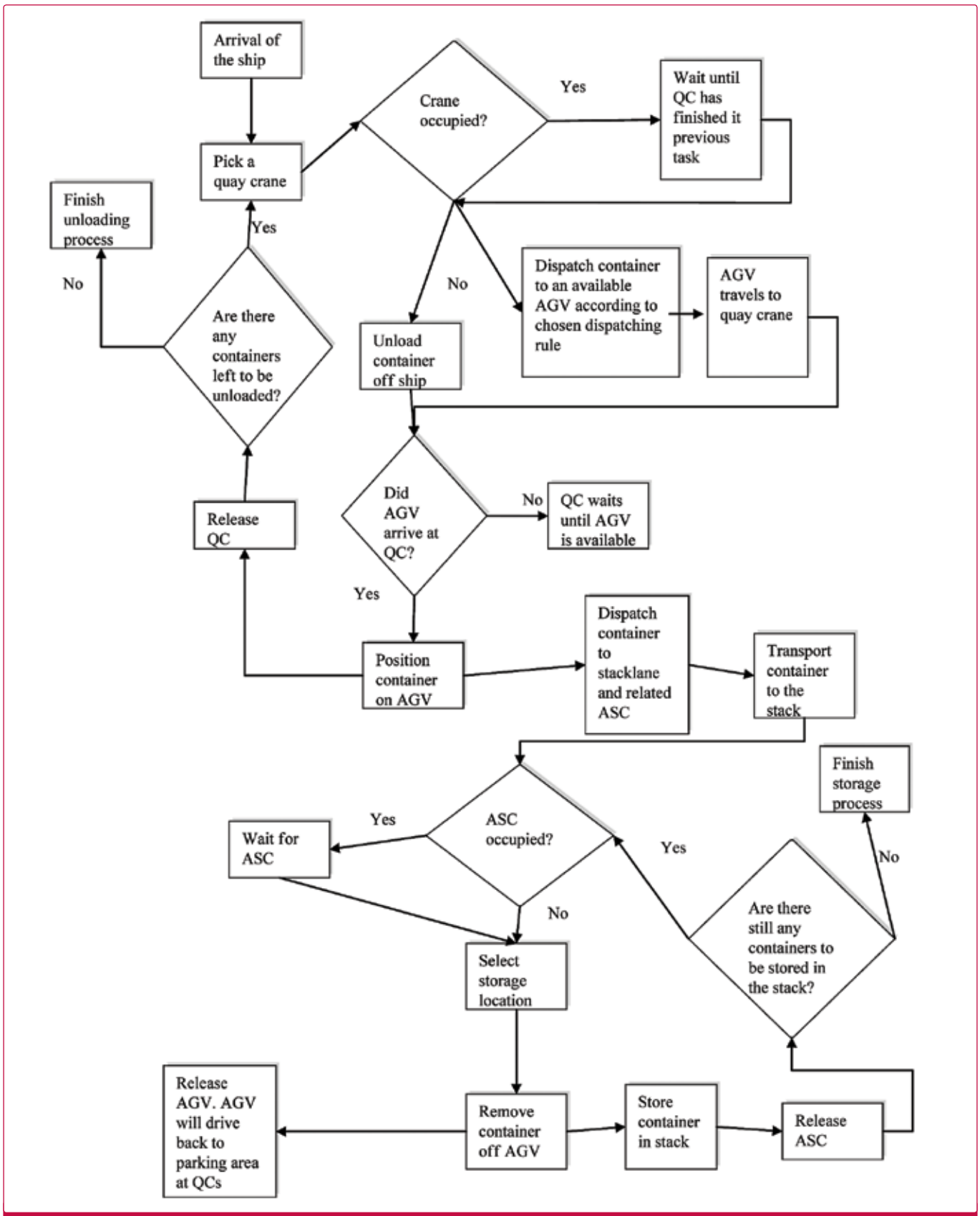

Figure 1. Conceptual model of unloading process at an automated container terminal.

We only focus on the size of containers. Initially, we assume that 50 per cent of the containers have a length of 20 feet (1 TEU), and the other 50 per cent have a length of 40 feet (2 TEU). Manned QCs unload the containers from the ship. The time (i.e. cycle time) required to unload a container off the ship and position it on an AGV follows an empirical distribution of which the average equals 65.9 seconds. Initially, we assume that the capacity of an AGV equals one 20-foot or one 40-foot container. The speed of a full AGV equals 4 m/s, and that of an empty AGV 5.5 m/s. The travel speed of an ASC equals 3.5 meters per second.

First, we examine the various AGV dispatching rules in combination with the cyclic selection of ASCs. We have varied the number of AGVs from 24 to 36, which corresponds to six

TABLE 1: RESULTS X/Y/Z FOR ALL COMBINATIONS OF ASC AND AGV DISPATCHING RULES. WHEREAS, X = MINIMAL TOTAL CYCLE TIME IN SECONDS, Y = MINIMUM NUMBER OF AGVS AND Z = AVERAGE UTILIZATION OF AGVS

ASC/AGV	Nearest	Farthest	Random	Cycle	Preferred
Cyclic	58758/29/0.49	60371/25/0.54	59264/34/0.41	58865/35/0.40	60004/24/0.57
Random	58593/34/0.45	60284/29/0.51	59183/35/0.43	58937/34/0.45	59899/31/0.48
Farthest v = 0	59232/36/0.48	60761/34/0.49	60011/35/0.49	59539/35/0.49	60476/35/0.48
Farthest v = 1	60152/34/0.53	61366/34/0.50	59831/42/0.45	60072/36/0.49	60810/38/0.46
Farthest v = 2	62165/35/0.57	62669/38/0.53	62214/34/0.57	62016/36/0.55	62462/37/0.54

to nine AGVs per QC. Figure 2 represents for each of the AGV dispatching rules the total cycle times in seconds for a varying number of AGVs.

From Figure 2 we can conclude that the lowest total cycle time can be obtained if we apply the nearest-vehicle-first rule. However, the differences in cycle times with the random and cyclic vehicle rule are small (less than one per cent). Contrary, the differences in the minimum number of vehicles required to reach these minimal cycle times are larger (approximately 20 per cent). Namely, while applying the nearest-vehicle-first rule, we need 29 AGVs. 34 and 35 AGVs are respectively required for the random and cyclic rule to achieve a similar performance. If we incorporate costs of AGVs, the difference between the rules becomes more significant. However, the mutual differences in cycle times with a varying number of AGVs for a certain dispatching rule are small. For example, if we allow an extra unloading time of 12 minutes, we can also apply the random rule also with 29 AGVs.

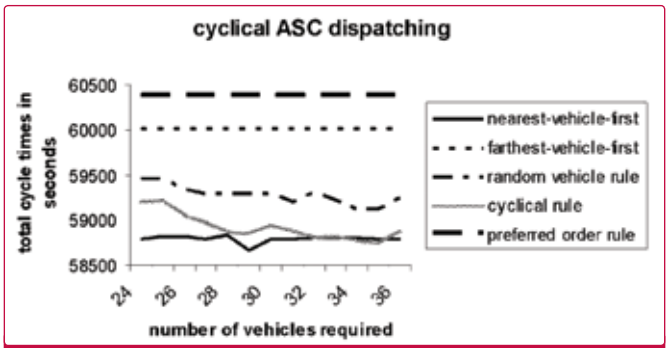

Figure 2. Total cycle times in seconds for a varying number of AGVs for each of the vehicle dispatching rules if we assign vehicles to ASCs according to the cyclic ASC rule.

As described, we need to decide how many vehicles (= v) may be on their way to the same ASC. Clearly, lines of AGVs waiting at the ASCs need to be avoided. Based on deterministic calculations, it is estimated that no more than two AGVs should be on their way to the same ASC. From the results in Table 1, we can conclude that waiting lines of AGVs at the stack arise and that, as a result, the average utilization of AGVs and total cycle times increase. Only when $v = 0$ can acceptable results be obtained. However, both the cyclic and random ASC rule outperform the farthest ASC rule in total cycle times and number of vehicles required. Similar results for the nearest ASC rule can be expected and, therefore, we did not perform these experiments.

Table 1 summarizes the minimal cycle times with the related number of vehicles and utilization for all combinations of AGV dispatching and ASC selection rules. Based on these results, we have decided to concentrate on the nearest-vehicle-first, random and cyclic rule for dispatching AGVs and on the cyclic and random rule for selecting ASCs.

Twin-load capacity of AGVs

From a technical and economical perspective, it is also interesting to study the impact on total cycle times, and the number of vehicles required if one AGV can transport two 1 TEU containers simultaneously. Containers with a capacity of 2 TEUs are still transported one at a time.

Assuming a varying distribution of 1 and 2 TEU containers, the impact on dispatching rules and cycle times is studied, by decreasing the number of twin-load AGVs. Starting with a 50-50 per cent distribution, the number of AGVs is decreased from 35 to 10. The minimal total cycle time decreases on average with 0.1 per cent. Furthermore, it can be noticed that a 19 per cent decrease in the number of AGVs can be obtained, on average.

For random and cyclic AGV dispatching, we need to use 29 AGVs. For the nearest-vehicle-first rule, 25 AGVs are required to minimize the total cycle time. We continue with these amounts of vehicles and vary the distribution of 1 and 2 TEU containers. Table 2 represents the results for the cyclic ASC rule. (The results for the random ASC rule are comparable to the results of the cyclic ASC rule and therefore we did not include them in the paper.)

From the results in Table 2, we can conclude that the number of AGVs can be decreased if more 1 TEU than 2 TEU containers need to be transported. If more than 90 per cent of 1 TEU containers need to be transported, it is even possible to use half the number of vehicles to obtain total cycle times which are similar to the total cycle times with single load

TABLE 2: TOTAL CYCLE TIMES (IN SECONDS) FOR THE COMBINATION OF THE CYCLIC AS RULE WITH VARIOUS AGV DISPATCHING RULES FOR A VARYING AMOUNT OF 1 AND 2 TEU CONTAINERS WHILE USING RESPECTIVELY 29 AND 15 AGVS

% 1 TEU containers	Number of AGVs	Nearest	Random	Cycle
40%	29	58232	58547	58297
40%	15	63554	63537	63554
50%	29	58225	58306	58337
50%	15	62245	62373	62252
60%	29	58231	58381	58313
60%	15	61183	61140	61243
70%	29	58266	58233	58235
70%	15	60187	60131	60223
80%	29	58237	58349	58237
80%	15	59321	59402	59386
90%	29	58310	58285	58310
90%	15	58621	58705	58649
100%	29	58277	58290	58277
100%	15	58243	58293	58240

vehicles. If we need to transport more 2 TEU than 1 TEU containers, the total cycle times and number of vehicles required are similar to the case of single load vehicles. Also, in these experiments the results for the various dispatching rules are close. Furthermore, if we need to transport only 1 TEU containers on twin-load AGVs, there is no difference in performance between the various dispatching rules.

Conclusions

To summarize, we can conclude that the choice for a certain AGV dispatching rule hardly impacts the total cycle times, for all different experiments. However, the amount of vehicles required differs per dispatching rule.

While considering both the unloading times and the number of vehicles required, we recommend the nearest-vehicle-first rule, for all different settings.

For the selection of the ASC, we suggest that the workload should be evenly distributed over the various ASCs (cyclic ASC rule), instead of dispatching AGVs randomly or to the nearest or farthest ASC.

Finally, it is wise to use the technical property of twin-load AGVs to transport two 1 TEU containers at the same time, such that transportation costs and annual depreciations of the vehicles can be reduced significantly.

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