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Simulating Dispatching Strategies for Automated Container Terminals

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1 Introduction

The practical relevance of container terminal logistics has led to an enormous scientific interest in this field. Publications cover not only optimization algorithms (e.g., for equipment scheduling and vehicle routing) and decision problems (e.g., for finding grounding positions for containers in the yard) but also simulation models to study such approaches in a realistic dynamic environment. Recent literature surveys have been given by Steenken et al. [3] and Vis and Koster [4]. In this paper, we consider a highly automated terminal with quay cranes, automated guided vehicles, and automated stacking cranes. Such a terminal configuration is sketched in Figure 1.

Arriving containers are stored in the terminal for a certain period of time until they are picked up either on the landside by trucks or trains or on the seaside by vessels. The stacking area is divided into blocks. Each of them is served by one or more rail mounted gantry cranes (RMG). The RMGs put arriving containers into the stack, remove containers from the stack when they are picked up, and carry out so-called shuffle moves, i.e., move containers to another position within the stack if they stand on top of containers that have to be moved out of the stack.

Vessels are served by quay cranes (QC). They either discharge containers from vessels or load them onto vessels. This has to be done according to a given stowage plan. The latter imposes precedence relations on some of the containers. This leads to a partial order in which containers to be loaded have to arrive at a QC.

The transportation of containers between RMGs and QCs is done by automated guided vehicles (AGV). AGVs are unmanned vehicles that are unable to load and unload themselves, thus quay cranes and stacking cranes have to load and unload them. The AGV area can be divided into lanes alongside the quay (which are also used as handover lanes at the quay cranes), lanes alongside the stacking area, lanes connecting quay and stacking area, and handover lanes at each RMG stack. At each QC, some lanes are used as a buffer area where AGVs wait either because another AGV with a predecessor container has to pass or because the handover position is still occupied by another AGV.

Terminals with this type of configuration exist in Rotterdam, Netherlands (Delta Terminal of Europe Container Terminals, ect) and Hamburg, Germany (Container Terminal Altenwerder, CTA). This study has been carried out in cooperation with CTA. The focus of this paper is on the simulation of scheduling strategies for AGVs. First, we describe a simulation model for testing those strategies. Subsequently, we propose two specific strategies, employ them in our model and present first results.

2 Simulation Model

2.1 Material Flow

In what follows, we describe the material flow components of the model which cover the behavior of the equipment. The underlying approach is to model the equipment behavior by means of time distributions for their actions (instead of modeling the behavior in full detail).

Quay Cranes. The QCs repeatedly either handle containers or wait for AGVs. When working, we have a cyclic process of serving vessels and AGVs. While the duration of QC waiting phases results from the AGVs, the duration of the container handling cycles of the QCs must be defined. We divide a cycle into two parts: The first one is the interaction with an AGV, namely releasing/picking the container and lifting the spreader high enough such that the AGV can leave. This part represents the handover time of an AGV at the QC. We define a distribution describing the duration of this part. The second part covers the remaining time of the QC cycle, that is, the time for transporting a container between AGV and vessel and getting ready for the next AGV. For the duration of this part of the cycle, we again define a distribution. This part is the time that has to elapse until the next AGV-related handover time can start. After an AGV has been served, the next AGV which does not have to wait for a predecessor is allowed to move from the buffer to the QC.

Automated Guided Vehicles. The behavior of the AGVs consists of either carrying out transportation jobs or waiting for further jobs. When an AGV handles a job the following process can be divided into four parts. First, it drives to the container's pick-up location (if it is not equal to the AGV's current position). Afterwards, it waits for service either by QC (if the container is a discharged one) or by RMG (if the container is to be loaded). When the AGV has received the container, it drives to the container's destination. Finally, it has to wait for service again to be

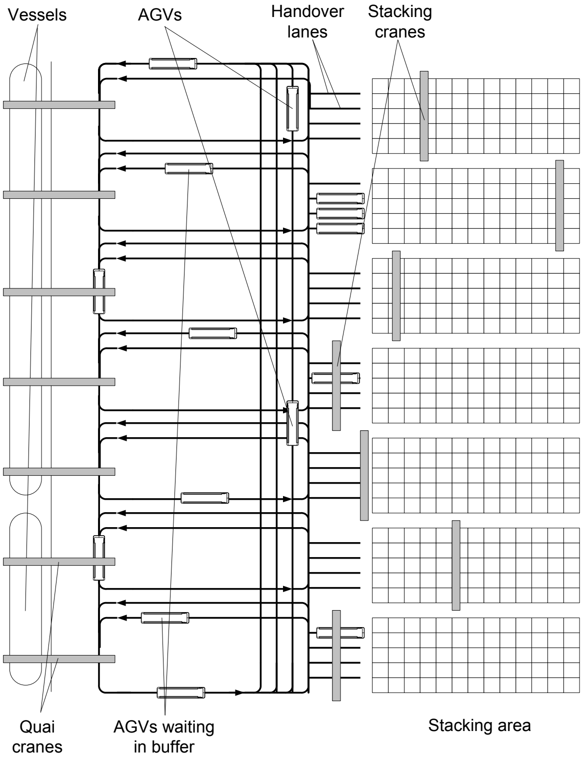

Figure 1: Layout of the container terminal

unloaded. Note that if the container's destination is a QC this final part consists of waiting in the buffer (if necessary), driving to the QC and waiting for service.

Waiting times in handover lanes do not depend on AGVs themselves, thus, they are determined by QCs and RMGs. However, driving times have to be defined to describe the AGV behavior accurately. To do so, we calculate an ideal driving time based on the distance and the number of curves etc. Subsequently, this ideal time is multiplied by a factor that leads to the actual driving time. This factor reflects AGV interferences on the layout such as congestions. For this factor, a distribution is employed.

Rail Mounted Gantry Cranes. Besides serving AGVs, RMGs carry out many tasks such as shuffling containers, serving the landside interface of the stacking area, etc. Because these activities are beyond the scope of our simulation purposes, we do not consider them explicitly. Therefore, instead of modeling the RMG behavior itself, we define a distribution for each RMG representing the time span an AGV is tied up in the handover lane including waiting for service and lifting or releasing the container.

2.2 Information Flow

In addition to the behavior of the equipment, the simulation model contains the decision logic of the terminal control system. We obtain the information flow components described in the following.

Jobs. We consider only AGV jobs. Each job is associated with a container and hence with a pick-up and a delivery location. For each QC, we generate a list of related AGV jobs. In case of a discharging QC, the delivery location (stack) is selected using a distribution which assumes that the containers from one QC are brought to the k_D nearest blocks. Analogously, for a loading QC, the pick-up location (stack) is determined with a distribution that assumes that containers to be loaded were stacked into the k_L nearest blocks. This way, we do not have to consider a stacking strategy or positions inside the blocks. Instead, we use distributions to reflect the impact of the strategy, namely that the AGV should have a short way to drive and that the nearest block cannot always be selected because this would lead to excessive workloads of individual RMG blocks.

The overall number of jobs is large (virtually unlimited), such that the simulation model will lead to the maximum waterside productivity (jobs completed per hour) that the AGV dispatching strategy is able to achieve. Note that this is realistic since a real terminal also tries to discharge and load containers as fast as possible.

AGV Assignment Procedure. The core of the strategies to be simulated is the decision which AGV shall carry out which job at which time. Whenever an AGV finishes its current job or a new job enters the system the assignment procedure is executed. Only the assignments of currently available AGVs are fixed, the remaining AGVs are considered again when the assignment procedure is executed the next time. The basic idea of the strategy is presented in Section 3. The strategy makes use of estimates for the availability time of an AGV, that is, the completion time of its current job. This estimate is generated a certain time before the job is actually completed (i.e., before the AGV is unloaded by a QC or an RMG). Both the time the estimate is generated in advance and its deviation from the actual availability time is controlled by corresponding distributions.

RMG Assignment Procedure. Since we do not model the behavior of the stacking cranes explicitly (see Section 2.1), we did not have to consider an RMG scheduling procedure that selects the next job for a crane. The impact of the stacking cranes on the AGVs has been captured by explicitly incorporating the distribution of the AGV waiting times at the stack. Moreover, the RMG scheduling selects the job for a crane and hence determines the container to be loaded onto an empty AGV (note that we propose that the AGV scheduling plans for a container when sending an empty AGV to a block but the container to be actually loaded onto the AGV is determined by the RMG scheduling). Here, we assume that the RMG assignment procedure selects the most urgent container. The urgency of a container is defined analogously to the AGV strategy under consideration. Note that we only consider container urgency here and not other criteria of the RMG scheduling such as emtpy travel time minimization.

3 AGV Dispatching Strategy based on Inventory Levels

AGVs either supply QCs with containers or receive them from QCs. Therefore, the main objective for AGV scheduling strategies is to guarantee a constant inflow of AGVs to the QCs. This is a substantial condition for a high productivity of the terminal measured by discharged or loaded containers. In order to obtain a balanced inflow of AGVs, we count the AGVs currently on the way to a QC q. We interpret this number as an “inventory level” belonging to the QC. Consequently, the QC having the smallest inventory level and hence the smallest number of AGVs should be most likely to receive the next AGV that becomes available.

We obtain a standard linear assignment problem with AGVs and transportation jobs (which is solved to optimality using the Hungarian method, see Kuhn [1]). The cost c_{ja} of assigning job j to AGV a represents the time which will pass until a can pick up the container related to j as well as the urgency of job j which is measured by the inventory level of the related QC. Then we determine the number of AGVs to be considered, denoted as n, and select the n most urgent jobs with respect to the inventory levels. We compared two variants of this assignment approach which differ in the way the AGVs to be considered are determined:

- **Few AGVs.** This variant considers only the AGVs which are currently free and could start the next job immediately. Note that in case of a high workload this will usually be a single AGV which will be assigned to the most urgent container (which is similar to a greedy heuristic employing a priority rule).
- **More AGVs.** Here, we consider those AGVs which are currently free and those which will finish their current job within a certain time horizon (we assume that we have an estimate of the availability times of these AGVs).

4 Results

We implemented the simulation model and the two dispatching strategies in the Java-based simulation framework Desmo-J (cf. Page et al. [2]). The model includes 10 QCs, 20 RMG blocks and 40 AGVs. We created five scenarios which differ in the structure of the precedence relations between containers (see Section 1). For each scenario and each strategy, 100 simulation runs were carried out. The distributions for modelling the equipment behavior were derived from original statistics of CTA.

In order to evaluate the two strategies, we consider the terminal's waterside productivity given as the average number of discharged and loaded containers per QC and hour. The results are given in Table 1 where the scenarios are listed in decreasing order of the density of the precedence relations. For reasons of confidentiality, we cannot give absolute values. Instead, we selected the variant with few AGVs as a base (having a value of 1.0 in each column) and give relative results for the variant with more AGVs. We can see that the case with more AGVs is clearly superior since it leads to a productivity that is about 10% higher in every scenario.

Approach	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
Few AGVs	1.000	1.000	1.000	1.000	1.000
More AGVs	1.090	1.097	1.099	1.095	1.107

Table 1: Simulation results for inventory approach (relative productivity)

5 Conclusions

We proposed a simulation model for the seaside processes at automated container terminals. The model contains the equipment behavior as well as the strategies of the terminal control system. Rather than considering every detail, the model employs distributions that cover processing times of the equipment as well as stacking decisions. The main advantage of this simulation model is that it can easily be adapted to a specific real-world terminal. This can be done by using statistics of the terminal for the distributions defined in the model. Moreover, one can focus on the strategies to be examined—in our case, we employed strategies for AGV dispatching, but instead of also considering RMG dispatching strategies that were not within focus, we simply incorporated the AGV waiting time distribution at the RMG blocks. Hence, we modelled the impact of the RMGs on the AGVs rather than the RMGs themselves. Summing up, we obtain a simple model with short run times which can easily be configured and produces realistic results.

The simulation model was used to test two variants of a strategy for AGV dispatching. The variant with a longer horizon (which also considers AGVs which are not available yet) proved to be superior in terms of terminal productivity. The reason for this is that this variant includes more degrees of freedom for optimization. This seems to be more important than the potential drawback of uncertainty of the time estimates for AGV availability. The next step will be a more in-depth analysis of the inventory-based strategy and a comparison with a conventional time-based scheduling strategy.

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