A case study on the application of automated guided vehicles at container terminals: A simulation comparison

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1 Introduction

In our paper Li et al. [2015], we proposed a novel discrete-event based zone control modeling and traffic control for automated guided vehicles (AGVs). Utilizing the results, in this note, we wish to design an AGV system that can be used for the container transshipment at a container terminal. In particular, we focus on the quayside container transshipment, where the quay cranes (QCs) and yard stackers (YSs)[1] are, respectively, in charge of the container pick-up and drop-off handling in the quay area (QA) and yard area (YA); and a team of AGVs are used to shuttle between these two areas to serve the cranes with containers (See Figure 1 for an illustration of the container transshipment operation). More specifically, in discharging a vessel, a handful of QCs take the containers off the vessel and put them in associated container buffers. These containers will be later on picked up by the AGVs and transported across the transportation area (TA) to the container buffers of scheduled YSs. Then the containers will be put in container stacks by the YSs. The other way around, in loading a vessel, the containers are collected from certain stacks by the YSs and transported to designated QCs by the AGVs.

To test the performance of our designed AGV system, we carry out simulation comparisons with some existing designs of AGV systems for automated container terminals. In particular, we compare our results with those in Vis

[1]Also called automated stacking cranes (ASCs) in the literature.

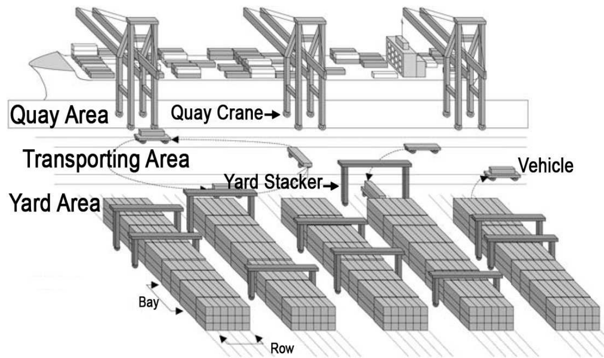

Figure 1: Quayside container transport at an automated container terminal

and Harika [2004] and Bae et al. [2011]. The main reason for picking these two works is that they provide complete and detailed information of the simulation settings, including workspace dimensions, cycle times of cranes, and vehicle specifications. In both the papers, the performance of two types of vehicles, i.e. vehicles with and without the capacity of lifting containers by themselves, are simulated and compared. It was found that the vehicles that can lift containers by themselves (named automated lift vehicles (ALVs) in the two papers) in general achieve higher container transport efficiency. This is mainly because the container cranes do not need to hold a container while waiting for some vehicle to pick it up. In this note, we only simulate the transportation with ALVs (will be also called AGVs hereafter). Lastly, since our goal here is a fair comparison of system performance, we do not include vehicle faults in the simulations.

2 A design of an AGV system for container transshipment at a container terminal

We consider AGVs of the size 10m×4m. For the guide-path over the TA, we apply the layout design with four roads and big crossings presented in Section 5.3 in our previous paper Li et al. [2011] (illustrated therein by Figure 8). It was shown therein that this layout renders the best performance among its peers. The layout designs for the QA and YA follow the same idea given also in Li et al. [2011], i.e., using a zone (in some lane) as a container buffer under each QC or YS and connecting the guide-path over TA with these QC and YS buffers by a couple of lanes and crossings. The specific layouts over QA and YA which we use for the two comparisons are based on the respective simulation settings (e.g. numbers of QC and YS buffers, distance between adjacent QCs or YSs etc.) in Vis and Harika [2004] and Bae et al. [2011]. In addition, the routing algorithm for the AGVs used in our simulations is the one presented in Section 4.2 in Li et al. [2011], and is briefly mentioned at the end of Section 4 in Li et al. [2015].

3 Comparison with the design in Vis and Harika (2004)

In the paper Vis and Harika [2004], 4 QCs are used in discharging one vessel, and the containers are stored in 16 container stacks. The AGVs move along a loop guide-path to serve the QCs and YSs so that the traffic control reduces to the minimal and there is no routing issues (See Figure 2 in Vis and Harika [2004] for an illustration of this layout.). Moreover, multiple lanes are laid in the QA, on which 4 container buffers are placed under each QC, such that more than one vehicles can pick up containers under one QC without conflicting with each other. The numerical details of this setting are summarized in Figure 2. The task dispatching rules in Vis and Harika [2004] can be roughly put as follows: Empty vehicles are dispatched to QCs according to the nearest-vehicle-first principle; and the YS with the least number of serving vehicles has the priority to get a new serving vehicle, i.e. a vehicle carrying a container that is to be put in some stack.

For a fair comparison, the same number of buffers and cycle time distributions of QCs and YSs are used in our simulations. However, we set the maximum deceleration of each vehicle to be 2.5m/s^2 rather than 0.5m/s^2, which is used in Vis and Harika [2004]. According to the remarks at the end of Section 2.2 in Li et al. [2015], our zone-control model allows the length of each zone to be lower bounded by the maximum of the length of a vehicle and the distance for a vehicle to make a full stop from its maximum speed. Thus, by letting the deceleration be 2.5m/s^2, we can put the length of non-SZs and SZs on any lane 14m and 28m respectively (See Chapter 7.5 in Adriaansen [2011] for the details). In this way, the guide-path over the TA can be designed the same as that shown in Figure 8 in Li et al. [2011]. We

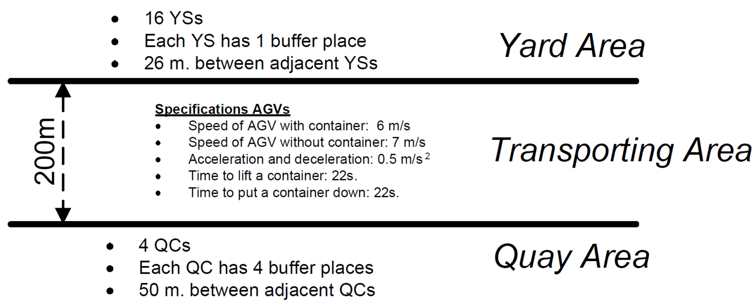

Figure 2: Specifications of the simulation setting in Vis and Harika [2004].

think that the difference in the maximum deceleration of a vehicle does not do much favors for our approach in a comparison of the discharging time of a vessel. This judgement is based on the following reason: In Vis and Harika [2004], because of the loop layout of the guide-path, a vehicle basically needs to make a full stop only at a handling crane. Hence, the time that a vehicle takes to make a full stop from its maximum speed just occupies a very small part of its total travel time.

In Figure 3, we depict the simulation results obtained by the two methods regarding the discharging time of a vessel with 2000 containers (Note that in Vis and Harika [2004] no simulation results are given for less than 16 vehicles). The two points below can be concluded from the simulation results:

- The minimum number of vehicles to minimize the discharging time, i.e. to maximize the QCs' capacity, is about 17 by our design, while is about 23 in Vis and Harika [2004].

- By our approach, the discharging time with small vehicle fleets is substantially shorter than that achieved in Vis and Harika [2004].

In addition, the use of the Manhattan-like guide-path in our approach makes the distance that a vehicle needs to travel for a QC-YS or YS-QC container transportation task much smaller than that in Vis and Harika [2004], where a vehicle has to travel the whole loop for each transportation. On the other hand, as mentioned before, the loop-following strategy in Vis and Harika [2004] greatly simplifies the traffic control and routing for the AGVs; thus is easier to be implemented.

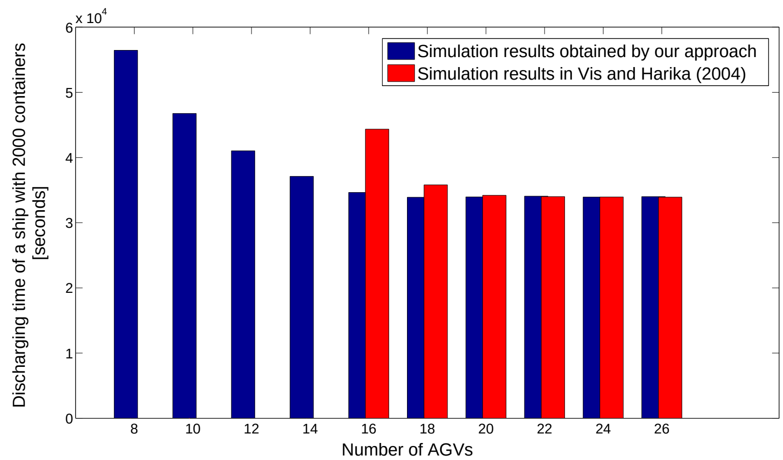

Figure 3: Simulation results with our approach and the one in Vis and Harika [2004].

4 Comparison with the design in Bae et al. (2009)

In Park et al. [2008], Bae et al. [2011], a more flexible guide-path, composed of intersecting straight lanes, is used so that the traveling distance from a QC to YS or vice versa is drastically decreased from that in the loop layout mentioned in Section 3. However, the traffic control becomes much more complicated. The authors proposed a conflict-free routing algorithm to guarantee the absence of collisions and deadlocks. More specifically, after selecting a route for each vehicle, the route is divided into a series of occupation areas and the entry and exit time of each area is precisely scheduled to avoid conflicting with those vehicles whose movement has already been scheduled. See Figure 3 in Bae et al. [2011] for a schematic illustration of this scheduling approach. The dispatching strategy employed by Bae et al. is based on an inventory-based dispatching method (see Briskorn et al. [2006]). This strategy basically says that each time a vehicle needs to be assigned to a QC or YS, the QC or YS assigned with the smallest number of vehicles is selected.

In Bae et al. [2011], simulations of discharging and loading of one vessel

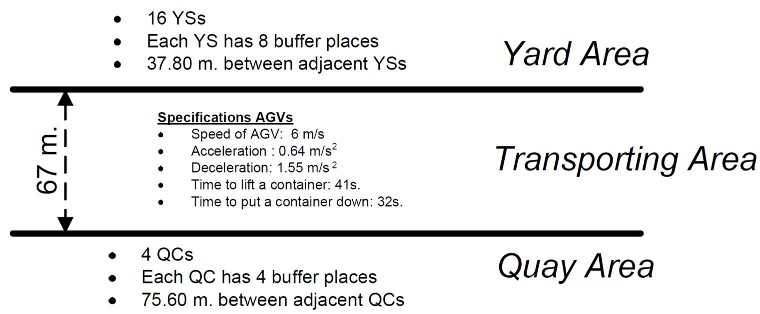

Figure 4: Specifications of the simulation setting in Bae et al. [2011].

with 3600 containers are performed with different types of QCs. The numerical specifications of the simulation setting are given in Figure 4. Only the results with the tandem-lift QC will be used here for the comparison. For a fair comparison, the same number of buffers and cycle time distributions of QCs and YSs are used in our simulations. Moreover, we use the same dispatching algorithm.

Figure 5 shows the average numbers of discharged containers per QC per hour obtained by simulating the two methods. Note that the total number of vehicles used in each simulation is equal to 4 (i.e. the number of the QCs) times the corresponding number on the X axis. The following two conclusions can be made from the simulation results:

- The minimum numbers of vehicles required to saturate the productivity of the QCs are the same for both the methods.
- Our approach makes the QCs reach the maximum possible throughput (62 container/hour), while the one in Bae et al. [2011] does not. In addition, our approach gives slightly better performance with small fleets of vehicles.

Note that in Bae et al. [2011] no fixed guide-path is used so that the AGVs are more flexible in choosing their routes and less space may be required to accommodate the AGV system. However, the conflict-free routing algorithm used in Bae et al. [2011] is not robust to the changes of schedules or faults of the AGVs and QCs/YSs. This is because the conflict resolution of the AGVs are achieved by precisely pre-planning the time windows over which

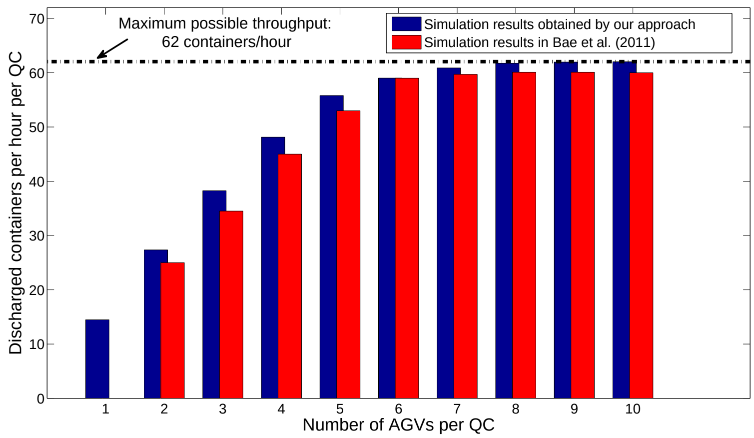

Figure 5: Simulation results with our approach and the one in Bae et al. [2011].

a vehicle visits certain areas in the workspace. If there are some changes to the loading/discharging schedule or disturbances/malfunctions happening to some vehicles or container handling cranes, then it is possible that the routes of many AGVs have to be rescheduled, which is very time-consuming, not only for good performance but for conflict (collision and deadlock) avoidance as well. In comparison, our traffic control (for collision and deadlock avoidance) is completely decoupled from the routing, which is based on real-time traffic information and thus quite robust to the schedule changes and other sorts of disturbances.

References

A. C. Adriaansen. An automated guided vehicle system in a container terminal. Master's thesis, Eindhoven University of Technology, Eindhoven, The Netherlands, February 2011.

H. Y. Bae, R. Choe, T. Park, and K. R. Ryu. Comparison of operations of agvs and alvs in an automated container terminal. *Journal of Intelligent Manufacturing*, 22:413–426, 2011.

D. Briskorn, A. Drexl, and S. Hartmann. Inventory-based dispatching of automated guided vehicles on container terminals. *OR Spectrum*, 28:611–630, 2006.

Q. Li, A. C. Adriaansen, J. T. Udding, and A. Y. Pogromsky. Design and control of automated guided vehicle systems: a case study. In *Proc. of the 18th IFAC World Congress*, pages 13852–13857, Milano, Italy, 2011.

Q. Li, A. Y. Pogromsky, A. C. Adriaansen, and J. T. Udding. A study on collision and deadlock avoidance control of automated guided vehicles Part I: fault-free case. 2015. URL ??

T. Park, Y. H. Bae, R. Choe, and K. R. Ryu. Travel time estimation and deadlock-free routing of an agv system. In H. Haasis, H. Kreowski, and B. Scholz-Reiter, editors, *Dynamics in Logistics*, pages 77–84. Springer, 2008.

I.F.A. Vis and I. Harika. Comparison of vehicle types at an automated container terminal. *OR Spectrum*, 26:117–143, 2004.