AGV Dispatching Strategies at Automated Seaport Container Terminals

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Abstract *A key issue in automated seaport container terminals is the assignment of transportation orders to automated guided vehicles (AGVs). For AGV dispatching two basic types of strategies can be applied, which differ by the length of the look-ahead period and the rescheduling strategy. The on-line dispatching strategy uses myopic dispatching rules, which have been adopted from flexible manufacturing systems. This strategy schedules only one operation at a time without ever changing an existing schedule. As an alternative, a pattern-based off-line heuristic developed by the authors can be applied. This heuristic creates predictive schedules comprising a sequence of pick-up and drop-off operations for each vehicle getting available during a given look-ahead horizon. To evaluate the performance of the dispatching strategies a comprehensive simulation study is performed. The scenarios investigated reflect realistic terminal environments and consider stochastic variations in the timing and processing of loading and unloading operations of containers.*

Keywords automated container terminals, AGV dispatching, vehicle routing, on-line logistics control

1 Introduction

Driven by the trend towards globalization of the economy world trade volumes have increased dramatically during the last decade. Today, maritime cargo transportation has become the predominant transportation mode in international trade. For instance, 78.7% of the United States foreign trade in 2001 was accomplished by maritime cargo transportation (cf. BTS, 2004). At the same time the number of container terminals worldwide increased considerably. Their major function is to serve as multi-modal interfaces between sea and land transport.

In order to cope with increased transportation volumes and to benefit from the economies of scale, ship owners have constantly increased the capacity of their deep-sea container vessels, recently culminating in the projected 10,000 TEU (twenty-feet equivalent units) container ship generation. Operators of seaport container terminals have primarily responded to this development by increasing their terminals in size and making use of more efficient transportation and handling equipment. There are, however, a great number of existing terminals, which have reached their limits for further expansion. Hence, new automated container terminals are constructed worldwide. These terminals are better suited to serve the huge modern deep-sea container vessels and to employ improved logistics equipment.

One direction for improving the overall productivity of a container terminal and to reduce the berthing times of vessels is to enhance the degree of automation of the handling and transportation equipment. Hence, manually operated cranes have been replaced by automated ones and AGVs are used instead of manually driven carts. Nevertheless, for transportation between different terminals at one location, as is the case in the city of Busan (Korea), conventional trucks are still the primary mode of transportation (cf. Koo et al., 2004a). For intra-terminal operation, dual-load AGVs represent a recent development in transportation technology. Such vehicles offer the advantage of being able to transport two 20 ft containers or one 40 ft container at a time. Another recent development is represented by so-called automated lifting vehicles (ALVs) which, in contrast to AGVs, are capable of lifting a container from the ground by itself (cf. Vis and Harika, 2004; Yang et al., 2004). However, despite their superior handling capabilities ALV systems have not been realized in automated container terminals so far.

Since a container terminal represents a complex system with various interrelated components, computerized logistics control systems have recently gained considerably higher attention. The use of automated equipment in turn requires much more sophisticated control strategies in order to exploit the capabilities of advanced automated equipment (cf. Günther and Kim, 2004; Steenken et al., 2004). For instance, in automated container terminals dual-load AGVs are still operated in single-carrier mode, mainly because adequate dispatching strategies, which allow for the efficient use of their enhanced transportation capacity, are missing. Obviously, the dispatching problem for dual-load carriers is considerably more complex than that one for single-load carriers.

In the academic literature, the AGV dispatching problem arising in seaport container terminals has been widely neglected. Two exceptions are the papers by Bae and Kim (2000) and Koo et al. (2004b). Their investigations, however, consider selected issues related to dispatching of single-load carriers. Another noticeable exception is the paper by Kim and Bae (2004). They develop an efficient look-ahead heuristic for dispatching single-load AGVs. In a numerical investigation it is shown that their heuristic outperforms conventional dispatching rules. A problem similar to AGV dispatching is the yard trailer routing problem investigated by Nishimura et al. (2005). They consider man-driven multi-load trailers and develop a genetic algorithm based dispatching approach. In a simulation study, it is shown that a dynamic routing strategy, i.e. one which does not assign a vehicle to a specific crane, is superior to a static routing strategy with dedicated crane-vehicle assignments. However, because of the excessive computational requirements their approach is barely applicable in a real-time dispatching strategy.

In our paper, dispatching strategies for dual-load AGVs are presented. In particular, on-line and off-line dispatching strategies to be applied in highly automated container terminal configurations are discussed. To evaluate the efficiency of different dispatching strategies, a comprehensive simulation model has been developed. This model reflects conditions, which are typical of a real automated terminal environment. While the main focus of our investigation is on AGV dispatching, the interface to quay crane and stacking crane scheduling is also considered in the simulation model.

A specific issue of considerable importance in decentralized control of complex logistics systems is the handling of deadlock situations. Various strategies can be pursued to detect and resolve deadlocks arising between different resources in the terminal configuration. Related procedures for application in real-time control of AGV systems at automated container terminals are presented in Lehmann et al. (2005).

This paper is organized as follows. In Section 2 the AGV dispatching problem is explained in greater detail. Next, on-line and off-line dispatching modes are discussed in Section 3. This is followed by the detailed presentation of related dispatching strategies (Section 4) and the outline of a simulation study (Section 5). Finally, the main contributions of this paper are summarized and conclusions are drawn.

2 AGV Dispatching

A typical seaport container terminal is divided into a berthing, an AGV, and a storage area. Figure 1 illustrates the layout of one of the latest highly automated seaport container terminals. The berthing area is equipped with quay cranes for the loading and unloading of vessels. When a vessel arrives at the port, it has already been determined at which position the vessel is berthed and which quay cranes will be working on the vessel (cf. Guan and Cheung, 2004). Equally, the unloading sequence of the containers is known in advance for each vessel (cf. Kim et al., 2004). Thus, detailed schedules for the quay cranes can be derived from the given unloading sequence (cf. Park and Kim, 2003). At the same time, the final destination in the storage area is determined for each container. The storage area is divided into blocks each of which is serviced by one or more stacking cranes. After unloading a container, the stacking cranes at the affected block are scheduled to meet the estimated arrival time of the container. The transport of the containers from the berthing area to the storage yard is realized by dual-load AGVs. (For a general framework of scheduling operations in container terminals see Hartmann, 2004a).

In the container terminal considered, AGVs are operated in single-carrier mode, but shall be used as multi-load carriers in the future. The particular difficulty of AGV dispatching in a highly automated container terminal is that AGV pick-up and drop-off times for each container have to coincide with the schedules of the quay and stacking cranes to avoid idle times of this equipment and to guarantee short berthing of the vessels. The operations necessary to load a vessel are similar.

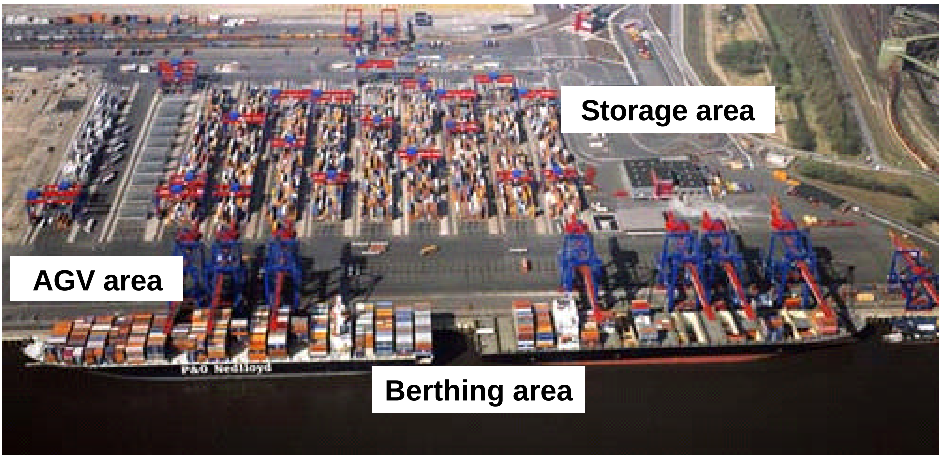

Figure 1. Layout of the container terminal Altenwerder, Hamburg, Germany (Source: http://www.hhla.de/C/cont.htm, visited on June 14, 2005)

AGV dispatching usually consists of three sub-problems, namely assigning AGVs to transportation orders, routing the AGVs, and traffic control. Generally, algorithms for routing and traffic control are already included in the control software provided by the AGV manufacturer. Thus, only the assignment problem is investigated in this paper. In contrast to applications of AGVs in manufacturing systems, rigid pick-up and drop-off time constraints have to be considered which significantly increase the problem complexity.

In the case of single-load carriers (cf. Bish et al., 2005), AGV dispatching can be reduced to an m:n assignment problem with the objective of minimizing the costs associated with not meeting target times imposed by the quay cranes' schedule. (Note that quay crane waiting times directly affect the vessels' turnover time and thus the productivity of the container terminal.) The corresponding linear optimization model can be solved rather efficiently due to its pure binary nature. However, in the case of multi-load carriers the assignment problem is significantly more complex. In addition to the basic order-vehicle assignment, the various pick-up and drop-off operations have to be sequenced for each one AGV.

Throughout the paper, we make the following basic assumptions:

- Each AGV is capable of carrying one 40 ft container or two 20 ft containers.
- All AGVs in the fleet are identical in their function, loading capacity, speed, etc.
- AGVs are not pooled, i.e. they operate independently from each other and are not dedicated to a specific quay or stacking crane.
- AGV travel times are assumed to be deterministic. In particular, effects of congestion among AGVs on the guide path are neglected.

- Transportation of special-purpose containers, e.g. reefer or hazardous goods containers, is not considered.

3 On-line and Off-line dispatching mode

Scheduling in dynamic application environments has been an active research area in recent years. Much work has been carried out to compare on-line and off-line scheduling strategies and to find out which of them is more suitable. However, a general answer to this question will always depend on the specific application environment. While for master production planning in manufacturing systems a predictive approach might be adequate, in short-term scheduling, for instance, plant managers often prefer to initiate only the next operation in an on-line manner.

When dispatching dual-load vehicles in seaport container terminals, the choice is not so obvious. The high degree of stochasticity seems to favour myopic on-line strategies, whereas predictive plans constructed by off-line strategies promise to exploit the optimization potential resulting from the combination of different transportation orders into a joint tour.

On-line dispatching is usually seen as appropriate in a highly dynamic planning environment where only limited information about future events is available. In the case of container terminals, the stochastic nature of the handling system is due to internal as well as external factors. Internal factors are, for instance, short-term decisions of quay crane operators to alter the sequence of handling operations, while external factors include weather conditions, the unknown state of a container or congestion in the AGV traffic system. Because of these uncertainties, decisions must be made without complete knowledge of the future events. One option to deal with the stochastic nature of the logistics system is to employ on-line dispatching. According to this dispatching mode, a decision is made when needed and immediately executed (cf. Fiat and Woeginger, 1998; Sgall, 1998). In this case, no predictive plan is generated. The schedule rather results from a sequence of on-line decisions, which are made one at a time as the system status changes (cf. Sabuncuoglu and Bayiz, 2000). While the application of these rules is simple, their inherent myopic and greedy nature may sacrifice their performance.

Off-line dispatching requires decisions to be made simultaneously for all transportation orders occurring within a short-term look-ahead period. Thus, a predictive schedule is constructed. However, due to the uncertainty of the future events the schedule may have to be revised when significant deviations occur, e.g. late arrival of AGVs, breakdown of equipment, or delays in performing the loading and unloading tasks (see Figure 2). This type of planning approach is therefore also termed reactive planning (cf. Sabuncuoglu and Bayiz, 2000).

Depending on the factors which trigger rescheduling, the following policies can be distinguished:

- Periodic rescheduling takes place after predefined time intervals using rolling time horizons (cf. Church and Uzsoy, 1992).

- Event-driven rescheduling is carried out on significant deviations from the current schedule. But also specific events, such as arrival of a new job, may cause rescheduling (cf. Smith, 1994; Viera et al., 2003).
- In hybrid rescheduling a combination of the above policies is applied (cf. Church and Uzsoy, 1992).

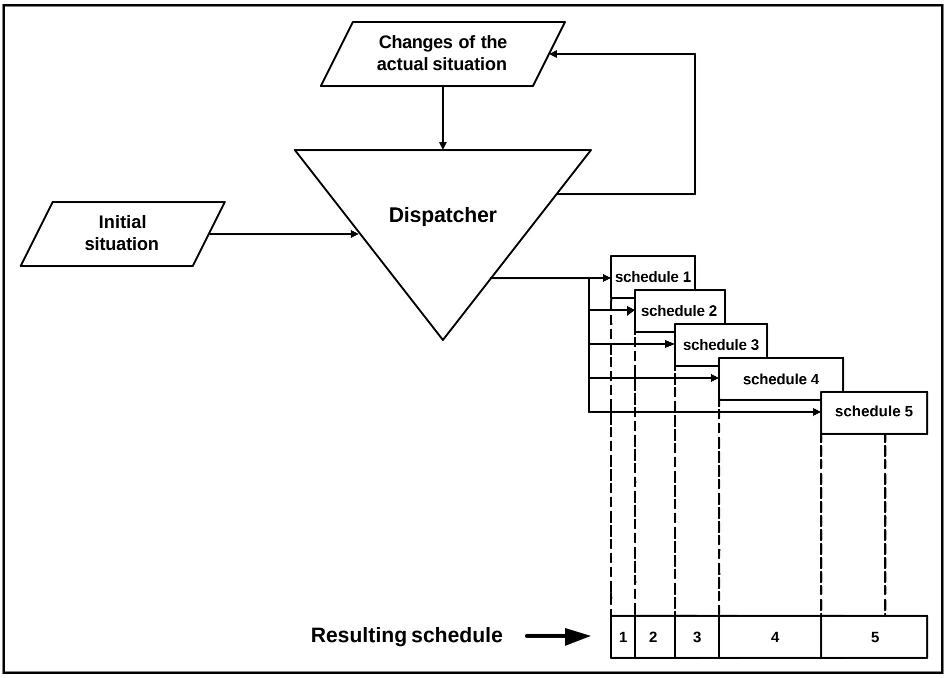

Figure 2. Construction of a schedule by use of a predictive-reactive planning approach

In this paper, we consider an event-based logic of the logistics control systems. Thus, decisions are triggered by certain events, e.g. the completion of a transportation order, or when the development of the logistics system deviates from its predicted behaviour, e.g. loading or unloading operations take significantly longer than expected. A typical on-line dispatching strategy, adopted from flexible manufacturing systems, is compared with a more sophisticated off-line heuristic developed by the authors.

4 Dispatching strategies

4.1 Characteristics of dispatching strategies

As stated above, the vehicle-dispatching problem at hand consists of assigning transportation orders to AGVs and of determining the sequence of transportation orders assigned to each vehicle. In the case of dual-load AGVs, which allow up to two 20 ft containers to be loaded on one vehicle at the same time, also the individual pick-up and drop-off operations of each order have to be sequenced. Once the assignment and sequencing decisions have been made, the corresponding pick-up and drop-off times can be derived in a straight-forward manner for single as well as for dual-load carriers.

Since scheduling in a dynamic environment is usually accomplished by solving a sequence of static problems, it has to be decided when a new static problem should be solved. Within the paradigm of event-driven dispatching certain triggering events have to be identified. For the problem at hand, dispatching requests are generated, when a new transportation order is released (*transportation-order-initiated dispatching*) or an AGV becomes available (*vehicle-initiated dispatching*). In the case of transportation-order-initiated dispatching, the only important information is when a new order is going to be released. This issue will usually differ between on-line and off-line mode. In on-line mode, information about new transportation orders will be available very late (and therefore be fairly reliable) whereas off-line approaches also include early uncertain information. For vehicle-initiated dispatching, however, the concept of vehicle availability has to be concretized.

There are two different views on when a vehicle should be considered available. From a physical point of view a vehicle is available when it is unloaded, i.e. no container is placed on its loading platform. This concept, however, is rather myopic and not suited for most planning decisions, since information about the logical status of the vehicle (i.e., its actual schedule) is neglected. We therefore adopt a different approach, which derives the availability of a vehicle from the number of transportation orders assigned to it. There are two categories of transportation orders in this aspect: temporarily assigned ones and fixed assignments. An order is temporarily assigned if during a future dispatching request the assignment can be broken up and the order can be assigned to another AGV, while this is not feasible in the case of a fixed assignment. Obviously, fixed assignments decrease the possibility (and therefore the optimization potential) of reactive scheduling and should be used carefully. In our off-line approach fixed assignments are only used for the actually performed orders of each vehicle. In the case of on-line strategies, according to the myopic nature of this mode, every assignment is fixed.

The availability of an AGV is determined by its status after completing the current trip. A single-load AGV is considered available during its trip to the drop-off location. Dual-load vehicles are fully available during the trip to their last drop-off location and partially available during the trip to the first pick-up location of a 20 ft container or to the first drop-off location. Of course, both types of vehicles are considered available when parked idle at some dwell point in the guide path.

4.2 On-line dispatching strategy

The first approach employs dispatching rules, which are already known from manufacturing and warehouse applications. In these environments basic rules are used for the dispatching of single-load carriers or to find an initial assignment for multiple-load carriers (see e.g. Egbelu and Tanchoco, 1984; Hwang and Kim, 1998; Klein and Kim, 1996; Lim et al., 2003, de Koster et al., 2004, and recently Le-Anh and de Koster, 2005). Typically, on-line dispatching rules are restricted to a one-to-many assignment. Accordingly, either one out of the feasible vehicles is assigned to a transportation order or from a set of unassigned transportation orders one is assigned to an available vehicle.

Certainly the most popular representative for the first case, transportation-order-initiated dispatching, is the *nearest-vehicle* (NV) rule which assigns the vehicle located the closest to the pick-up location of a transportation order whenever a new transportation order is initiated. This rule, however, may discriminate vehicles that are very far from *any* active quay or stacking crane and may thus lead to a rather disproportionate use of the available vehicles. One way to avoid this drawback is to apply the *least-utilized-vehicle rule* (LUV) instead. This rule aims at balancing the vehicles' workload by preferring less utilized vehicles for actual assignment. The utilization of a vehicle is measured by counting the transportation orders completed so far and those already assigned to the vehicle.

Vehicle-initiated dispatching normally resorts to the *first-come-first-served* (FCFS) strategy, which is applied to prioritize waiting transportation orders. Another adequate dispatching strategy is the *shortest-travel-time* (STT) rule, which is the vehicle-initiated counterpart of the NV rule. By this rule, transportation orders are chosen according to the distance the vehicle would have to cover to service them.

After some initial experiments we decided to define an on-line strategy, which consists of a transportation-order-initiated and a vehicle-initiated component. From the various decision rules available, we decided to combine the nearest-vehicle rule and the first-come-first-served rule.

As opposed to the basic rules, extended dispatching rules from flexible manufacturing systems were far less suitable for the problem at hand. Such rules are normally used for multiple-load carriers to determine which additional orders should be loaded en route to the drop-off location of the actually loaded container or in which order the loaded containers should be dropped off. A common criterion for such rules is the deviation from the route that has been scheduled so far. These rules therefore clearly require information about the routing of the AGVs. However, in the case of container terminals, routing and traffic control routines are often rendered by the AGV manufacturer and encapsulated in the vehicles' traffic control software. Therefore, they have to be considered a black box for vehicle dispatching. It is mainly for this reason that extended rules could not be adopted for the problem at hand. Instead, we developed simple extensions to cope with dual-load carriers. For the pick-up of a second container we stated that it should always take place after that of the first container. As a result, no deviation from the actual trip could occur. The sequence of the drop-off operations of two loaded containers is determined by the *nearest-destination rule*, prioritizing the container with the nearest drop-off location.

4.3 Off-line dispatching strategies

Off-line approaches, in contrast to their on-line counterparts, generate a predictive schedule. As an off-line strategy a pattern-based heuristic has been developed by the authors. In the sequel only a sketch of the heuristic procedure will be given.

(For details the reader is referred to Grunow *et al.*, 2004). This is followed by some extensions of the basic version of the heuristic.

In the pattern-based heuristic, an m:n assignment of vehicles to transportation orders is determined by iteratively solving an m:1 assignment. The transportation orders in the planning horizon are considered one by one as they are released by the overall logistics control system. For each transportation order in this sequence the possible assignment to each (partially or fully) available vehicle is evaluated. Furthermore, for each possible assignment to a partially available vehicle different assignment patterns are tested, reflecting the feasible sequences of pick-up and drop-off operations of the new transportation order and the one that has already been assigned to the same vehicle in a previous step.

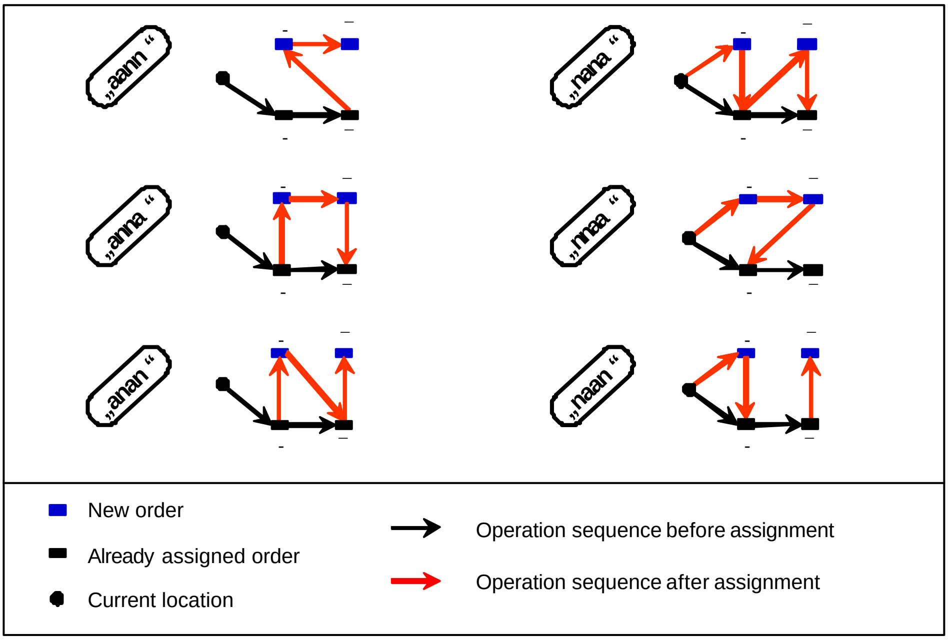

Figure 3. Possible assignment patterns

In our heuristic we allow for patterns, where pick-up and drop-off operations of the new order are sequenced after those of the already asigned order (assignment pattern "*aann*", read assigned (pick-up) – assigned (drop-off) – new (pick-up) – new (drop-off)), in between them ("*anna*") or alternating ("*anan*"). Similar sequences can be generated starting with the pick-up of the new transportation order ("*nnaa*", "*naan*", "*nana*"). In Figure 3, all possible assignment patterns for 20 ft containers are shown. Pick-up and drop-off operations are indicated by an arrow pointing upwards or downwards, respectively. From the six theoretically possible assignment patterns only three are considered in our pattern-based heuristic. At the time the dispatching request is initiated, the vehicles might already be on their way to the service point of the next operation. Thus, in order to avoid re-routing of a vehicle's mission and to prevent that an already assigned transportation order is infinitely delayed, assignment patterns "*nnaa*", "*nana*", and "*naan*" are not considered here.

It should be noted that in the basic version of this procedure (cf. Grunow *et al.*, 2004) at most two transportation orders (of 20 ft containers) can be assigned to a vehicle before it becomes unavailable. Since the schedule of each AGV could thus comprise at most four operations (two pick-up and two drop-off operations), the possibility of constructing extended tours is not given. Especially in an off-line strategy, AGV schedules comprising more than two transportation orders may be advantageous. Hence, a natural extension of the basic pattern-based heuristic is to allow more than two transportation orders to be assigned to each AGV.

An increased number of transportation orders naturally leads to an exponential growth of combinations of pick-up and drop-off operations, resulting in a prohibitive runtime requirement for extended schedules. Therefore, in the extended pattern-based heuristic we restrict the number of feasible pick-up and drop-off patterns in such a way that each transportation order can be interlocked with at most one other transportation order (in the case of two 20 ft containers), i.e. pick-up and drop-of operations p1 and d1 of a first order may only be interlocked with pick-up and drop-off operations p2 and d2 of a second order, but never with the corresponding operations p3 and d3 of a third order, unless the drop-off operation d1 of the first transportation order has been completed. Another reason for this restriction is a practical one. Obviously, the more transportation orders are interlocked, the more orders are affected, if a specific order cannot be performed in time. As a result, extensive delays for a great number of orders could occur. Despite these restrictions, the proposed approach is able to create extended schedules, taking more advantage of the capabilities of the off-line dispatching strategy.

In the *extended pattern based-heuristic*, instead of identifying the status of an AGV as simply fully available, partially available or unavailable, each AGV shows only two conditions, depending on the last order in its current schedule. If the pick-up and drop-off operation of the last order are scheduled successively, the vehicle is labelled as "S | pd", meaning that its schedule consists of some sequence of operations "S" followed by the pick-up and drop-off operation of the last order in the current sequence (for a 20 ft container). A new (20 ft container) order can now be appended to the current sequence of the AGV according to the best of the three assignment patterns "*aann*", "*anan*" or "*anna*" shown in Figure 3. If, on the other hand, pick-up and drop-off operations of the last order in the current sequence of the AGV are interlocked with those of another transportation order (e.g. "p1-p2-d1-d2" or "p1-p2-d2-d1"), the label of the vehicle is set to "S". This label indicates that the schedule of an AGV consists of a sequence of operations, where the last transportation order is interlocked with some other order. In such a case, a new order can only be assigned to that AGV according to the pattern "*aann*", i.e. appending pick-up and drop-off operation of the new order at the end of the current schedule.

In Figure 4, the possible transitions between condition "S" and condition "S | pd" are shown. There is only one single arc leading from "S" to "S | pd" indicating that assignment pattern "*aann*" is the only feasible one in condition "S" and that this pattern converts the status of the AGV into "S | pd". On the other hand, should the

AGV be in condition “S | pd”, then assignment pattern “*aann*” maintains the initial condition, while patterns “*anan*” and “*anna*” convert the AGV’s condition into “S”.

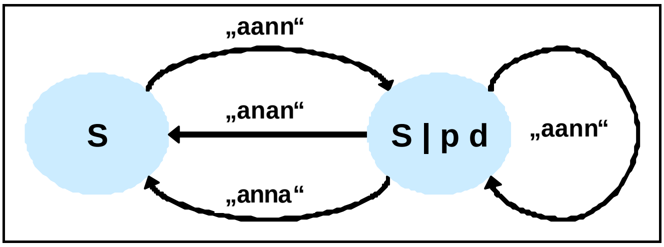

Figure 4. Feasible transitions between the conditions of an AGV schedule

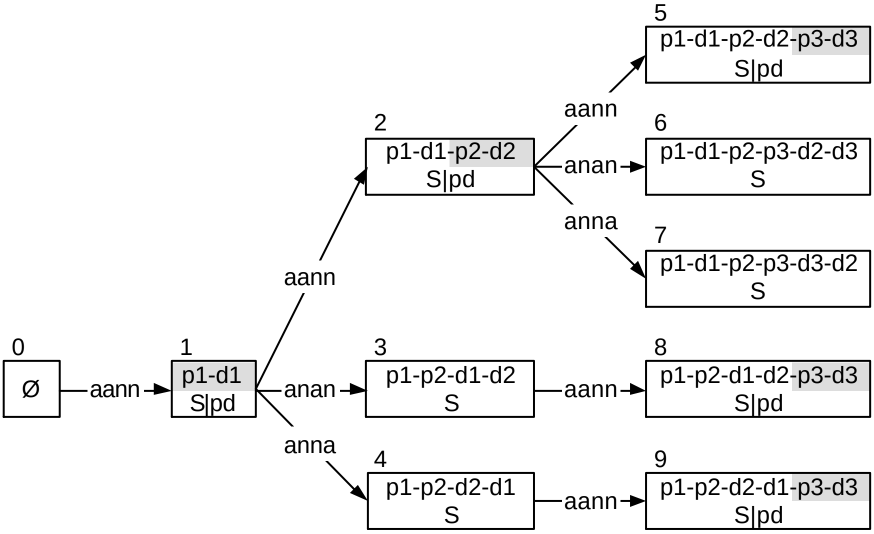

Figure 5. Generation of chains of transportation orders for a single AGV (Grey-shaded areas show non-interlocked pick-up and drop-off operations at the end of an operation chain.)

The feasible options for generating a chain of transportation orders for a single AGV are illustrated in Figure 5. At first, pick-up and drop-off operations p1 and d1 of the first order are assigned to the vehicle. The resulting condition of the vehicle is “S | pd” (node 1). The second order with operations p2 and d2 can be appended by use of any of the assignment patterns, “*aann*”, “*anan*”, or “*anna*” leading to nodes 2, 3, and 4. In node 2, the two orders are executed successively, i.e. the corresponding handling operations are not interlocked and the condition of the vehicle is identified as “S | pd”. Thus, any of the assignment patterns can be used to append order 3 with operations p3 and d3 leading to nodes 5, 6, and 7. If, however, patterns “*anan*” or “*anna*” are selected, the handling operations of the two orders are interlocked and the vehicle changes to condition “S” (nodes 3 and 4). Hence, pattern “*aann*” is the only feasible to append the third order leading to nodes 8 and 9, respectively. For each of the nodes 5 to 9, the condition of the vehicle is identified as “S” or “S | pd” and the next order is appended to the existing chain.

Regardless of which assignment option is used, after evaluating all feasible assignments the one with the lowest cost (e.g., waiting time of the quay crane) is selected. The vehicles’ availability (or condition) is updated and a new iteration is initiated for the next transportation order, now considering the modified condition for each AGV. The heuristic terminates if all transportation orders in the planning horizon are assigned to a vehicle.

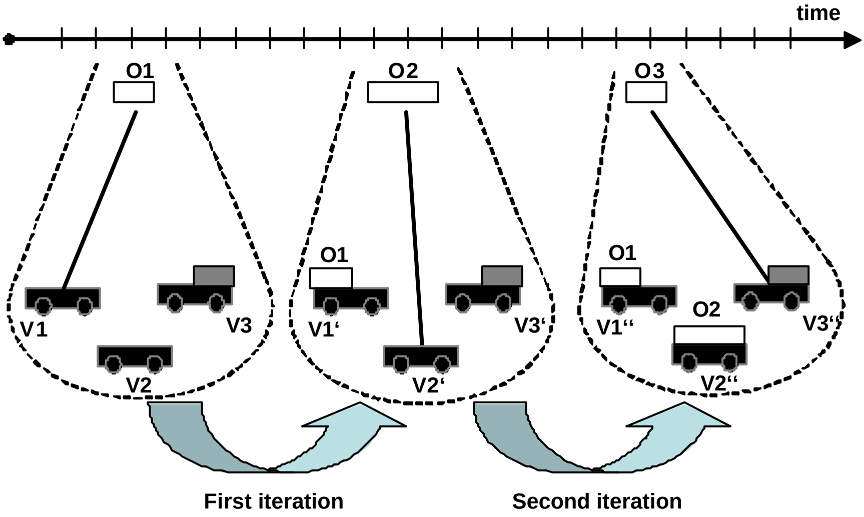

Figure 6. Iterations of the pattern-based heuristic

In Figure 6 the pattern-based heuristic is outlined using a simple example. The set of AGVs available and the change of their loading conditions are shown along the horizontal time bar. Three transportation orders O1, O2 and O3 are released at specific points in time. Assignments carried out in the course of the heuristic procedure are represented by solid lines. Boxes on top of the vehicles indicate loaded or assigned containers. Grey-shaded boxes represent loads assigned during former dispatching requests, while white boxes indicate actual assignments made in the current iteration. In this example, the transportation order with the earliest starting time, order O1, is assigned to vehicle V1 in the first iteration. As a result, the status of the vehicles changes from iteration to iteration, which is indicated by apostrophes at the vehicles’ names. In the subsequent iterations, the modified status of the AGVs has to be considered.

The pattern-based heuristic could also be used as an on-line strategy. However, it only reveals its full potential in the off-line mode and has therefore been exclusively used as an off-line approach in our investigations.

5 Simulation study

To evaluate the effectiveness of the various dispatching approaches a comprehensive simulation study has been conducted. A discrete event-based simulation model has been developed using the eM-Plant 6.0 simulation system. For modelling a real logistics system through simulation, a major issue in the design of the simulation model refers to the definition of the system boundaries. We decided to build up the simulated system around an AGV guide path and a fleet of vehicles which transport 20 ft or 40 ft containers between quay cranes located at the berth side and automated stacking cranes which operate at the different storage blocks arranged at the opposite side of the guide path. Thus, sub-systems not included in the simulation model are, for instance, the stowage and berth planning for vessels, the storage planning for containers inside the storage blocks, the interface to the hinterland, and the traffic control of the AGV system.

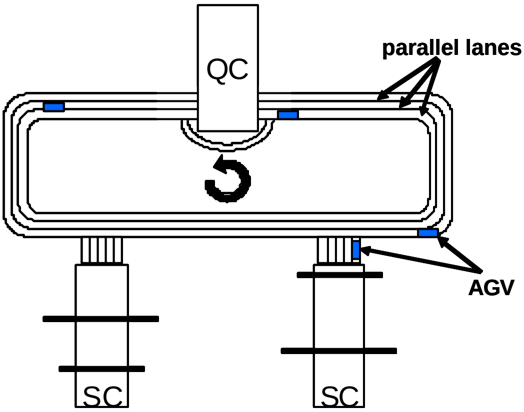

Figure 7. Basic module of a terminal configuration (QC: quay crane; SC: stacking crane)

In order to simulate automated container terminals of different size, a basic module was defined which constitutes the building block of a flexible terminal configuration (see Figure 7). Hence, by combining various modules a larger terminal configuration can be generated. The basic module consists of four elements: (1) the AGV guide path laid out as a four-lane uni-directional loop, (2) a fleet of AGVs, (3) a single quay crane, and (4) two storage blocks equipped with two automated stacking cranes each. In optional modules, one or two of the storage blocks or the quay crane are omitted. Thus, an arbitrary combination of quay cranes and storage blocks can be simulated. This design is used to generate a terminal configuration with a series of storage blocks concentrated in the centre of the storage yard. To generate a new terminal configuration, only four parameters are required:

(1) the number of quay cranes,

(2) the number of storage blocks,

(3) the AGV travel time between two quay cranes,

(4) the AGV travel time between the storage area and the berth side.

As an example, Figure 8 displays a medium-sized terminal configuration with 8 quay cranes, 12 storage blocks, and AGV travel times of 25 and 20 seconds between two quay cranes and between the storage area and the berth side, respectively. All cranes in the system are linked by a uni-directional mesh-type guide path in which only the traversals between the quayside and the storage yard show a bi-directional orientation.

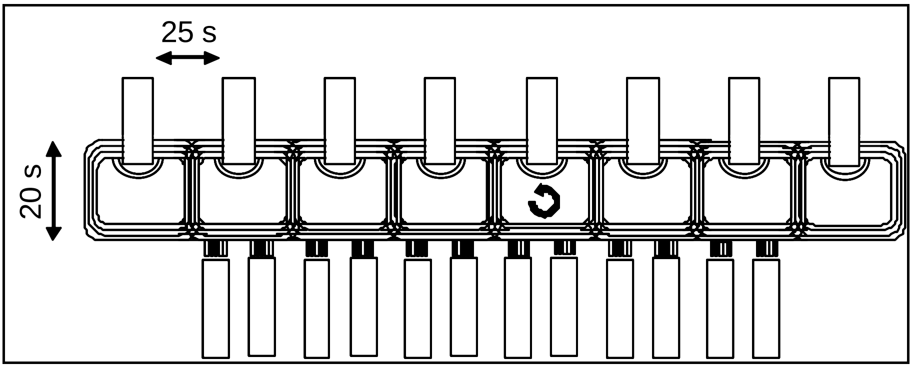

Figure 8. Medium-sized terminal configuration generated from basic modules

Since minimizing turnover time of the vessels is the most important performance criterion for AGV dispatching, the different approaches are compared in terms of quay crane utilization. The theoretical optimum of a utilization of 100% would be reached if all quay cranes worked uninterruptedly throughout the whole simulation. Idle times of a quay crane (which means the quay crane has to wait for a vehicle) impair the performance. The overall quay crane utilization is determined by the average utilization of the individual quay cranes. Detailed simulation results will be presented in a separate paper.

6 Summary and conclusions

The main contribution of this paper is the development of rule-based methods for the AGV dispatching problem in seaport container terminals and their evaluation by use of a scalable event-based simulation model which allows to model terminal configurations of practical size. After a brief discussion of the AGV dispatching problem at hand two principle approaches – on-line and off-line dispatching – are introduced. A basic on-line dispatching rule and a more sophisticated off-line heuristic are developed. In the course of our simulation study, we detected that the performance of the dispatching rules suffered from the occurrence of deadlock situations. Therefore, we decided to develop a comprehensive scheme to handle deadlocks occurring in the operation of the AGV system. It will be integrated into the simulation model and used in our future numerical investigation in order to improve the performance of the dual-load AGVs.

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