Barge rotation planning and quay scheduling
in the port of Rotterdam

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Abstract

We consider the problem how to align barge rotations with quay schedules of terminals in the port of Rotterdam. In the port of Rotterdam, barges are used to transport containers to the hinterland and from the hinterland back to the port. Every time a barge visits the port, it has to make a rotation along on average eight terminals to load and unload containers. To plan a rotation in practise, the barge operator (who contracts the barge) communicates with the concerning terminal operators about time slots the barge can be handled.

A central solution, in the form of a trusted party that coordinates the activities of all barges and terminals, is not feasible for several reasons. One of the reasons is that barges and terminals want to stay autonomous and in control of their own operations. We therefore propose a multi-agent based approach of the problem, since a multi-agent system can mirror to a large extent the way the business network is currently organized and can provide a solution that is acceptable by each of the parties involved. A simple multi-agent control, which is currently implemented in the port of Rotterdam, was developed in a previous project. We examine the application of more sophisticated agents and evaluate the performance by means of simulation. We compare the results with an off-line scheduling algorithm. Besides theoretical inside, we focus also on application in practise in the near future.

Introduction

In this extended abstract we introduce the problem and problem setting. We explain the approach we choose and how the problem is related to several problems in the literature. After that we briefly describe the multi agent model we designed and we conclude with an indication of our results.

Problem and problem setting

The problem we consider in this paper is inspired by a real problem in the port of Rotterdam (see Figure 1 for an impression of the port). In the port of Rotterdam barges are used as means to transport containers from the port to the hinterland and back. Most terminals use the same transhipment capacity for barges as for large sea-going vessels. Down times of terminals are caused by i) sea-going vessels (which have absolute priority over barges), ii) closing times or iii) technical disturbances. To be able to operate efficiently it is necessary for terminals and barges to align their activities. Due to increasing road congestion, limited rail capacity and growing container transportation, barge transport is increasingly important for
serving the hinterland connections. For terminals this means that their quay activities will grow and need to be planned carefully in order to obtain high quay utilisations.

The barge rotation planning and quay scheduling problem is complex, not only because of the scale but also because of the specific business network. In the port of Rotterdam there are about 30 terminals and on average 75 barges visit the port daily, visiting about eight terminals each. Additional complexity results from the current business relations. Although the performance of terminals and barges are mutually dependent, central coordination is hard to establish. First, because barge operators compete with each other (as terminal operators do) and are therefore very reluctant to share information that possibly deteriorates their competitive position. Second, no contractual relationships exist among barges and terminal operators. This means that barge operators and terminal operators cannot force each other contractually to deliver a certain service or charge each other for poor services. Third, both barge and terminal operators want to stay autonomous, i.e., in control of their own operations.

Currently a poor alignment of activities, uncertainties during operations and strategic behaviour of both terminals and barge operators lead to inefficient use of quays and long dwell times of barges in the port, which also affect the reputation and the attractiveness of barges as transport modality.

**Approach**

In our presentation we present a multi-agent based model for the barge rotation planning and quay scheduling problem, where the planning of rotations and quays is done in real-time. We
examine the performance of the multi-agent based solution by means of discrete event simulation and especially consider the effect of different levels of information exchange and several algorithms for barge and terminal operators. We compare the results with an off-line scheduling algorithm, assuming that all information during a certain time period is known in advance (static and deterministic).

In our multi-agent model we define a barge-operator agent for every barge operator and a terminal-operator agent for every terminal operator. Aim of the barge operator is to leave the port within the time window determined by the sailing schedule of the barge. Aim of the terminal operator is to maximize its quay utilisation. Other parties are omitted in our model, since we are mainly interested in the performance of a distributed barge rotation planning and quay scheduling system compared to a central solution.

**Related literature**

The problem we consider is about routing and scheduling decisions. We mention only two related problems in the literature, namely the berth allocation problem and the attended home delivery problem.

The berth allocation problem (BAP) concerns the assignment of berths to ships (see for an overview e.g. [1, 2]). In the BAP it is usually assumed that the arrival times of ships, as well as the processing times are known at the time the berth plan is made (see, e.g., [2, 3]). In our problem, arrival times of barges are uncertain and terminals have to plan quays based on partially known information. We therefore model the terminal as an online parallel machine scheduling problem, where barges can be processed by one or more machines simultaneously. By creating schedules we not only focus on minimizing the lateness of activities, but we also consider the robustness of the schedules (see, [4, 5]).

The problem we consider is also related to the attended home delivery problem (AHDP) [6], where a carrier offers attended deliveries of packages at the home of customers. Attended deliveries mean that a customer has to be present when the package is delivered. To optimize the route the carrier travels, [6] consider incentive schemes to influence the preferred time windows of a customer. We consider a similar problem, however, now we have multiple carriers each visiting a subset of the total set of customers. Customers can deal with only one carrier at a time and customers want plan carriers close to each other in order to decrease the time they need to be at home. In our problem customers can use incentive schemes to let the carriers apply for convenient time slots. Carriers in turn aim to minimize the time they have to travel for delivering all packages.
Multi agent model
In this section we describe the multi agent model. We discuss the communication mechanism and the barge and terminal operator intelligence successively.

Communication mechanism
As communicating mechanism we opt for negotiation instead of a contract net protocol, because of the lacking contractual relationships in the current situation and the reluctance of parties to accept a system in which a (virtual) currency is introduced.

Since terminals are very reluctant to share information that can be used by others to improve their competitive position, we consider two alternatives. First, terminals provide a barge possible time slots during a certain time horizon. Based on the provided time slots, a barge plans its rotation and announces the time it arrives at a terminal. Based on the response of the barge the terminal updates it schedule.

Second, terminals provide a waiting profile (see, Figure 2) during a certain time horizon, i.e., the maximum waiting time when a barge arrives at a certain moment during the time horizon. Providing waiting times instead of time slots has some benefits. In fact a waiting time expresses the time till the next time slot. However, a terminal operator can express the preferred time in the time slot by adapting the waiting time within the time slot. Moreover, a terminal operator can add some extra waiting time to get some flexibility in planning a barge. We assume that barges decide in real-time about their preferred rotation and communicate this with the terminal operators.

Barge operator intelligence
The barge operator has to solve a travelling salesman problem (TSP) based on the information provided by the terminals, either time slots or waiting times. We focus on the waiting times, since time slots can be translated to waiting profiles as well. We can model the

![Example waiting profile](image-url)
rotation planning problem as a time dependent TSP (TDTSP), where we define the time
dependent travel time \( \tau_{ij}(d_i) \) between terminal \( i \) and \( j \) as:
\[
\tau_{ij}(d_i) = s_{ij} + h_j + 2 \cdot m_j + w_j(d_i),
\]
where \( s_{ij} \) is the sailing time between terminal \( i \) and \( j \), and \( h_j \) and \( m_j \) the handling and mooring
time respectively time at terminal \( j \) (all deterministic). The waiting time \( w_j(d_i) \) is depending
on terminal \( j \) and the departure time \( d_i \) at terminal \( i \). The number of terminals a barge has to
visit is usually between five and twenty terminals. To solve the TDTSP we use a depth-first
branch and bound for smaller instances and beam search for greater instances. A barge can
adapt its planned rotation during execution by making new appointments.

To decrease the propagation of disruptions among terminals, we force barge to include
enough slack in between terminal visits. Terminals can force barge to do so, by refusing the
handling of a barge if it arrives after its announced arrival time. This is to prevent that sailing
schedules of barges become so tight, that the system becomes very sensitive for small
disruptions.

**Terminal operator intelligence**
The terminal operator has to solve a parallel machine scheduling problem, where every
machine is represented by a quay-crane-team combination (QTC) and barges can be
processed by more than one QTC. To provide time slots or waiting times to a barge, a
terminal operator has to take uncertain information about possible arrivals of new barges into
account. To optimize the quay utilisation, a terminal operator therefore needs to consider both
the make span as well as the robustness of the schedule. We describe the robustness of a
schedule by the nervousness, flexibility and stability of a schedule (see also [5]). Nervousness
means that a schedule experiences frequent and large changes, which is not desirable, at least
not a few hours before execution of the plan due to the fact that containers have to be stacked
at the quay for loading. Flexibility reflects how easy a schedule can be repaired in another
high quality schedule. Stability is about the extent to which the propagation of disruptions can
be suppressed.

We present algorithms to create baseline schedules that lead to high quay utilisation and are
also robust, as described above.

**Off-line benchmark algorithm**
For the offline benchmark algorithm we model the barge rotation planning and quay
scheduling problem as a resource constraint project scheduling problem (RCPSP) [7] which
we adapt for specific characteristics of the problem we consider. We solve the adapted
RCPSP using an algorithm that is based on an adaptive search algorithm [8]. We adapt this
algorithm, for example to deal with the resource profiles, which are not present in the basic RCPSP. For further reading about the exact modeling we refer to [9].

Results

To evaluate the performance of the multi-agent based solution we perform a simulation study and compare the results with an off-line scheduling algorithm. From the experiments we see that both terminals and barges are able to realize their objectives, although the extent to which depends highly on the activities of other barges and terminals.

Consider, for instance, that two barges are waiting at a terminal to be handled and suppose that one barge can benefit a lot by being handled first and that the other is not harmed if the terminal would choose so. The terminal considers these two barges as equal and just chooses the barge that fits best to the quay schedule. Another example is when one terminal in a region has limited capacity due to e.g. the fact that it processes a sea-going vessel, we see that barges sidestep to other terminals near by. This means that the ability of terminals to level their workload depends of the activities of other barges and terminals.

The problems we illustrated are inherent to the way the business is currently organized. In our presentation we provide insight in the way the multi-agent system performs and the extent of optimization that can be realized.

References

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