APPROACH: Decentralised Rotation Planning for Container Barges

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Abstract This paper presents the engineering and development process of a software tool (APPROACH) that is designed for decentralised rotation planning for container barges in the port of Rotterdam. For domain analysis and requirements engineering for the tool, a formal organisation dynamics modelling approach was adopted. We present the APPROACH tool demonstrating the added value of automation of rotation planning over traditional planning. The development trajectory of the tool demonstrates the benefits of the used formal modelling approach in a practical real-world setting, resulting in a concrete software tool that can be put into work in the harbour. Preliminary analysis indicates that execution times of barge rotation in the harbour decreases when the tool is used.

1 Introduction

The port of Rotterdam consists of a number of terminals (approximately 18-24) at which sea vessels and a number of barges (approximately 120 in total) continuously load and unload containers. Rotation scheduling concerns the problem of assigning rotations to barges over a number of terminals (approximately 7 per port visit) that they have to visit. This problem assumes the existence of some given schedule of terminal visits of sea vessels, around which the barge vessels must be scheduled. The key issue of this problem is in the following statistics: the average rotation time is approximately 22.5 hours, of which only 7.5 hours are used for loading and unloading. The remaining time is spent sailing and waiting [6] [7]. This paper presents work that has been a first step towards decreasing the rotation time. In close cooperation with people working in the port of Rotterdam, we have developed a planning tool (called APPROACH) that partially automates rotation planning for terminal and barge operators.

A bottleneck analysis has been performed to investigate the issue of rotation planning. This analysis concludes that barge operators and terminal operators keep each other caught in a process of increasingly more delays and a decreasing utilisation of capacities. As such, they generate a process in which each party tries to eliminate the disadvantageous effects caused by the other. However, the measures undertaken for this have a harmful effect again on the other party. As such, the process is circular and cannot be stopped by any of the parties.

The system using the APPROACH planning tool has a decentralised functionality. The reasons for this are as follows. Firstly, a decentralised system may simplify the planning process by dividing complex tasks into simpler tasks. Secondly, a decentralised solution agrees very much with the network structure of the barge handling process. The particular problem under investigation here does not even allow for a centralised solution because of organisational and technical issues. These include the necessary information hiding (concerning autonomy and interests) for each of the involved parties; the missing of contractual relations between terminal operators and barge operators; the fact that barge handling is a complicated problem taking place in a changing and dynamic environment such that flexibility is imperative; and finally, that the logistic chain is a network that cannot easily be captured in a centralised or hierarchical manner.

The functionality of the decentralised planning system captures the following. Firstly, it enables the exchange of information between parties where the owner of the information can indicate who receives what information. For example, the quay planning of a terminal operator will be communicated to barge operators but explicitly not to other terminal operators. Secondly, the planning between barge operators and terminal operators is synchronised and optimised. Finally, we prepare for the online generation of alternative plannings to respond to possible disruptions during execution.

The objective of the APPROACH project is twofold. Firstly, the project should give insights into the effects of decentralised planning on the reliability of barge handling in the harbour. Secondly, the applicability of multi agent technology is considered for modelling and realising a decentralised planning system. The main contribution of this paper is also twofold. Firstly, we outline the potential of the APPROACH tool as a ready, decentralised, agent-based solution towards the rotation planning problem in the port of Rotterdam. Additionally, we demonstrate the practical viability of our formal organisation dynamics modelling approach based on the Agent-Group-Role model.

The development team of APPROACH consists of 8 persons and spanned a development period of 2 years. At the time of this writing, a prototype of the tool is being tested by the end-users and the work described in this paper is considered to be a first step in longer term tool development.

2 Barge Handling

Barge operators are responsible for cargo handling and co-ordinating inland shipping activities. They operate the inland shuttles between the port and the hinterland and, in consultation with the captain, determine the order of calling at the various terminals. It is vital that capacity reservations are made well in advance, particularly when larger terminals are concerned. After all, barge operators want to achieve rapid and, more important, reliable barge handling.

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Terminal operators are responsible for the transhipment of containers from seagoing vessels to other means of transport or hinterland transport. To facilitate the scheduling of the transhipment activities, they need to know well in advance how many containers are to be loaded / unloaded and at what time. Terminal operators want to maximise the use of the scheduled available transhipment capacity.

Accommodating seagoing vessels is a key priority in scheduling terminal activities. Barges are scheduled in after seagoing vessels, which is why barge operators must inform large terminals at least 24 hours in advance of the number of barges that will be calling and the activities required. The requests are collected and included in the terminal schedules. The barge operator receives a confirmation of the scheduled times. In the event of significant discrepancies between the requests and the actual schedule, further consultations may be held by telephone. Currently, only the barge operator works to harmonise the various terminal schedules. However, he has no say in the final schedules, which are determined unilaterally by the various terminal operators.

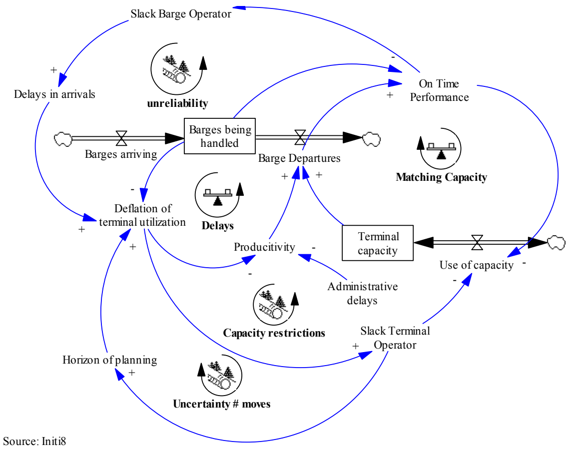

Figure 1. Overview of causal structure

3 Bottleneck Analysis

A system dynamics analysis has been conducted to gain insight in the complex interactions between the delays in dispatchments of barges, planned time of arrivals of barges and the unreliability of planned rotations. This bottleneck analysis identifies (positive and negative) feedback loops in the causal structure of the problem. Positive feedback loops are those that tend to increase themselves. A negative feedback loop has a stabilising effect with respect to changes. The combination of these feedback loops provides insight into the behaviour of systems and indicates how to intervene most effectively.

Figure 1 shows an overview of the causal structure for the delays and unreliabilities in barge handling. Positive feedback loops are indicated by a snowball icon and negative loops are indicated by a balance icon.

The conclusions of the system dynamics analysis for barge handling can be summarised as follows:

- The absolute available capacity is not the cause problems in barge handling. Shortage in capacity can worsen the problem and extending the capacity may lessen the problem. However, the actual solution can be realised to less costs and efforts.
- Delays in planned arrivals lead to idling of the terminal. A consequence of this is that fewer barges can be dispatched with the available capacity. This leads to waiting queues.
- Slack is built into the system in various ways, because all participants expect delays during the execution. This slack cause further worsening of mutually tuning the asked and offered capacity leading to further waiting queues.
- Call slots are singularly determined by the terminal operator and do not always agree with the requested times of the barge operators. As such, no other planned terminal visits are taken into consideration. If the number of terminals that a barge has to visit increases, then the chance increases that these visits are not mutually tuned.
- A longer planning horizon worsens the situation.
- The speed of administrative dispatchments of barges contributes to further delays.

A simulation model has validated the qualitative analysis.

3.1. Key Performance Indicators

On the basis of the performed bottleneck analysis, the departure point for the key performance indicators is the combination of the On Time Performance (OTP) of barges and the Booking Performance (BP) of terminal capacity. The OTP is concerned with loading and unloading of barges at the terminals; the BP depends on the degree of utility of terminal quays. The conclusion of the bottleneck analysis was that these aspects can be influenced positively by applying and incorporating a tool like the APPROACH application presented here.

4 Agent-Group-Role Modelling

This Section describes the Agent-Group-Role (AGR) modelling approach in theory and practice.

4.1. In Theory

In an AGR-model, an organization is described as a structure for activity and interaction of multiple agents through the definition of groups, roles and their relationships: an organization is regarded as a structural relationship between a collection of agents. A role is the abstraction of recurrent agent behaviour. Interactions define the relationship linking the roles to each other. A group structure is a set of roles and interactions between these providing a common (communication) context and rationale.

An AGR organisation model does not specify the behaviour of roles, of groups or of the overall organisation, nor how these dynamics relate to each other. To be able to analyse dynamics of an organisation at different levels of aggregation (i.e., roles, groups, and organisation as a whole), an extension is needed to the AGR-model. This dynamic extension has been developed in [5], [2], [4], [3].

By applying the dynamic organisation modelling method to decentralised rotation planning, we aim to lay out an infrastructure of the port of Rotterdam on which a multi-agent system can be built that may better achieve individual goals of all parties involved.

4.2. In Practice - Modelling barge rotation planning

In APPROACH, we use the AGR method to lay out the infrastructure in which the planning tool will eventually function[4].

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[4] We also modelled individual calls and complete rotations of barges. These models provided insights into the consequences of interruptions and

The method provides us with ways of setting up a detailed formalisation of this structure. This Section describes the models and simulation that resulted from the formalisation. However, note that here, firstly, we do not go into the verification of the key performance indicators, and, secondly, we are not concerned with the actual workings of planning itself. Concerning the latter, we merely use the AGR method as a tool to very precisely lay out the communication structure in the problem domain, within which the APPROACH tool will eventually function. The workings of the tool itself are described later.

4.2.1. Initial Planning Modelling

The emphasis in the APPROACH project is the initial planning phase in which the plans of the barge operators have to be matched with the plans from the terminal operators. We have constructed an organisation dynamics model of this phase and present this here.

The model consists of 1) a specification encoding the planning process and 2) a subsequent simulation resulting from executing the specification. We describe the domain analysis, specification and simulation.

Domain analysis

During planning, we can distinguish four different phases. These are 1) sending preliminary call announcements from the barge operators to the terminal operators, 2) sending the definitive call announcements from the barge operators to the terminal operators, 3) sending the replies from the terminal operators to the barge operators, and 4) sending the rotation schedules to all concerned barges.

One working day before execution of the call, the definitive number of containers to be loaded and unloaded must be communicated. We let the planning method here be *collect-24*. This method denotes that the terminal operators collect all call requests until 24 hours before the actual execution of the call. Other planning methods are collect-48, collect-72 and FIFO.

The information above is the starting point for modelling collect-24 in an example scenario with 1 barge operator, 2 barges and 3 terminals. The scenario involves 3 terminals each operating on the basis of collect-24 and 1 barge operator who arranges the rotation schedules of the 2 barges. Based on some given set of bookings (not modelled), the barge operators send announcements to the 3 terminals, receive replies, and sends rotation schedules to the barges.

Of this scenario, we implement the communications between the barge operator and terminals and barge operators and barges on Monday and Tuesday about the announcements and the replies on Tuesday and Wednesday.

We model the collect-24 planning based on the following bookings.

Tuesday 12.00	terminalA	(planned for barge1)
Tuesday 16.00	terminalB	(planned for barge1)
Wednesday 08.00	terminalB	(planned for barge1)
Wednesday 21.00	terminalC	(planned for barge2)
Thursday 08.00	terminalC	(planned for barge2)

unexpected disturbances during rotation execution. Since the work described in this paper focuses on the context in which the APPROACH tool is currently used, we have not included these models here.

The corresponding announcements on Monday and Tuesday take place as follows:

Monday	Tuesday
definitive announcements:	*definitive announcements*
barge1, terminalA, tue 12.00	barge1, terminalB, wed 08.00
barge1, terminalB, tue 16.00	barge2, terminalC, wed 21.00
preliminary announcements:	*preliminary announcements*
barge1, terminalB, wed 08.00	barge2, terminalB, thu 08.00
barge2, terminalC, wed 21.00	

Specification

The specification of our model consists of a set of so-called 'leads-to' rules. These rules can be considered 'if-then' rules with which one can associate a temporal aspect. The complete specification consists of an input and output part. In the input part, barge operators announcements are generated based on the available bookings. The output part, e.g., the engine, concerns the communication between the 1) barge operator and terminal operator and 2) barge operator and barge in order to set up quay plannings and rotation schedules.

The complete specification consists of 22 'leads-to' rules. Of these, 4 are for the input part and the other 18 rules are for the output part. In the input, different scenarios can be set up of the following dimensions:

- Number of terminals
- Number of barges
- Preliminary announcements (barge, terminal, ETA)
- Definitive announcements (barge, terminal, ETA)
- Replies (barge, terminal, ETA)

The input rules thus contain information on the specific scenario based on which quay plannings and rotation schedules must be constructed. Consider the following rule as an example.

```
input(planner)|bookings
↠
output(planner)|info(pre_ancmnt,bargeslot(barge1,termA,tue,1200)) &
output(planner)|info(pre_ancmnt,bargeslot(barge1,termB,tue,1600)) &
output(planner)|info(pre_ancmnt,bargeslot(barge2,termC,wed,2100)) &
output(planner)|info(pre_ancmnt,bargeslot(barge1,termB,wed,0800)) &
output(planner)|info(pre_ancmnt,bargeslot(barge2,termC,thu,0800)) &
```

This rule says that the barge operator generates preliminary announcements based on some given set of bookings. The announcements concern barges 1 and 2 for executing dispatchment calls at terminals A, B and C.

The output rules are the engine of the specification and implement the process of constructing quay plannings and rotation schedules on the basis of some collection of bookings. Consider the following rule as example.

```
∀ b:'BARGE',c:'CALL',t:'TERMINAL',r:'REAL' :
output(role_in(radio,b))|info(rotation,call(c,t,r))
↠
input(role_in(shipper,b))|info(rotation,call(c,t,r))
```

This rule states that the radio of the barge shipper communicates the rotation schedule to the shipper.

Simulation

The specification can be executed and, as such, the process of rotation- and quay planning can be simulated detailed. The execution of a leads-to specification results in a trace, which can be verified on certain properties. A trace is a chronological overview of activities that are part of the modelled (business) process.

Consider a partial trace as shown in Figure 2. This trace shows the movements of two barges (barge1 and barge2). One can, for example, observe that barge 1 is in Andernach between times 72 and 82.

Figure 2. Partial trace of initial planning model

4.3. Summary

To summarise, the contribution of the AGR model to the development of the tool is as follows. Firstly, we have used the AGR model to map out the infrastructure of the necessary communication between the barges, barge operators and terminal operators. Secondly, we have laid the foundation of testing the added value of the APPROACH tool over the current way of rotation planning. With further formal development and experimental testing, we use this foundation to evaluate the on-time and booking performance indicators. On the basis is of the collect-24 planning model, a trace has been generated. This trace shows the activities from the moment that a barge operator receives a set of bookings until the moment that barge receive their rotation schedules.

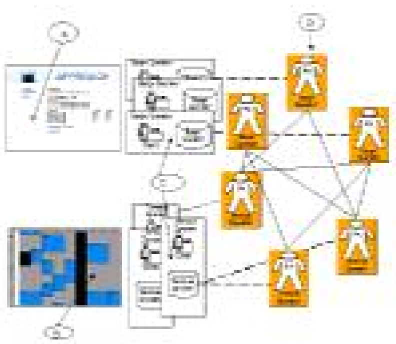

Figure 3. Architecture of the APPROACH prototype

5 Approach Tool

The developed APPROACH tool is a multi-agent based and distributed planning system [8]. Initial results show that is possible to construct efficient and realistic rotation plans for barges with a distributed multi-agent planning system. Additionally, it has proven possible to improve individual as well as combined plans of parties who are competitive or have counter interests. It has been shown that in this case there is no need to for parties to share company confidential information and therefore they can retain their autonomy.

5.1. Architecture

Figure 3 shows the basic architecture of the overall APPROACH system. Via websites for the barge operators (A) and terminal operators (B), information is supplied to the system and results can be obtained from it. Each operator has its own company database (C) that is not accessible to other participants. Each participant is represented by its agent (or: personal assistant PA) as shown at (D). These PAs will use available information from the databases and try to construct realistic rotations and quay plans. Most of the administration and communication necessary between barge and terminal operators in this matching process is taken care of by the APPROACH system.

Communication between barge operator agents (BOA) and terminal operator agents (TOA) is relatively simple. The process involved here concerns mostly steps of timeslot request (from BOA), timeslot reply (from TOA), and confirmation or cancellation (from BOA). As communication in this process is, computationally, cheap (as compared to traditional faxing or calling), the power of it lies in the fact there can be many rounds of which one will eventually be as good as possible as well as realistic.

5.2. APPROACH Planning

This Section describes the planning process from start, the tasks of barge and terminal operators and the matching of plans of both operators. APPROACH supports the barge operator and terminal operator during the preparation phase (the initial planning). A barge operator hands in a loading plan for each barge. Also other requirements like ‘expected time of arrival’ and ‘expected time of departure’ will be communicated. A terminal operator puts in the timeslots for the dispatches of the barges. Other requirements on planning of the dispatches (priorities, opening times, capacities) are assumed to be available beforehand, but may be subject to change.

Barge Operator Tasks

A task decomposition for the barge operator includes the following tasks:

1. *Generate scenarios*
   On the basis of a set of prior requirements (like prioritising of terminals, desired timeslots, prioritising of containers) and the desired loading plan, APPROACH generates a series of scenarios for terminal visits.
2. *Prioritise and select scenario*
   APPROACH presents the generated scenarios to the barge operator, of which the barge operator selects the most appropriate. APPROACH then decomposes the scenario in a set of terminal visits. Finally, APPROACH sends the desired terminal visits to the appropriate terminal operator agents.
3. *Evaluate feedback*
   APPROACH evaluates the feedback received from the terminal operator agents. Proposals that do not comply with the desired visits are rejected. After proposals have been rejected, a new scenario is selected after which the individual terminal visits are communicated to the terminal operator agents again. When proposals are accepted by the barge operator, this is confirmed to the terminal operator agents.

Terminal Operator Tasks

The workflow of the terminal agent consists of the following tasks:

1. *Input requirements*
   The terminal operator puts in prior requirements and the agent processes these. These requirements can be put in at any time.

Examples of such requirements include: desired plans, prioritising of barge operators, desired timeslots, prioritising of crane and staff.

2. *Plan and schedule*
   Definitive announcements for visits are collected from barge operators. These are prioritised (on the basis of prior requirements). Announcements are planned and scheduled on the basis of prior requirements and planning. All announcements are reserved. Finally, the reserved timeslots are reported back to the barge operator agent.
3. *Send confirmed reports and rejected reports*
   If proposed timeslots are accepted by the concerned barge operator, these are made definitive in the planning of the terminal operators. Rejected timeslots are released again in the planning of the terminal operators.

Mutual tuning rounds

Barge operators know their calls some days in advance but minor and sometimes major changes will keep coming in. To rule out most uncertainties, reservations should be made as late as possible. The terminal operators too have an interest in accurate reservations but need some time to organise and schedule manpower. Normally 24 hours gives enough time for the terminal operators and therefore reservations will have to be made one day in advance (the day before the actual tour is started).

The process of matching plans of barge operators and terminal operators involves subsequently execute their tasks as described in the previous Sections.

Generate rotations

As for the generation of possible rotations, two hard constraints must be taken into account:

- the Planned Time of harbour Arrival (PTA) and Planned Time of harbour Departure (PTD), which come from the sailing schedule of the barge
- the loading plan (e.g., first unload a big container before loading a large number of containers).

The first constraint is predictable in the way that barge operators follow their sailing schedule even if that means that they have to skip a visit. On average, currently sailing schedules allow for barges to be in the harbour for approximately 22 hours, of which much time is waiting time. The second constraint cannot be so easily predicted, as it can vary much for different rotations.

APPROACH can flexibly deal with these constraints. The point of departure is to focus on a schedule that is as compact as possible and stable and reliable. Stability and reliability are defined as such that a barge operator can expect to get a rotation that has the same duration as equivalent tours scheduled and obtained in the past. The variation should be low and predictable, which gives way to the barge operator to define a new sailing schedule that shorter in-harbour-time's for barges.

6 Conclusions

The project described in this paper has had the purpose to set up a decentralised planning system (APPROACH) with which the terminal visits of barges in the port of Rotterdam can be planned more efficiently and effectively. The application developed in the context of this project shows that it is possible to construct efficient and realistic rotations for barges with a distributed multi-agent planning system. It is possible to improve the individual and joint plans of competitive parties having conflicting interests. The essential feature of the tools is that this improvement can be achieved while both parties keep their autonomy and no company information needs to be exchanged.

Concerning the application of the Agent-Group-Role (AGR) model in the context of APPROACH, we draw the following conclusions. At first, we have found that the used method to set up a correct AGR model required an analysis of the domain that has given all parties involved in the design process insights into the domain that have proven useful for the development of the APPROACH tool. Secondly, we have used the AGR model for a requirement analysis for the APPROACH software tool. This mainly concerned setting up a function model of the developed software. In combination with the above-mentioned organisation analysis insights were gained into the actual application of the software.

We consider two possible future research tracks. At first, our experience with this domain has been that it offers possibilities concerning more dynamic kinds of planning (e.g. runtime) than those that have been used until now. Secondly, we intend to set up a detailed verification model for the rotation scheduling process. This model can give guarantees concerning which party needs which information when and that this really happens.

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