

DISTRIBUTED ROTATION PLANNING FOR CONTAINER BARGES IN THE PORT OF ROTTERDAM

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Abstract

The transport of containers by barges has a share of approximately 40% of the containers transported from and to the hinterland of the Port of Rotterdam. The planning and coordination of the rotation of the barges in the port is still a complex task. Barge operators have to make reservations with on average eight different terminal operators. Due to delays and changes in the quantities of containers to be load and unloaded many changes have to made to the schedule during the execution of the rotation. The lack of transparency in the availability of terminal capacity creates inefficient rotations in the port and causes much frustration with each of the parties. To find a solution to these problems, the 'Approach consortium', comprising Free University Amsterdam, Illyan, Initi8 and the Rotterdam Municipal Harbour Service, explore the application of distributed planning supported by agent technology. This new technology has advantages over concepts that were suggested and based on centralized decision making and data collection.

1 THE CONTAINER BARGE HANDLING PROBLEM IN THE PORT OF ROTTERDAM

Rotterdam is a key container transshipment port in the northwest of Europe. The quality of a port's hinterland connections is becoming an increasingly decisive competitive factor. Until recently, road traffic was by far the primary hinterland connection. However, since the early 1980s, the Rhine has increasingly been recognised as a 'natural' connection with the German hinterland. Currently commanding a 40% market share, inland container shipping has in recent decades developed into a vital hinterland connection. Although barges are not a fast mode of transport, they can be operated according to regular shipping schedules. Their success can largely be attributed to the scale of operations and the ability to operate regular services. Inland shipping has become an inexpensive and reliable link in the logistics chain.

As a result of spectacular growth, container transshipment capacity in Rotterdam is now under pressure. Barges are handled at the terminal's quayside, using the same transshipment capacity (i.e. cranes and quays) as large seagoing vessels, placing ever greater demands on effective and reliable planning. In addition to the co-ordination of handling seagoing vessels and barges, there is another complicating factor affecting transshipment capacity planning: barges in the port of Rotterdam call at an average of eight terminals. 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

To reduce the rotation time, barge operator aim to plan the visits to the various terminals as tight as possible. The complicated nature of this planning is borne out by the fact that only 62% of the barges leave the port of Rotterdam on time, taking into account a time margin of 60% (stichting RIL, 1998). This does not tally with the inland shipping's reputation as 'reliable and inexpensive'.

In this paper we describe the Approach project. With the 'Approach' project, Initi8, together with the Rotterdam Municipal Port Authority has taken the initiative to investigate ways to improve the barge handling planning process in Rotterdam. The key question of the project is how to co-ordinate the various schedules and how to respond to schedule deviations. To find a solution to these problems, the 'Approach consortium', comprising Free University Amsterdam, Illyan, Initi8 and the Rotterdam Municipal Harbour Service, is investigating the application of distributed planning supported by agent technology. This new technology has advantages over concepts that were suggested and based on centralized decision making and data collection.

The outline of this paper is as follows. First, we describe the barge handling process, followed by the bottlenecks identified in the coordination and planning in the port. Section four describes the concepts and projects that have been initiated in the part five years to solve the problems. In section 5, the concept of distributed port rotation planning are presented. The projected steps of the application of agent technology in Approach are described in section 6.

2 THE BARGE HANDLING PROCESS

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.

Terminal operators are responsible for the transshipment of containers from seagoing vessels to other means of transport or hinterland transport. To facilitate the scheduling of the transshipment 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 transshipment 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.

Barge captains calling at Rotterdam must observe the agreed schedule. However, the schedule may be disrupted for many reasons. A delay that arises at one terminal means that the barge will be late at the next terminal (domino effect). Captains and terminal operators often try to change the schedule to avoid unnecessary waiting and underutilisation of terminal capacity. However, as information about schedule deviations and available transshipment capacity is not always available on time or is incomplete, this is only possible to a limited extent. As a result, barge captains must often cope with long delays and terminal operators experience substantial underutilisation of capacity.

3 BOTTLENECK ANALYSIS

To obtain an accurate understanding of the problem described, the data from 'bargeplanning.nl' was analysed. This system registers barge operators' requests, terminal operators' schedules and data regarding actual barge handling [Stichting RIL, 2000]. It also records the key causes of serious schedule deviations. The data analysis revealed the most frequent causes:

- Delays during barge handling due in part to:
 - lack of available transshipment capacity (cranes and staff)
 - deviations in the number of containers scheduled to be loaded and unloaded (fewer than or more than were scheduled)
 - problems with documentation, exemptions and loading / unloading lists
- Arrival delays due in part to:
 - delays at previous terminals (domino effect)
 - external factors such as equipment failure on board and the weather
- Unreliable schedules due to:
 - unreliable estimates from barge operators regarding the number of containers to be loaded and unloaded
 - lack of co-ordination between the various terminal schedules
 - schedule 'slack' created intentionally by barge operators and terminal operators
 - different deadlines applied by terminal operators for the submission of requests

Obviously, these factors are closely interrelated and influence each other a great deal. In order to address such a complex problem effectively, it is essential to understand the various causal relationships and their cumulative influence on the barge handling process. These relationships were assessed on the basis of information obtained during interviews and workshops with barge operators and terminal operators. Figure 1 depicts the causal relationships and feedback patterns in a system dynamic model of the barge planning and handling process.

At the heart of the model is the number of barges queuing at the terminal before being handled and leaving. Depending on the deadline for requests to visit a terminal, the terminal operator receives the requests from the barge operators one or several days in advance. Obviously, requests submitted a couple of days before the actual visit are not completely reliable since barge operators have not yet received all the bookings and must estimate the number of containers to be loaded and unloaded. Estimates made well in advance are even less reliable. The reliability of requests also depends on the

extent to which barge operators include leeway ('slack time barge operator') on the basis of previous experiences at a specific terminal.

The terminal operators schedule the requests they receive and allocate terminal capacity accordingly. It is possible that they, too, build in slack time based on previous experiences of late arrivals and deviations from the scheduled number of moves. Calls at other terminals are not taken into account when terminal schedules are prepared.

It is therefore not surprising that, due to unreliable requests, intentional slack and lack of co-ordination, some rotation schedules are infeasible from the start. Against their better judgement, barge operators tend to stick to because in many cases the time windows for requesting visits at terminals have already past and some slack has been built in the in the shipping schedule already. Often, terminal operators are not even notified of potential delays that are foreseen by the barge operators.

As a result of unreliable planning, the arrival time of barges often deviates from the schedule. Unexpected delays at previous terminals and administrative problems cause further delays.

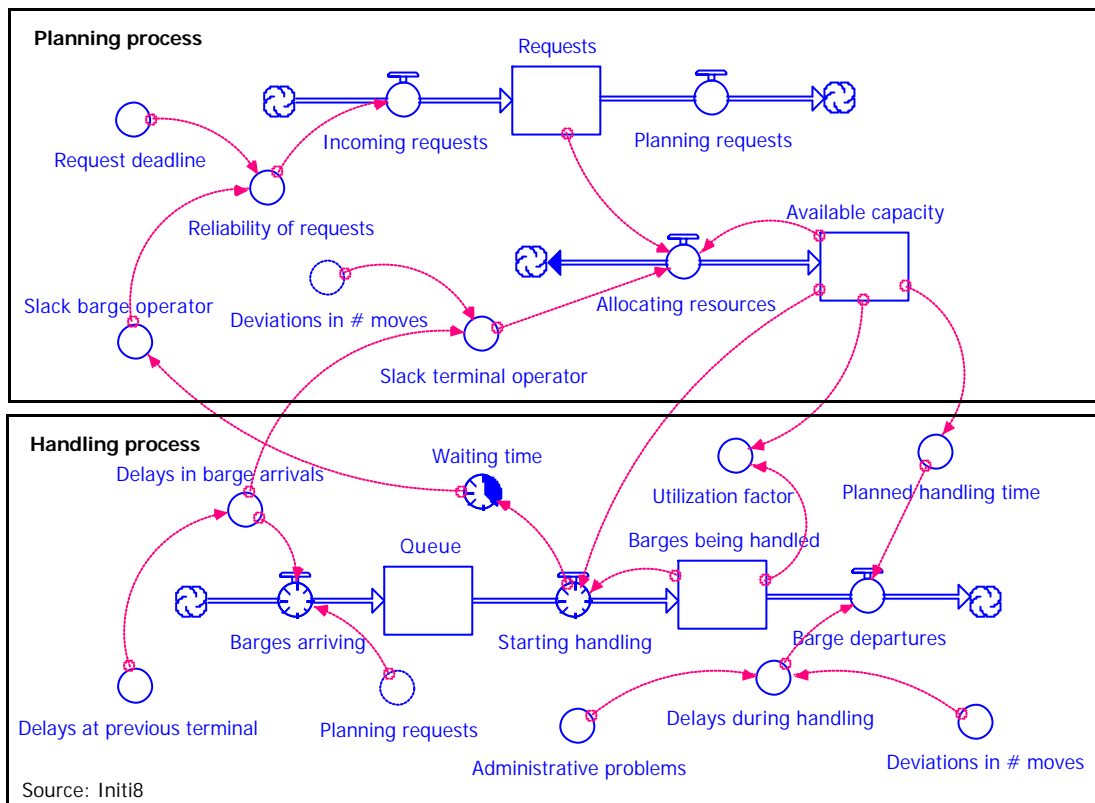


Figure 1: System dynamic model of the barge planning and handling process

In the end, such delays result in long and unreliable handling times, which affect barge operators in particular, and low utilisation rates resulting from unused terminal capacity, which is an important consideration for terminal operators.

Conclusions

Barge operators and terminal operators are both bound by a process involving increasing delays and underutilisation of terminal capacity. Each tries to mitigate the negative effects caused by the other. However, the measures taken to that end may again create drawbacks for the other party, who will then apply additional measures, etc.

4 ADDRESSING THE PROBLEM

In recent years, various initiatives have been taken to address the bottlenecks described above. In order to clarify their link with the 'Approach' project, a brief description of the key initiatives is presented. In 1997, the Rotterdam Internal Logistics Foundation (RIL) conducted the B-RIL study, an exploratory study of the bottlenecks and the scope of the delays and deviations in the handling

process. The study provided excellent insight into the complex problems and contributed a great deal to the conclusion of the covenant between the barge operators and ECT stevedore company. Some advanced solutions for transparency and planning were suggested, but not accepted by the participants. A first step to improvement was made in 2000. The Central Bureau for Rhine and Inland Shipping (CBRB) represented the barge operators in concluding a covenant with ECT, which covenant included operational agreements regarding barge handling at ECT terminals. The covenant described agreements on handling procedures and performance levels. A next step towards transparency was the Barge Planning Support (BPS) project that was implemented within the framework of a European study. Its goal was to assess the feasibility and added value of stevedores' quay schedules that were published on the Internet. Barge operators appreciated the insight obtained in quay schedules. The stevedores, however, obtained no valuable additional information and regarded the technical solution that was chosen as being too labour-intensive. The 'bargeplanning.nl' web application was developed to verify whether the parties observe the stipulations of the covenant. Its primary goal was to enable performance measurements during the barge handling process at ECT terminals. The system registers the planned and realised activities (number of containers planned and delivered, planned and realised arrival and processing times, etc.). The web application also helps barge operators and stevedores to observe the agreed planning procedures. Maersk Delta Terminal recently started using the application as well. Port Infolink BV (PIL) is currently developing Barge Infolink. This is intended to facilitate timely and reliable exchange of information between barge operators and terminal operators in order to prevent delays caused by missing shipping or customs documentation. Barge Infolink is restricted to the exchange of administrative information.

As is clear from the above descriptions, BRIL has been a useful tool for mapping out the problem. However, with the exception of the BPS project, no additional efforts were made to improve the planning process and harmonise terminal schedules. Only the planning process was formalised with the covenant and 'bargeplanning.nl'. As the list of initiatives and projects indicates, achieving improvement of the coordination between terminals and barge operators is a very long path with small steps. During the process it has become clear that none of the stevedore companies and barge operators is willing to give up some autonomy to improve the planning and execution of the rotations in the port. The project Approach develops a solution for the barge handling process based on distributed planning and multi-agent technology. This approach takes into account the complex nature of the problem that is difficult to solve on a central level and meets the present culture and preferences in the way of working of the various actors in the port.

5 DISTRIBUTED VERSUS CENTRALISED PLANNING

Centralised planning versus decentralised planning

To address the lack of co-ordination, it has been suggested in the past to develop a centralised planning system to register all container barges that call on terminals at the port of Rotterdam. However, such a centralised planning system raises some organisational and technical issues.

Organisational issues:

- The goal of centralised planning is to optimise the entire barge handling process at the port. The individual interests and autonomy of the parties involved are of secondary importance, which is unacceptable to the companies involved, who require full control over operational planning to execute their core tasks.
- There is no contractual relationship between stevedore companies and barge operators. Shipping agencies pay stevedores to tranship containers and conclude shipment contracts with barge operators. However, these agencies do not direct the operational process, which means that a shared view of optimisation is lacking. To make matters worse, the parties involved have conflicting business interests, i.e. a short stay of the barges versus a high utilisation rate of the quays and cranes.

Technical issues:

- The barge handling planning process is a complex process and takes place within a continually changing and dynamic environment. Centralised systems, however, have rigid structures, which makes it difficult to respond to changes.

- The logistics chain is a network that is hard to fit into the hierarchical structure required to operate a centralised system. Centralized planning systems aim to optimize the complete system, but defining a joint objective that meets the goals of all actors is almost impossible.

Given these issues associated with a centralised system, the possibilities offered by a decentralised solution were investigated. A decentralised system (or distributed system) is expected to simplify the planning process by dividing complex processes into less complex subtasks. Furthermore, a decentralised solution is better adapted to the network structure of the barge handling process and is modular by definition, which strongly enhances its flexibility. For these reasons, methods and techniques were sought to develop a decentralised or distributed planning system.

6 MULTI-AGENT TECHNOLOGY

What is a software agent?

'An agent is a standalone problem-solving software entity exhibiting the following characteristics: autonomy, social ability and responsiveness' (Wooldridge & Jennings, 1995). Accordingly, one can conclude that an agent is clearly more sophisticated than an object.

While Object Orientation (OO) focuses on modelling and rendering complex software manageable, Agent Orientation (AO) deals with describing and modelling parties and roles involved in a complex process at a higher level of abstraction.

An agent is capable of performing tasks independently (e.g. consulting a database, asking other agents questions, etc.) in order to achieve its objective (e.g. supporting a barge operator in drafting a rotation schedule). A system of several agents working together is referred to as a multi-agent system.

Agent technology shows its true worth in distributed, dynamic domains involving interaction between various parties that are not necessarily part of the same organisation, i.e., there is a loose connection between individuals, between organisations, or between both.

In analysing such processes as port container handling, a number of companies and organisations are identified, each with their own role and interests. Agent technology is ideally suited to do justice to this complexity and the wish of each of the parties involved to maintain control over their own business process. In modelling this process, each of the parties involved can be modelled as one or several software agents working together.

One of the advantages of agent technology is the rapid exchange of information between software agents in the processes of co-ordination, planning and collaboration that cannot be achieved by people by fax, e-mail or telephone. Moreover, since agent technology dovetails well with distributed processes, business processes need not be changed. Better still, they are used as starting points. A barge operator agent will be used to represent a barge operator, a terminal operator agent for a terminal operator, etc. Each of the parties involved maintains control over their own business processes and is able to safeguard critical business information.

In short: Agent technology is a natural way of supporting complex processes in dynamic, distributed domains. An agent is a software entity that can undertake tasks independently in order to achieve its objectives. The application of agent technology is extremely promising as it enables rapid communication between market parties, protection of critical information and utilisation of the existing organisational structure and, moreover, does not necessitate the modification of existing business processes.

Dynamic Organisation Modelling

The barge handling planning process is extremely complex due to its dynamic nature and the large number of parties involved. In collaboration with other research institutes, the Free University Amsterdam (VU) has developed a modelling method for dynamic organisations, which makes it possible to describe the behaviour of the parties involved and of the interrelationships. This modelling method is based on the 'Agent Group Role' model (Ferber & Gutknecht, 1998) and is designed specifically to analyse, design and simulate complex, decentralised dynamic organisational structures. The advantage of such a dynamic organisational modelling method is that it can deal with behavioural complexity, in particular for multi-agent systems with heterogeneous global behaviours.

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. Thus an organization is described solely on the basis of its structure, i.e. by the way groups and roles are arranged to form a whole, without being concerned with the agents that actually play these roles.

In APPROACH, the activity and interaction concerns the necessary communication lines between the different parties and the containers that move from barge to terminal to barge. Barges, barge operators and terminals are considered as groups that together form the overall organised multi-agent process.

Within an AGR-model, a role is the abstraction of a recurrent agent behaviour, linked to a status in a the organisation and interacting with other roles. The notion of role becomes independent of any particular agent, an agent playing several roles and a role being played by several agents if needed. The 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. The notion of group structure can capture goal-oriented organizations, points of view on a multi-agent system or design patterns in a software engineering perspective.

Needless to say, the port of Rotterdam is a very complex organisation. As mentioned, the parties involved have their individual goals; terminals benefit most from the effective use of their available space on their quays, barge operators are most helped when the barges make a fast as possible visit to the terminals. In this complex environment, some way must be found for individual goals to be satisfied as much as possible.

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 Jonker & Treur (2003), Ferber et al. (2003), Jonker et al. (2002), Jonker et al. (2001) as follows.

For further analysis a crucial issue here is how exactly structure is able to affect dynamics. An organisational AGR-structure is used as a basis to define dynamics (or organisational behaviour) at different levels of aggregation. Thus the AGR-method can be used to develop an organisational model that takes into account not only organisation structure, but also organisation behaviour (i.e., the internal dynamics at different aggregation levels) and its relation to organisation structure.

In terms of APPROACH, this means the following. The dynamics of a complex background as the Port of Rotterdam inherently thrives on its own structure. If this structure cannot support the complicated web of activities and interactions that take place, there is no solution which guarantees that any of the individuals achieve their set goals.

A dynamic organisational model then defines relations between different elements in an organisation (organisational structure), where the dynamics of these different elements can be characterised by sets of dynamic properties (organisational behaviour). As such, an organisational structure has the aim to keep the overall dynamics of the organisation manageable; therefore the structural relations between the different elements or aggregation levels within the organisational structure impose relationships or dependencies between their dynamics.

Finally, by applying the dynamic organisation modeling method to distributed 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. The dynamic organisation modelling method supports the analysis and design of such an infrastructure and identifies the functionality of the multi-agent system to be built. In particular, the specifications of the dynamic properties of the different roles, serve as behavioural requirements for agents to be allocated to these roles. In this sense the dynamic organisation model is a high-level model, abstracting from the particular agents fulfilling the roles involved. An agent that is designed to be allocated to a given role has to fulfill as requirements the dynamic properties characterising the role's behaviour. Moreover, the way in which the dynamic organisation model is structured according to different aggregation levels, and the relationships between the dynamic properties for these levels, provide insight in how parts of the organisation contribute to the overall dynamic properties of the organisation. For example, if a desired

property for the overall behaviour is not satisfied, by a diagnostic process it can be found out which part or element of the organisation is responsible for that (Jonker et al., 2002).

7 THE APPLICATION OF AGENTS IN THE 'APPROACH' PROJECT

The two key initial goals of the 'Approach' project were to understand the effects of distributed planning on the reliability of the barge handling process in docks and, secondly, to study the applicability of 'multi-agent technology' in modelling and developing a distributed planning system.

The 'Approach' project will demonstrate the effects of the distributed planning concept and the use of agent technology in a real time simulation environment, enabling the parties involved in the barge handling process to learn about the system and its pros and cons. The 'show case' that will be developed will also be used to inform other port sectors and educational institutions about distributed planning concepts and agent technology.

'Approach' uses agents to represent the parties ('barge operator' and 'terminal operator') and investigate and harmonise planning possibilities. The agents know the commissioning party's 'business rules', which means that they are aware of that party's priorities and planning rules and that they will take them into account. The agents gain experience over time and may develop some negotiation strategies and to identify the need for building less or more slack in the schedule.

The system consists of various autonomous agents. This requires a certain level of co-ordination, as they must bring their actions into line with those of others..

'Approach' creates an environment in which various agents communicate, receive orders from their owners – involving, for instance, the arrival and departure times of a barge at the port of Rotterdam and its loading schedule – and start working. Using the data made available to them, the agents determine at which terminals the barge should call and in what order. The next step is to ask the terminal operators about the available capacity and, subsequently, select the best options and present them to the commissioning party. If necessary, the agent of another barge operator can be approached to negotiate about a scheduled time slot. The selected time slots are registered in the Approach system.

An example of the interactive process between agents is provided below. Only one form of co-ordination is illustrated, namely the initial shipping schedule planned by a barge operator. Other forms of co-ordination as described above have been omitted for brevity's sake.

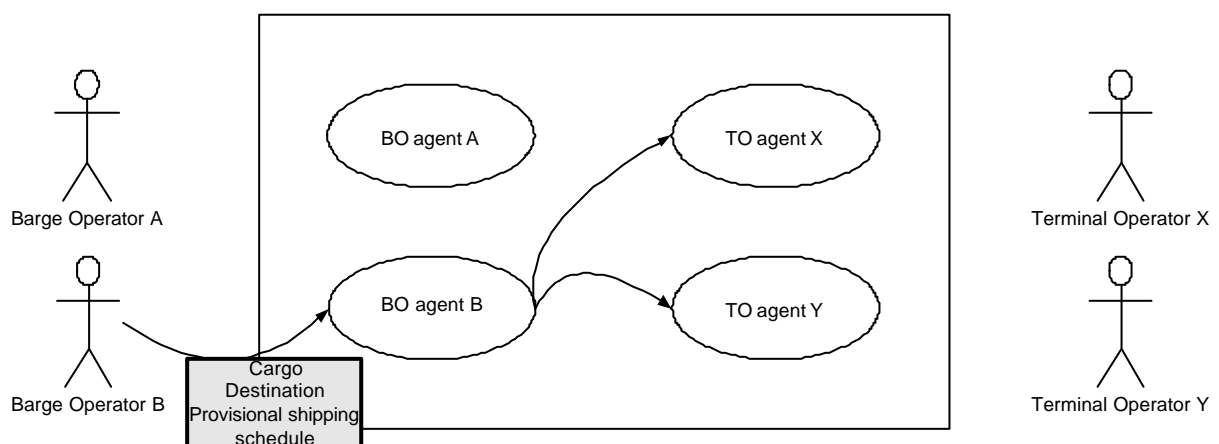
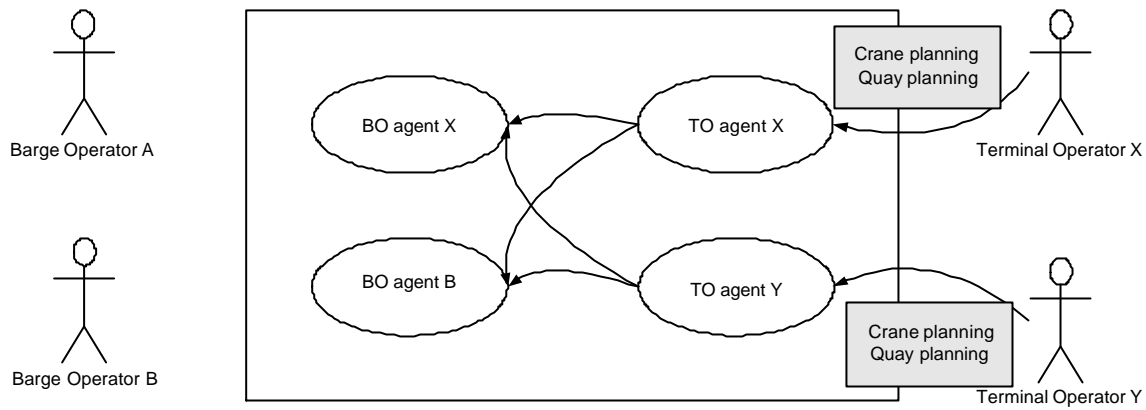


Figure 1: Through his agent, a barge operator registers his cargo, destination and provisional shipping schedule involving several terminals in the system.



[Kraan planning] Crane schedule
 [Kade planning] Quay schedule

Figure 2: The various terminal operators' agents inform the barge operators' agents about the available time slots and capacity.

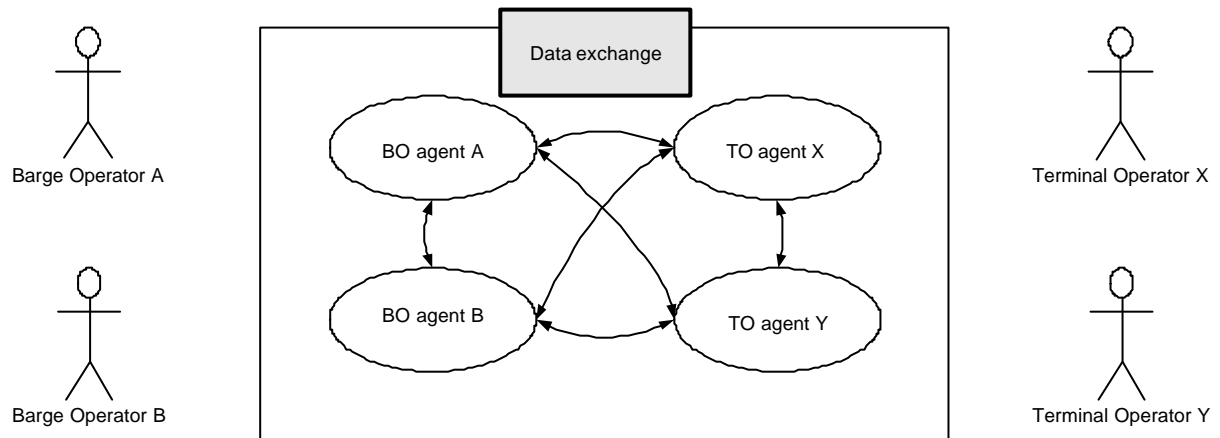


Figure 3: The agents negotiate on the basis of the information exchanged.

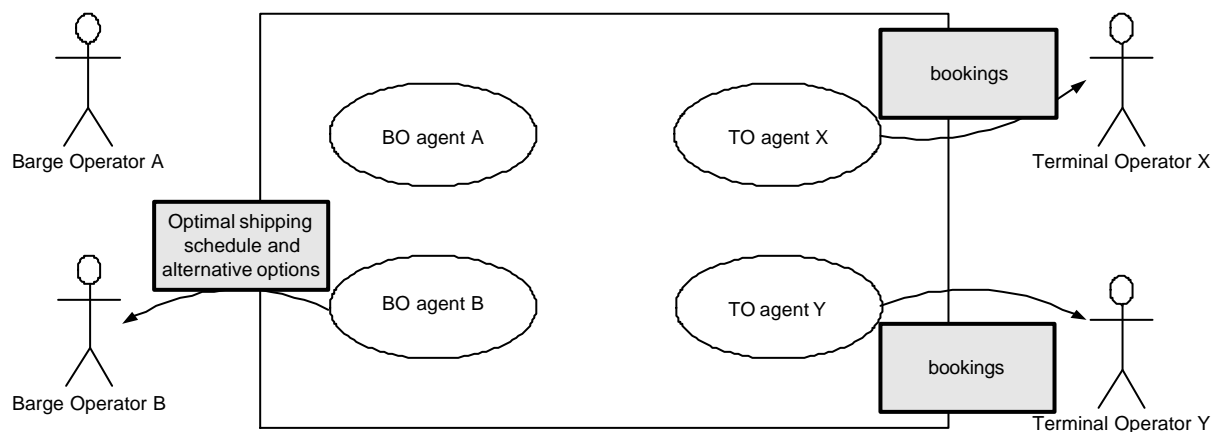


Figure 4: The agents report the options to the commissioning party.

The bookings made with the terminal operators are not definite. Bookings and planning schedules should be confirmed by the commissioning parties themselves, particularly in phase 1 of 'Approach'.

Functionality

Functionality of the distributed planning system:

- Information exchange between parties, in which the information owner can determine which information is to be released to whom. For example, a terminal operator's quay schedule is released to barge operators, but not to other terminal operators.
- Co-ordinating and optimising planning between barge operators and terminal operators.
- Online generator of alternative, schedules following delays at a certain location.

The 'Approach' pilot will comprise the following elements:

- The Ilyan multi-agent framework (agent communication, rule-based reasoning mechanism, agent environment, etc.)
- Approach platform (application-server, database, etc.)
- Quay planning (man-machine interface (MMI), data structure, database)
- business rule editor
- circulation generation
- circulation co-ordination (dynamic planning)

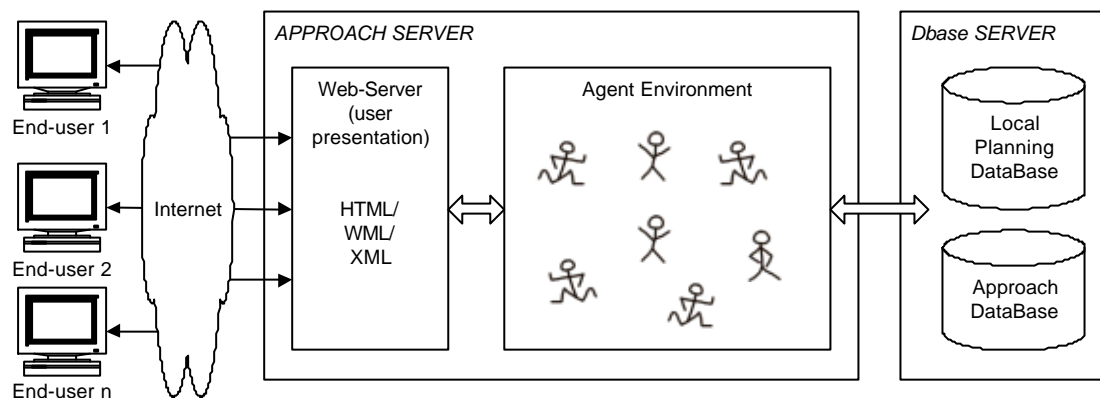


Figure 5: The global architecture of Approach.

Development path

It is expected that a phased development path will be required to ensure successful implementation of the 'Approach' concept in the port of Rotterdam.

Phase 1 (completed): Problem analysis and a possible cost-benefit scenario for the decentralised planning system, in other words determining whether the scope of the problem is really that wide and whether the system will eventually be cost-effective.

Phase 2 (in execution): Technical feasibility assessment and development of a pilot application.

Phase 3: If there is sufficient support among the barge operators and terminal operators in the port, the best solution will be implemented in a pilot-environment. The functionality of Approach will primarily consist of supporting the preparation of rotation schedules. The labour intensive activity of gathering data and coordination will take place automatically with a number of options as the result. The barge planner will still select the most appropriate option and confirm this to the terminal.

Phase 4: As the system becomes more widely accepted, its functionality may be extended. More barge operators and terminal operators can access the system. Barge operators and terminal operators may negotiate to achieve further optimisation and deal with disruptions (barge operators negotiating about time slots)

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