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ERIM REPORT SERIES *RESEARCH IN MANAGEMENT*	
ERIM Report Series reference number	ERS-2005-027-LIS
Publication	April 2005
Number of pages	21
Persistent paper URL	
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REPORT SERIES
RESEARCH IN MANAGEMENT

ABSTRACT AND KEYWORDS	
Abstract	The Port of Rotterdam is a key container transshipment hub for Europe. Inland container shipping is important to connect the hinterland (40% market share). Barges visit several terminals per round-trip through the Port, thus requiring a proper planning support – to avoid planning problems such as double-bookings. A pilot version of an inter-organizational system has been build, titled APPROACH. This paper describes an industry workshop where a game-setting was used to evaluate the current manual planning practices with the APPROACH outcome – and delivered interesting findings; both for actual implementation of the system as well as it unveiled issues for further research.
Free Keywords	agent technology, supply chain management (SCM), inter-organizational systems (IOS), Port of Rotterdam, industry application
Availability	The ERIM Report Series is distributed through the following platforms: Academic Repository at Erasmus University (DEAR), DEAR ERIM Series Portal Social Science Research Network (SSRN), SSRN ERIM Series Webpage Research Papers in Economics (REPEC), REPEC ERIM Series Webpage
Classifications	The electronic versions of the papers in the ERIM report Series contain bibliographic metadata by the following classification systems: Library of Congress Classification, (LCC) LCC Webpage Journal of Economic Literature, (JEL), JEL Webpage ACM Computing Classification System CCS Webpage Inspec Classification scheme (ICS), ICS Webpage

Agent Technology supports Inter-Organizational Planning in the Port

Workshop results illustrate the benefits of APPROACH in the Port of Rotterdam

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1. Introduction

The Port of Rotterdam is a key container transhipment hub for Europe. The quality and the accessibility of the port and the port's hinterland connections is becoming an increasingly decisive competitive factor. Until recently, truck transportation was by far the primary hinterland connection. However, since the early 1980s, the river Rhine has increasingly been recognized 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 (Melis *et al* ,2003) (Schut *et al*, 2004).

As a result of the spectacular growth, container transhipment capacity in Rotterdam is now under pressure. Barges are handled at the terminal's quayside, using the same transhipment 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 transhipment 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 operators aim to plan the visits to the various terminals as tight as possible. The complicated nature of this planning is illustrated by the fact that only 62% of the barges leave the port of Rotterdam on time

(Stichting RIL, 1998). This does not match with the inland shipping's reputation as 'reliable and inexpensive'.

The pre-planning of terminal visits is recognized as one of the key sources for those supply chain inefficiencies – it is a process asking for a synchronization of activities between the barge operators and the container terminals. Currently, this planning is performed manually – which results in local-optimizations. In the government-funded APPROACH project (Connekt, 2003) a conceptual design has been made for a new inter-organizational information system, which is capable of synchronizing and optimizing terminal visits, promising a win-win outcome for all parties involved.

In September 2004, we conducted a workshop, in Digital Port Rotterdam, with representatives from container terminal-operators, and barge-operators, with a twofold objective. First, the workshop had the intention to analyze the manual barge rotation planning process in a controlled workshop setting, and compare it with the outcomes of the APPROACH pilot-system, as developed in the earlier mentioned Connekt project. Second, the need and interest for an implementation was discussed. Third, we explored industry support for further research and development of the APPROACH concepts.

The workshop was conducted in a sort of "gaming environment". The industry representatives had to manually make a planning run for the data as given. What meant that the barge operators had to plan their visits, and communicate these with the terminals. In parallel, the APPROACH pilot system utilized the same data, to derive to a solution for a planning as well. Later the outcomes of the manual planning and the APPROACH planning were analyzed and compared. The outcomes were rather shocking, in favour of the APPROACH pilot system. One of the workshop's objectives was to research the market-possibilities for an agent-based planning system. The participants were unanimous enthusiastic, and some of them even asked: "when can we have this system working?", or "how can we contribute to further developments?". The workshop further grounded our thoughts and plans for continued research in this area, and is a first step towards a commercial application. The workshop however, also led us to the identification of several weaknesses in the current concept, and we suggest areas where improvements can be made.

The famous MIT Beergame does illustrate the bullwhip effect (Lee *et al*, 1997), (Chen, 1999) and the need for information sharing in a supply chain. In this workshop the effect of, and need for, joint-planning was well illustrated – providing a similar insight in the problem field as the Beergame does, now illustrating the need for collaboration. The case of APPROACH is not simply a linear supply chain coordination problem, but encompasses synchronization between many different parties (suppliers/customers as well as competitors) – thus making it a good example of cross-organizational networking, which was identified as a promising area for the application of agent-based software systems (Hillegersberg *et al*, 2004).

In this paper we report on the APPROACH workshop, and the spectacular results we collected. The workshop grounded our thoughts for further research and created enthusiasm amongst market parties – important in making the next steps in implementing APPROACH and co-developing future extensions. The outline of this article is as follows: we first describe the logistical problem of barge-terminal-visit planning, and show the bottlenecks that arise in current practice. In the next section we introduce the APPROACH concept and design. The main focus in this paper, however, is on the workshop. We briefly describe the workshop design, discuss the results, and compare these with the planning outcome from the APPROACH pilot system. The paper concludes with a further directions section – giving recommendations for further research – and a conclusion section.

2. Logistical problem descriptions

2.1 The business case of barge-terminal-planning

Barge operators are responsible for cargo handling and coordinating inland shipping activities. They operate the inland shuttles between the port and the hinterland and, in consultation with the captain of the barge, 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 involved. 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 (un)loaded, and at what time. Terminal operators want to maximize the use of the available transshipment capacity, combined with an efficient utilization of its labour force.

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 time, further consultations may be held by telephone, or the Internet (e.g. e-mail). Currently, only the barge operator tries to harmonize the different rotation schedules over the various terminals. However, he has no say in the final schedules, which are determined unilaterally by the various terminal operators.

Barge captains calling at Rotterdam must monitor 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 as well; the so called domino effect. Captains and terminal operators often try to alter the schedule to avoid unnecessary waiting and underutilization 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 often have to cope with long delays and terminal operators experience substantial underutilization of capacity.

2.2 Bottleneck analysis using system dynamics

In order 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, a system dynamics analysis (Sterman, 2000) has been conducted in the beginning of the APPROACH project (Connekt, 2003) (Schut *et al*., 2004). Interviews and workshops with barge- and terminal operators delivered input for the analysis. A system dynamics 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 stabilizing effect with respect to changes. The combination of these feedback loops provide insight into the behavior of systems and indicate 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 summarized as follows (Melis *et al*, 2003):

- The available capacity is not the root problem in barge handling. Shortage in capacity can worsen the problem and extending the capacity may lessen the problem. However, the actual solution can be realized 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 causes further deterioration of mutually tuning capacity, which then leads 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.

To summarize, we can conclude that the barge operators and terminal operators keep each other caught in a process of ever increasing waiting times and less utilization of capacity. One of the most stringent problems in the planning is that, although the planning process is truly of a multi-party nature – where the different entities influence one another – there is hardly any synchronization of planned visits, resulting in a rotation pre-planning that is already infeasible. This results, when moving the plan in the execution phase, in huge delays and problems.

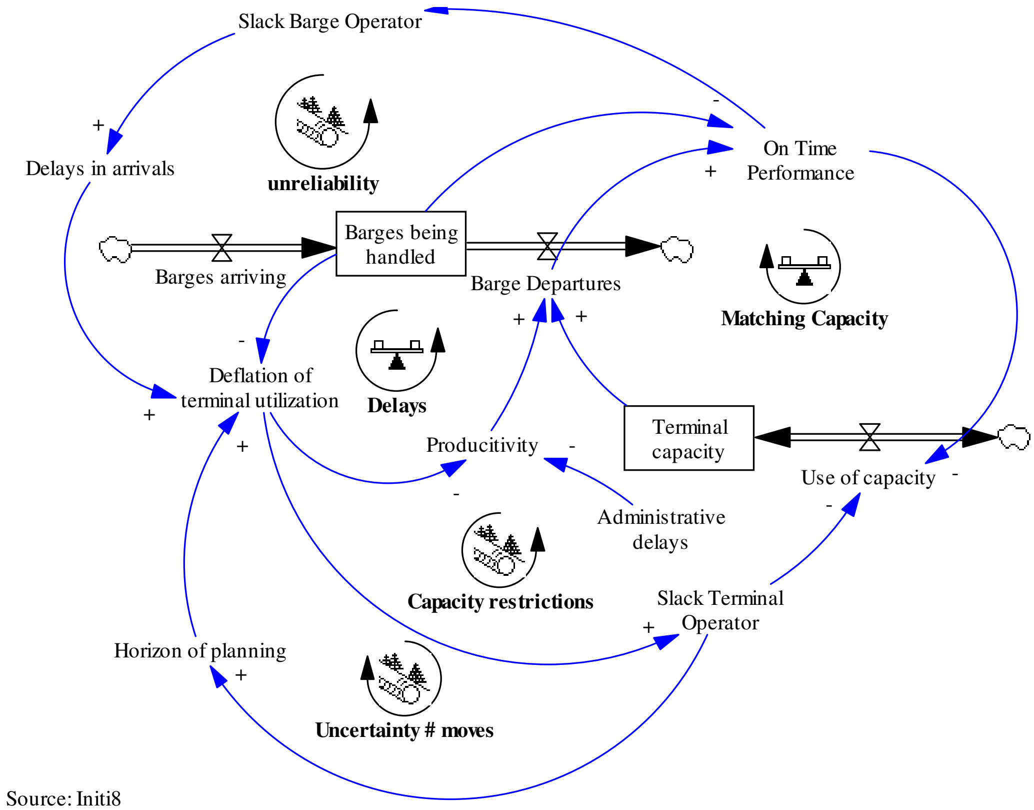

Figure 1: Overview of causal structure

3. The APPROACH planning concept

3.1 Rotation planning via an inter-organizational system

The main problem for barge-terminal-visit pre-planning, lays in synchronization and communication between the different parties involved. The barge operators need to synchronize, and not just communicate, their plans with the different container terminals. It is a process of collaboration, with many parties involved: as of today, there are some 35 different barge-operators, and 20 different container terminals. On a normal day, 25 barges visit the Port of Rotterdam. Each barge visits on average 8 different container terminals.

The planning for such an environment cannot be made manually anymore, since it should be perceived as a very complex puzzle. A smart planning system, that includes all the available restrictions and addresses the company specific business rules, is needed. Therefore an inter-organizational information system that produces a feasible pre-planning is suggested as the solution. From an implementation and adoption perspective, the system needs to be open, and flexible, and should ideally not give any of the parties involved a considerable competitive advantage over the others. The current Port infolink Bargeplanning 2.1 application as is used in the port does not have multi-party planning functionality, it is primarily used as a communication platform for paperwork related to customs, container-number information, arrival times, etc. This transaction system is therewith an interesting source of information for research purposes, as well as a valuable backbone system to construct an advanced planning application upon.

3.2 Agent based system

Realizing the potential agent-technology offers, the choice was made to develop a prototype utilizing agent-based software design principles. This technology has the following characteristics (Wooldridge and Jennings, 1995), (Jennings, 2001), (Luck, *et al*., 2004) it is autonomous, goal-oriented, and asynchronous, has learning abilities, is reactive as well proactive, and has social abilities. A system assembled from individual software agents, derives to a solution, through communicating and negotiation between the different individual software agents.

Parties are represented in the APPROACH system by their own Personal Assistant (PA) by means of a software agent. All agreements between parties only take place within the degrees of freedom that each PA has received from its participant. An automatic planning layer generates a set of all possible plans, sorts these out and tries to establish the optimal and most realistic planning. Intelligent resource mapping arranges the agreement between requests of a barge operator and available quay space of a terminal operator. The booking infrastructure is a layer in which individual requests of barge operators is accommodated.

Initial results (Connekt, 2003) show that it 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 with conflicting interests. It has been shown that in this case there is no need for parties to share company confidential information and therefore they can retain their own autonomy.

3.3 APPROACH architecture

Figure 2 shows the basic architecture of the overall APPROACH system – for a more detailed description we refer to the earlier project report (Connekt, 2003). Information to the system is supplied though different webpages for the barge operators (A) and terminal operators (B), and results can be obtained from it. Each operator has its own company database (C) that is not accessible to other participants. Each participants 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 done through the APPROACH system.

Communication between barge operator agents (BOA) and terminal operator agents (TOA) is relatively simple. The process involved here concerns, mostly, timeslot request (by BOA), timeslot reply (by TOA), and confirmation or cancellation (by 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 negotiation – which eventually will be as good as possible as well as realistic.

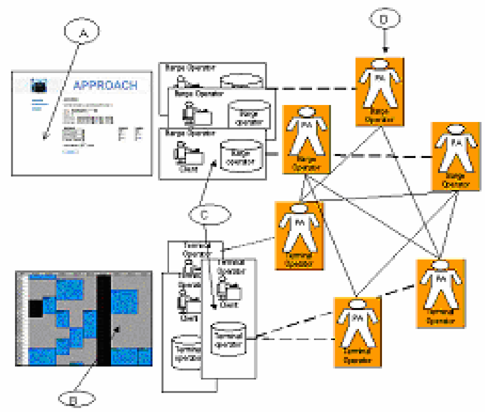

Figure 2: Architecture of the APPROACH prototype

3.4 System characteristics

APPROACH supports the barge operator and terminal operator during the preparation phase – the initial rotation pre-planning. A barge operator hands in a loading plan for each barge. Also other requirements like 'estimated time of arrival' (ETA) and 'estimated time of departure' (ETD) will be communicated; those are important since they come from the sailing schedule of the barge. On average, currently sailing schedules allow for barges to be in the port – the time between ETA and ETD – for approximately 22 hours, of which much time is waiting time. It is current practice that barge operators follow their sailing schedule even if that means that they have to skip a terminal visit. A terminal operator puts in the timeslots for the dispatches of the barges. Other requirements on planning of the dispatches (e.g. priorities, opening times, capacities) are assumed to be available beforehand, but may be subject to change. A last important constraint is the loading plan (e.g.: first unload a large number of containers before loading a large number of containers, stacking plan, et cetera).

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. Also the terminal operators have an interest in accurate reservations but need some time to organize 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. By means of internal computation, plans are generated by APPROACH for the barge operator. On the basis of this, timeslots are being reserved by the terminal operator.

4. Industry workshop – workshop design

4.1 Goal of the workshop

On the 16th of September, 2004, INITI8 organized a workshop, in Digital Port Rotterdam, with representatives from industry (e.g. people from container terminals, and barge-operators). Central in this workshop was a sort of "gaming environment". The industry representatives had to manually make a planning run for the data as given – what means that the barge operators plan their visits, and communicate this planning with the terminals. In parallel, the APPROACH pilot system utilized the same data, to derive to a solution for a planning as well. The goal for this workshop was:

Analyze, in a controlled workshop setting, the (manual) barge rotation planning process as terminal- and barge-operators currently perform it in practice, and compare this with the current APPROACH pilot system. Evaluate the pilot system, in order to examine the need and interest for an implementation, and review the need for (industry involvement in) further research in this area.

The workshop thus really focused on a critical evaluation, together with several industry parties, of the developed APPROACH concept, and tried to analyze the interest for and possibilities of an implementation. Furthermore, it was intended to gain industry support for further research in this area, through early involvement of terminal- and barge-operators.

4.2 Game setup

Today, the Port of Rotterdam is served by around 35 barge-operators and 20 different container terminals. On an average day, 25 barges visit the port for a rotation trip, underwhile visiting about 8 different container terminals. Nearly all rotation trips visit at least one of the four large terminals (ECT Home, ECT Delta, APM, Hanno). Each terminal has one or more quays, which are used for serving barges. 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.

For the purpose of the game the situation was somewhat simplified. Only 6 barge-operators were used, and 8 different container terminals. In total 22 rotation trips needed to be planned for a period of the next 24 hours – thus meaning that each barge-operator needed to plan more than one rotation trip (either 3 or 4), in practice it is sometimes only one trip a day per operator; depending on the size. Table 1 and 2 show the barge-operators and container terminals as used in the game. Table 2 shows also the number of quays that can be used in parallel, and the time-window restrictions that apply for a terminal.

Table 1: Barge operators – as used in the workshop

Barge operator	# of rotation trips
Alcotrans	4
BBT	3
CCS	3
Interfeeder	4
Rhine Container	4
Danser	4

Table 2: Container terminal operators – as used in the workshop

Terminal operator	# of quays	Opening times
ECT Delta	2	All day
ECT Home	2	All day
APM	2	All day
Hanno	1	All day
Uniport	1	All day
RST	1	All day
Waalhaventerminal	1	06:00-22:00 hours
HT Holland Terminal	1	06:30-21:00 hours

In the game setting, a rotation trip consists of a visit to between minimum 4, and maximum 8 terminals. The sailing-times are calculated based upon an average sailing-speed of 15 kilometers per hour and the geographical location of the terminals. The geographical position of the terminal locations in the game are the same as they are in the real port – therewith the players of the game can plan a rotation trip based upon their experience from their daily job. The rotation trips are based upon the database Bargeplanning 1.0 – which contains data from 2001 (Stichting RIL, 2000). The average rotation-time, handling-time at the terminals, and sailing-time are inline with the industry practice. The database delivered the data for the 22 (virtual) rotation trips – for each trip containing information such as ETA, ETD, # of terminals, requested terminal order, and call sizes. The quays of ECT Delta, ECT Home and APM are partly blocked, because in the presented game those terminals handle seaships at the same quays where they handle the barges.

The game as such was like a board-game: the barge operators planned their terminal visits on paper cards, and those were handed over to the container terminal planners. It was only a one-way communication, there was thus no feedback loop from the terminals to the barge planners. This however pretty well reflects the current practice, in where there is also hardly any feedback from the terminals to the barge planners. Although all planning was done by hand and written down on paper, all barge operator players also entered the data in a computer screen that had a similar look as the Bargeplanning 2.0 / 2.1 application as is currently in use in the Port of Rotterdam, and deployed by Port infolink. The container terminal players entered their planning in the screen as well, showing the initially requested time, and the time as planned. The barge operators than received this feedback, but had no chance anymore to rearrange their planning. Behind the screen, however, was an Microsoft Access database that captured all the plan-data, in order to compare the data with the data-output from the APPROACH pilot system run.

4.3 Barge operator planning

For all the barges to plan, a barge operator received a list of terminals to visit, the Rotterdam ETA and the Rotterdam ETD. Furthermore the number of containers to load and unload, as well as the inter-terminal sailing-times, were listed. Figure 3 shows the computerscreen as used by the barge operator planners, showing the Interfeerder 1, one of the barges from Interfeeder. The rotation trip, and its order, can be found in the lower part of the screen, showing that in this planning the Interfeeder 1 will visit the terminals in the following order: (1) ECT Delta, (2) HTHolland, (3) Hanno, (4) ECT Home, (5) RST. The Uniport and Waalhaven terminals are not planned yet.

4.4 Terminal operator planning

The container terminal operators were equipped with a large wall-mounted planboard, showing the planning for the terminal's quays – thus including the seaships, and closing-times of the terminal. See Figure 4 for an illustration of a possible planboard. The planners received sets of small plan-cards from the barge planners that could be placed on the planboard. Note that a longer handling-time was represented by a larger card than a short handling-time – therewith making visible planning a possibility. The task was – just like in daily practice – to assign the quay space as good as possible to the request from the barge operators. After the planning was made, the planners had to enter the planning in the database – see Figure 5 for an illustration. This also resulted in a planned starttime feedback signal to the barge-operators' screen; see the red column in Figure 3. There was no possibility for direct feedback to the barge operators in case of major planning conflicts – whereas in daily practice, the phone is used to solve real stringent problems manually. This is however not perceived as a major problem by the workshop participants, since this feedback process is of a painful nature anyway, and frequently causes more problems than it solves.

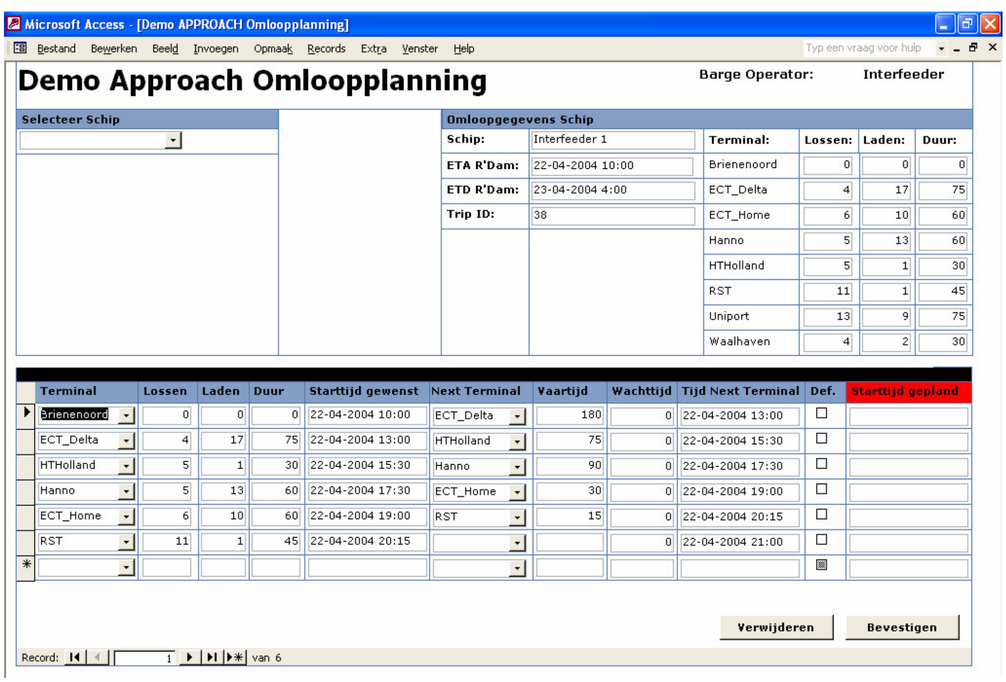

Figure 3: APPROACH workshop computer input screen for the barge operator planner

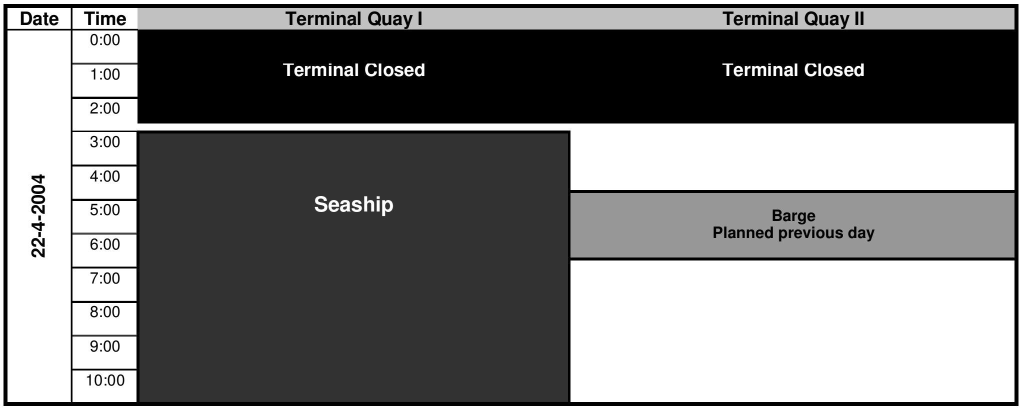

Figure 4: Illustration of the planboard of a container terminal; the white space representing the available quay space

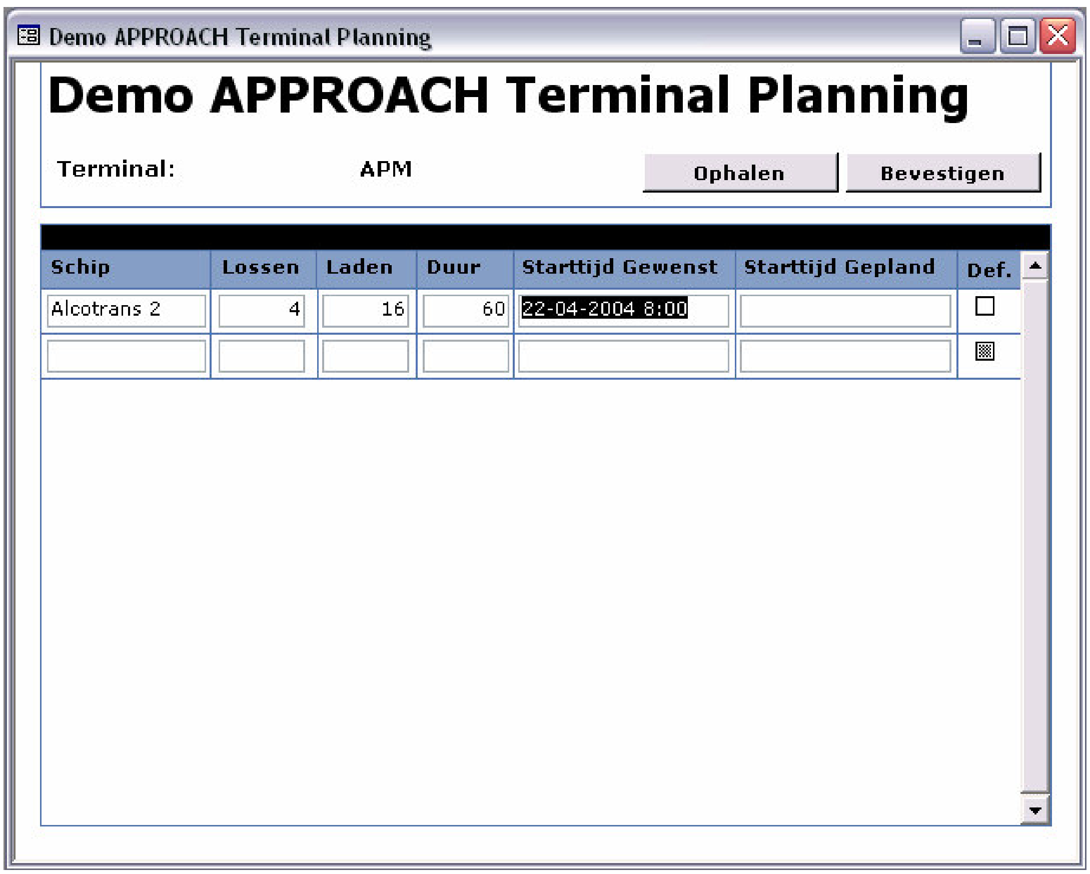

Figure 5: APPROACH workshop computer input screen for the container terminal operator planner

5. Workshop results

The results of the manual planning process were stored in the database. Resulting in a large amount of information, describing a ship's rotation scheme. Here we would like to show the example of the planning of the Rhine 1, one of the ships from barge operator Rhine Container. The Rhine 1 has an ETA of 22-04-2004 at 0:30, and its ETD is 22-04-2004 at 18:30. The barge therefore can take 18 hours for its rotation trip, underwhile visiting 6 different terminals. Table 3 shows the initial plan as made by Rhine Container – this plan was communicated with the different container terminals, requesting certain timeslots for terminal visits. In Table 4 we show the final rotation plan, which was the outcome of the planning by the container terminal operators (after having received the timeslot requests from the barge operators). Note that there was a shift in the order of terminal visits: the HTHolland is now planned to be visited before the ECT_Delta – as a result, there will be an extra waiting time of 4:00 hours; due to the fact that HTHolland has opening time restrictions.

Table 3: Workshop output: initial manual planning for the Rhine 1 (by the barge operators)

Terminal	Duration	Starting_time	Shipping_time	Next_terminal	Next_arrival	Waiting_time
Brienenoord	0:00	22-04-04 0:30	3:00	ECT_Delta	22-04-04 3:30	
ECT_Delta	1:45	22-04-04 3:30	1:15	HTHolland	22-04-04 6:30	
HTHolland	0:30	22-04-04 6:30	1:00	RST	22-04-04 8:00	
RST	0:45	22-04-04 8:00	0:45	Waalhaven	22-04-04 9:30	
Waalhaven	0:45	22-04-04 9:30	0:15	Hanno	22-04-04 10:30	
Hanno	1:30	22-04-04 10:30	0:15	Uniport	22-04-04 12:15	
Uniport	1:00	22-04-04 12:15	1:00	Brienenoord	22-04-04 14:15	

Table 4: Workshop output: confirmed manual planning for the Rhine 1 (by the terminals)

Terminal	Duration	Starting_time	Shipping_time	Next_terminal	Next_arrival	Waiting_time
Brienenoord	0:00	22-04-04 0:30	2:00	HTHolland	22-04-04 6:30	4:00
HTHolland	0:30	22-04-04 6:30	1:15	ECT_Delta	22-04-04 8:15	
ECT_Delta	1:45	22-04-04 7:15	2:30	RST	22-04-04 11:30	
RST	0:45	22-04-04 8:00	0:45	Waalhaven	22-04-04 9:30	
Waalhaven	0:45	22-04-04 9:30	0:15	Hanno	22-04-04 10:30	
Hanno	1:30	22-04-04 10:30	0:15	Uniport	22-04-04 12:15	
Uniport	1:00	22-04-04 12:15	1:00	Brienenoord	22-04-04 14:15	

After the manual planning has been conducted, the APPROACH pilot system utilized the same data as a starting point for its own optimization run, resulting in a rotation planning. The rotation planning includes all the container terminals and barge operators, and consists of rotation schemes that result in feasible, or as feasible as possible, rotation schemes for all 22 different barges, under while giving the terminals a sufficient capacity utilization – no barge visits planned at the same time, some safety time included (in case the terminal prefers that), et cetera. The working of the APPROACH system was shown live to, and discussed with, the participants, showing the software being busy searching for a feasible solution.

The results of the APPROACH planning run were also stored in a Microsoft Access database, thus enabling a comparison of the results. The results looked as follows: per rotation trip the ETA was shown, along with the different visits to make in the rotation trip. Again, the Rhine 1 serves as our example; for this barge the APPROACH planning outcome is shown in Table 5.

Figure 6 shows a part of the quay assignment planning for the APM terminal for both the manual planning, as well as the planning made with APPROACH. Both assignment plans look good at first glance. Main problem with the manual planning however is that the plan is not feasible, which means that in the execution the terminal operations will not look like this initial plan. Please note that in the current APPROACH planning the ships are planned with some safety times in between, thus allowing some space for unpredictable interruptions in the execution phase. Since safety time also consumes capacity, further research should reveal how to optimally work with, and assign, safety times in the system.

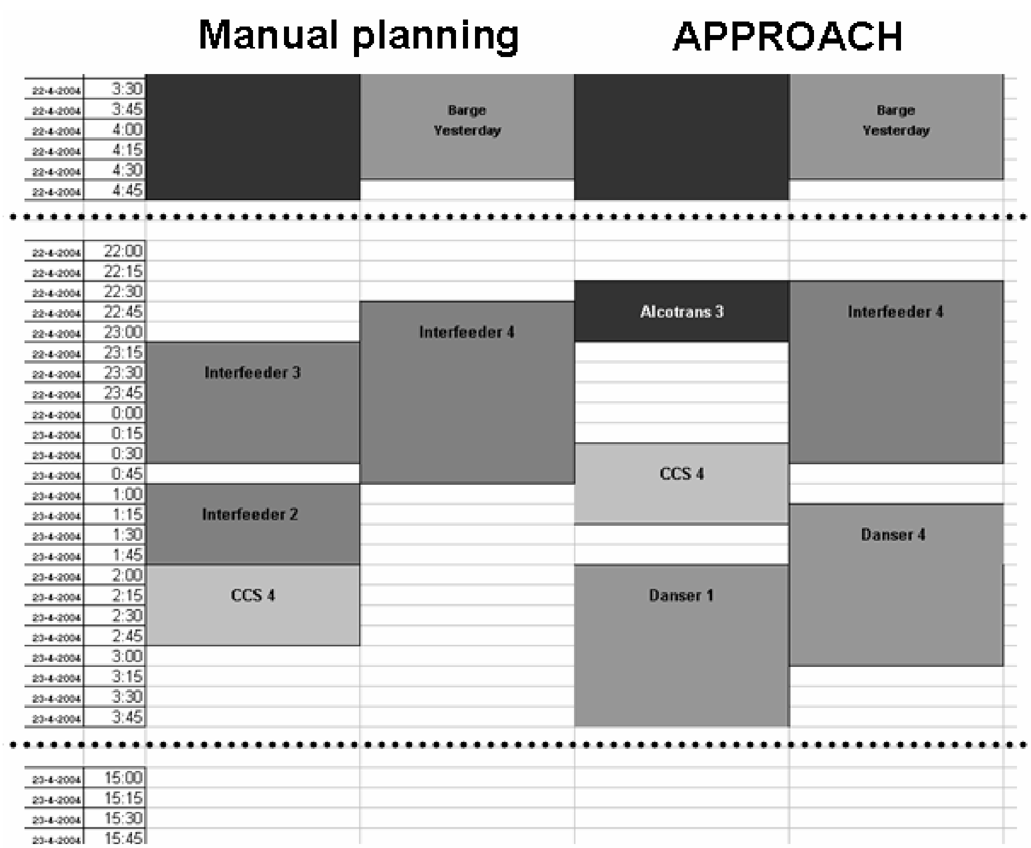

Figure 6: Example of a quay planning – showing the manual planning, and the approach planning, for the two quays of the APM terminal

Table 5: Workshop output: APPROACH planning for the Rhine 1

Terminal	Duration	Starting_time	Shipping_time	Next_terminal	Next_arrival	Waiting_time
Brienenoord	0:00	22-04-04 0:30	1:00	Uniport	22-04-04 1:30	
Uniport	1:00	22-04-04 1:30	0:15	Hanno	22-04-04 2:45	
Hanno	1:30	22-04-04 2:45	0:15	Waalhaven	22-04-04 5:30	0:45
Waalhaven	0:45	22-04-04 6:15	0:45	RST	22-04-04 7:45	
RST	0:45	22-04-04 7:45	1:00	HTHolland	22-04-04 9:30	
HTHolland	0:30	22-04-04 9:30	1:15	ECT_Delta	22-04-04 11:15	
ECT_Delta	1:45	22-04-04 11:15	3:00	Brienenoord	22-04-04 14:15	

6. Analysis

6.1 Double bookings

When we analyze the workshop output data, we see that the manual planning often results in confirmed rotation pre-plannings that can not be feasibly executed. Requested time-slots are not honored, because more barge-operators try to claim the same timeslot at a terminal, and the terminal can only accept one – or sometimes two, if more quays are available. Therefore, often barges are expected at more terminals at the same time – they are double-booked. Thus the terminals do reserve capacity that they should not have reserved – since the barge can never be there at the planned time. When the barge later arrives at the next terminal – where it thus should have arrived earlier already, but could not due to the double booking – it is likely to find another barge in the queue, and so it cannot be served right away.

Looking at the Rhine 1 example, several double bookings are present in the current manual practice – see Table 4, and the graphical representation in Figure 7. At 8:05 AM for example, the barge is expected to be at three different terminals at the same time: namely, the RST and Waalhaven terminal, while it just left the ECT_Delta terminal. In the execution phase, this results in severe problems: the ship can only visit one terminal at a time, and is likely to either re-arrange its route in order to arrive on time at the planned terminals, or visits a terminal where it was expected earlier already. In our example, the decision to be made is as following: the Rhine 1 is ready at the HTHolland terminal at 7:00, however, sailing to the ECT_Delta consumes 1:15 hour, and thus it cannot be there at the planned 7:15 – it may however consider going there, and arrive one hour late. The decision could also be to first go to the RST or Waalhaven terminal, and to skip the ECT_Delta for now, and do it later in the rotation. Something else the example learns us is that the order in the rotation scheme is different for the manual plan, as compared to the APPROACH planning. This is not a surprise, since APPROACH starts from scratch, and considers the entire system in its planning.

Double bookings are a serious problem. Table 6 shows the total double book time, per barge, per rotation trip. Our Rhine 1 example shows how we calculated the double-book time: the Rhine 1 is booked from 7:15 – 11:30 (including sailing time to RST) at ECT_Delta, and at the same time from 8:00-9:30 at RST. This counts as one double-booking with an overlap time of 3:30 hours; since the barge can only first arrive at RST at 11:30, although it is planned there at 8:00. The double-book time therefore is: 11:30-8:00 = 3:30. The total double-book time – for the three double bookings of the Rhine 1 – account for four hours and thirty minutes. From the 22 rotation trips planned manually, 19 trips are unfeasible due to a double-booking. Furthermore, 7 from the 22 trips, even contain a double double-booking. Note that the APPROACH planning has no single double-booking, and that the double-book time for the APPROACH planning therefore is zero.

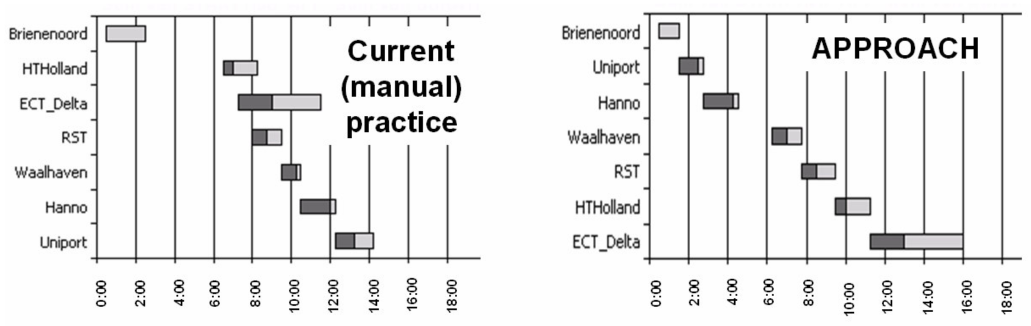

Figure 7: Graphical representation of the manual and APPROACH rotation plans [bar-colors: dark gray = handling-time at the terminal, light gray = sailing time to next terminal]

Table 6: Total double book time, for the manual planning results from the workshop (per ship, per rotation trip)

Barge	Total double-book time (hours)	# of double booking	Barge	Total double-book time (hours)	# of double-bookings
Alcotrans 1	2:00	3	Danser 2	2:15	2
Alcotrans 2	0:45	3	Danser 3	0	0
Alcotrans 3	2:15	4	Danser 4	0:30	1
Alcotrans 4	1:30	1	Interfeeder 1	2:00	2
BTT 2	1:00	1	Interfeeder 2	0	0
BTT 3	0	0	Interfeeder 3	0:30	1
BTT 4	0	0	Interfeeder 4	0	0
CCS 2	2:30	2	Rhine 1	4:30	3
CCS 3	1:15	2	Rhine 2	0	0
CCS 4	1:15	1	Rhine 3	0:45	1
Danser 1	1:00	1	Rhine 4	1:45	1

6.2 Late arrivals at the terminal

The late arrival of barges at container terminals – caused by the already mentioned double-bookings – is illustrated in Figures 8 and 9. Figure 8 shows the percentage of barges arriving too late at the terminal according to the confirmed manual (pre-) planning, whereas Figure 9 shows the delays in hours per terminal, and the number of barges arriving to late at that terminal. The figures illustrate for example that at the Uniport terminal, 6 of the 18 barges (=

33%) will arrive too late – based on the manual (pre-) planning. At the RST terminal, we see (in Figure 9) a total delay-time of 6:15 hours. The Rhine 1 is one of the barges that is expected to arrive too late; namely, with a 3:30 hours delay. Next to the Rhine 1, 4 other barges will arrive too late at RST.

There is a significant difference between the APM, ECT_Delta and the ECT_Home terminals, and the other terminals – which is due to the fact that the first three terminals in this game have two quays to handle barges, whereas the others only have one. More quays result in some extra flexibility in the plan.

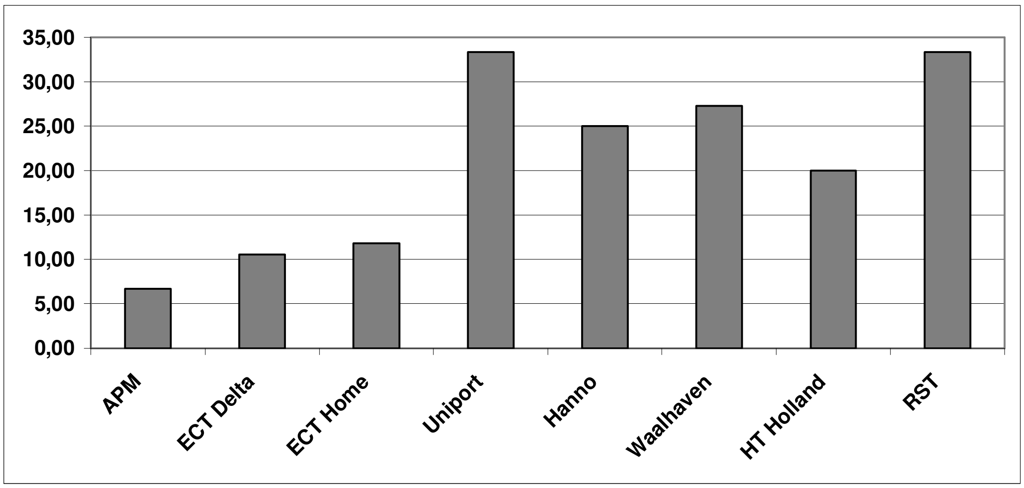

Figure 8: Percentage of barges arriving too late at the terminal (manual, current situation)

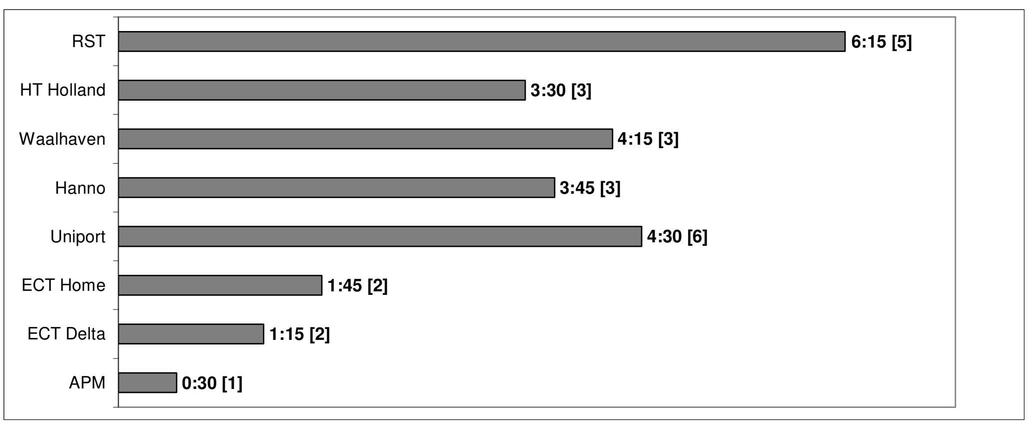

Figure 9: Delays, based on confirmed manual planning per terminal [between [] the number of barges that cannot arrive on time, on basis of the planning]

7. Workshop results summarized

The workshop made clear that the traditional way of offline manual planning of barge rotation schemes results in severe problems, as the analysis showed. Furthermore, the workshop illustrated that the APPROACH pilot system was capable of establishing a feasible plan with zero double-bookings utilizing the same input-data. In the current APPROACH concept, the sole focus is on finding a solution for the pre-planning issue. This is a large step forward: with the APPROACH system, plans generated are likely to result in a feasible execution during the operational phase, whereas the manual planning leads beforehand already to major problems in execution.

The industry participants were shocked, but not entirely surprised, to see the magnitude of planning problems that their manual planning processes caused, and were enthusiastic about the results the APPROACH pilot system delivered. Reactions were, among others: "When can we have this system working? It would help us solving (part of) our business problems.", and "How can we contribute to further development of this system?". The representative from Port infolink – the Rotterdam Port Information Services firm – suggested to discuss the possibility of including the APPROACH concept in a next release of the "Barge planning" application as Port infolink offers it nowadays to its customers.

The participants had critical remarks as well. They noted, for example, that the outcome of the APPROACH planning contained unlogical routes; routes with longer sailing times than needed, due to visiting terminals in an order that a human planner would not allow. This is indeed true, and partly due to non-optimal system settings for the APPROACH pilot system, as well as it is included in the nature of APPROACH, which is to consider all kinds of routes – even 'unlogical' sailing schemes – to construct a feasible plan for all. Fine-tuning however is needed, to help system optimality. Another remark relates to the role of human planners at the barge-operators and container terminal-operators. Will they disappear because of APPROACH, or will their task change? What about all their planning knowledge? Many questions are hard to answer right now. However, when moving towards an implementation of APPROACH, those are issues to consider. A last category of remarks relates to all kinds of extra restrictions the workshop participants considered as missing in the current APPROACH system, like, for example: an inclusion of the stacking plan, rules to handle important customers with a special treatment (e.g. giving them high priority in a rotation trip planning), an inclusion of business rules (i.e. related to competitive advantage issues), et cetera.

The workshop did clearly illustrate the benefits of a system such as APPROACH in a complex environment as barge rotation-planning in the Port of Rotterdam is – with its many container terminals, and many barge operators. The parties involved in the project – a.o. INITI8, and the Port of Rotterdam – now work on a real-life implementation of the APPROACH system. Many of the workshop participants offered to take actively place in steering- or design-teams and/or to give access to their actual plan data.

We, therefore, expect an actual implementation of the system within a relative short period of time. The implementation is expected to take place in a phased-manner, thus making it possible to test the system first with a small group of participants, and develop the next generation of functionality-enhancements in close collaboration with them. Please note that although the system is likely to perform best if the entire industry – that is: all container terminals, and all barge-operators – would participate, this is not necessary. Even with a small amount of participating companies, the system would be beneficial, simply since it makes the planning more reliable and feasible.

8. Future directions

Future work is not only to be done in the area of implementing the current ideas; we see a need for additional research as well. The current software system architecture has only little intelligence. The system basically operates through a trial-and-error puzzle solving mechanism, not focused on an optimization of the entire system.

Hillegersberg *et al*. (2004) identified different categories of agent-based software systems, and as we earlier mentioned, APPROACH could ultimately be of the cross-organizational networking type – the business environment of barge-rotation planning is a good example of such a type. Cross-organizational networking encompasses interactions and coordination between upstream and downstream supply chain partners. It relates to the inter-organizational coordination of activities of many different actors that are closely coupled and highly interconnected in a network. These interdependencies include both vertical and horizontal collaboration between the parties.

An improved version of the APPROACH platform should incorporate more agent-system characteristics (Wooldrigde & Jennings, 1995), (Jennings, 2001), (Luck *et al*., 2004) such as, pro-activeness, autonomous behaviour, learning abilities, and social-abilities. Furthermore it should exploit the potential of multi-party planning, where interaction and negotiation between different parties helps in deriving to the right solution.

The current architecture is basically a central planboard, where software components (or objects, or agents) try to find an individual working solution. And the system keeps on re-trying till a solution is reached that satisfies all involved parties. The different parties however, do not communicate with one-another, or synchronize activities. Terminals could, for example, smoothen their operations by synchronizing visits between terminals; therewith for example saving on labour for the quay-workforce, or more predictable barge-visits. Instead of a trial-and-error system design, terminals could give back slot-time alternatives that would suit with their schedules.

The current system has a star-topology, in where all communication goes through the electronical hub in the center (the APPROACH system). It could however be beneficial to include peer-to-peer (P2P) functionality as well, enabling agents to directly communicate with other agents – utilizing negotiation protocols such as the ContractNet protocol.

Improved pro-activeness of the system relates on the one hand to the issue of turning pre-planning into re-planning and real-time planning. The APPROACH pilot system as designed now, only solves the problem of pre-planning as it is capable of realizing a feasible planning. It does not include possibilities for dynamic or static re-planning. Dynamic, if the environment changes, static, to further optimize a current planning through additional rounds of planning and negotiation when the execution phase approaches. An even more advanced extension would be true real-time planning in the execution phase – to solve disturbances in the system (e.g. a barge with engine-troubles, delays at certain quays due to unexpected events, et cetera). Real-time coupling with location positioning systems and water-way traffic control systems may be needed.

Second, pro-activeness could be expected to play a role from a monitoring and control perspective: the system monitors continuously its state, compares this with historical data patterns, and reacts accordingly. Closely connected are the system's learning abilities. Inclusion of learning abilities in the system make it possible to let the system learn from its past, the decisions made, its results in the execution phase, and so on, and therewith empowering better forecasts for the future.

We thus state that a true exploration of all the possibilities that real intelligent agent systems offer for this business environment, would be an interesting research direction from a systems design perspective. Other interesting research directions connected to the APPROACH case are studies towards the business characteristics of the Port of Rotterdam barge-rotation planning environment, ideal system behaviour, and the adoption and implementation of a system such as APPROACH in industry.

A thorough and detailed scan of the planning practice in the port is an essential element to start with. Connected, a simulation study could reveal what the impact of the current manual way of pre-planning really is, as it can provide an insight in APPROACH' real impact and perform a sensitivity-analysis. During the workshop, the pilot system was only deployed for one particular situation, which gave a good insight in the way manual planning works, and how APPROACH can be beneficial, it however does not deliver hard generalizable data. A simulation model could help in providing this, and could also serve as a "closed" environment to test future extensions and changes to the system. In order to research and develop proper algorithms and system characteristics it might be interesting to use traditional OR techniques to find a system-optimal or null-variant as a benchmark for the simulation model.

The adoption/implementation of such a system is another interesting area for research. Interesting, since APPROACH is on the one hand an agent-based system – not that many agent implementations have been seen in industry yet – and on the other hand it is an inter-organizational system (IOS). IOS implementations are not easy, and many past implementations were not the success they were intended to be. A system-wide insight in the performance benefits the system offers to all parties involved may actually help in the adoption process; thus making the results visible, through a performance-dashboard or alike. In order to report the proper performance indicators, an analysis of the individual company- as well as supply chain-benefits is required.

9. Conclusions

As the MIT Beergame opened the eyes of (generations of) supply chain managers, procurement officers, and logistical controllers for the need for information sharing in supply chains – to overcome the bullwhip effect – this APPROACH workshop, illustrates the need for joint-planning in a supply chain. The barge-rotation planning process within a port such as the Port of Rotterdam, is a complex process, that encompasses synchronization between many different parties – parties that can be eachother's suppliers, customers, or even competitors.

The workshop outcomes were very positive, and generated concrete interest from the participating industry representatives. The comments and analysis, however, were not only positive. The industry representatives identified some minor weaknesses in the setup of the game. Our analysis of the system provided us insight in the true working of the system, what led us towards the identification of some major weaknesses and misfits in the design, and therewith brought us towards the identification of several areas for further research.

A system such as APPROACH would help in solving most of the problems identified in a system dynamics analysis of the situation of barge handling in the Port of Rotterdam. Barges arrive without, or with only little, delays at the terminal, what leads to less idling and less queuing. Since everything is better predictable, building in slack is also less needed. Altogether, this shall result in better feasible barge rotation trips, less disruptions of operations, and thus lower costs.

Industry representatives were clear. There is surely a need for a system such as APPROACH in the Port of Rotterdam, and many volunteered to be actively involved in the implementation of the current system, and the continued research on future versions. The scientific community should welcome more research as well. It is an interesting area for further studies, and it could include different research domains: simulation, agent-based systems, system design, system adoption, and IOS implementation. Following this APPROACH, we can plan for an interesting future!

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