

Coordination of Interdependent Planning Systems, a Case Study

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Abstract: The decomposition of planning and scheduling problems is a well known technique to make these problems tractable. The resulting dependable subproblems were often solved using different planning systems. In this article we focus on an example from the container terminal management. We point out the dependencies between the planning systems. Using a subset of the container terminal management problem we show that an uncoordinated or only naively coordinated solution is not sufficient to generate feasible or effective plans.

1 Introduction

Container Terminals (CT) represent an important interface in the global transport network. Today's continuous increasing number of container shipments leads to increasing requirements for logistic processes at container terminals. Container terminal operations might be enhanced by terminal extensions, a modern operation system, additional resources and also through well-organized and improved logistic processes. In order to improve the CT performance, process optimization becomes more important, when considering that terminal extensions and other technical modifications are highly cost intensive and underlie strategic long-term restrictions [Saa04]. Operations planning is part of the container terminal management (CTM). The task of the CTM is a very complex planning problem, e.g. vessels have to be allocated to quays, quay cranes (QC) have to be scheduled, storage locations have to be assigned and transports have to be planned. A comprehensive overview of container terminal operations can be found in [SVS04].

A common technique to handle such complex tasks is to decompose the task into smaller planning problems. Up to now resulting subproblems were often considered isolated and planning systems have been proposed solving such subproblems efficiently. But because these subproblems result of a decomposition of the original problem, dependencies exist

between them. Consequently the need for coordinated problem solving arises. In this paper dependencies between subproblems of the CTM problem decomposition are presented and a simple coordination is investigated. Dependencies between the existing planning problems are presented in section 2. We then present a case study where two interdependent planning systems from the CTM context were coordinated in a simple iterated way and discuss the results of the case study. Finally we draw our conclusion and outline further work.

2 Container Terminal Management

2.1 Problem Decomposition

A typical and widely used approach for solving the CTM is to formulate subproblems and a hierarchy among them. The subproblems then are solved sequentially, see e.g. [ZLW⁺03]. In [MF06] it is shown, that this approach might lead to undesirable results and suboptimal solutions, even if isolated parts of the problem are solved optimal. The reason is that the dependencies between subproblems are violated in the sequential approach and replaced by assumptions. [SVS04] points out, that *'the need for integrated optimization becomes more and more relevant'*. The CTM task is commonly decomposed into the following subproblems.

1. Berth Allocation Problem (BAP): Defines where and when vessels will be allocated at the quay. Solutions have been proposed e.g. by [GC04].
2. Crane Scheduling Problem (CSP): Quay cranes have to be allocated to bays (one vessel consists of several bays) to perform the loading and unloading of containers. Solutions have been proposed e.g. by [ZL05].
3. Storage Location Problem (SLP): Containers are stored on the container yard. They have to be placed in the storage, depending on their properties, e.g. port of destination, weight, etc. Solutions have been proposed by e.g. [MLWL05]
4. Transportation Planning Problem (TPP): Straddle carrier (or other equipment) transport containers from and to the QCs. Solutions have been proposed e.g. by [BRSV00].

In this decomposition the container stowage problem at vessels is not considered, because it is mainly given by shipping companies. In the literature further decompositions can be found, see e.g. [SVS04], which would not be suitable for this level of abstraction. Obviously there exist dependencies between these planning tasks. These dependencies have been summarized in table 1. Dependencies between planning systems can be modelled as a dependency graph. This representation is intuitive and allows a formal definition. Furthermore the representation of graphs allows the usage of concepts and algorithms, well known in graph theory. Cycle detection, for example, is a fruitful method in the dependency analysis of planning problems. A planning system is, from a very abstract point

Problem	Requires	Provides
BAP	QC allocation, storage position	vessel mooring time, berth section
CSP	vessel mooring time, berth section, job time	QC allocation
SLP	vessel mooring time, berth section, job time	storage position
TPP	QC allocation, storage position	job time

Table 1: Dependencies between subproblems

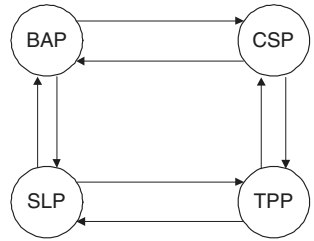


Figure 1: Dependency graph of the container terminal management

of view, an algorithm, that transforms an input I to an output O concerning a set of constraints C . A dependency exist between two planning systems a, b iff the output of a has an effect on the input or constraints for b . The dependency graph is defined as follows.

- $G \quad (V, E)$
- $V \quad \{\text{Set of nodes, each representing a planning entity}\}$
- $E \quad \{\text{Set of dependency edges, an edge connects two nodes}(a, b), \text{ iff there exist a dependency relation as previously defined}\}$

The definition of the dependency graph may be extended towards a labelled directed graph. The edges can be labelled to describe the dependencies in more detail. The dependencies for the CTM are sketched in the figure 1.

2.2 Implications of interdependencies between planning systems

Cyclic dependencies occur, if at least two planning systems depend mutually on each other, direct or indirect. Obviously cyclic dependencies exist in the CTM. To generate a plan the planning task is simplified. Needed information, that are originally generated by other planning systems are estimated. But actually in practise, if the results for the estimated values are available, no feedback exist, which leads to suboptimal and possibly inconsistent results in planning. [MC94] define coordination as '*managing dependencies between activities*'. In order to manage dependencies for the CTM problem, a simple solution one

could think of, is to use feedback information. First planning systems work on estimated data. During the planning process more data becomes available, which could be used to update the planning system's input, as it is shown e.g. in [MCP06] for the berth allocation and storage location problem. This would be a simple but computational intense solution. To ensure termination it would be necessary to show that the coordinated schedules converge to a stable state. But scheduling problems can be chaotic, i.e. small changes in the input of a scheduling algorithm can lead to a wide divergence of the computed schedules [Par91]. Thus for the general case it is not possible to show the convergence of a coordinated schedule towards a stable state.

An alternative approach for the coordination of planning systems would be to integrate the different subproblems. Thus the originally decomposition of planning problems is recomposed. This is done for the BAP and CSP by [MB06]. On the one hand solution can offer a better schedule quality as uncoordinated solutions. On the other hand this integrated approach has some major disadvantages. This approach does not scale neither on the conceptual nor the computational level. The integration becomes more complex with each additional planning system that have to be integrated. The developed solutions can not easily be extended, because reuse becomes a problem. Moreover the needed computation time growth rapidly.

The following case study investigates an iterated approach for a subset of the CTM, namely BAP and CSP.

3 The Case Study

The case study is based on the following use case from the CTM scenario. The berth planner tries, among others, to minimize the vessels waiting time, while the crane planner tries to maximize the QC productivity to ensure fast vessel operation times by minimizing their waiting times and QC movements. The problem here is that the berth allocation depends on vessels processing times, which will be determined within the crane scheduling. In a sequential planning process, there is no feedback from crane scheduling to the berth planner. If both solutions do not match, vessels would have been allocated based on wrong assumptions. An example might be the following. A vessel has been planned to stay at the port for 12 hours. If operations elongate because of wrong assumptions, this might disturb the successors plan.

This study therefore investigates an iterated information flow to simulate the use of feedback information within the planning process. CSP results will return as input for the berth planning agent, which will restart its calculation based on updated information. So it is possible to analyze the iterated behaviour of the system as a first approach towards a more sophisticated and integrated model, based on coordination of existing planning systems. Another aspect is the interdependence between berth allocation and yard planning. The yard planner has to focus on fast access to stored containers. Berth and yard objectives might be conflicting if it is better to berth a vessel in a suboptimal section in order to get fast access on a nearby storage location. This trade-off forces berth and yard planner to find a way to solve the conflict. In the mentioned sequential solution, this conflict is solved

with force from the superior planner.

Storage location and transport planning are not considered in this study.

3.1 Description of the scenario settings and evaluation environment

We use a realistic data set and simulate the planning process of BAP and CSP within a planning horizon of three days and 24 arriving vessels in this time, served by 15 QCs available. Each vessel is given the expected time of arrival, TEU (twenty foot equivalent unit) to be processed, size and assigned weight. No other properties are considered. The processing time will be initially estimated with an average QC rate of 25 TEU/h and vessels assumed feeder, medium, jumbo to be served by 2,3,4 QCs, so that the processing time for a 500 TEU feeder vessel will be estimated with 10 hours of processing. We assume that every vessel can be berthed at every quay position and every QC can handle every bay. There are no restrictions determining the minimum number of QC per vessel.

Model formulations are used from literature, using [GC04] for the berth allocation and [ZL05] for the crane scheduling problem. Each planning system is wrapped by an agent using the JADE framework [JAD07]. Thus a multi agent system is formed which maps the organizational structure of the terminal. This approach is flexible, extendable and allows a more realistic modelling of port processes. Multiple models can be applied, if they use the interfaces given as dependencies in 1. Knowledge from existing models can be used and analyzed within the terminal environment, which importance is underlined e.g. by [BRSV00]. New solution methods may be accessed. Agents are able to change objectives including weights, so that they can influence the overall solution, e.g. in order to solve a conflict.

After assigning berth section and mooring time for every vessel using a simulated annealing approach, the solution will be send to the CSP agent, which will start assigning QCs to vessel bays with the use of a genetic algorithm. Different to the sequential approach, in this iterated attempt, the berth planning agent is now able to adapt vessel processing times, which will affect the BAP assignment.

3.2 Evaluation of Experiments

As a termination criterion, we use a pre-defined number of iterations, because of computational complexity. The following results were observed after 12 iterations and 30 replications. As it is the initial step, results after the first iteration will be equivalent to the sequential solution, results from step two to twelve represent the iterated approach using feedback information. The coordination between the agents remains simple. There is no adjustment of objective functions, information flow nor of solution methods. Simply input parameters, i.e. vessel processing times for the berth planning agent as well as vessel positions and mooring times for the crane scheduling agent will be adapted. Measured figures are *time of last event*, indicating the completion time of the last vessel in the plan (TLE), and also *time in port* (TIP) which consists of *waiting time* (WT) and *operation time* (OT).

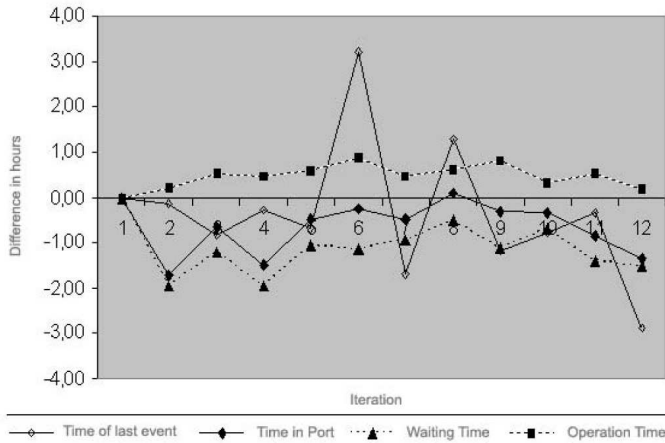


Figure 2: Mean Difference to Sequential Solution

We examine mean results from all replications. Comparing the mean difference between iterated and sequential results, it is interesting to observe that OT is increased, while the mean difference of WT is less than the sequential value for each iteration. The sum of both figures, TIP, oscillates as also results for TLE do.

As CSP results never reach the initial BAP plan in this case and respectively its estimated processing times, it can be seen as a bottleneck in this planning process. As a consequence processing times have to be adapted strongly, especially after the first iteration, because it is the step from estimated to calculated data. We can observe one important property of the sequential solution at this time: Underestimating processing times lead to an increased mean waiting time, because vessels planned for one berth section will have to wait in average longer for their predecessor to be processed. Using the feedback information within the iterated approach in order to adjust processing times, consequently leads to a lower mean waiting time, as it is shown in figure 2. The effect of adjusted operation times can be seen. Table 2 shows the best (minimum), mean and standard deviation results for TIP found in each iteration. These results show that this simple type of coordination is not sufficient. The overall best (minimum) TIP result can be found in iteration 2 and is only little lower than the sequential result. Mean TIP values on the other hand oscillate on a lower level than its comparative sequential solution, except in one case in iteration 8. Unsteady results and relative high values for standard deviations in each iteration show, that results in each replication may differ strongly. This supports our assumption based on the results of [Par91], that the here used planning systems show chaotic behaviour.

Together these results indicate, that there is a potential for optimized processes through an iterated approach, when more sophisticated coordination methods could be applied.

The effect of getting lower mean TIP results within our iterated approach can be compared to an approach from [MCP06]. The authors design a berth template in a first step and use it as a key input for the storage location problem, which is, in turn again input for a nearer

Iteration	1 (seq)	2	3	4	5	6
TIP	12.388	12.298	13.253	12.671	14.000	13.865
mean	17.690	15.963	17.032	16.217	17.214	17.453
sd	3.827	1.779	3.350	2.407	2.658	2.491
	7	8	9	10	11	12
TIP	13.432	12.388	13.940	12.641	12.835	13.686
mean	17.225	17.803	17.393	17.350	16.835	16.340
sd	2.502	3.473	2.553	3.538	2.498	2.035

Table 2: Minimum Time in Port for Iterations

specified berth allocation. This approach can be interpreted as a two-step iteration in our attempt, which we applied for the BAP and CSP. As our results show, an excessive use of iterations does not seem to lead to better results than the two-step-case, without further and more sophisticated coordination.

Our approach supplies promising results for analyzing the co-operation of planning systems within the terminal environment.

4 Conclusion

In this work, we simulated the planning process in the CTM domain, using existing, but isolated model formulations from literature, within a MAS terminal environment. We analyzed their dependencies, which are omitted in existing planning systems. We investigated an iterated approach, which differs from a sequential attempt by using adjusted processing times for the BAP. This paper only deals with a very simple coordinated iteration, i.e. up to now, agents will not change their objective functions or solution methods for helping solving a conflict, depending on the iteration's result. We showed that this kind of coordination did not converge to a stable state in this scenario, which would be critical for the termination of such an iterated coordination approach. This first attempt of using feedback information within the planning process should be analyzed with new and more sophisticated methods in the future. These models might base on knowledge from previous experiments in order to improve results and achieve convergence. Evaluating the iterated results, agents can use their experience, e.g. in situations with high vessel waiting times, to adjust objective functions for better matching results. Solution methods, like heuristics from literature or decision rules might be useful in specified situations, in order to react to a special setting for an improved coordination as defined in the previous chapter. Characteristics can be gained from previous iterations. Up to now, we did not change any of these parameters in this simple attempt.

This presented technique towards a coordinated solution shows promising results that encourage future research.

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