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An Algorithm For Integrated Tactical Berth, Crane, And Vehicle Scheduling Using Functional Mathematical Optimization

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ABSTRACT

A tactical discrete berth allocation is the primary issue examined in this study, with the scheduling of the quay movable crane and vehicle dispatching being sub-problems. In container ports, the most crucial equipment are berths, cranes, and yard vehicles. Reducing turnaround times for vessels while using fewer resources is the goal. The stowage plan and yard templates, or their approximations, are assumed to be provided.

Various techniques are used, including mixed integer linear programming, max plus algebra, greedy algorithms, dynamic programming written in functional language, and general algebraic modeling system. We integrate using functional decomposition, where smaller issues are solved repeatedly and in parallel, resulting in more modifiable and detailed factors to the main problem. We have chosen the sub-problems and their solution algorithms primarily because they are mathematically proven to be optimal or have proven properties.

Furthermore, we expand the sub-problems' features. We apply the quay crane profile concept while assigning the cranes. We rephrase the crane scheduling problem to allow for heterogeneous mobile cranes, including both quay and mobile cranes. Certain features, including double cycling and yard remarshaling, are optional. As an alternative, we can choose how we load stacks or discharge in order to minimize the number of trucks. The pragmatic requirements of Finnish port operators serve as the driving force behind the study.

INTRODUCTION

Container terminals are the source of a number of intriguing large-scale optimization issues in the maritime industry. These intricate systems necessitate a broader range of problem-solving approaches and greater understanding. Transferring containers between modes of transportation is the container terminal's primary duty. Typically 20 to 40 feet long, a container is a rectangular metal box. The port also serves as a short-term storage facility for a few days.

Export, import, and transhipment are the three categories into which container activities fall. Since import-export terminals in Finland are smaller than transshipment terminals and may therefore be optimized more easily, we shall concentrate on them here. Mother vessels and feeder vessels are alternate classifications for container boats. We'll concentrate on feeders here.

Nearly every pertinent issue in container terminal coordination is either NP-hard or NP-complete. Fortunately, restricted particular instances can be exploited because of their polynomial or pseudo-polynomial temporal complexity.

Because various procedures are interdependent, handling a container vessel takes a variety of components. Workforce, equipment, yard, and vessel planning are all closely tied to berth planning. A well-thought-out berth plan conserves resources, money, and time. The number of quay or mobile cranes assigned to a vessel determines how long it will be berthing. The deck and hold of a vessel are separated into bays. The strategy for handling bays, the quantity of yard resources used, and the distance or proximity of the containers to the vessel all affect how long it takes to process the vessel. These resources need to be distributed carefully when there are a limited number of docks, quays, and mobile cranes.

Finding a method to apply existing literature directly, through modification, or through integration to address practical issues in Finnish ports is the primary goal of our research challenge. The goal of our research is to develop an interactive planning and optimization tool for container ports. Only research papers that have been used or are pertinent to this study are reviewed. In addition to the tools mentioned above, we strive to shorten turnaround times for each vessel.

There are obviously two goals, which are addressed lexicographically: reducing the turnaround time of the vessel and minimizing the quantity of handling resources used in a given time frame. The goals could be impacted by the kind of contract that the port and the shipping business have. One vessel's time window may be loosened, for instance, so that other vessels could use more of its resources. Since the turnaround time is not affected by how containers are loaded into trucks or trains, we do not take that into account. Other goals can include reducing travel times, maintaining fuel, and renegotiating prices.

The trend in the literature is to incorporate the subproblems linked to resources. Deep integration might make it difficult to fix or change subproblems since they are combined into a single, complex issue. We employ functional modular integration, whereby subproblems are resolved both sequentially and concurrently, leading to the development of more specific and adjustable parameters for the primary problem. It should also be possible for the port planner to contribute his knowledge and expertise to the optimization process (for additional information, see Bruggeling et al. 2011). As a result, we employ modularization, where the operator can provide greater details for some characteristics and a rough estimate for others.

We provide pertinent literature, models, and solution techniques in the upcoming sections. The issue of allocating berths and resources can be viewed as a three-level optimization problem. We start by outlining the techniques utilized for truck dispatching, and then we look at quay crane scheduling issues. Third, we deal with the issue of allocating tactical berths. The paper is concluded in the last section.

The modular algorithm's organization

The input, the primary algorithm, and the selected programming paradigm are described in this section. We presume that the yard templates and stowage plan for the vessel, or their approximations, are provided. A three-dimensional matrix with containers stacked on top of each other and arranged in rows can be used to model container vessels. Containers are allowed to be placed in the yard storage area in either direction. They can typically be piled to create blocks. The triangle inequality between distances can be used to compute the distances between various container locations by first creating travel itineraries and then figuring out the shortest ones.

The program is organized as follows: we first determine the collection of possible processing procedures for a single ship berth. Parallel processing is an option for this calculation. We then determine the best vessel schedules for various quay crane profiles. Crane schedules are attached to the week schedule and berth allocation on the third level.

The benefit of functional programming, which is a declarative approach to writing a program with functions, is that sub-problems are handled as functions in a more mathematical meaning in this context. F# is used to code programs. Functions in this study behave deterministically and don't have any side effects. As a result, it is also simpler to rationalize the software and even to offer an official system verification. Programming in parallel and asynchronous environments is also simpler.

The general algebraic modeling system (GAMS), another declarative method for modeling optimization issues, is used in the program's non-functional section. The commercial solvers that it supports include CPLEX, which is used in mixed integer linear programming. In addition to being used as a communication tool, vector graphics may read and write data (such as time frames and container positions). You can also use databases or spreadsheets.

Yard side scheduling

One could think of vehicle dispatching issues as the algorithm's initial level. Because polynomial time methods typically solve them quickly, they are appropriate for a subproblem. According to Bish et al. (2005), Li et al. (2004), and Zhang et al. (2005), they were first mentioned in container literature. Although they can be used more broadly, they are made for automated guided vehicles to arrange a specific number of uniform vehicles and a crane sequence. Here, we're talking about their findings and applications.

Using these techniques, we ask: How many vehicles are required to load or unload one bay given the yard template and the stowage plan? We can also wonder how many vehicles are required if the makespan or total handling duration of the vessel is fixed.

Yard trucks, reach stackers, and straddle carriers are the yard transportation equipment utilized in manned terminals. The buffer time beneath the crane is assumed to be zero. The work is typically done in a group, known as a gang, that maintains a single crane and is made up of a selected mix of the previously described cars and other yard workers.

Vehicle dispatching problems

Finding the crane processing time for a container job—that is, how long it takes to transport a container from the ship to the yard or vice versa—is the first step in resolving vehicle dispatching issues. A precise approach would be to model the crane's movement and reduce its travel path using control theory. An alternative is to utilize the container's average time.

Second, we must figure out how long it takes a truck to pick up a container, move it to the yard, drop it off, and then return, or perform the same process but in a different direction. The drop-time depends on a number of variables, including the height of the stack and the usage of intermediate buffers or a yard servicing vehicle. We presume that the yard vehicle traffic is not congested.

Thirdly, the problem structure allows us to solve the unloading phase using a greedy approach, i.e., the first available truck rule as stated in Li et al. (2004), even though Zhang et al. (2005) structured it as a mixed integer program. Zhang's algorithm assumes employment starting times, whereas Bish's algorithm does not. The crane in Bish's algorithm starts unloading a container once the next vehicle arrives, not before. This is the other distinction. Zhang's technique permits the crane to wait for the vehicle before beginning the subsequent task. As a result, it is more effective.

The reversed greedy method is then given by a loading lemma that was also presented by Bish et al. (2005). It is identical to Li and Vairaktarakis's most recent busy truck regulation (2004).
Finally, it is also possible to combine the loading and unloading stages. Total enumeration works for minor issues. The study of heuristics was also conducted by Li and Vairaktarakis (2004). However, because the land trucks are designed to deliver their cargo straight to its destination, port planners may prefer to unload all of the bays before loading them, thus sometimes combining phases is not necessary (see Figure 2, section 4.2).

Servicing a block

Gilliambardo et al. (2010) calculated the cost of shipping a container based on distance using a piecewise linear function. A greedy structure is adequate for short distances, but a more intricate crane-mover-vehicle assignment is required when the block and the crane are located far apart. When containers are located far from the vessel, bay processing time can be decreased by combining greedy algorithms with Vis and Roodbergen's (2009) next tour optimization method. So, we have another way to deal with a ship bay.

The problem and its solutions are then explained. Consider storing and retrieving containers using a straddle carrier in a single yard block. There are several yard-bays or rows that make up the block. The stack consists of a single layer. An ideal tour for requests for storage and retrieval is the result. Block-scheduling is a more efficient method than using the first-come-first-served rule for each container that is requested. In this work, we optimize the straddle carrier's tour of the following few containers.

The modeling method used to optimize tours is intricate and fascinating. It is possible to think of a row as a special case of the Directed Rural Postman problem, which may then be transformed into an asymmetric Steiner Traveling Salesman problem, optimized using Monge matrices, and then converted back. Using dynamic programming and Bellman's optimization theory, we can merge rows from several orientations.

We see that if storage yard techniques are not implemented effectively, faster truck operations will not significantly increase terminal productivity. In order to shorten turnaround time, it is typically feasible to reorder the yard or a portion of it before the next ship arrives. You could use this as another tactic.

Berth-side scheduling

These days, we can calculate one ship-bay utilizing a variety of approaches and vehicle layouts. The next step is to think about how to use them.

Crane sequences

When loading and unloading containers to and from a vessel, a quay or movable crane is typically the terminal's bottleneck. Because the dock cranes are rail mounted and unable to cross one another, the mixed integer model is subject to non-crossing requirements. However, because they are not rail-mounted, mobile cranes are typically slower but easier to move within the port. Furthermore, mobile cranes are able to traverse other cranes. A further factor influencing the number of yard cars is the crane sequence, or the order in which containers are handled. Our assumption is that a crane can only move one container at a time, although this could alter in the future.

By unloading or loading the stack from the ship in a different order while maintaining the same bay makespan, Pap et al. (2011) observed that the number of yard vehicles can be reduced. They employed max-plus algebra, a popular technique for linearly modeling non-linear problems. Regretfully, Pap's study made no effort to determine the best stack handling sequence. The way we utilized max-plus algebra was very similar to how we employed the greedy algorithms that were previously discussed. A near-optimal stack handling order that minimizes the number of yard vehicles has been obtained by combining a max-algebraic formulation with a simple genetic algorithm.

Double cycling sequences are another kind of crane sequence where containers are loaded and unloaded simultaneously. This handling method was restated by Goodchild and Daganzo (2006) as a two-machine flow shop scheduling problem that is optimally addressed using Johnson's rule. In this case, the decision variable would be whether or not to use double cycling. Although the crane's cycle time is longer, depending on the vessel's structure, turnaround time can be shortened by as much as a fifth. Because some terminals have buffer capacity limitations, this method isn't always applicable.

Crane scheduling

We now go on to the second level of our algorithm, which addresses how to determine a vessel's processing time or makespan using these various bay techniques and their respective timeframes.

Regarding the quay crane scheduling problem, our objective is to minimize the makespan while taking into account the interference between quay cranes while determining a handling sequence of holds for quay cranes assigned to a container vessel. There are other limitations that we need to consider. Two cranes, for instance, cannot be placed too near to one another. In other words, a minimum separation requirement—typically at least one bay—must exist. The loading plan, the vessel stowage plan, and a yard map displaying the stowage positions of containers to be loaded on the vessel make up the input data for the quay crane schedule. It has been demonstrated that this problem is NP-complete.Recent research has aimed at adding features of practical relevance and developing efficient solution ideas (see Bierwirth and Meisel (2010) for more details).

After that, we model and expand on the issue put up by Lee et al. (2008), who used a homogenous set of quay cranes to simulate the quay crane scheduling problem. However, it is evident that we have a diverse collection of cranes if processing time is influenced by the type of crane being used, the number of personnel, the number of cars, or any specific technique. How long it takes to transfer containers using a selected method also affects processing time. The processing times for each bay during the unload and load phases may be determined because the yard locations are known.

By adopting this perspective, we can reduce the quantity of yard vehicles that are utilized by the gang operating in a bay. It would be fascinating to think about how vehicle pooling, in which cars collaborate with numerous cranes, would fit into this scenario, even though we assume that there is only one gang per crane. A solution to an example of this issue involving vehicles is shown in Figure 1. A more sophisticated quay crane scheduling model may serve as the foundation for further studies.

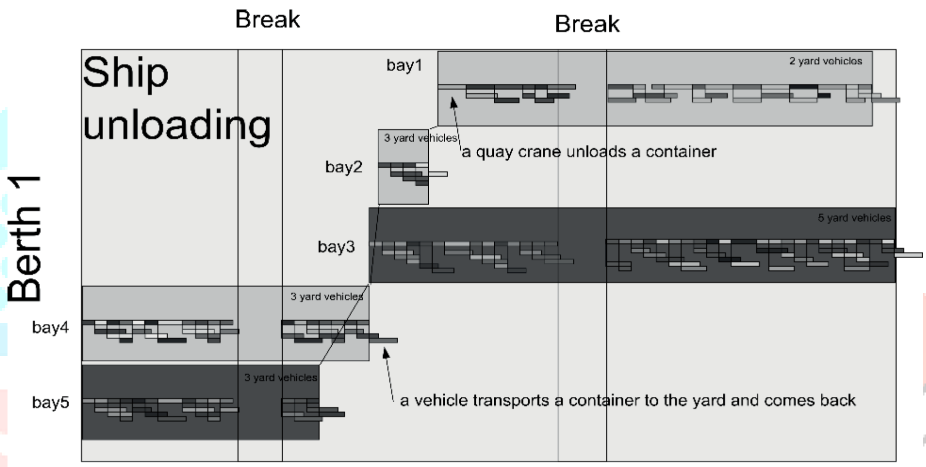

Fig. 1: A schematic example of the unloading phase with indicating breaks and amount of yard vehicles used. Crane one processes bays 5 and 3. Crane two processes bays 4, 2, and 1.

Crane models in the literature are predicated on the idea that work is done continuously. Work shifts and breaks have an impact on the model in staffed terminals as well. Although reducing a vessel's turnaround time and the number of vehicles needed for loading and unloading have been our main concerns, there are other aspects to take into account. It is reasonable to suppose that working nights costs more than working days. Whether or not to skip the night shift could be one of the deciding factors. Additionally, a penalty must be modeled in the event that the contracted time window is exceeded.

The single crane version, or a Traveling Salesman Problem with Precedence Constraints, is one of the specific scenarios that modular design allows us to handle independently. Otherwise, the crane scheduling problem might be quite time-consuming to address, depending on the accuracy available. Our formulation can be solved with CPLEX in the case of small-sized instances. It would be necessary to use metaheuristics to solve larger issues, such as branch-and-price, branch-and-cut, and still larger problems.

Berth allocation

Berth allocation problems, the third level of the algorithm, will be the focus of our final analysis. The scheduling of dock cranes is closely tied to these issues. Assigning arriving ships to suitable berthing locations is a berth allocation problem. It falls within the category of NP-hard issues. There are two types of problems: discrete and continuous. The problem is discrete if we can only allocate one ship at a time; it is continuous if we can assign multiple ships.

We assign several quay cranes to different vessels in a quay crane assignment problem. Contracts between shipping companies and the terminal frequently determine how many quay cranes are assigned to a given vessel. If the berth allocation problem includes quay crane assignment—where cranes are assigned to vessels over time—we refer to it as tactical.

Numerous attempts have been made to combine berth scheduling and crane allocation. Here, we make reference to the Gilliambardo et al. (2010) model. Although that specific model can be adapted for an import-export terminal, it was created for a transshipment terminal. In Gilliambardo's research, the concept of quay crane profiles for a discrete berth allocation model (how to assign cranes over time). Either at the start of the shift or in the middle of it, profiles can be created.

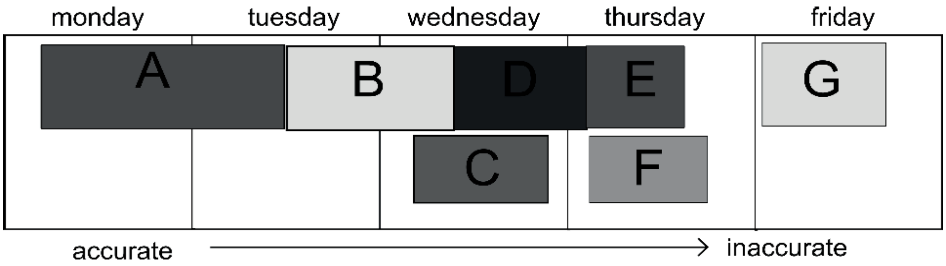

Fig. 2: Real-life time windows for vessels A to G and accuracy of information

Typical vessel time windows are shown in Figure 2. A handful of the automobiles in our scenario overlap. The goal is to plan and predict the week's schedule, with a maximum planning horizon of one week.

In actuality, not all of the information for the upcoming week is available on the terminal. In reality, the actual arrival timings are random and unpredictable. Winter, for instance, has an impact on the expected schedules. It is crucial to be able to provide both a precise and a rough approximation of the parameters due to inadequate data. The approach becomes more complicated when crane scheduling is viewed from the perspective of berth allocation. In reality, a ship's crane count fluctuates throughout time, with varying numbers of quay cranes being utilized during various work shifts. Thus, a new form of quay crane is required. Simultaneous berthed vessels present additional challenges. The primary issue here is determining the bare minimum of resources required to process any two ships within their respective time frames. The terminal must perform a specific number of moves per hour if the vessel is moored during the agreed-upon time window; if not, operators are free to select a berthing time outside of that window.

We expand the concept of quay profiles to include quay cranes and mobile cranes, two distinct types of cranes. It could be feasible to handle cranes separately in a smaller terminal. Additionally, we might designate a different group of vehicles and their tactics. Commercial mixed integer programming solvers can be used to tackle small issues, but larger problems may require a different approach.

Conclusion

In this research, we examined the integration of the quay crane scheduling problem, the berth allocation problem, and a number of associated sub-problems into a single functional solution. We conducted our investigation with a focus on Finnish ports. Our main focus was on calculating various bay times using various methodologies and using the results in quay crane scheduling. The primary conclusion of this paper can be summed up as follows. We suggested a way to combine the quay crane scheduling problem with the vehicle dispatching problem and its variants.

This was accomplished by determining the bay processing times using various approaches, which yields a range of parameters. Vehicle profiles for ship bays can be created using the same concept as Gilliambardo et al. (2010), who employed quay crane profiles to solve the berth allocation problem. As a result, our model included a diverse group of cranes. We also looked at double cycling and stack reordering as strategies to reduce the number of yard trucks. Along with using movable cranes and a quay, we also thought about taking breaks and avoiding night shifts. Rearranging the yard and hiring a yard server are two more ways. A different quay crane profile that includes both the quay and mobile cranes was also taken into consideration while allocating berths.

It is now simpler to add new features and eliminate extraneous components thanks to modular design. Rough guesses and precise facts can be used in tandem. Additionally, we observed that combining various algorithms in a concise and effective manner is possible with functional programming. We will conduct in-depth computer tests and provide a thorough mathematical explanation of the concept and technique in the future.

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