SIMULATION-BASED EVALUATION OF BERTH ALLOCATION POLICIES OF CONTAINER TERMINALS

BLEKINGE INSTITUTE OF TECHNOLOGY
DEPT. COMPUTER SCIENCE AND SOFTWARE ENGINEERING

SIMULATION-BASED EVALUATION OF BERTH ALLOCATION POLICIES OF CONTAINER TERMINALS

MASTER THESIS IN COMPUTER SCIENCE

INSTRUCTOR: RUNE GUSTAVSSON
SUPERVISOR: PAUL DAVIDSSON
ADVISOR LAWRENCE HENESEY

BY
ANATOLY CHERVYAKOV (IS99ATC)

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Abstract

The aim of this investigation is to test and verify a hypothesis concerning policies for berth allocation to ships in a container terminal. The chosen domain is a rich research area where simulation could be used. Because of the high amount of variables involved and demand for optimal usage of available resources management of a container terminal is a great challenge.

The approach used during the investigation was to a high extend experimental, meaning that experiments were done with the software developed for that purpose. The results from the experiment were used as a ground for verification of the hypothesis.

Two algorithm representing two berth allocation policies were developed and tested. The results show that a policy that favors the shortening of overall time spent by a ship in harbor may be a better choice than the policy used today which tries to minimize the distance between the berth assigned to the ship and the stacks where the containers are stored.
1 Introduction

The current situation in the container terminal industry in Sweden and US can be characterized by some overcapacity in terms of for example berth space and machine resources. The conclusion was drawn after visiting three ports (Gothenburg, Åhus, and Karlshamn) and e-mail and telephone contacts with two ports in US (Norfolk and Baltimore). We saw straddle carriers waiting in a queue to receive a container to be moved to yard in the port of Gothenburg. We were told about an expensive crane used just 800 hours a year in port of Karlshamn. According to the domain expert and advisor Lawrence Henesey those were indications of some overcapacity. The situation shall not be seen as a result of the lack of management skills of the port’s executives and managers. Instead that may be just a feature of the domain, meaning that it is necessary to have some overcapacity in machine resources.

The mentioned overcapacity is going to be consumed anyway, as it seems, by the growing amount of see transportation. According to [7] the currently existing number of containers-15 million is expected to increase at 8.5% for the next 10 years. The major European actors in the industry, such as Antwerp, Rotterdam and Hamburg [7] are investing already in expending capacity due to the expected growth of the container transportation. The port of Gothenburg (the major actor in Scandinavia) is even investing in increasing the water depth as the size of the ships grows.

Sture Larsson (Coordinator of Container Division of the Port of Gothenburg) names also such investments areas as a "machine park" (where equipment can park) and berth strengthening (containers are very heavy and special asphalt or even concrete must be used). As mentioned earlier, these investments are being done while there is some overcapacity present.

To shift from cranes and ships to decisions and policies there are a lot of challenging tasks that a container terminal coordinator (using terminology of the Port of Gothenburg) or a port captain (American term) has to do. The one, which this thesis is focused on, is a generation of a berth plan for 24 hours. The plan is done one day in advance based on the number of ships to arrive, the call (arrival) time, number of containers to load and to discharge, and some other data. The plan will allocate resources to serve each individual ship. The resources are berth space, gantry cranes, straddle carriers, and other resources depending on the container terminal in question.

The person in charge of that needs considerable experience of creating berth allocations as the quality of the plan decides the cost and level of service (ships turn around time) that container terminal is to have. The current way of generating berth assignments is very much influenced by the fact that it is very seldom (if ever) one has to decide which of two or more ships to serve first. Once again- there is overcapacity present in the container terminals today. In Gothenburg berth allocation is done using a white board and magnets that represent ships. One can like the visualization created by those artifacts but as the reader has guessed all the necessary calculations are performed in the planner’s head. This fact may mean that up to now there were no advanced calculations needed to perform the everyday routines. The experience and policies (rules of thumb) that originate from experience were enough even in such comparable big ports like the one of Gothenburg. It is worth mentioning that the port of Gothenburg is the largest port in the Nordic area.
There are indications that the current methods will have to change, as the amount of ships will grow to the level where one will have to choose a ship to put before another ship when planning for tomorrow’s work. Sture Larsson confirmed this assertion: “I would go crazy if I had to choose between several ships and berths every day”, he said.

Presently there is one widely accepted policy that states- assign the berth that is closest to the “target” yard. This policy will be called “the closest to the target stacks policy” in the paper. It is easy to see that this rule is a simple rule to follow when there is no queue of ships waiting. If there is another ship that “want” the same berth is may have to wait. According to Sture Larsson that can especially happen in case of a ship that carries cars.

1.1 Purpose and hypothesis

The purpose with this composition and the software that comes with it is to test and verify the hypothesis below.

In case there is ship congestion in a container terminal “the overall time shortening” policy increases the overall performance compared to the “the berth closest to the target stacks” policy that is used today (in terms of the same number of ships served under a shorter period of time).

“The berth closest to the target stacks” as the name says, is focused on putting a ship at the berth closest to the stacks where containers will be put into and taken from while serving (working) the ship. “The shortest time spent in harbor” policy takes the distance to the stack into consideration too but the difference is that it tries to shorten the overall time spent by the ship in harbor. While a ship may have to wait for the “best” (closest to the stacks) berth when the first policy is used, the same ship will be put to an alternative berth that is longer from the stacks (incurring longer time to work the ship) but in the end the ship will be able to leave the harbor sooner. That is due to the reduction of the waiting time.

The hypothesis was verified through experiments with the simulation software. The outcome of the experiments shows that putting aside the sole focus on shorter time spent by ships, when already berthed, gives an overall performance advantage in terms of the same number of ships handled during a shorter period of time.

2 Delimitation and the target auditory

2.1 Target auditory

The paper may be interested for computer science students, port managers, and others interested in the research domain. Some basic knowledge about programming and Java RMI model in particular is required. One without knowledge in the container terminal domain is recommended to read chapter 3, which presents the domain. The terms used in the thesis are explained in the dictionary that comes as an additional document.
2.2 Delimitations

The “overall time shortening” algorithm is called so just to stress that the other (“load-discharge time shortening”) algorithm is non-optimal. There is no intention to say that the “overall time shortening” algorithm is better than any other algorithm it is optimal in general. There are some other delimitation concerning the variables of the algorithms and the simulation software as a whole.

2.2.1 The algorithms

There are some simplifications that shall be mentioned here.

When the time needed to serve a ship is calculated the distance to the target stacks is actually calculated just once- from the middle of the ship, not from each individual bay. The number of the gantry cranes and straddle carriers is fixed (two cranes, six straddle carriers). Besides that it is worth mentioning that the time that it takes for a gantry crane to make a move is not considered.

2.2.2 The simulation software

The simulator does not include a common type of machinery, namely a transtainer. That is due to the fact that the author was mainly looking at the container terminal of the port of Gothenburg, where transtainers are not used for yard stack.

3 Container Terminals

In this chapter some short description of the container terminal domain will be made. What is a container terminal? A container terminal is a special part of a port where container handling is done. Containers require special type of equipment so that they can be lifted, moved, and stored. Containers can be very heavy so it is usually stated on them how many can be put on top. As virtually any cargo can be put into containers there are three main types of them kept in separate stacks: reefer (a refrigerator container that need electricity to keep the required temperature), hazard (that keeps hazardous materials), and standard (anything else). There are two main sizes: TEU (twenty-foot equivalent unit) and FEU (forty-foot equivalent unit).

A container terminal consists of one or several berths (port of Gothenburg has two- 900 m and 1300 m long), yard with stacks of containers, parking spots where trucks can be loaded/discharged, gates though which the trucks come in, and special gates for the trains that can carry containers. In some container terminals the yard stacks are equipped with special type of cranes- transtainers. One can put containers onto each other using transtainers. In Gothenburg there are no such cranes so the stacks are just two levels high. Figure 3.1 shows the container terminal of the port of Gothenburg.
3.1 Features of the business domain and objectives of container terminals

3.1.1 The management

The three key positions in the container terminals studied of visited during the work on the thesis are:

- Port captain (container terminal coordinator in Gothenburg). Port captain is responsible for doing berth allocations.
- Ship planner, who plans how containers are to be loaded on board. Shop planner often uses special software for planning the loading to make sure that the cargo is loaded so that the ship’s safety is not jeopardized.
- Yard planner, who is responsible for the yard and the yard stack.

The description is somewhat simplified but sufficient to understand the contents of this composition.

3.1.2 Features of the business domain

According to [1] harbor is a very intensive environment, namely it operates 24 hours a day, without weekends. The terminal employs very expensive equipment and requires special management skills.

The same authors claim that container terminal is the most complex and promising part, meaning that smart managing of this particular segment of a harbor could bring a lot of profit (in form of savings). They claim also that managing a harbor, as an organization is a great challenge as number of actors is rather high.
I’d like to present the most important, in the context of this paper, objectives of container terminals here.

- No delays of the ships’ departure times. Each ship that arrives at a harbor has a time window associated with it. That means that the ship line can afford expects the ship to leave and continue the voyage after the time that is the time window. If the time window of a ship is 24 hours then the managers of container terminal shall make sure the ship is worked and can leave before that time has passed. A failure to do so may imply penalties (money) or worse loosing of a customer (a ship line).
- To cut the cost of container handling (discharge, loading, rearrangements of the yard stacks).
- To shorten total "ship time" (time that a ship has to spend in harbor)
- To use the machinery in an efficient way, meaning no "empty" routs. The mechanisms such as a gantry crane are very expensive. The cranes we saw in the port of Karlshamn cost about 5 million dollars each. Of course, the managers do not want them to be idle and they do not want them to move without carrying a container.

The management of container terminals is a huge area so I’m going to focus on just one important part of it, namely planning for 24 hours, or planning for the next day. Such planning is common and it is used for example in the port of Gothenburg. The most important input data for that planning is a ship line schedule. The schedule is essentially a list of ships that are to arrive the next day, their arrival times and physical data, such as: length, draft, number of bays. Besides that there is bay plan for each ship, which includes a list of containers to load (load list) and a list of containers to discharge (discharge list).

Out of that data and of course the data about the container terminal resources (berth length and water depth, number of gantry cranes and straddle carriers, the types and capacities of these machines, number and locations of yard stacks etc) the key managers have to produce a berth assignment plan. That document will state which berth will be allocated to which ship and for how long. Besides that in a berth allocation plan will be decided which other resources (machines) will be allocated to work each individual ship.

There are two pictures on the next page that show some of the machines and concepts mentioned. The images were downloaded from the web site of the port of Gothenburg.
Figure 3.2. The picture shows gantry cranes that are about to start discharging a container carrier. The stacks of the containers on the ship are called bays. Such cranes cost 5-6 million dollars each. They can move along the berth on the rails.

Figure 3.3. The picture shows the ship’s bays (stacks of containers) and yard stacks. To the left of each of the two gantry cranes one can see a straddle carrier.
3.2 Berth allocation

The berth allocation plan is produced by a port captain (container terminal coordinator) and a ship planner. Some assistance of yard planner is possible.

Berths are allocated to ships on the basis of the arrival times and the expected amount of work (number of container to load and discharge). The planner tries to make sure that the distance from each individual ship and the yard stacks where containers to be put and taken from is minimal. The longer that distance is the longer it will take to work that ship, provided that the machine resources (number and type of gantry cranes and straddle carriers) allocated to the ship are the same.

Currently the numbers of ships are such that it is seldom that two or more ships “want” to be put to the same berth. If the number of ships increases (and that is what is expected to happen) then such conflicts will have to be resolved. One possible solution could be putting ships to alternative berths that happen to be free when the berths giving the shortest time to work a ship (berths closest to the yard stacks) happen to be busy. That will incur higher cost in terms that containers will have to be transported longer distances by straddle carriers. At the same time the waiting time (for a better berth) will be cut, giving a shorter time spent by the ships in harbor.

One shouldn’t get the impression that the idea of putting a ship to another, more distant berth has never crossed minds port managers. Of course such technique is being used sometimes. Instead my proposition is that putting the objective of overall capacity of container terminal (number of ships served during a given period of time) over the objective of cutting costs by putting ships to the best berth position may be justified as a mean of extending container terminal capacity without capital investments in new machinery, reconstruction and extension of berth, etc.

3.3 Working a ship

A “gang”, consisting of 4-6 dockworkers, works each ship, while the others work on the ship others operate gantry cranes. They communicate with each other using radios or some other communication equipment. The main task is to discharge the containers that are in the discharge list and to load those in the load list. Very often gangs discharge first and load after. According to Lawrence Henesey that is not optimal, as the gantry cranes will have “empty” moves. Empty moves do not generate revenue as each container move generates a cost to the ship.

Beside that, there is another issue, namely other containers may block some of the containers to discharge. As bays are essentially stacks of containers in the ship then naturally it may happen that the containers to be discharged are not always the ones on the top. This problem implies that a lot of time can be lost during discharging.

When it comes to loading of the containers some other considerations are important. Especially the consideration of the ship’s balance and safety is very important. If a lot of light (even empty) containers are in the bottom of the bays and a lot of heavy ones are on the top then an accident may happen with the ship. The problems mentioned above are so crucial that
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special software were developed to facilitate ship loading. One-called Ships is used in the port of Gothenburg. It is worth mentioning once again here that no software is used for berth allocation neither in Gothenburg, nor in the two ports in US that Lawrence Henesey was in contact to.

During the discharging containers are to be moved to the predefined (by container terminal mangers) yard stacks where the containers will be stored until departure with another ship, train, or truck.

3.4 A container’s life in a container terminal

It is worth explaining the containers’ movements from a ship to a yard stack and back. When a ship arrives to a container terminal all the containers in the discharge list are to be moved from the ship to a yard stack. First a container is lifted by a gantry crane and put down by the crane. Then the container is picked by a straddle carrier and moved to a yard stack. It stays there (or possibly moved to another stack) until a truck, or a train or another ship comes and has it in its load list. Then the container is fetched by the straddle carried and loaded using a gantry crane again on a ship (in case it is to leave the terminal on a ship).

The above description is very brief and simplified but it is quite sufficient for understanding the composition.

4 Method

The work on the thesis started in December 2002 when an extensive literature study was done. Mostly the scientific articles collected (and some of them even written) by Lawrence Henesey were read during his research. There was thus no need to spend time looking for the sources. The articles were collected, archived, and offered by Mr. Henesey. All of the papers were discussed with Mr. Henesey and his comments on both the ideas and the conclusions were very helpful for understanding the material. This work resulted in the paper that was submitted for the class DVD003 (“Advanced topics in computer science”). Another result, a more important one was the ground that had been built for the master thesis.

Next step to take was a development of a container terminal so that ideas and hypothesis could be tested. The idea of simulation came partially from the articles, partially from the fact that there was no real container terminal available to use, and partially from Lawrence Henesey. Initially the ambition was just to build a manager system and to borrow a container terminal simulator from some of the former colleagues of Mr. Henesey. Unfortunately it was impossible to get such a simulator, probably due to a high commercial value of that kind of software. So a simulator was developed from scratch.

There were initially one more student involved in the development project but later on he decided to take a pause so all the development had to be done by myself.
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When, finally, a sufficient part of the software necessary for producing the current composition was finished the work on the experimental part of the thesis began. There were discussions with the supervisor (Paul Davidsson) and the advisor and the domain expert (Lawrence Henesey) as to what kind of ideas could be tested and evaluated using the software.

In the end it was decided that two policies for berth allocation (described in chapter 4.2) should be evaluated in simulation experiments to prove the hypothesis and to show that reduction of the time spent in harbor by each individual ship results in the increase of overall capacity of a container terminal.

4.1 The simulation platform

A simulator of a container terminal (CT) and a simulator of a manager office (manager system) of a container terminal were developed with objects that mapped human decision makers. The objects are capable of "knowing" what happens in the CT and what kind of decisions are to be taken. They know their responsibilities and have to take decisions to assure that CT simulator is running and providing services for its customers (i.e. discharging and loading ships).

The objects’ knowledge, the requirements and the design of the software are based on decision making scenarios made during knowledge elicitation sessions with Lawrence Henesey. Besides that an additional daylong interview was made with the managers of the port of Gothenburg. The information collected during visits to two more ports- the port of Karlshamn and the port of Åhus was used as well.

Initially the objects of the manager system were designed to be implemented as agents. The lack of time and the fact that a second participant (a pt- student) in the development project decided to leave forced me to leave the ambition of implementing a multi agent system. Instead the main issue became the implementation of the necessary planning capacities of the manager system.

4.2 The policies

The feature of the manager system that the current composition is based on is the ability to generate a berth assignment plan by port captain object. The object uses two algorithms and produces two berth assignment plans. The first algorithm is called “overall time shortening”, the second one is called “load-discharge time shortening”. The “overall time shortening” algorithm’s output is a berth assignment plan that guarantees a shorter total time to serve a number of ships than the ”load-discharge time shortening” algorithm’s output.

The “overall time shortening” algorithm uses a policy for berth allocation that is called “the shortest time spent in harbor”. The “load-discharge time shortening” algorithm explores a little simpler policy that is used today that is called in this paper “the berth closest to the target stacks” policy. That policy focuses on putting ships as close to the yard stack where containers will be brought. There is nothing wrong with that in my opinion besides one thing, namely that it may be time to make the concern of putting a ship closest to the target stack
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just one of concern several others. Like, for example, the shortest time to serve all the ships to arrive. That will allow for expanding of the capacity without investments in machines and space.

Now that I’ve described the algorithms very briefly it is time like to present them formally. The presentation describes the variables, the calculation being performed, and, finally the output of the algorithms. The input variables are the same for the both algorithms, as well as the most of the calculations.

4.2.1 Berth and ship modeling

$B$ is a set of berth points, $B = \{0..n\}$

$S$ is a set of ships (given in ship line schedule)

$T$ is a set of yard stacks (given in the configuration file).

$C$ is a set of straddle carriers (given in the configuration file)

Parameters

$n$ is total length of the berth (how many meters or berth points), set in the configuration file

$l_s$ is the length of a ship $s \in S$

$d$ is distance to be kept between two successive ships berthed

$d_{bh}$ is distance between berth point $b \in B$ and a yard stack $t \in T$

$d_{bst}$ is distance between berth point $b \in B$ and the closest available standard stack $t \in T$

$d_{bht}$ is distance between berth point $b \in B$ and the closest available hazard stack $t \in T$

$d_{br}$ is distance between berth point $b \in B$ and the closest available reefer stack $t \in T$

$as$ is arrival time for ship $s \in S$

$r_{s\text{standard}}$ number of routs to standard stacks necessary to load/discharge the ship $s \in S$

$r_{s\text{hazard}}$ number of routs to hazard stacks necessary to load/discharge the ship $s \in S$

$r_{s\text{reefer}}$ number of routs to reefer stacks necessary to load/discharge the ship $s \in S$

$t_{bs\text{waiting}}$ waiting time for berth point $b \in B$ for ship $s \in S$

$t_{bs\text{service}}$ service time for ship $s \in S$ if she is berthed at the berth point $b \in B$

$v$ is the average speed of straddle carriers

$n_{sc}$ is number of straddle carriers assigned to serve a ship $s \in S$

$t_{tot}$ is the time needed to serve all the ships that will be coming according to the ship line schedule

$t$ is a yard stack, $t \in T$

4.2.2 Calculations

Waiting time $(t_{bs\text{waiting}})$ for a berth $b \in B$ is the highest waiting time of the set of berth points (meters) that a ship $s \in S$ will occupy. Naturally the number of berth points is equal with the ship’s length plus some distance that is to be kept between each two ships that are berthed.

$$t_{bs\text{waiting}} = \max \{ t_{bs\text{waiting}}, w_{b+1\text{waiting}}, \ldots, w_{b+m\text{waiting}} \}, \quad m = m_s = (ls + d)$$
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Approximate service time ($t_{bs\text{service}}$) needed to serve a ship $s \in S$ if she is berthed at berth point $b \in B$ is:

$$t_{bs\text{service}} = \frac{(2 \times (r_s^{\text{standard}} \times d_b^{\text{standard}} + r_s^{\text{hazard}} \times d_b^{\text{hazard}} + r_s^{\text{reefer}} \times d_b^{\text{reefer}}))}{(v \times n_{sc})}$$

4.2.3 The output

In the end there are two dynamic variables $t_{bs\text{waiting}}$ and $t_{bs\text{service}}$. The ”load-discharge time shortening ” algorithm chooses the berth giving the shortest service time ($t_{bs\text{service}}$). The “overall time shortening” algorithm will calculate another value $t_{tot}$ that is total time, which is a sum of $t_{bs\text{waiting}}$ and $t_{bs\text{service}}$. The berth giving the shortest $t_{tot}$ will be chosen, thus reducing the overall time needed to serve all the ships.

The better overall time does not come without cost, of course. Putting a ship to a berth that is further from target yard stacks will imply longer distances for the straddle carriers to travel, more fuel burned, higher wear of the straddle carriers, more traffic in general, etc. The management of the terminal has to take a decision if it’s worth to speed up the operations by putting a ship to an alternative berth.

5 The simulation software in the domain of container terminal management

In this chapter the software that has been developed for the experiments will be presented. In the beginning there is short review of possible applications of simulation in the management of container terminals that was collected during my literature study.

5.1 Applications of simulators

According to [1] the following application areas could be considered:

- Container terminal management
- Testing and predicting feasibilities and outcomes of introduction of new facilities and procedures in advance.
- Training of managers
- Operative and strategic management
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The idea of a simulator to be used for evaluation of new management policies is promoted by other researchers such as [2]. Yet, another application might be evaluation of a container terminal performance [3]. Almost all of the papers try to assess such sub-problems of the domain as yard management, resource allocation and loading/unloading of ships [4].

According to [5] a simulator can assist in validating computer-generated solutions, thus assuring an operator in the correctness of the solutions. As the authors state, a simulator can help to compare, for example computer-generated policies with operator's own experiences and ideas. Actually an idea of a computer-aided harbor consisting of a DSS (decision support system) and a simulator is highlighted.

Out of the ideas mentioned above I’d like to suggest the following applications of CT simulator in the area of education in universities and technology schools:

- Teaching logistics courses
- Providing a lab environment
- Teaching advanced software engineering courses

There is a possibility that a simulator could be used in educational purposes in colleges and universities. It could provide some visualization of the knowledge domain and thus assist a teacher in conveying ideas and concepts. A simulation could also provide a lab environment helping students to gain even some practical skills. Besides assisting in teaching of logistics, such computer software could even be used in any more or less in an advanced programming course concerned with simulation. Of course, besides what was mentioned above, there is other ways of using simulator software in computer science education.

5.1.1 A closer look at the functionality of a simulator

Here presented some ideas about what exactly container terminal simulator shall be able to do as a commercial product for the industrial applications:

- Should show outcome of a certain policy or rearrangement of yard space
- Should present a CT as a certain model, for example a transport network
- Should enable a user to see how a container makes its way from a ship to some storage location and vice versa
- Should be able to measure performance of a container terminal, meaning that some economical indicators should be calculated

Here is a short presentation of some examples of what a simulator could be used for as an educational aid. A simulator should be able to
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- Model a container terminal, meaning that it should present in some form information and physical (container) flow.
- Show outcomes of different yard management or other policies.
- Allow student to program additional modules so that to extend the functionality.

A question arises if one agrees that a computer aid of a container terminal should consist of a set of tools including a DSS (decision support system) and a simulator, namely if that DSS should be considered as a part of a simulator. The author believes that a DSS is a separate application, that's why any of the functionality of a DSS is not included into the above lists if features.

5.1.2 GUI/Animation

According to [1] "the graphic and animation" are very important for assuring end-users in correctness of the results. In the context of this thesis the animation and visualization are not given high priority, as the time available for developing software was very limited. Besides that my software is not targeted yet towards any commercial market besides the research of the container terminal domain.

5.2 The container terminal simulator developed and used for experiments

Here a description of the simulation software developed and used for testing of the hypothesis will be presented.

The CT simulator consists of 7 packages and totally 55 classes (plus a couple interfaces). The manager system is smaller: there are classes 10 (plus 2 interfaces) that form 2 packages. The communication is built using the RMI facility of Java. There was no need to spend time choosing or producing an own communication protocol as RMI perfectly facilitates what the two processes (CT simulator and manager system) need, namely sending objects to each other.

In the appendix 2 there are some class diagrams representing pieces of the two applications.

5.2.1 Configuration

The simulator’s general purpose is to enable a researcher to test ideas and hypothesis considering management of a container terminal.

The CT Simulator that was developed is a Java program that is to simulate a container terminal. There is an extensive set of variables that are configurable for each individual running of the simulator. The variables are set in a configuration file for a simulation scenario. The file is loaded and used by the simulator to run a simulation session.
Initially it was planned to develop a configuration program for the simulator. Now that program is still being contracted so presently the configuration files for the experiments were edited manually.

The most important variables in the context of this thesis that can be set in the configuration file include length of the berth, type, capacity and cost of gantry cranes and straddle carriers, and finally types and positions of the yard stack. The total number of variables is over 50 and it may grow as the work on the software goes on. Some of the entities such containers for example are configured by the CT simulator. It would be too time consuming to set over 20 attributes of each of several thousand containers to participate in the simulation.

In the beginning of the simulation session a ship line schedule and a bay plan for each ship are built by the simulator (Ship Broker object) and sent to the manager system. Those documents are going to be several thousand lines long, if printed, because each individual container, configured automatically by the CT simulator has a large set of attributes. The schedule and the bay plans are generated using ship data like length, arrival time, number of container to load and discharge. That data is read from configuration file too.

When the ship line schedule along with bay plan are sent to the manager system the generation of the berth assignment plan starts. As soon the plan is generated it is sent back to the container terminal simulator. This is the end of a simulation session in the context of this paper. The outcome is a berth assignment plan. That plan is characterized by two numbers—total time needed to serve all the ships in the ship line schedule and the total distance that straddle carriers will have to drive.

5.3 Manager System

In general the manager system receives notification about all the events occurred in the container terminal simulator (i.e. an arrived ship’s request for a berth), makes an appropriate decision and sends it back to the container terminal simulator.

In the context of the theses the interesting part is a reception of a ship line schedule, generation of berth assignment plan and sending in back to the container terminal simulator. To produce a berth assignment plan managers have to know a lot of things about the container terminal. So they ask and receive snapshots of how the berth looks like (the length), what kind of machines (capacity, cost, type) are available, what are yard stacks’ properties (positions, types), etc. The berth assignment plan can be produced using either of the two policies.
6 The experiments

6.1 Description of the experiments

Manager system produced two berth assignment plans using two policies described above for each of the three scenarios (based on three configuration files). Thus the total number of berth assignment plans was six. The number of ships in the configuration files was the same, as well as the physical characteristics of the ships (lengths, number of bays). The differences were in the arrival times and the number of containers of different types (reefer, hazard, standard) to load and discharge from each bay. The three configuration files were called worst case (there is ship congestion), average case, and best case (no congestion).

6.1.1 Worst case

The worst case is characterized by short time intervals of time between the ships arrivals, which results in a queue (congestion) of ships. By short here it is meant, that the intervals are shorter than needed to finish serving the ship arrived previously. By congestion it is meant here that each ship (besides the first one) cannot be put to the berth closest to the target stacks immediately, because there is a ship arrived before being berthed there. Besides that, the composition of the three different types of containers to be loaded/discharged is such that each ship (besides the first one) “wants” the berth that is already taken. Here it is worth reminding again that a ship carrying a lot of, say hazard containers is best positioned by the berth closest the yard stack (target stack) containing hazard containers, because in that case the straddle carriers will have to have the shortest routs. It is clear that in this situation the “overall time shortening” algorithm will put ships to alternative berths instead of putting them in a waiting queue. It is provided that the waiting time for the “best” berths (closest to the target stacks) is longer than the time (service time) needed to serve the ships if they are put to alternative berths. The ”load-discharge time shortening” algorithm on the contrary will let the ships wait until the “best” berth for each is clear. So basically they will be served one after another in order of arrival.

6.1.2 Best case

The best case is called best because there are no ship congestion, thus no need to do a choice between putting a ship into a waiting queue and finding an alternative berth. The time intervals between ships arrivals are set in the configuration file to be sufficiently long. That means that if two ships “want” the same berth (due to the same type of containers to be loaded/discharged) then the intervals between their arrivals are long enough for the first ship to be served before the second one arrives.
6.1.3 **Average case**

The average case has some conflicts comprised (ship congestion) but not as many as the worst case. Only one ship of the six has to be given an alternative berth. That is why the case is called average.

Of the three cases it is the best case and very seldom average case that is most characterized for the current workload of the terminals studied during the work on the thesis and software.

To summarize: the purpose of the three cases is to show that working with the worst case (all the ships “want” the same berth plus there is ship congestion) the “overall time shortening” algorithm does a better job in terms of shortening the overall time needed to serve all of the ships. The average case is managed by the ”load-discharge time shortening” algorithm almost as good as by the “overall time shortening” algorithm. And finally the best-case is managed equally by the two algorithms, the berth assignment plan is 100 % equal.

Now, that enough has been said about the experiments it’s time to take a look at the results’ graphical representation. The time is measured in hours and the distance that straddle carriers have to drive is measured in meters. Outcome of the “overall time shortening” algorithm is marked with “O” (from “optimal”), while the result of the “load-discharge time shortening” algorithm is marked with “S” (from “simple”). Finally it is worth reminding again that a berth assignment plan is characterized by two in the context important figures: total time needed to work all the ships and total time that the straddle carriers will drive to move the containers (the ones to be discharged) from the gantry cranes to the yard stacks and to move the containers to be loaded from the yards stacks to the gantry cranes.

6.2 **Results of the experiment**

**Best case outcome**

![Graph of Best Case Outcome](image)

Figure 6.1 The results of the best-case scenario. The results show that in the best case there
are no differences between the outputs of the two algorithms. The total time spent serving all of the ships is 22.3 hours and the total distance to drive for straddle carriers is 7 184 344 meters.

### Average case outcome

![Average case outcome graph]

Figure 6.2 The results of the average case scenario. The results show that there are some differences between the outputs of the two algorithms. The total time spent serving all of the ships is 0.8 hours shorter when using the “overall time shortening” algorithm, while the total distance to drive for straddle carriers is 75 984 meters longer.

### Worst case outcome

![Worst case outcome graph]

Figure 6.3 The results of the average case scenario show that there are considerable differences between the outputs of the two algorithms. The total time spent serving all of the ships is 19.2 hours shorter when using the “overall time shortening” algorithm, while the total distance to drive for straddle carriers is 467 962 meters longer.
7 Conclusion

It is easy to see that the total time needed to serve all the ships in the berth assignment plan produced by the “overall time shortening” algorithm is almost equal to the result of the ”load-discharge time shortening” in the average case, it is equal in the best case and it is much better (shorter total time) in the worst case. The hypothesis thus proved to be true.

The “overall time shortening” algorithm is better when the objective is to expand capacity of the terminal that is necessary if number of ships will increase. The price to pay for this capacity boost is almost 500 km extra for straddle carriers to drive in the simulation. That is approximately 6.2 % more driving for the straddle carriers. Compared to 52% capacity increase it is an easy choice to make between the cost of the service of an individual ship and the total number of ships served that can be achieved under a given period of time. The question to be asked here is: “Is it still worth it in all situations? Is it worth burning more fuel, wearing machines, increasing traffic to speed up the operations?”

To answer that question some additional variables (those are not included in the CT simulator yet) have to be taken into consideration. The most important is whether putting the ships in the waiting queue will result in “breaking” their time windows. If so then some action must be taken to serve the ships so that they can leave on time. That is the opinion of Sture Larsson- the container coordinator with more than 20 years of experience. In another situation when time allows some waiting it may be wise to save money and let the ship wait until the best berth position is free.

Which other factors are pros and cons the “the shortest time spent in harbor” policy? Obviously it depends on what performance indicators are most important for the management of an individual container terminal. It the berth utilization and gantry cranes utilization are important then the “overall time shortening” algorithm that represents “the shortest time spent in harbor” policy becomes attractive. If the container terminal is to extend capacity and to serve more ships without any funds being available for “physical” extension (expansion of the berth space for example) then the policy may be appropriate too.

On the other hand if it is the cost of operations that is in focus and the work load of the container terminal reminds the best or the average case scenarios then the “load-discharge time shortening” policy (represented by ”load-discharge time shortening” algorithm) may be the one to choose.

8 Reflections

The domain of container terminals is an area where the data for experiments or research is very hard to come by. For several weeks we have been trying to get the data about number and characteristics of ships from the port of Norfolk (US). The intention was to use the data in the experiments and for validation of the software. The management of the port of Norfolk is very cooperative but we still have to continue the dialog and e-mail exchange to receive all
The described problems originate in the fact that all the data in the domain has commercial value. That was also the reason why we couldn’t find anybody willing to give to us a ready to use simulation software. The biggest hope was to receive a container terminal simulator from the port of Riga but in the end we had to develop everything from scratch.

The domain of container terminal has a large amount of terms and concepts that one has to learn before going into research or development of software. It took over 2 month for me to learn enough about the domain to be able to proceed to making the design for the simulators. The visits to the ports helped a lot as well as the kind assistance of Lawrence Henesey, who made sure that myself and one more student (from PT- program) had a the best introduction possible that we needed for doing the research.

9 Future work

There are quite a few ideas for future work that will be presented just to show that there are a lot more of possible applications for the simulation software in several areas.

9.1 Improvements of the CT simulator and the (Management system)

First of all there are a lot of things that are to be developed and added to the current version of the software. The CT simulator is probably going to be used for a master thesis that is being done by another student. The thesis is about evaluation of market-driven policies for container terminal management.

One of the goals for the future concerning the berth allocation algorithm (the “overall time shortening” algorithm) is to include the ships’ time windows and some other considerations in it. As was stated earlier there may be no need to rush and try to serve a ship earlier if its time window is such that she can wait.

Yet another important thing to do is to reconstruct the objects of the manager system and make agents out of them as it was planned in the beginning of the project, when the manager system was planned to be designed and implemented as a multi agent system.

9.2 Education

The proposition is that the software (container terminal simulator and manager system) can be used as an educational tool for both industry and educational establishments.
9.2.1 Educational establishments

In the area of education the software could be used to exemplify terms, concepts and problems of the CT domain. It can be also used as a lab environment, that is to say it can be used by students for evaluation of some proposed policies and yard layouts.

9.2.2 Industry

For the industry purposes the software shall be set so that the manager system can act as a teacher grading a performance of a human object. For example a manager can be given a task of producing a berth assignment and the manager system could grade the results using some preset indicators.

9.3 Knowledge Elicitation Validation

The proposition is that the software can be used for validation of knowledge elicitation. The knowledge (i.e. knowledge about how to do berth assignments) collected during knowledge elicitation project is then encoded as software program that can manage container terminal simulator.

The validation step is to let the domain expert (the knowledge source) to take one of the objects’ positions (i.e. the position of the ship planner object) and manage his part of the container terminal simulator. The possible outcomes could be that the domain expert conducts the management exactly as he had stated during the knowledge elicitation sessions. In such a case, the knowledge elicitation was successful. Or the expert works the management system differently, thus indicating that the knowledge elicitation was a failure.

9.4 Simulator based knowledge elicitation

The proposition is that the software is a tool for knowledge elicitation, that to say container terminal simulator will generate typical situations that shall be managed. The objects of the manager system shall just be able to see what happens and know their responsibilities. The task of the developer/researcher and a domain expert is to teach the dumb objects how they shall go about when solving the problems so that the container terminal is managed.

9.5 Automatically generated policies

The proposition is that the manager objects using historical data can execute or even generate policies for berth allocation, machinery allocation and yard stacking.
SIMULATION-BASED EVALUATION OF BERTH ALLOCATION POLICIES OF CONTAINER TERMINALS

10 Acknowledgements

I would like to thank the supervisor Paul Davidsson for all the help with writing the thesis, defining the hypothesis, and the experiment needed to verify it.

I would like to thank the advisor and the domain expert Lawrence Henesey. Without him neither the composition would be written nor would the software be ever developed. His help with the introduction and teaching me the business domain was excellent and absolutely invaluable.

I would like to thank the managers of the port of Karlshamn Bengt Melin and Pär Carlsson and the managers of the port of Gothenburg Sture Larsson, Hans Lenberg, and Kjell Svensson for the presentation of the container terminals and answering all of my questions.
SIMULATION-BASED EVALUATION OF BERTH ALLOCATION POLICIES OF CONTAINER TERMINALS

Bibliography


### Appendix A. The dictionary

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apron</td>
<td>Part of Berth close to ships where Temp stacking is done.</td>
</tr>
<tr>
<td>Bay</td>
<td>A Cargo Unit stack on a ship.</td>
</tr>
<tr>
<td>Bay Plan</td>
<td>List of containers to be loaded/discharged (according to cell location- optional), yard location, Container Characteristics, description of Bays on the ship and Ship Data.</td>
</tr>
<tr>
<td>Berth</td>
<td>Location where vessel is loaded or unloaded at Container Terminal. It has a length and some other characteristics.</td>
</tr>
<tr>
<td>Berth Agreement</td>
<td>An agreement between Stevedore and a Ship Broker which Berth and which machinery (how many GC) is assigned to a particular ship. Ship Broker can then judge based on the info in the agreement how fast the ship will be worked and get out of the harbour.</td>
</tr>
<tr>
<td>Berth Assignment</td>
<td>A final document that describes where ship is to be unloaded/loaded. How many and exactly which GC and other machines are assigned to a certain Berth, and Ship Data.</td>
</tr>
<tr>
<td>Berth Assignment Plan</td>
<td>A document describing which Berth and machines are to be assigned to a specific Ship. This decision is based on Ship line schedule (Ship Data), Bay plan (no. of Cargo Units being loaded/unloaded), Contracts, Berth Availability and Resource Availability.</td>
</tr>
<tr>
<td>Berth Availability</td>
<td>Availability of a Berth.</td>
</tr>
<tr>
<td>Berth Location</td>
<td>Location on a specific numbered or labeled berth, i.e. Berth</td>
</tr>
<tr>
<td>Berth Request</td>
<td>A document with Ship Data that it requires a Berth to be assigned to it.</td>
</tr>
<tr>
<td>Berth Suggestion</td>
<td>Suggested Berth Location (number), how fast the ship can be worked.</td>
</tr>
<tr>
<td>Bill of Lading</td>
<td>Port of discharge (POD), port of loading (POL), cargo contents (a physical description), shipper, vessel and voyage number, seal number.</td>
</tr>
<tr>
<td>Cell</td>
<td>Document that lists in detail all the Bills of Lading issued by a carrier or its agent or master for a specific voyage. A detailed summary of the total cargo of a vessel.</td>
</tr>
<tr>
<td>Cell Location</td>
<td>Location in a cell.</td>
</tr>
<tr>
<td>Cargo Unit / Container</td>
<td>A truck trailer body that can be detached from the chassis for loading into a vessel, a rail car or stacked in a container depot. Containers may be ventilated, insulated, refrigerated, flat rack, vehicle rack, open top, bulk liquid or equipped with interior devices. A container may be 20 feet, 40 feet, 45 feet, 48 feet or 53 feet in length, 8'0&quot; or 8'6&quot; in width, and 8'6&quot; or 9'6&quot; in height. In the Simulation we will have three categories: 20', 40', 40'Reefer</td>
</tr>
</tbody>
</table>
### Cargo Unit Characteristics
- **weight category**: [1- Heavy (15<+ tons), 2- Medium (10-15 tons), 3- Light (10> tons)], **category**: [2-20', 4-40', 9-Reefer (40')], **cargo contents category**: (1-empty, 2-load, 3-Hazardous).

### Container Release
- Release by **Ship Broker** to **CT** to allow **Container** to be dispatched

### Container Terminal Data Base
- Data base that is used in the Container Terminal describe the whole terminal

### Container Yard
- Usually accessible by truck, railroad and marine transportation. Here containers are picked up, dropped off, maintained and housed.

### Contract
- A contract between the port and a **Ship Line** that says among other things how many **Cargo Units** the Ship Line brings. The more **Cargo Units** the more important it is to provide better service.

### CT
- Container Terminal, An area designated for the stowage of cargoes in

### Full Containerships
- Ships equipped with permanent container cells, with little or no space for other types of cargo.

### Fork Lift
- Machinery that can lift container

### Gantry Crane/GC
- Gantry Crane. An entity (an object/agent) of the simulator.

### Load List
- A list of containers to be loaded.

### Lorry
- Mode of transport than can carry **Cargo Unit**

### Lorry Parking Spot
- Place where lorries are loaded and unloaded

### Manifest
- Document for ship that lists in detail all the bills of lading issued by a **Carrier** (Ship Line) for a specific voyage. A detailed summary of the total cargo (containers) of a vessel.

### Partial Containerships
- Multipurpose containerships where one or more but not all compartments are fitted with permanent container cells. Remaining compartments are used for other types of cargo.

### PC
- Port Captain. An entity (an object/agent) of a manager system.

### Port Calls
- Ship arrival at a port.

### Reefer Stack
- Is a **Stack** of **Cargo Units** that are plugged to refrigeration unit.

### Resource Availability
- Availability of specific resources (machines or equipment), i.e. **GC**, **SC**, etc.

### Roll-on/Roll-off vessels
- Ships specially designed to carry wheeled containers or trailers using interior ramps.

### RMG
- Rubber Mounted Gantry.

### RTG
- Rubber Tired Gantry.

### Service Time
- Time that vessel is served may include down (time that is non productive stop time for lunch, maintenance, etc.

### Shifting Factor
- Number of non-productive moves divided by total number of containers being unloaded and loaded for that specific vessel and voyage measured in percentage.
## SIMULATION-BASED EVALUATION OF BERTH ALLOCATION POLICIES OF CONTAINER TERMINALS

| **Ship Broker** | - representative of the ship line, also known as a ship's agent. Provides information to **PC** of **Ship Line Schedule**, to **Stevedore**: **Load List**, **Bay plans**, and **Manifest**. |
| **Ship Data.** | - ship name, length, etc |
| **Ship Line** | - an owner of ships and containers, it has an agreement with **CT** on services and associated costs. |
| **Ship Line Schedule** | - a timetable of fixed dates, fixed **Port Calls** and vessel’s names and voyage number. |
| **Ship Types** | - types of ships used for shipping containers. Cellular, RoRo, Geared, etc. |
| **Stack** | - physical arrangement of containers assigned according to yard layout. |
| **Stevedore** | - individual or firm that employs longshoremen and who contracts to load or unload the ship. In our simulator Stevedore works for the benefit of a customer (**Ship Broker**). |
| **Stevedore Request** | - a preliminary document that describes how many and exactly which berth, **GC**, and other machines are asked to serve a certain vessel. |
| **Straddle Carrier/SC** | – Machinery that is used to move **Cargo Units** in the **CT** and can stack the containers |
| **String Piece** | - a part of **Apron** where **GCs** rails are put. |
| **Temp Stacking** | - stacking of **Cargo Units** in advance on the **String Piece** or on the **Apron** |
| **Temp Stacking Plan** | - it is a plan how **Temp Stacking** will be done based on expectation of ship arrivals (**Ship line schedule** sent by **Ship Broker**), **Bay plan**, **Cargo Unit Characteristics**, and, **Resource Availability** |
| **TIR** | - Transport International par la Route (road transport agreement allowing sealed containers to cross national frontiers), name of the **Carrier** (shipping line), container number, seal number, weight and type of **Cargo Units** |
| **Train** | - mode of transport than can carry **Cargo Units** |
| **Transporter** | - Mode of transport that is able to carry a **Cargo Units**, in the terminal, i.e. train, lorry, ship |
| **Vessel Operations Time** | - how long it takes to work a ship. |
| **Yard Location** | - a cell in a container stack according to **Container Characteristics**. There are several types of **Stacks**, for example a hazardous stack or reefer stack, etc. |
| **Yard Location Assignment** | - assignment of container to a location of a **Stack** in the **Container Yard** |
| **Yard Plan** | - a list of discharged **Cargo Units** containing location to be placed on yard (which **Stack** based on a set policy). |
| **Yard Truck** | – Machinery used to transport container on a chassis in the Yard. Similar to a lorry. |
| **Yard Planner/YP** | - Yard Planner. An entity (an object/agent) of a manager system. |
12 Appendix B. The class diagrams

The class diagram that represent the communication package of the manager system. CT simulator has a similar package. All the communication is implemented using RMI.

Figure 11.1 The class diagram of the ManagerSystem.Communication package.
Figure 11.2 The class diagram of the CTSimulator .Machines package. The diagram shows all the machines that are to be implemented, the Transtainer class and the Straddle Carrier class are not fully implemented yet. The most important is though not the machines themselves but their schedules, which are represented on the next figure (fig. 11.3)
Figure 11.3 The class diagram of the some of the classes contained in the CTSimulator.Documents package. All the machines have a schedule associated with them. The schedule makes it possible to check the machines availability and to book the machine (i.e., to assign a gantry crane n01 to work a particular ship at particular location.)
Figure 11.4 The class diagram of the some of the classes contained in the CTSimulator.Documents package. Each machine has to receive a job description from the manager system. The job descriptions will be built during the creation of the berth assignments. For the moment the implementation of the job classes is not completed.
Figure 11.5 The class diagram of some of the classes contained in the CTsimulator.Documents package. There are a large set of documents needed for functioning of a container terminal. Those documents are captured in the classes above.
Figure 11.6 Shows the collaboration diagram that represent the objects and method calls that are done during creation of a berth assignment plan. The picture shows that two manager objects: portCaptain and shipPlanner are involved in the activity.