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16. Abstract

The “container revolution” of the last forty years has altered the manner in which transportation modes interact. Containerized freight continues to increase with ever larger ships, double stack train service, and trucking companies dedicated to intermodal container movements. The goal of “seamless” interaction between modes is based on a desire to reduce container dwell times at facilities and thus improve productivity and profitability. Consequently, the design of intermodal container terminals, the selection of appropriate lift equipment, and manpower allocation is of paramount importance to facility productivity. Tools for facility design undergo continual improvement. Simulation is one such tool that has become more flexible and more powerful over that last several years. The current research is dedicated to developing a general simulation model of ship-to-rail intermodal container movements with the goal of providing analytical support to operations and facility design personnel.

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Optimal Design of Intermodal Transportation Facilities: Simulation as a Tool to Model Intermodal Container Movements

A Research Study

by

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August 1998

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DISCLAIMER

ABSTRACT

The "container revolution" of the last forty years has altered the manner in which transportation modes interact. Containerized freight continues to increase with ever larger ships, double stack train service, and trucking companies dedicated to intermodal container movements. The goal of "seamless" interaction between modes is based on a desire to reduce container dwell times at facilities and thus improve productivity and profitability. Consequently, the design of intermodal container terminals, the selection of appropriate lift equipment, and manpower allocation is of paramount importance to facility productivity. Tools for facility design undergo continual improvement. Simulation is one such tool that has become more flexible and more powerful over that last several years. The current research is dedicated to developing a general simulation model of ship-to-rail intermodal container movements with the goal of providing analytical support to operations and facility design personnel.

EXECUTIVE SUMMARY

Intermodal container movements have represented the largest single area of growth in freight systems over the last 40 years. The use of standardized containers to package goods and material has allowed tremendous improvements in the efficiency with which shipments are handled. Ports, railroads, and trucking companies have been dramatically changed as a result of this "container revolution."

The efficiency of containerized cargo movements has not only changed the way transportation modes operate, it has changed the manner in which transportation modes interact with each other. The idea of moving cargo from one mode to another is not new. What is new, however, is the seamless interaction of modes brought about by relying on a standardized container which moves with relative ease between ships, trains, and trucks. This innovation has given rise to transportation facilities, equipment, and management practices dedicated to intermodal freight movement.

The design or re-design of facilities and equipment to better accommodate intermodal container movements has been the topic of countless studies, research projects, and consulting assignments. Tremendous progress has been made in the manner in which planning has been brought to bear on the design challenge. Computerized tools such as computer aided design systems (CAD) offer significant benefits to the design function. Simulation is a second tool offering benefits to the design activities surrounding intermodal freight movements and the interaction between modes. Recent advances in simulation models, enhanced software with increased ease-of-use, and more powerful microcomputers suggest that computerized simulation of intermodal container movements can become more widely used in planning for facility layout and equipment selection. In addition, changes to existing traffic loads may be examined to assess throughput, adequacy of resources, and the need for additional space requirements.

Simulation can be defined as: creating a computer model of a real or proposed system and conducting experiments on the model to describe observed behavior and/or predict future behavior before investing any time or money. Because experimenting on a real system could be costly and/or impractical, simulation has become an extremely important tool for designing and analyzing complex systems; it is a cost-effective way of pre-testing proposed systems, plans, or policies before incurring the expense of prototypes, field tests, or actual implementations.

Introduction to Simulation Using SIMAN (McGraw Hill, 1995) lists the following benefits associated with simulation:

- New policies, operating procedures, decision rules, organizational structures, information flows, etc. can be explored without disrupting ongoing operations.
- New hardware designs, physical layouts, software programs, transportation systems, etc., can be tested before committing resources to their acquisition and/or implementation.
- Hypotheses about how or why certain phenomena occur can be tested for feasibility.
- Time can be controlled: it can be compressed, expanded, etc., allowing us to speed up or slow down a phenomenon for study.

- Insight can be gained about which variables are most important to performance and how these variables interact.
- Bottlenecks in material, information, and product flow can be identified.
- A simulation study can prove invaluable to understanding how the system really operates as opposed to how everyone thinks it operates.
- New situations, about which we have limited knowledge and experience, can be manipulated in order to prepare for theoretical future events. Simulation's great strength lies in its ability to let us explore "what if" questions.

The current research is aimed at building a simulation model of the interactions between shipping and rail at a port-based intermodal container facility. The objective of the research is to demonstrate that a general simulation can be developed to model container movements between modes and provide value to managers of intermodal movement facilities in gauging the effects of layout and resource allocation as it interacts with traffic loads. The model selected for use is the Arena Simulation System developed by Systems Modeling Corporation. The port facility used to guide the simulation was the Barbers Cut Intermodal Terminal at the Port of Houston. Site visits, interviews and background research provided the data needed to guide model development.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. BACKGROUND

Intermodal container movements have represented the largest single area of growth in freight systems over the last 40 years. The use of standardized containers to package goods and material has allowed tremendous improvements in the efficiency with which shipments are handled. Ports, railroads, and trucking companies have been dramatically changed as a result of this “container revolution” and the trend toward ever increasing numbers of container units seems unabated. Container ships are increasing in size, railroad double stack intermodal service is on the increase, and trucking companies continue to expand their share of the short and intermediate haul market.

The efficiency of containerized cargo movements has not only changed the way transportation modes operate, it has changed the manner in which transportation modes interact with each other. The idea of moving cargo from one mode to another is not new. Certainly centuries ago, goods were transferred between sea and land vessels in route to their final destination. What is new, however, is the seamless interaction of modes brought about by relying on a standardized container which moves with relative ease between ships, trains, and trucks. This innovation has given rise to transportation facilities, equipment, and management practices dedicated to intermodal freight movement.

Intermodal facilities, whether they are dedicated to transfers between rail and truck or to transfers between ship and land modes, involve the use of lift mechanisms to remove and replace containers for the next leg of their journey or ready them for movement to their final destination. The layout of these facilities and the selection of equipment are important factors in determining the productivity of the facility. Movement within a facility is also an important productivity consideration. Cranes, lift and dray vehicles, storage sites, and yard logistics each contribute to the number of containers that may be handled per unit time and, thus, determines the efficiency and profitability of the operation.

At the start of the container revolution, cranes mounted on ships served to load and unload the vessel. As the number and diversity of container movements increased, their was a corresponding increase in the types of equipment used to move containers. The most commonly used equipment today in ship-to-shore movement is the rail-mounted gantry crane. This system has a fixed horizontal boom extending over the vessel be loaded or unloaded and usually operates on wheels allowing motion along the pier. Straddle cranes, stacking cranes, and forklifts are also used to facilitate the rapid and efficient handling of containers for intermodal transfer or storage. The specially designed lifting equipment may cost millions of dollars, and thus the investment in the appropriate array of container handling devices is a major part of intermodal facility design.

The design or re-design of facilities and equipment to better accommodate intermodal container movements has been the topic of countless studies, research projects, and consulting assignments. Tremendous progress has been made in the manner in which planning has been brought to bear on the design challenge. As a result, new intermodal facilities are much more efficient than those facilities retrofitted to handle containerized freight. The array of skills and tools used in these activities is extensive and rapidly developing as the requirements for interacting modes becomes better understood and more formalized.

Nature of the Current Research

Three principal characteristics of a good intermodal terminal design are location, access, and supporting infrastructure. The need to accommodate multiple interacting modes at a facility gives rise to the requirement to plan in advance how these interactions are arranged and managed. The continual change in intermodal facility operations driven by the constant evolution of containerized freight systems means that re-design and re-deployment of assets is an ongoing, never ending function. The corresponding layout design function in support of these continually changing needs can be expensive and time consuming.

Computerized tools such as computer aided design systems (CAD) offer significant benefits to the design function. Simulation is a second tool offering benefits to the design activities surrounding intermodal freight movements and the interaction between modes. Recent advances in simulation models, enhanced software with increased ease-of-use, and more powerful microcomputers suggest that computerized simulation of intermodal container movements can become more widely used in planning for facility layout and equipment selection. In addition, changes to existing traffic loads may be examined to assess throughput, adequacy of resources, and the need for additional space requirements.

The current research is aimed at building a simulation model of the interactions between shipping and rail at a port-based intermodal container facility. The objective of the research is to demonstrate that a general simulation can be developed to model container movements between modes and provide value to managers of intermodal movement facilities in gauging the effects of layout and resource allocation as it interacts with traffic loads. The model selected for use is the Arena Simulation System developed by Systems Modeling Corporation. The port facility used to guide the simulation was the Barbers Cut Intermodal Terminal at the Port of Houston. Site visits, interviews and background research provided the data needed to guide model development.

CHAPTER 2. INTRODUCTION TO SIMULATION

Simulation can be defined as: creating a computer model of a real or proposed system and conducting experiments on the model to describe observed behavior and/or predict future behavior before investing any time or money. Because experimenting on a real system could be costly and/or impractical, simulation has become an extremely important tool for designing and analyzing complex systems; it is a cost-effective way of pre-testing proposed systems, plans, or policies before incurring the expense of prototypes, field tests, or actual implementations. In fact, many managers have come to view simulation as an inexpensive insurance policy. In an increasingly competitive world, simulation has become a powerful tool for the planning, design and control of systems.

In summary, simulation involves the modeling of a system or process in such a way that the model mimics the response of the actual system to events that take place over time.

Introduction to Simulation Using SIMAN (McGraw Hill, 1995) lists the following benefits associated with simulation:

- New policies, operating procedures, decision rules, organizational structures, information flows, etc. can be explored without disrupting ongoing operations.
- New hardware designs, physical layouts, software programs, transportation systems, etc., can be tested before committing resources to their acquisition and/or implementation.
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- New situations, about which we have limited knowledge and experience, can be manipulated in order to prepare for theoretical future events. Simulation's great strength lies in its ability to let us explore "what if" questions.

Basic Principle of Simulation

The most basic building block of a simulation model can be explained in terms of the queue, hold, delay and seize blocks. The hold block is used to represent all modeling functions that delay an arriving entity based on the current state of the system. The arriving entity spends time waiting in the queue until the state of the system changes so that the entity can proceed. For example, an entity can arrive at a workstation to be processed. Due to limited capacity of the workstation it might have to wait in the queue until the server is ready to start processing the entity. Once the server is ready to start, the entity seizes the server and leaves the queue. The actual processing time might be modeled by delaying the entity for an amount of time before the before the entity releases the server and proceeds to the next workstation. Statistics can be collected for the amount of time that the entities spent waiting in the queue, the processing time, server utilization and others.

Randomness can be introduced in the model by using distribution functions to create the time between successive arrivals, the processing times and the destinations of the departing entities. Siman/Arena has a number of continuous and discrete distribution functions available. Some of the continuous function that can be used are uniform, triangular, exponential, Erlang, gamma, Weibull, normal, lognormal and beta. The discrete uniform, binomial, geometric and Poisson are available discrete distributions.

At the end of the simulation run, point estimates and confidence intervals of the statistics are displayed. It is very important to realize that these estimates are not accurate estimates of the true parameters that are being estimated since the observations that were used are not independent and normally distributed. Textbooks like *Introduction to Simulation Using SIMAN (McGraw Hill, 1995)* give in depth discussions on how to improve estimates by using uncorrelated observations. Siman/Arena's output analyzer provides the capabilities to do this kind of data analysis.

Who Uses Simulation?

Although manufacturers have traditionally used simulation technology, many other industries have discovered the benefits of modeling a process and seeing potential results before investing precious resources such as time and money. In fact, according to Systems Modeling Corporation (the developers of Siman/ Arena) simulation has been used in the following industries:

health care	publishing
communications	waste management
fast food	railroads
aerospace	governments
electronics	package delivery
textiles	consumer goods
pharmaceuticals	and many, many others.

Some of SMC customers include Arthur Anderson, General Motors, Ford Motor Company, Microsoft and UPS.

CHAPTER 3. GENERAL PORT ACTIVITIES

In general, three different modes of transportation can interact at a port facility. First of all, containers can enter the facility on ships; these containers can either leave the port on trains or through the road system on trucks. Similarly, containers that enter the facility on trains can leave on ships and trucks, while containers that enter on trucks can leave on ships and trains. Although all these combinations are possible at a port facility, in most instances the truck-to-rail and rail-to-truck interaction are unlikely to occur since better located railyards, that specialize in these kind of transfer of transportation mode, are usually available. Table 1 illustrates this point.

Table 1. Types of transportation mode transfers possible at port facilities

From/to	*Ship*	*Rail*	*Truck*
Ship	-	Likely	Likely
Rail	Likely	-	Unlikely
Truck	Likely	Unlikely	-

The ship-carriers have contracts with the port authorities and these arrangements come usually in two flavors. In some cases the ship-carrier have all the control and the sole use of a dock and its resources and is responsible for all the activities relating to the wharf-cranes and storage-cranes. The arrangement that the Port of Houston have with Sealand is an example of this kind of contract. In most cases however, the port authority is responsible for offloading the ships, transporting the containers either to the rail intermodal yard or dock storage yard. The containers are then stored until they are taken away either through rail or trucks. With both of these arrangements, ships of a specific carrier are assigned to specific docks. This is done so that containers that enter the facility on trains or trucks and are outbound via ships, can be stored at a dock storage area while waiting on the ship.

A port consists of a number of docks, usually each dock has one or two wharf-cranes that are used to load and unload the containers from the ships. Ships that enter the port are piloted to their designated dock. The containers are offloaded with the wharf-crane from the ship and are loaded onto a gang-truck or dray-vehicle. Depending on the specific destination of the container, the gang-truck either transports the container to the rail intermodal yard or the dock storage yard where the container is offloaded from the gang-truck. The empty gang-truck returns to the wharf-crane and the cycle repeats until all containers that are due for the port is offloaded from the ship. Only when all the offloading is done, the loading of the ship starts and the gang-trucks transport containers from the dock storage yard to the wharf-crane. The turnaround time of the ships (time spent at the dock) is extremely important since this is a crucial factor that influences which port a carrier will use. To minimize the turnaround time, a ship will never wait for a container still on a train or a road-truck. As soon as all containers at the dock storage area that are due for the ship, have been loaded, the ship departs.

Each dock has its own gang of trucks that are used to transport the containers between the wharf-crane, dock storage area and rail intermodal yard. Gang-trucks are generally not shared among docks but only service the docks they have been assigned to. The dock storage yard is used as a storage area for containers waiting to be exported by ship, as well as for containers that came by ship while they wait for a truck to take them away via the road system. Each dock has its own dock storage area and containers are usually stacked using a crane. These cranes are also used to load and offload the gang-trucks.

The rail intermodal yard (RIY) consists of a number of railroad tracks, each with storage space next to them. To maximize the utilization of the cranes at the RIY, the trains are sequentially offloaded from the train. To avoid "cherry-picking", a train is sequentially offloaded before the loading-phase is started. The containers that entered the RIY on trains are taken to the dock storage area by the gang-trucks where they wait upon the right ship. Due to the limited space at the RIY these containers are usually taken to the dock storage area as soon as possible.

Once the train is empty, the containers that are due for the train's destination are loaded onto the train where after the train departs from the RIY.

CHAPTER 4. SPECIFIC MODEL

Modeling an operation as complex as a port with all its interrelated activities can be a daunting enterprise. A number of assumptions were made, some of them to simplify the programming task while others were made simply because of a lack of better information. Since the rail intermodal yard does not exist, and is yet to be built, no data is available and many assumptions were made.

The simulation model was developed with the goal of being as flexible as possible. The modularity that the Arena modeling language offers, helped to make the program flexible. Although the operation of the Barbors Cut Port in Houston Texas was used as a guideline, the program is flexible enough so that other situations can also be simulated. By default the port has five docks; each with two wharf-cranes, eight gang-trucks and a dock storage area and storage cranes. The intermodal railyard consists of four tracks and three cranes. Changing the number of any of the above mentioned resources is very simple and step by step procedures are presented later in this paper.

In the simulation model there are random arrival of ships, trains and trucks. It is also possible to use data of a specific ship schedule and to read this data from an Excel spreadsheet.

Some of the questions that the simulation model can help to address are as follows:

- What is the effect of changing some of the port resources on the performance? For example is it possible to predict how much throughput will be affected by adding another lane in the intermodal railyard. The effect of changing any of the port resources can be determined.
- The random arrivals can be used to get the system to the steady state; the data for a ship schedule can then be used to predict the average throughput and turnaround times for the ships on the schedule.
- The effect of changing port resources can be determined for a given ship schedule. This can help to answer questions like how many gang-trucks should be assigned to each dock.
- Different allocations of ships to dock can be tried out and the effect on port performance can be determined.

Layout of Animation Screen and General Description

Animation has been added to the simulation program to aid in the understanding of the behavior of the operations. This feature is of tremendous help since it provides a visual interpretation of the activities that can help to identify bottlenecks, inefficient operation rules, etc. Another important benefit is that animation can help to convince people with little background in simulation to implement the model and to trust the quantitative results because the visual interpretation can convince skeptics of the accuracy of the model.

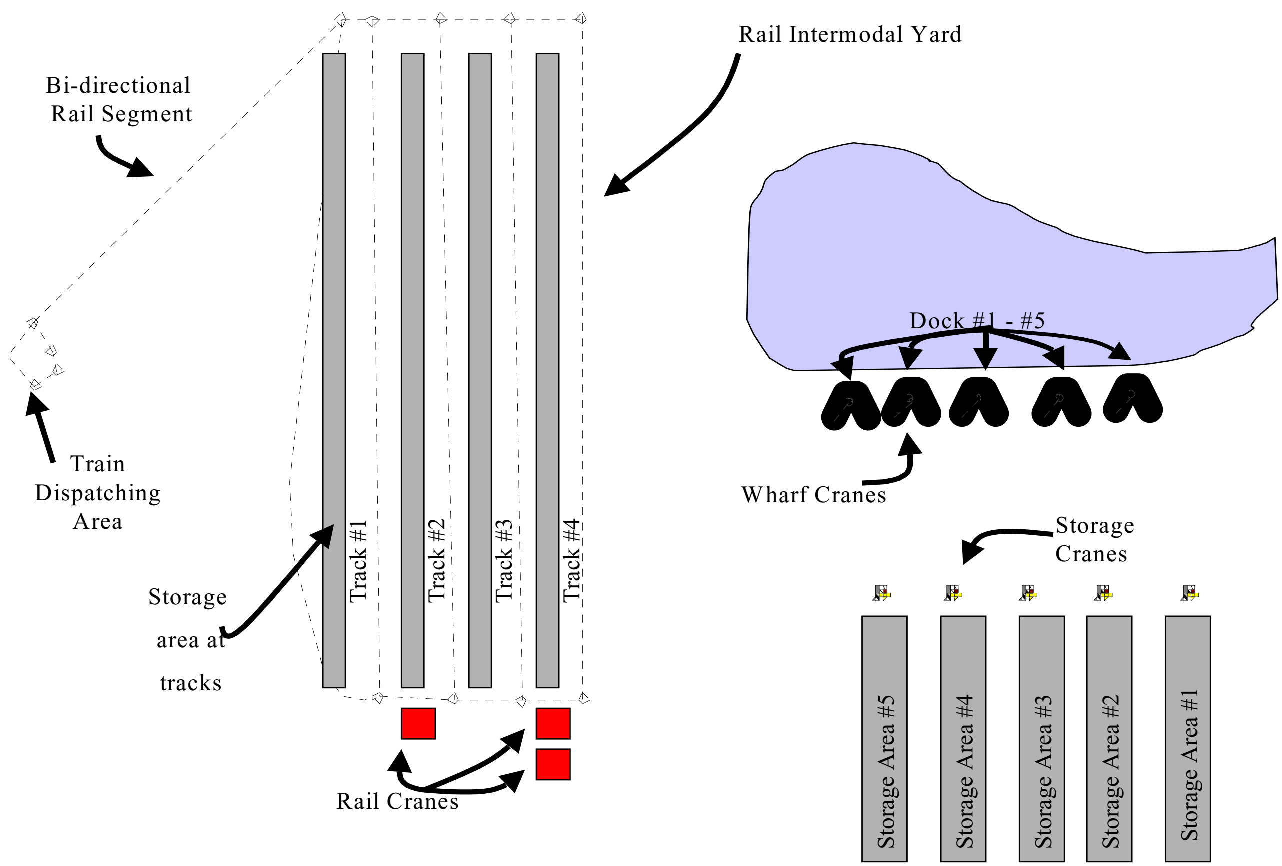

Figure 1. Animation Screen

Brief overview of movement of containers

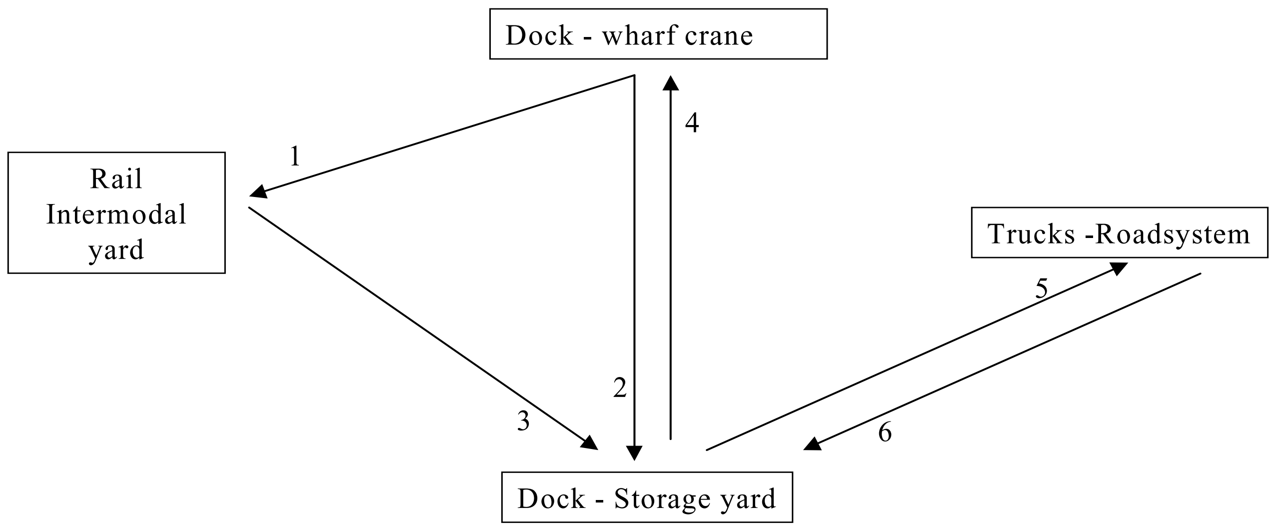

Figure 2. Movement of containers

Dockside operations

By default, the ships arrive according to a Poisson arrival process at the port. A ship number in the range of 1 to 10 is assigned to each ship with an equal likelihood. These probabilities can easily be changed when better data is available about the port operations. Each ship carries 20 containers that must leave the port on trains and 10 that must leave on trucks. Up to 100 containers can be exported from the dock storage area when the ship leaves the port. These numbers are used to generate the random arrival of ships and can very easily be changed. It is also possible to generate these numbers randomly according to a probability distribution.

In addition, a specific ship schedule can be read from the Excel file *ship.wks* that must be in the same directory as the *.doe* file. The random arrival of ships stops when the first ship in the schedule arrives. The layout of the *ship.wks* file is shown in Table 2.

Table 2. Layout of the ship.wks file

	A	B	C	D	E	F	G	H
1	3	numlines						
2	ship#	arrive_time	in_rail#	in_road#	out_#	bridge	train_time	take_ship#
3	1	100	10	10	15	1	10	1
4	2	500	15	20	100	1	400	1
5	3	200	10	25	30	0	300	3

The number in cell A1 corresponds to the number of ship arrivals on the schedule. The ship arrival in line 3 can be interpreted that ship number 1 is arriving at time 100 with 10 containers that has to leave the port by train and 10 that has to leave by truck. The maximum number of containers that can be loaded on this ship is 15, thus up to 15 containers that are waiting at the dock storage area on ship 1 will be loaded before the ship departs. If there are less than 15 containers waiting at the dock storage area, only these containers will be loaded since the ship can not wait for containers.

The number in the "bridge" column is used as binary variable that indicates whether a landbrige train must be scheduled. If a train must be scheduled, the value in the *train_time* column determines when the train is to leave the train staging area for the RIY. The value in the last column, namely *take_ship#* determines which containers will leave the port facility on the landbrige train. In the example in Table 2 the second landbrige train will be scheduled to leave at time 400 from the dispatching area with a load of 100 containers that are due for ship 2. Once the train is emptied, containers that entered the port on ship 1 and that are waiting to leave the RIY by rail will be loaded onto the landbrige train and leave the port by train.

When a ship arrives, the ship number is used to lookup the assigned dock number for the ship. The ship waits until the dock is available and as soon as it docks, the gang-trucks are moved to the wharf-cranes where containers are being offloaded from the ship onto the gang-trucks. A gang-truck transports each container to the RIY or the dock storage area where the container is offloaded by a crane from the gang-truck. The empty gang-truck returns to the wharf-crane and this cycle is completed until all containers are offloaded from the ship. Once all the offloading is done, the gang-trucks move to the dock storage area where the containers that are due for the ship are being loaded onto the gang-trucks. They are then moved to the wharf-crane where they are loaded onto the ship so that the empty gang-trucks can return for another load. The ship leaves as soon as all containers that waited at the dock storage yard for the ship has been loaded, or when the maximum allowable number has been reached, whichever occurs first.

Table 3. Assignment of ship to docks in port.wks

	A	B
1	10	numlines
2	ship#	dock#
3	1	1
4	2	5
5	3	1
6	4	1
7	5	4
8	6	2
9	7	3
10	8	2
11	9	4
12	10	5

The simulation model determines the assignment of ships to docks from the Excel file *port.wks* . A example of such an assignment is given in Table 3. The number in cell A1 is the number of lines in the file. Every ship that can enter the port must be assigned to a dock.

Dock Storage yard operations

Each dock has its own dock storage area with storage cranes. The dock storage yard (DSY) is involved in 5 different movements of containers (see Figure 2). The storage-cranes are used during each movement to load or unload the containers from the gang-trucks or road-trucks.

Containers that enter the DSY from the RIY and road (movement 3 and 6 from Figure 2), are offloaded and stored while they wait upon their ships. When they are eligible to be loaded onto the ship, these containers are loaded onto the gang-trucks and transported to the wharf-cranes at the dock.

All containers that enter the facility by ship and are due for the road are transported by gang-trucks from the dock to the DSY (movement 4 from Figure 2). At the DSY they are offloaded and stored while they wait for a road-truck. Whenever the truck arrives, the cranes are used to load the container onto the truck and the truck departs (movement 5 from Figure 2).

Since the storage cranes are involved in all of these activities, the tasks must have priorities. Whenever a crane becomes available it is assigned to the task waiting with the highest priority. The tasks and their priorities are given in Table 4. A small number refers to a high priority.

Table 4. Priority of tasks at storage yard

Priority	Task Description	Movement Number - see Table 3			
1	offloading container from gang-truck that came from wharf-crane	2			
2	loading of container that must leave by ship onto gang-truck	4			
3	offloading container from gang-truck that came from RIY	3			
4	loading of container that must leave by road onto road-truck	5			
4	offloading container from road-truck that came by road-system	6			

These priorities were chosen in such a way so that the time spent waiting by the gang-trucks will be minimized. This strategy minimizes the ship turnaround time, however it easy to change this if a particular port uses another strategy.

Roadsystem

Containers arrive by truck arrive according to a Poisson arrival process at the port facility. They are due to leave the port by ship. The ship destination of these containers are generated randomly with a equal likelihood among all ships, but can be altered as more data becomes available about the port operations. The containers that were imported by ship are stored for a amount of time, generated from a exponential distribution, before a roadtruck arrives. As soon as the roadtruck arrives, the container is loaded onto the truck using the store-crane at the dock storage area. The priorities of these two service requests for the store crane is 4 (see Table 4) and is therefor only done when no other tasks are waiting for the store-cranes.

Train Staging Area and Rail Intermodal yard

The train staging area and RIY is connected with a bi-directional rail segment. This represents the rail connection between the RIY and the closest train dispatch center. Since the rail segment's direction change depending on which way the moving trains are going, a train has to wait for the correct direction before it can enter this rail segment. There is an upper limit on the number of trains that can be in the RIY and on the connecting rail segment. When this limit has been reached, a train wishing to leave for the RIY from the dispatching area has to wait for other trains to leave the RIY before it can enter the connecting rail segment.

There are two types of trains that can leave for the RIY namely common trains and landbrige trains. The common trains leave according to Poisson arrival process for the RIY from the dispatching area. The length of the common trains is a random value between an upper and lower limit. The capacity of a train is 2 times the length of the train since we assumed dual-stack trains. All the containers on a common train are not due for the same ship; the ship destinations are randomly assigned. By default the likelihood of all the ships as destinations are equal but this can be altered when more data is available about the port operations.

The common trains are further subdivided between west- and eastbound trains. This classification is according to their destination after they *leave* the RIY. After the rail cranes have offloaded the containers from the train all containers that must leave by train and that have the same destination as the train are being loaded onto the train. The train leaves when all containers with the same destination has been loaded or when the train is full (the train may have to wait for the direction to change of the connecting rail-segment to change).

The landbridge trains are created only if a ship on the ship schedule (from the *ship.wks* file) requests them. The number of containers on the landbrige train is equal to the value in the *out_#* column in the *ship.wks* file. In contrast with the common trains, all containers on a landbrige train are due for the same ship – the one that requested the train. When the time is equal to *train_time* the landbrige train enters the queue for entering the bi-directional rail segment. After the landbrige train has delivered the load, containers that are waiting at the RIY with the same destination as the train are loaded onto the train. As mentioned earlier, a landbridge train's destination is determined by the last column (the *take_ship#* value) in the *ship.wks* file.

When a train arrives at the RIY, the train pulls into an available track. If there are multiple tracks available, the track with the most containers that are due for the train's destination, is chosen. A train is always fully offloaded before any containers are loaded onto it. Every container that enters the RIY is due for a specific ship. After the container has been offloaded from the train, it is taken to one of the dock storage areas by a gang-truck (movement number 3 from Figure 2). The container's ship destination determines which dock storage area and gang of trucks are chosen since a ship dock only at a specific dock (from *port.wks* file). The containers that came by rail, are stored at the side of the track after they were offloaded while they wait to be taken to the dock storage area.

The rail cranes are important port resources and are used in a variety of tasks. First of all, they are used to load and unload the trains. They are also used to load the containers onto the gang-trucks when they being are transported to the dock storage area. Another task of the rail cranes is to unload the gang-trucks that arrive from the wharf-crane. The default priorities that are used to determine which of several waiting tasks should be done are given in Table 5.

Table 5. Priority of Rail Crane tasks (default)

Description of Task	Priority
Offloading of container from train	3
Loading of containers that are waiting at RIY onto train	4
Loading container that is due for the dock storage area onto a gang-truck	2
Offloading a container from gang-truck that came from a wharf-crane	1

This choice of priorities were chosen so that the gang-trucks are delayed as little as possible. This will result in minimum turnaround times for the ships. It might appear from table 6 that all trains at the RIY are offloaded before any containers are loaded onto a train but this is misleading, this is only true for a *given* train. In other words when more than one train needs attention from the railcranes, the train that arrived first is completely offloaded, then loaded before the cranes start offloading the next train.

When a container arrive by gang-truck at the RIY from the wharf-cranes, there are a number of different possible scenarios. If the train, that the container is due for, happen to be at the RIY when the gang-truck arrives and there is still space on the train, the container is offloaded and stored at the space next to the train. If the train is not there, the container can be stored by the side of any of the railroad tracks. The track is chosen where the most containers are stored that are due for the same train as the container that is being offloaded. This strategy ensures that containers that have the same destinations are clustered together.

The rail cranes can move to any track at the RIY and are not dedicated to a specific track. Whenever a container has to be moved, the closet idle rail crane will be used. The strategy of keeping same-destination containers together, minimizes the time being wasted by the cranes moving between tracks. This traveltime is calculated by taking the distance between the tracks and moving-speed of the cranes in account.

CHAPTER 5. CHANGING THE DEFAULT VALUES OF THE SIMULATION MODEL

Flexibility was a very important consideration throughout the development of the model. In this section the default values are given and instructions are presented on how to change them.

Maximum allowable trains in RIY and rail segment

The default value for the maximum number of trains that can be simultaneously be in the RIY and on the rail segment is 4. This value can be changed to any value less than of equal to the number of lanes in the RIY. Change the capacity of the **max_trains** resource in the resources element.

Number of cranes at the RIY

By default, there are 3 cranes at the RIY. This value can be changed by to any value between 1 and 8 by doing the following:

- Changing the capacity of the **dummy_crane_r** resource in the resources element.
- Changing the number of units of the **t_rail_crane** transporter in the transporter element.

If more than 8 cranes are required in addition to the above mentioned steps, extra **move_time_rc#** and **tot_time_rc#** tallies must be added in the tallies element. These tallies must also be added to the **ts_move_time_rc#** and **ts_tot_time_rc#** sets in the sets elements.

Number of cranes at the dock storage area

For each of the five storage areas, there are a number of storage cranes. By default there are 1 crane at each of these areas. This can be changed by making changes to the capacity of the **crane_store1** through **crane_store5** resources, in the resources element.

Number of wharf-cranes at each dock

Each dock has a number of wharf-cranes, the default value of 2 can be changed by making changes to the capacity of the **w_crane1** through **w_crane2** resources in the resources element.

Service times of the cranes at RIY

The default value for the service times of the rail cranes are exponential service times with a mean of 3 minutes. Editing the rc_time variable in the variables element can change this.

Service times of the cranes at the dock storage areas

The default value for the service times of the cranes at the dock storage yard are exponential service times with a mean of 3 minutes. Editing the sc_time variable in the variables element can change this.

Service times of the wharf-cranes

The default value for the service times of the wharf-cranes are exponential service times with a mean of 4 minutes. This can be changed by editing the **wc_time** variable in the variables element.

The number of gang-trucks (dray-vehicles) serving each dock

By default, each dock is serviced by 8 gang-trucks, resulting in a total of 40 trucks. The number of trucks can be varied for each dock by following these steps:

- Change the capacity of the **dummy#** resource in the resources element (# designates the dock number).
- Change the number of units in the corresponding **gang#_truck** transporter element.

Distances traveled by the gang-trucks

The default distances that the gang-trucks travel is given by the distance matrix in Table 6.

Table 6. Default distances in meters

From / to	Dock	Dock Storage Area	RIY
Dock	-	500	5000
Dock Storage Area	500	-	5000
RIY	5000	5000	-

The default values indicate that the distances from the RIY to the different docks are the same. This is not a constraint of the model since the distances between the RIY and the different docks and dock storage areas can be individually set. To alter the default values, change the values in the **gang_dis** distance element. The distances between the docks and RIY are the distances between the **store_yard#** and **rail_truck_int** stations. The distances between the docks and dock storage areas are the distance between the **s_dock#** and **store_yard#**. The distance between the **rail_truck_int** and **s_dock#** stations refer to the distance between the RIY and the docks.

The gang-trucks move at an average speed of 667 meters per minute (25 miles/h) and this can be changed in the **gang#_truck** transporter elements.

Distances traveled by the cranes at the RIY

The cranes at the RIY can move between the tracks. The time that such a move takes is equal to the speed that the crane moves divided by the distance between the tracks. The default distances between the tracks are provided in Table 7.

Table 7. Distances between tracks at RIY (meters)

From/To	Track 1	Track 2	Track 3	Track 4
Track 1	-	30	60	90
Track 2	30	-	30	60
Track 3	60	30	-	30
Track 4	90	60	30	-

These default values can be modified by changing the values between the *begin_ #* stations in the **rail_crane_dist** distances element. The default speed, at which the rail-cranes move of 30 meters per minute (1.1 mph), can be changed in **t_rail_crane** transporters element.

Number of tracks at the RIY

Changing the number of tracks at the RIY is a little more complicated than the changes encountered above. The number of lanes can be changed by from the default value of 4 by following these steps:

- Change the array sizes the following arrays in the variables element.
  1. **train_done**
  2. **c_due_stat**
  3. **track_stat**
  4. **space_on**
  5. **real_space**
  6. **num_on_train**
  7. **arrive_order**
- Change the value of the **tracks** variable in the variables element.
- Add a **track#_sto** and **on_train##** storage element for each new track and add them to the **sts_track_sto** and **sts_on_train** sets respectively.
- Add a **stop#** and **begin_#** station element for each new track and add them to the **ss_stop** and **ss_begin** sets respectively.
- Modify the **rail_crane_dist** distance element by adding the new **begin_#** to the distance element.
- Add a **que_on_train#** queue element for each new track and add them to the **sqs_on_train** set.
- Add a **nsto(track#_sto)** dstat element for each new track.
- Two changes must also be made in the *model* part of the program. Find the first *assign* block that is marked with red (hint – use the *find* feature under *edit* in Arena and enter the keyword **red_1**). The attribute **lane#** is assigned a random track number in this assign block by using the disc() function. The arguments of the disc() must be changed so that all the tracks have an equal likelihood of being used.

Find the second *assign* block that is marked with red (keyword **red_2**). The attribute **train_len** is assigned the value of:

aint(.5*mx(out_#, (c_due_stat(1,t_type)+c_due_stat(2,t_type)+c_due_stat(3,t_type)+c_due_stat(4,t_type))))

This expression ensures that the capacity of the train is enough to handle the incoming and outgoing containers waiting for that specific train. When new tracks are added to the RIY, this expression must be modified so that a **c_due_stat(#,t_type)** term is added for each new track (# designates the track number).

- Add new links and intersections to the **train_ntw** to account for the new tracks. The current layout of the **train_ntw** with the link- and intersections names is given in Figure 3.

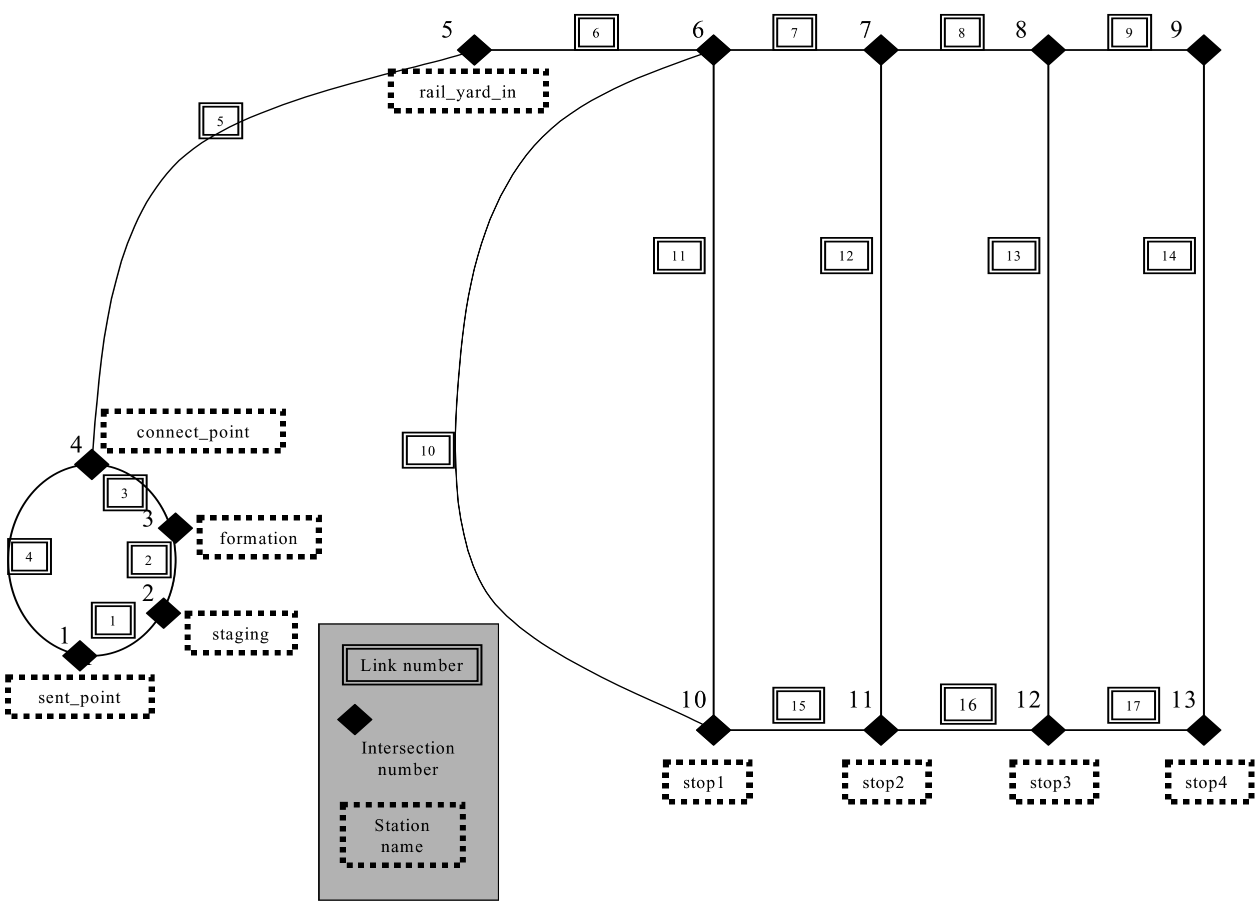

Figure 3. Layout of Train network (train_ntw)

Number of docks

By default, there are 5 docks, each with a separate dock storage area.

- The number of docks can be changed by adding an element for each new dock as figure 11 indicates. The # must be replaced by the dock number. The structure of the new elements must be identical to that of the existing members of the sets.

Table 8. Changes to stations, queues, resources, storages and transporter elements

Element	Type of element	Set
s_dock#	stations	sts_dock#
store_yard#	stations	sts_store_yard
stop#	stations	ss_stop
wait_st_crane#	queues	qs_wait_st_crane
wait_crane_w#	queues	qs_wait_crane_w
wait_dock#	queues	qs_wait_dock
wait_gang#	queues	qs_wait_gang
due_ship#	queues	qs_due_ship
dummy#	resources	rs_dummy
w_crane#	resources	rs_w_crane
dock#	resources	rs_dock#
crane_store#	resources	rs_crane_store
at_store#	storages	sts_at_store
gang#_truck	transporters	**no set

- The size of the following array must be changed to the number of docks in the variables element: **ship_done**, **ship_arrive**, **dock_stat**, **s_alloc_out**, **space_out** and **m_tot_imp**.
- Edit the **gang_dis** distance element by adding the distances between the new **s_dock#** and **store_yard#** stations as well as the distances between the **s_dock#** and **rail_truck_int** stations.
- Nine changes must also be made to the model section of the program. The positions where the program must be altered are marked by the keywords *green_1* through *green_9*, they are also marked with green borders around the blocks (hint – use the find feature of Arena to locate them). Each one of these changes follows a *branch* block in the model. A new branch must be added for each new dock. The structure of these branches are identical to the existing branches, just alter the dock numbers.

CHAPTER 6. EXAMPLES OF USING THE SIMULATION MODEL

In this section three different examples are presented to illustrate the general usage of the model. In the first example it is demonstrated how the model can be used to estimate the long run, steady state performance of the port. In the second example it is shown how the model can be used to forecast the performance of the port associated with a specific ship schedule. The statistics are only collected for containers that pertain to ships on the schedule and this can help to determine whether the port have the capacity to deal satisfactory with the ship schedule. In the third example it is suggested how to determine the sensitivity of the performance to some resource. This can aid in predicting the benefits of adding resources and can help to justify capital expenses. Specifically, in the third example the influence of varying the number of cranes at the RIY is investigated.

Example 1

In the first example it is demonstrated how the simulation model can be used the estimate the behavior of the port in the long run. The default values, as described in the previous section, were used and the results of a single replication of 60 000 minutes of operation is displayed in Table 9. A warm-up period of 5000 minutes was used to get the system in steady state before any statistics were collected. No ship schedule was used and all ships that arrived at the port were therefor randomly generated.

A number of important statistics are computed and displayed in Table 10. For example, the **rail_to_ship** statistic is an estimate of the average time that the containers that entered the port facility on a train and left by train, spent at the port facility. This statistic is calculated by measuring the time since the train on which the containers came stopped at the RIY until the ship on which the container leave, departs from the port. Table 10 reveals that 12105 containers entered the port by train and left by ship. The average of the total time that these containers spent at the port is 2908.1 minutes with minimum of 255.29 minutes and a maximum of 11986 minutes. The half width of the 95% confidence interval is 319.77 but it is unlikely that this value is correct since the observations are most likely correlated. This data can be analyzed using Arena's output analyzer to determine a more accurate confidence interval. The meaning of other important statistics that were collected during the simulation run are displayed in Table 10 and explained in Table 9.

Table 9. Statistics and their meanings

Name	Meaning
ship_to_rail	Total time spent at port by containers that came by ship and left by train. Measured from time that ship arrived at port until train left the RIY.
train_sojurn_time	Total time spent by trains at the port. Measured from the time the train arrived at the RIY until it departed.
ship_sojurn_port	Total time spent by all ships at the port. Measured from the time the ship arrived at the port until it departed.
ship_schl_sojurn_port	Total time spent by ships on the schedule at the port. Measured from the time the ship on the schedule arrived at the port until it departed.
tot_time_rc#	Total time *per container move* that rail-crane number # took to load/unload a container.
move_time_rc#	Total time *per container move* that rail-crane number # spent by moving between tracks at the RIY to load/unload containers.
gang#_truck Busy	Average number of trucks of gang number # that is busy. This reflects trucks that move containers and those that wait in queues for the cranes.
gang2_truck Active	Average number of trucks of gang number # that can be used. This is the maximum trucks in gang # that can be used
contnrs stored track#	Average number of containers that were stored at track number #.
cont_out_with_ship	Total number of containers that left the port by ship.
cont_out_with_rail	Total number of containers that left the port by train
ship_count	Total number of ships that visited the port.
ship_schl_count	Total number of ships on the schedule that visited the port.
train_count	Total number of trains that visited the RIY.

ARENA Simulation Results - Example 1
Paul Koster - License #9610124
Summary for Replication 1 of 1

Project: Run execution date : 4/ 6/1998
Analyst: Model revision date: 4/ 6/1998

Replication ended at time: 60000.0
Statistics were cleared at time: 5000.0
Statistics accumulated for time: 55000.0

Table 10. Output of Simulation model – example 1

TALLY VARIABLES					
Identifier	**Average**	**Half Width**	**Minimum**	**Maximum**	**Observations**
move_time_rc4	--	--	--	--	0
move_time_rc5	--	--	--	--	0
move_time_rc6	--	--	--	--	0
rail_to_ship	2908.1	319.77	255.29	11986.	12105
tot_time_rc1	4.4947	.23353	.00108	35.963	10577
move_time_rc7	--	--	--	--	0
tot_time_rc2	4.5156	.17437	4.9286E-04	31.610	10473
move_time_rc8	--	--	--	--	0
tot_time_rc3	4.4875	.17937	7.1871E-04	37.366	10484
tot_time_rc4	--	--	--	--	0
tot_time_rc5	--	--	--	--	0
ship_schl_sojurn_port	--	--	--	--	0
tot_time_rc6	--	--	--	--	0
tot_time_rc7	--	--	--	--	0
train_sojurn_time	719.24	(Insuf)	63.693	1719.8	173
tot_time_rc8	--	--	--	--	0
ship_sojurn_port	347.97	(Insuf)	100.33	976.60	293
ship_to_rail	955.47	(Corr)	8.9341	3132.0	8890
move_time_rc1	.48312	(Corr)	.00000	3.0000	10577
move_time_rc2	.49709	.06124	.00000	3.0000	10473

Identifier	Average	Half Width	Minimum	Maximum	Observations
move_time_rc3	.49647	.06879	.00000	3.0000	10484
DISCRETE - CHANGE VARIABLE					
Identifier	**Average**	**Half Width**	**Minimum**	**Maximum**	**Final Value**
gang2_truck Active	8.0000	(Insuf)	8.0000	8.0000	8.0000
gang5_truck Active	8.0000	(Insuf)	8.0000	8.0000	8.0000
gang1_truck Busy	3.4584	.50627	.00000	8.0000	8.0000
gang4_truck Busy	3.1001	(Corr)	.00000	8.0000	1.0000
gang3_truck Active	8.0000	(Insuf)	8.0000	8.0000	8.0000
contnrs stored track4	73.635	(Corr)	.00000	327.00	.00000
contnrs stored track3	35.302	12.569	.00000	219.00	22.000
gang2_truck Busy	3.3877	.47320	.00000	8.0000	6.0000
contnrs stored track2	29.869	17.650	.00000	267.00	92.000
contnrs stored track1	16.913	9.3805	.00000	199.00	.00000
gang5_truck Busy	3.4104	.48131	.00000	8.0000	6.0000
gang1_truck Active	8.0000	(Insuf)	8.0000	8.0000	8.0000
gang4_truck Active	8.0000	(Insuf)	8.0000	8.0000	8.0000
gang3_truck Busy	3.5843	.43985	.00000	8.0000	5.0000

COUNTERS		
Identifier	**Count**	**Limit**
cont_out_with_ship	13903	Infinite
ship_count	293	Infinite
cont_out_with_rail	8890	Infinite
ship_schl_count	0	Infinite
train_count	172	Infinite

Simulation run time: 8.60 minutes.
Simulation run complete.

Example 2

In the next example it is illustrated how to use the model to estimate the performance of the port for a specific ship schedule. The statistics are collected only for the time period starting with the arrival of the first ship and ending with the departure of the last ship. Table 11 shows the ship schedule was used for the simulation run.

Table 11. Ship Schedule for example 2

	A	B	C	D	E	F	G	H
1	7	numlines						
2	ship#	arrive_time	in_rail#	in_store#	out_#	bridge	train_time	take_ship#
3	1	5000	30	10	60	1	4500	1
4	2	5500	15	20	40	1	4600	1
5	5	6000	10	25	30	0	0	0
6	6	6100	45	50	100	0	0	0
7	8	5700	30	0	50	0	0	0
8	1	8000	20	10	100	0	0	0
9	3	7500	30	5	100	0	0	0

The length of this simulation run was controlled by placing a limit on the **ship_schl_count** counters element. This limit was equal to the number of ships on the schedule, namely 7, and causes the simulation run to stop when the last ship on the schedule departs. The warm up period was specified as the time when the first ship on the schedule arrives by entering 5000 in the ***replicate*** element. In essence, this strategy gets the port in steady state and then statistics are collected only for the time period starting with the arrival of the first ship on the schedule and ending with the departure of the last ship. The result of this simulation run is displayed in Table 12.

ARENA Simulation Results
Paul Koster - License #9610124
Summary for Replication 1 of 1

Project: Run execution date : 4/22/1998
Analyst: Model revision date: 4/22/1998

Replication ended at time : 8410.69
Statistics were cleared at time: 5000.0
Statistics accumulated for time: 3410.69

Table 12. Statistics for the Schedule Example

TALLY VARIABLES					
Identifier	**Average**	**Half Width**	**Minimum**	**Maximum**	**Observations**
move_time_rc4	--	--	--	--	0
move_time_rc5	--	--	--	--	0
move_time_rc6	--	--	--	--	0
rail_to_ship	2035.2	(Corr)	532.84	5072.3	407
tot_time_rc1	3.6511	(Corr)	.00354	20.903	650
move_time_rc7	--	--	--	--	0
tot_time_rc2	23.9241	.50338	.00801	21.892	599
move_time_rc8	--	--	--	--	0
tot_time_rc3	4.0248	(Corr)	.00710	25.505	581
tot_time_rc4	--	--	--	--	0
tot_time_rc5	--	--	--	--	0
ship_schl_sojurn_port	312.37	(Insuf)	166.44	482.62	7
tot_time_rc6	--	--	--	--	0
tot_time_rc7	--	--	--	--	0
train_sojurn_time	380.11	(Insuf)	90.640	825.92	16
tot_time_rc8	--	--	--	--	0
ship_sojurn_port	321.91	(Insuf)	166.44	482.62	9
ship_to_rail	864.78	(Corr)	46.994	1747.0	400
move_time_rc1	.24769	(Corr)	.00000	3.0000	650
move_time_rc2	.24000	(Corr)	.00000	3.0000	600
move_time_rc3	.23621	(Corr)	.00000	3.0000	580
DISCRETE - CHANGE VARIABLE					
Identifier	**Average**	**Half Width**	**Minimum**	**Maximum**	**Final Value**
gang2_truck Active	8.0000	(Insuf)	8.0000	8.0000	8.0000
gang5_truck Active	8.0000	(Insuf)	8.0000	8.0000	8.0000
gang1_truck Busy	4.3529	(Corr)	.00000	8.0000	8.0000
gang4_truck Busy	1.3454	.58209	.00000	8.0000	.00000

Identifier	Average	Half Width	Minimum	Maximum	Observations
gang3_truck Active	8.0000	(Insuf)	8.0000	8.0000	8.0000
contnrs stored track4	17.981	(Corr)	.00000	55.000	30.000
contnrs stored track3	32.077	(Corr)	.00000	213.00	.00000
gang2_truck Busy	2.5615	(Corr)	.00000	8.0000	.00000
contnrs stored track2	12.758	(Corr)	.00000	88.000	.00000
contnrs stored track1	13.656	(Corr)	.00000	67.000	15.000
gang5_truck Busy	2.6154	(Corr)	.00000	8.0000	.00000
gang1_truck Active	8.0000	(Insuf)	8.0000	8.0000	8.0000
gang4_truck Active	8.0000	(Insuf)	8.0000	8.0000	8.0000
gang3_truck Busy	2.8319	(Corr)	.00000	8.0000	.00000

COUNTERS

Identifier	Count	Limit
cont_out_with_ship	470	Infinite
ship_count	9	Infinite
cont_out_with_rail	400	Infinite
ship_schl_count	7	7
train_count	15	Infinite

Simulation run time: 1.13 minutes.
Simulation run complete.

The statistics reveal that the 7 ships on the schedule spent an average time of 312.37 minutes at the port and that a total of 407 containers were taken from the RIY to the ships. These containers spent on average 2035.2 minutes at the port (time elapsed since train arrived until ship departs).

The statistics also reveal that 400 containers arrived at the train-dispatching center during the time period starting with the arrival of the first ship on the schedule and ending with the departure of the last ship. These containers entered the port by ship and left by train and the average time that they spent at the port was 864.78 minutes.

The **ship_to_rail** statistics are only computed for containers that arrived at the train-dispatching center during the simulation run. The **train_count** counter counts the trains that made it all the way to the train-dispatching center while the **train_sojurn_time** tallies are updated as soon as the train departs from the RIY. The statistics reveals that 16 trains left the RIY but that only 15 made it to the train-dispatching center by the time the simulation run ended. When the average number of containers per train is computed, it is important to use the correct value. During this run, a total of 400 containers were transported on 15 trains from the port to the dispatching center, therefor the average load per train was 26.7 containers. The **train_sojurn_time** tally reveals that the 16 trains that departed from the RIY spent an average of 380.11 minutes at the RIY.

Example 3

The third example serves to illustrate how the model can be used to determine the sensitivity of the port's performance to some parameter. In this example the number of cranes at the RIY was varied and the effect on the port's performance was determined. Eight different simulation runs were made and the number of cranes was varied from 1 to 8. This example serves only to illustrate the use of the simulation program and no conclusions must be made from the output since only one sample run was taken of each scenario. This example serves only to illustrate the general methodology and no interpretations can be made. Random arrivals of ships were used with run lengths of 15000 but statistics were only recorded for the last 10000 minutes to account for the transient behavior.

Figure 4 illustrates the effect of the number of cranes on the throughput of containers from the RIY to the ships.

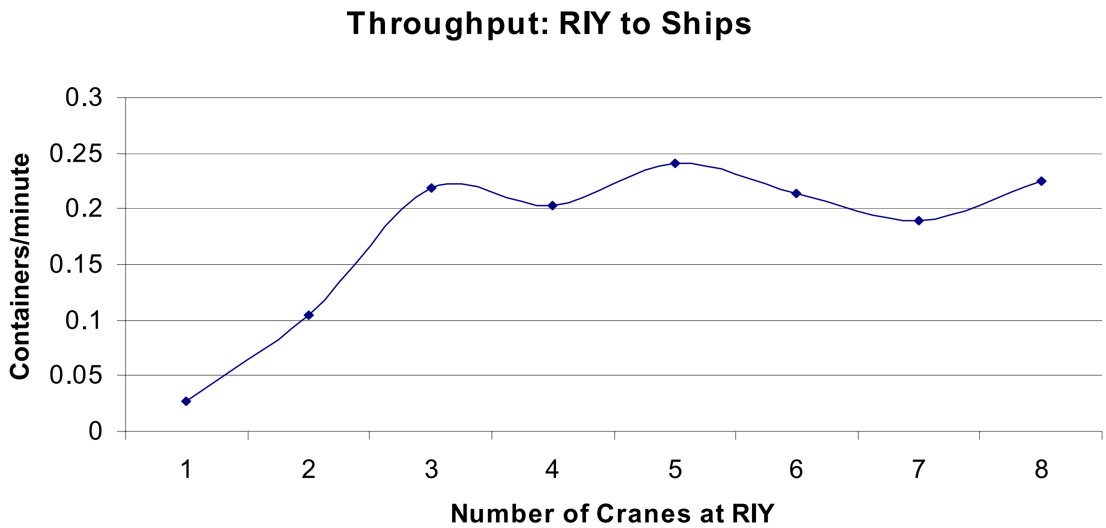

Figure 4. Sensitivity of throughput of containers from RIY to Ships

Figure 5 illustrates how the throughput of containers from the ships to the train dispatching area varies when the number of cranes at the RIY is changed.

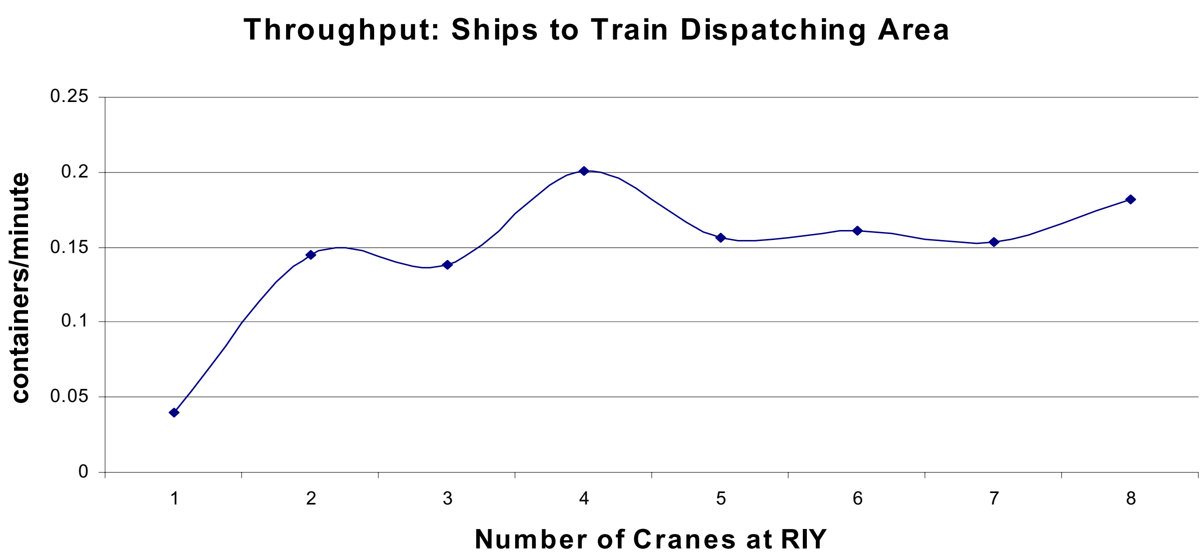

Figure 5. Sensitivity of throughput of containers from Ships to Train Dispatching Area

In Figure 6 the average times that the ships spent at the port is plotted as a function of the number of cranes at the RIY. This is a clear example of the danger of looking at one performance parameter in isolation. If one looks at Figure 6 in isolation it might be possible to conclude that more cranes lead to longer sojourn times. This is due to the fact that ships never wait for containers and therefor spent less time waiting for containers to be loaded onto the ships when there is fewer containers waiting at the dock. The fact that the throughput of containers from the RIY to the ships increases with more cranes confirms this. More cranes at the RIY causes more containers waiting at the docks for ships and hence the longer sojourn times.

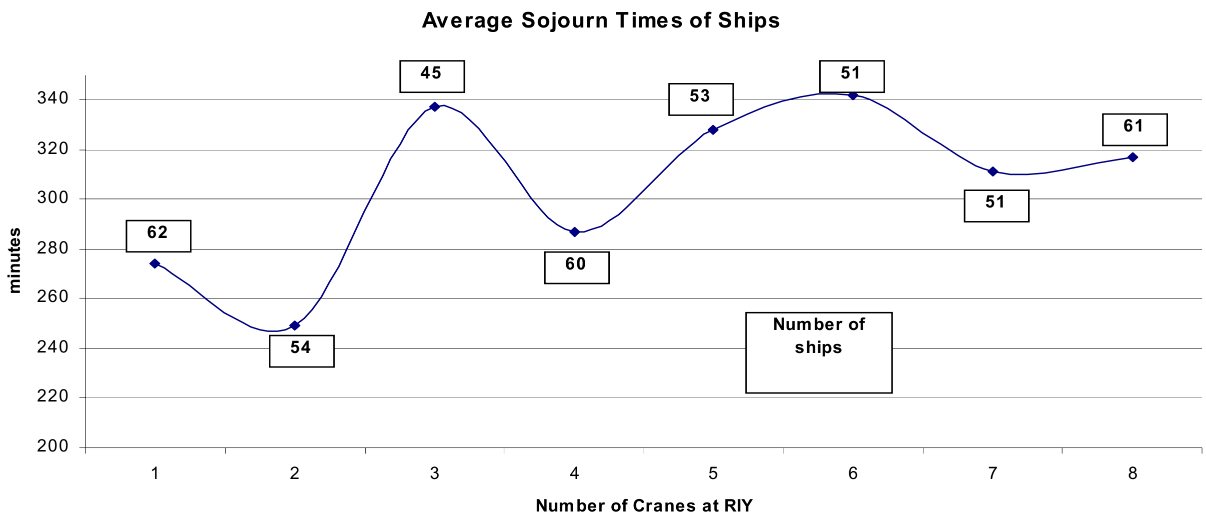

Figure 6. Sojourn times of ships at the port

The next step was to determine the effect that the number of cranes at the RIY have on the times spent by the trains at the RIY. The results are plotted in Figure 7. As mentioned earlier, no interpretation should be made using this data since only one sample run was used to generate each case. Usually, multiple simulation runs would be made and the data would be analyzed using the output analyzer to get better estimates of each performance measure. These reliable estimates would then be plotted like Figures 4, 5, 6 and 7 before any conclusions should be made.

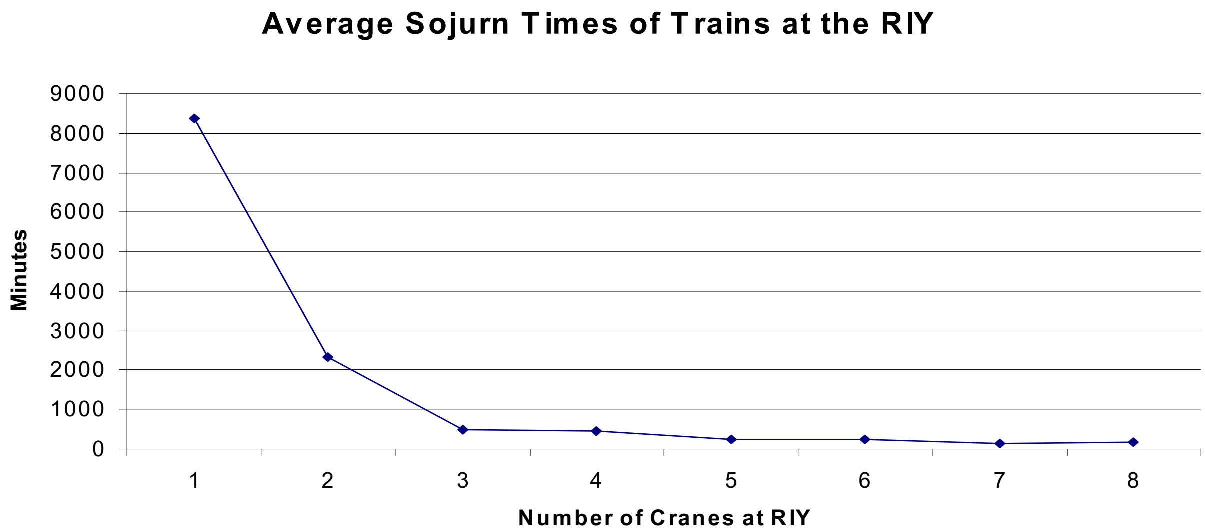

Figure 7. Average Sojourn times of trains vs. number of cranes

The danger exists to look at one performance measure in isolation and making erroneous conclusions. Assume for the moment that multiple simulation runs has been made and that reliable estimates were used to generate Figures 4 through 7. It is clear that it is not such a easy task to conclude how many cranes should be used. Figure 4 seems to indicate that 3 cranes seems to be sufficient whereas, Figures 5 and 6 might suggest 4 is better. A helpful method might be to look at a graph where all four performance parameters are used simultaneously. One way of taking all four performance measures in account is to plot the value of

$$\frac{(throughput\_RIY\_to\_ships)\bullet(throughput\_ships\_to\_RIY)}{(sojourn\_ships)\bullet(sojourn\_trains)}$$

versus the number of cranes at the RIY. The result is plotted in Figure 8 and this graph seems to suggest that more cranes at the RIY result in better performance. However, the analysis has ignored the cost of the cranes until now, the next step would be to do a cost benefit trade off.

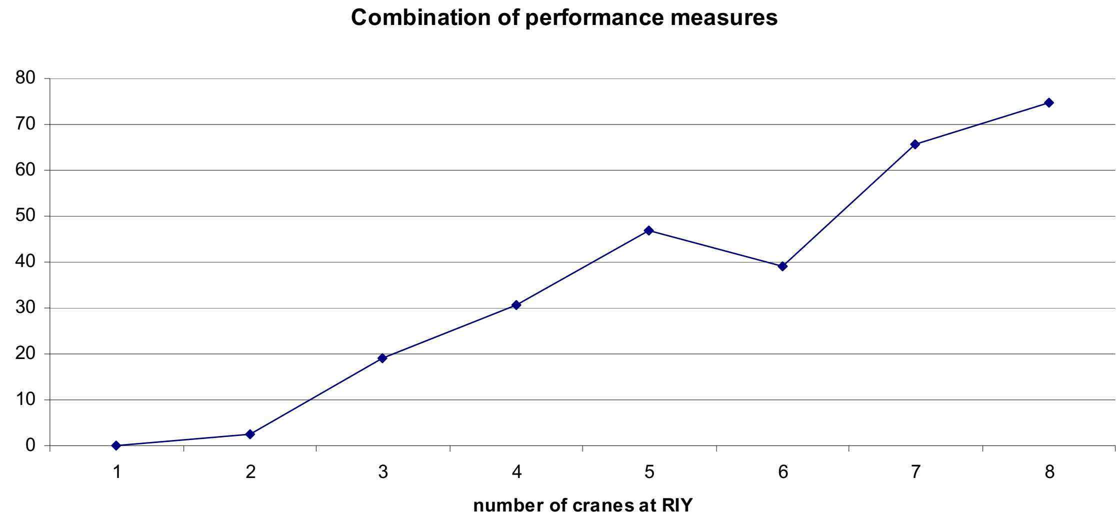

Figure 8. Looking at four performance measures simultaneously

CHAPTER 7. CONCLUSION

A general simulation model was developed and presented that can be used to model the interaction between ships, trains and trucks at port facilities. The goal was to make the model as flexible as possible so that the model can be easily customized for most port setups. Although the model was developed by taking the setup of the Barbours Cut Container Terminal with its proposed rail intermodal yard with four tracks in account, instructions have been provided on how to adapt the model to situations where the number of docks and tracks at the RIY differs from BCCT. Additionally, instructions have been provided on how to change the model so that any allocation of port resources such as cranes and dray-vehicles can be modeled.

Three different examples have been provided. In the first example it was demonstrated how the model could be used to predict the performance of a given port setup. This can be a powerful tool during the design phase of a new port facility.

The second example it was shown how the model can be used to determine whether the port has the capacity to handle a specific ship schedule. This might aid the port facilities in the day to day planning of the operations such as determining the best allocation of ships to docks, allocation of dray-vehicles to docks and the number of cranes.

The third example served to illustrate how the model can be used to determine the influence of changing the number of cranes at the RIY on the overall performance of the port. This example shows how the model can be used in cost trade-off analysis when new capital investments are contemplated. The same analysis can be done for different port resources and this will identify which resource expansion would result in the most “bang for the buck.”

A considerate amount of time has been spent to verify that the model function as intended. The next step would be the validation process. This would require data gathering at an existing port to feed the model with the correct distributions and comparing the output with reality. Obviously in the

BCCT case this would be difficult since the RIY exists only on paper. However, some validation can be done since the animation features can help to validate the model.