A Simulation Model for Analysing Terminal Management Operations

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Abstract

Globally, container terminals are trying to expand capacity and increase performance at a minimum of investments. Often the container terminal operations are changing to meet increased customer demands as well as to adapt to new technologies. This paper proposes a simulation model for container terminal system analysis. A simulation model is developed, called SIMPORT, which uses a Multi-Agents Systems approach that provides a modular and scalable method of modeling the entities in the container terminal domain. SIMPORT is used to test various berth assignment management polices and yard stacking management policies in the context of a case study of a major container terminal in India. The results indicate that by arranging the stacks according the 'ship profile', the port in India was able to reduce the waiting time of container ships and thus save costs. The increasing costs of container terminal development do justify the use of computer simulation to assist in planning and policy making.

1. Introduction

Congestion and increasing cargo dwell times is a common scene in many of the world's ports. Over 255 million TEU (twenty-foot equivalent unit steel container) was handled in 2003 by container terminals (CTs) world wide representing an increase of more than 30 million TEU from the year before *Cass (2004).* The current CT capacity in many parts of the world is not able to handle the growing volumes (cf. *Henesey 2004).* The hypothesis studied in this work is that by modeling the decisions through simulation an increase in a CT´s performance can be realized without having to acquire expensive property or equipment. Often the construction or building of a new CT is not possible and expansion is limited, placing emphasis on operating a terminal as efficiently as possible. CT managers attempt to devise new scenarios to reduce costs and provide more services with the resources that they have. In many cases, it is not known in advance whether a particular strategy can produce increased terminal throughput.

The proposed CT simulator, SIMPORT (SIMulated container PORT), is developed to be used as a tool for CT managers to test various management polices for increasing performance while considering costs, yard and berth configurations (please see Appendix A for costs for purchasing types of CT equipment). The SIMPORT system is unique in that it adopts a Multi-Agent Systems (MAS) approach in which the decision makers and entities are modeled as a system of computational agents able to "reason" and communicate with each other in reaching goals. This technique provides a realistic handling of the containers in the simulation in that several agents are communicating and taking decisions based on policies. A policy is expressed on how a ship is to be handled during operations. The agents handle the communication between each other as in a real world CT system, e.g. the ship reports to the stevedore, the stevedore asks the terminal manager.

SIMPORT is developed as a part of a Decision Support System (DSS) in order to assist CT managers in the yard layout, container stacking polices and the assignment of container ships to be berthed using simulation. The SIMPORT consists of a simulated representation of physical entities in a CT (cranes, berths, quays, transport equipment, containers, and ships). A management system that represents the decision making entities of a CT by issuing and sending documents (i.e. ship schedule, resource schedule, waiting time, crane schedule, etc.) Together, the two parts of SIMPORT assists in analyzing berth schedules for arriving ships under various yard and container stacking polices. The objective of SIMPORT is to find policies that efficiently use the resources available during the operating time when a container ship is being handled at a berth. The policies used in the simulation are able to be compared in monetary terms for both the ship and terminal.

The use of simulation tools such as SIMPORT can assist in evaluating policies involved in the berth assignment problem, such as considering the impact of yard configurations and in developing new interesting management policies. As mentioned by *Ojala (1992)*, simulation used as a part of a Decision Support Systems (DSS) can be beneficial to port organizations. According to *Leathrum and Karlberg (2000)*, the primary purpose for the use of simulation is to determine the necessary resources in order to complete the processes (e.g., loading and unloading a container ship) within certain constraints. Though much research has concentrated on optimizing the resources at the operational level, this paper seeks to examine strategic planning and tactical decisions that are made by the CT managers. As observed through port visits and interviews, decisions are often made from set plans, established layouts or procedures and policies. The simulation of berth assignment and stacking policies with SIMPORT is not expected to provide optimal solutions for resource scheduling; its goal is to provide a means of analyzing and evaluating terminal management policies. However, it can conceptually be used as part of an automatic optimization procedure. The balancing of transferring containers with the efficiency in stacking containers in the yard could be improved leading to cost savings and higher CT performance.

In the next section the background is described in more detail. This is followed by the presentation of the simulation model and experiments performed with SIMPORT. Finally, conclusions and pointers to future work are provided.

2. Background on Container Terminal Management

CT management is characterized as complex in that performance is determined by a variety of inputs, outputs, actors, intrinsic characteristics and external influences *Persyn (1998)*. The vessel operators are interested in minimizing "ship turn-around time", i.e. the loading and discharging of containers should be done as quickly as possible. In addition, the CT operators are trying to provide a fast ship turn-around time service while attempting to minimize their costs. According to *Villalon (1998)*, a typical container ship of 4,000 to 5,000 TEU incurs a daily operating cost in excess of $40,000, and the cost of containers to fill it are in the $10-to-15 million range, not including the supporting CT equipment and infrastructure, including multi-million-dollar gantry cranes. An average container ship spends 60% of its time in port *Kia (2000).*

According to *Nishimura et al. (2001)*, the berth allocation plays a primary role in minimizing the ship turn-around time, the time that a container ship is worked depends on where the ship is berthed. Ship turn-around time is one of the main performance measures used in port operations. To shorten the ship turn-around time, in this paper, the potential of CT managers of increasing production capacity by better management decisions, which often have non-optimal objectives, is investigated. The storage system or yard operations of the CT is viewed by many managers as what "steers" the overall CT performance *Miller (2002)*. The stacking density of the containers and the equipment employed can influence the capacity of the yard immensely. The yard operations are heavily interdependent upon the other operations in order to maintain good container handling performance. Different berthing points may influence the handling time and distances being traveled by the transporters in order to "work" a container ship. The problem of assigning transporters to retrieve or send a container to a stack location is complex in that specific containers must be placed in specific locations while not making unnecessary moves or aversely affecting the gantry crane. A properly laid-out terminal can benefit the performance of a CT by segregating containers according to various characteristics; such as by port of discharge, commodity, ship line, size and type.

The main problem with developing tools for CT management is to model the complexities that exist in the tasks of planning, scheduling, and controlling. Existing methods that are used in planning and analyzing CTs such as queuing theory, linear programming and traditional simulation have had mixed success *Bruzzone (1999)* and *Ferber (1999)*. The use of agent technology has been suggested to be a viable approach for decision making in CTs when managing uncertainty or evaluating decisions are complex (c.f. a survey paper by *Davidsson et al., 2004)*. Papers that have investigated solutions using agent technology such as *Buchheit et al. (1992); Gambardella et al. (1998); Rebollo et al. (2000); Carrascosa et al. (2001); Rebollo et al. (2001); Degano and Pellegrino (2002); Lee et al. (2002)* and *Thurston and Hu (2002)* have mostly focused on techniques for automating or controlling the CT. In this paper the view taken is to assist human CT managers by assisting the decision making process in a CT as part of a DSS. The decision making is seen from a strategic to a tactical level.

3. SIMPORT Model Architecture and Policies

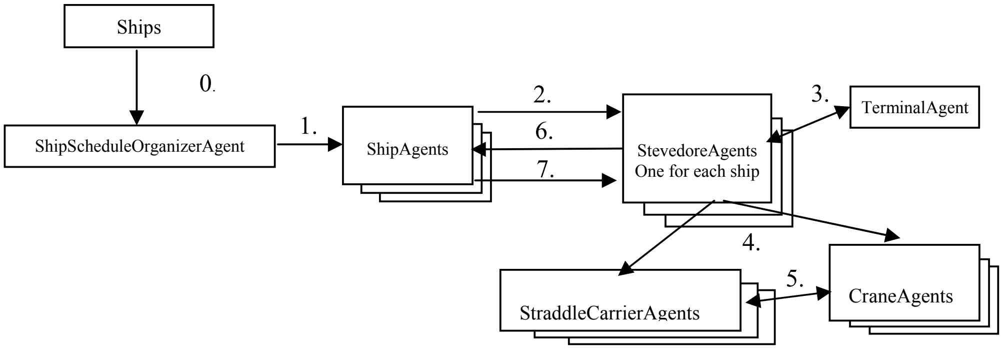
The SIMPORT model is a much extended and improved version from a prototype called BAMS (Berth Allocation Management System) *Henesey et al. (2004)*. SIMPORT models the yard and stack configurations in more detail and allows for testing additional policies. The SIMPORT consists of two parts, a CT system that models the physical entities in the CT and a management system that models the actual managers. The motivation for developing a CT simulator platform from which to run experiments is due to the limited access to port and terminal simulators that have been built by industry and academic researchers.

SIMPORT was developed using MS Visual Studio 6.0 using the C++ programming language for Windows and is aimed for further research, e.g. the implementation of a market-based approach (see *Henesey, 2003)*. To store the data, the Microsoft Access database was used in which the database is connected via ODBC. The number of input variables used for the configuration of the simulated CT is over 50. The most important input variables include: quay length; berth spacing; yard capacity; speed and size of the gantry cranes and straddle carriers (SC), a type of machinery for carrying and stacking containers; and yard stack positions and types. The managers that correspond to agents in the software program are the following: *ship schedule organizer agent; stevedore agent; ship agent, straddle carrier agent, crane agent* and *terminal agent*. Table I describes the roles and goals for the agent types that are used in the SIMPORT. The agents make their decisions based on the information in the messages they receive from each other. The intelligence level of the agents can be considered reactive in that a specific action in the CT is executed upon a certain message. The reactive agent's goals are only implicitly represented by the rules, and the desired behavior is difficult to ensure.

Table I: SIMPORT agent types, their roles and goals in the simulation

Actors/Agents	**Roles**	**Goals**
ship schedule organizer agent	Constantly searching for arriving ships to place and schedule them at the CT.	Seeks to schedule ships according to policies.
stevedore agent	Communicates between ship and terminal manager.	Service ship agent requests with minimal costs.
ship agent	Communicates its demands to ship stevedore agent.	Ensure that ship is turn-around as fast as possible. Seeks to minimize the cost of being berthed at a CT.
straddle carrier agent	Moves containers from quay to stack and from stack to the quay by communicating with stevedore agent and with crane agents.	Move containers to locations as fast as possible and ensure that crane is idle.
crane agent	Loads/unloads containers from ships and communicates with stevedore agent and straddle carrier agents.	Lift containers as fast as possible and ‘feed’ straddle carrier with containers
terminal agent	Assigns cranes and acts as an overall manager.	Terminal resources are used efficiently when serving ships. Tries to make profit from handling ships.

To make the system as scalable and reusable as possible SIMPORT is divided into several *sub-systems* (c.f. *Henesey et al, 2004)*. Each sub-system has its own responsibilities and includes several smaller classes and systems. To make the system as reusable and easy to upgrade/add features, several user interfaces are implemented in the system. This has provided much assistance in adding/modifying parts of the system without disturbing the other parts. A description of SIMPORT is provided in Figure 1, illustrating the communication and coordination between the agents.



0.	A Ship arrives
1.	The ShipScheduleOrganizerAgent spawns a new ShipAgent
2.	The ShipAgent contacts its StevedoreAgent and sends time of arrival and request for resources
3.	The StevedoreAgent forwards the ShipAgent requests to the TerminalAgent, which answers back with information (e.g. allocates available resources, considers costs associated for serving a ship, etc.)
4.	The StevedoreAgent calculates if the number of resources is sufficient for satisfying the request from the ShipAgent. StevedoreAgent communicates with CraneAgents and StraddleCarrierAgent assigned by the TerminalAgent to move containers.
5.	The CraneAgents and the StraddleCarrierAgents communicate their status with each other during the operations on the ship, e.g. container being moved, available, busy.
6.	When all "operations" on a Ship are completed, the StevedoreAgent sends message to the ShipAgent
7.	ShipAgents send a reply that terminates the simulation run. (The Simulation system which contains the "runs" of the simulation, calculates the results. The "running environment" uses this collected data and prompts the end user if the results should be saved to the database or exported to an excel worksheet).

Fig.1: SIMPORT Model Architecture and Process Description

In the model, a SC agent is provided with a complete route as soon as it knows its next destination. A SC determines its next destination through communication with the crane agent in order to establish a routing. The SC moves to that position and subsequently establishes its next position by communicating back to management agents that it has reached its assigned destination and is waiting for another task.

A SC moves through a container yard to perform a series of tasks. A task may be defined as a SC stopping at a container handling activity such as a storage location or at a quay crane. A task is comprised of one or more container processing transactions. Once a SC has completed a transaction, its current status within its task is updated, and the next destination for the SC is discerned through the model rules. The task provides essential information for moving a SC to various positions in the CT. Its function is to provide specific yard destinations rather than the container processing sequence. The SIMPORT model contains rules which determine an appropriate yard location based on current yard conditions, CT management policies and attributes of the SC. In Fig.2, a diagram of a CT, which was used in the experiments, illustrates the algorithms in berth assignment of ships. In addition, the yard layout of container stacks and the configuration of containers in the stacks are presented in the diagram. Because the CT yard is arranged into a series of rows and stacks of containers, it is possible to move in different streets to reach a particular stack. However in the simulation the terminal is adopting a recognized rule that is widely used in CTs the SCs always travel along one-way streets in order to avoid accidents.

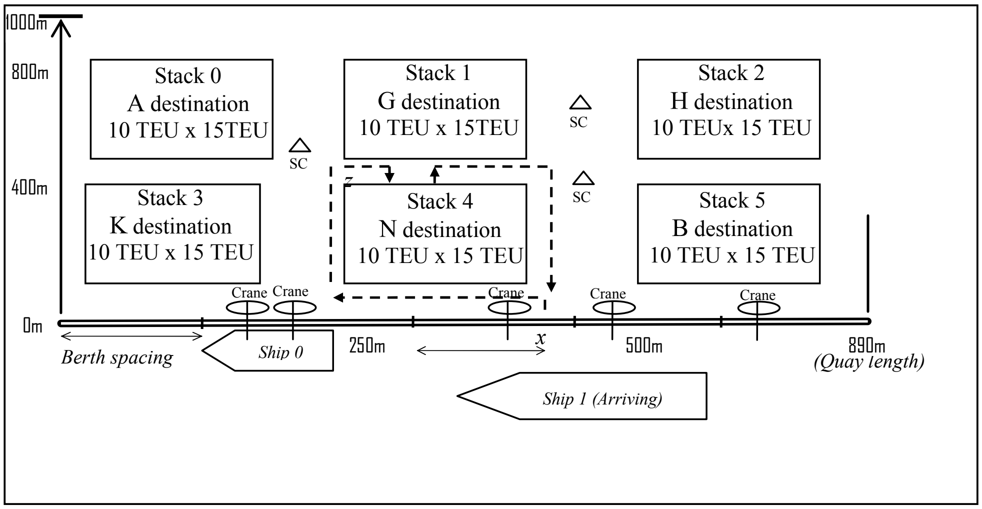


Fig.2: Illustration of Berth Assignment and Layout of Yard Stacks in SIMPORT

3.1 Policies

The SIMPORT model is designed to be utilized by the terminal managers of a major CT in order to evaluate proposed policies for yard layouts, sequence of ships, berthing assignments and container handling strategies. To compare proposed alternatives for a given terminal, three primary measures of performance are defined:

- Ship turn-around time needed to complete a stevedoring operation for a container vessel. This offers an indicator of berth productivity and ship turn around-time in relation to the overall yard configuration.
- Cost for the time that resources are assigned to work a ship.
- Distances traveled for each of the SCs used to serve a crane assigned to a ship are saved.

In the experiments presented here, there are two types of polices usually made by CT managers: for berth assignment and for sequencing of ships to be worked. The berth allocation policies that are evaluated are Berth Closest to the Stack Policy (BCSP) and the Shortest ship Turn-around Time Policy (STTP). The BCSP places a ship closest to a 'target' stack. The target stack is the stack that will be the most visited by the SCs during the operations, i.e. the one that have the largest sum of (i) containers to be stored and (ii) containers to be fetched. The BCSP will wait until a berth that is closest to the stack is available. The STTP objective is to place ships to berth positions in order to minimize the total ship turn-around-time for each arriving ship.

The two sequence polices that are tested are the First In First Out (FIFO) and the Highest Earning First (HEF). The sequence polices decide the order in which a ship will be served at the CT. The FIFO assigns a container ship first to be served depending on its arrival time. The HEF assigns a ship a berth and resources according to the number of containers to be handled. The more containers worked, the higher the earnings are for the terminal in serving the ship. The HEF is determined from a list of ships in a ship schedule that are expected to arrive during a twenty-four hour period.

In determining the berth point for an arriving ship the STTP calculates the *Waiting Time* during the simulation from a potential set of berth points. The number of possible berth points depends on the berth spacing as well as a ship's length plus a buffer distance. The ship *Waiting Time* may include time left in serving another ship that is occupying a part of the quay. The computation of the *Service Time* is based on the number of SCs employed, the routes covered by SCs and their average speed. A route is calculated from the Berth Point along the quay, x to the far left position of a stack, z (see Fig.2.). The routes are measured in meters. The sums of all the routes traveled by each SC are totaled to provide the distance being covered by the SCs for each ship. From the sum of the *Service Time* and *Waiting Time*, the STTP will place a ship wherever the shortest ship turn-around-time is achieved. The STTP can be characterized as considering the time dimension, where as BCSP is considering the space dimension when determining to place the ship.

3.2 SIMPORT Model Validation

The SIMPORT was validated by comparing the output of the model with actual field collected measurements from a real CT in India. Model validation as defined by *Schlesinger et al. (1979)* to mean "substantiation that a computerized model within its domain of applicability possess a satisfactory range of accuracy consistent with the intended application of the model", this definition is considered in developing and using SIMPORT. The existing configurations of the CT under study were entered into the model. A particular daytime work shift was chosen; with the stevedoring plans of real container vessels were placed into the dataset (an example of one ship is illustrated in Fig.3). The measures of performance provided by the SIMPORT were compared with actual field observations from the real CT. Additional field visits were made and some key observations were that each container ship would have a certain "ship profile" in how the containers were stacked in the ship's bays. This was attributed to the personal choices of the ship planner. The SIMPORT model rules were refined to reflect these differences, and the validation procedure was repeated. The second validation process produced results that were similar to the field observations and led to further testing leading to 16 scenarios to be analyzed. The testing of the simulated CT in India could proceed with confidence in the evaluation of alternate physical layouts and operational scenarios.

4. Implementation of SIMPORT and Initial Results

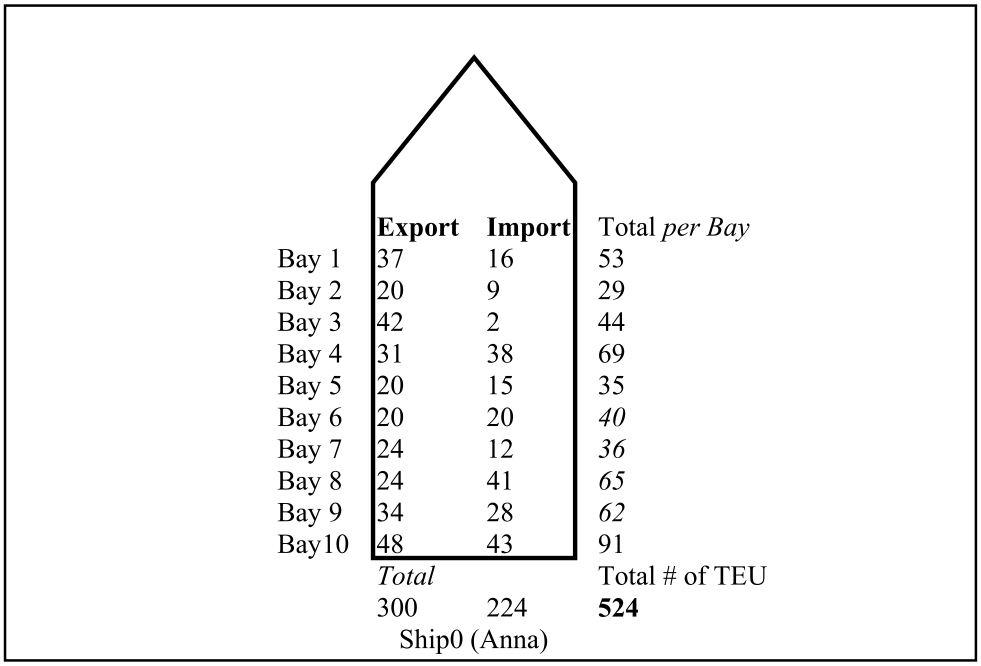
The primary objective of the project is that the SIMPORT should be flexible to changes in layout in the yard and berth as well as container management policies. The SIMPORT can be modified to reflect any of these types of changes. The manager system produced berth assignment schedules using the management policies described above for a small case simulation with three ships. Their physical characteristics (lengths, number of bays, and container characteristics) were configured into each ship and stored in a database. The ships are being worked according to the sequence policies, berthing polices, and storage management policies. The storage management polices are defined by two types of polices; one policy called ship line in which the containers are stacked according to the ship line that they belong to. The second storage management policy is destination, which refers that all containers are stacked according to the destination they are going to. An illustration of the process flow for running a CT simulation in SIMPORT is described in Appendix B. The input to a simulation experiment includes the following:

- *Berthing Policy:* Shortest Ship turn-around Time Policy (STTP) or Berth Closest to Stack Policy (BCSP).
- *Sequencing Policy:* First Come First Serve (FIFO) or Highest Earning First (HEF).
- *Storage management polices:* Ship Line or Destination.

Sequence of arriving ships: The data was provided by CT managers in India for making the scenarios; the arrival time intervals of the 3 container ships (3 x 200m), the number of containers and the type of container, e.g. reefer, hazard, and standard, to load (export) and discharge (import) from each bay. In Fig.3, the assignment of containers was conducted through a random function and is illustrated.
The input variables that are experimented in SIMPORT:

- Berth Assignment Polices (Positioning and Sequencing):
  - BCSP and FIFO
  - BCSP and HEF
  - STTP and FIFO
  - STTP and HEF
- Yard Stacking Management Policies:

    - Stacks by Destination
    - Stacks by Ship Line
- Ship Profile (Ship Bay Stowage Configurations):
    - Random – in that containers are randomly placed in bays in a ship
    - Fixed – which places the containers in exact fixed bays in a ship
- *Quay length:* The length in meters along the CT that is able to serve docked container ships is tested at 890 m to reflect the actual CT in India.
- *Terminal width*: The width in meters is set at 1000m as it is the same in India.
- *Berth spacing:* The spacing is fixed at 200 m reflecting the actual CT in India.



	Export	**Import**	Total *per Bay*
Bay 1	37	16	53
Bay 2	20	9	29
Bay 3	42	2	44
Bay 4	31	38	69
Bay 5	20	15	35
Bay 6	20	20	*40*
Bay 7	24	12	*36*
Bay 8	24	41	*65*
Bay 9	34	28	*62*
Bay10	48	43	91
	Total		Total # of TEU
	300	224	**524**

Ship0 (Anna)

Fig.3: Example of Ship Configurations and Container Assignments to each Bay on arriving Ships

The output from the simulation experiment includes the following:

- *Berth assignment plan*: Schedule for assigning ships to berth points along the quay.
- *Crane assignment:* Cranes are assigned and their final locations are stored.
- *Cost:* Terminal handling costs that are charged by CT in handling a TEU
- *Straddle Carrier assignment:* SCs are assigned to a specific Crane.
- *Performance measures:*
    1. *Distance:* Measured in meters the distance traveled by SCs in order 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
    2. *Service time:* The total time ship turn-around time, measured in hours, for all ships
    3. *Profit:* Ship profit is calculated from the initial estimated cost from the actual cost by multiplying the hourly ship costs with the scheduled ship time, which is then subtracted from the actual ship turn-around time.

A *ship profile* is often observed in many terminals and ports in which CT managers will attempt to establish stacks based on the bay assignment for a given vessel. The method in which the containers are placed in the bays of the ship influences the ship profile and the CT operations. This strategy is used more in common with vessels that are involved in a strict port rotation that experiences very little deviation. For example, if the container vessel has a rotation where it loads containers in port A while calling port B, port C, port D and port E; please see Fig.4 for a description of ship profile.

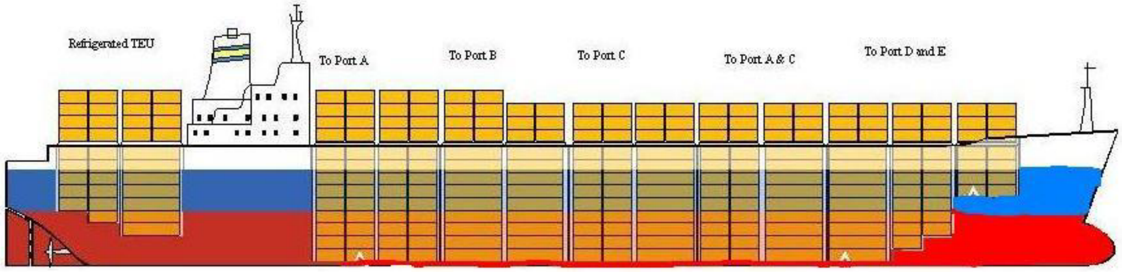
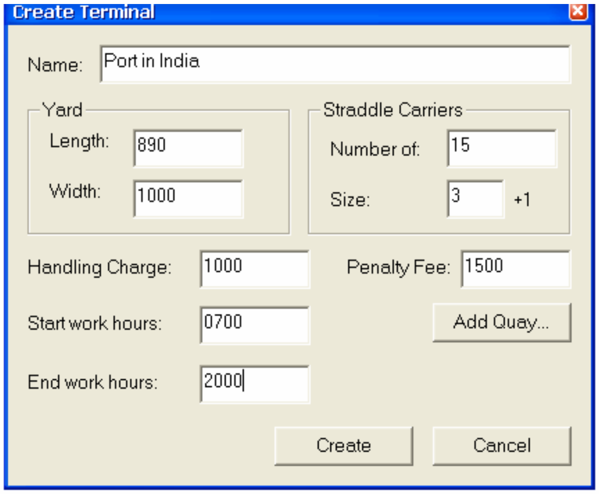


Fig.4: Ship Profile of a Container Ship

The simulation experiments compared and evaluated policies of the real CT in India. Real data that was provided by the management was employed into the simulation experiments, i.e. working hours, berth sizes and terminal configurations, etc. A screen shot of the 'Create Terminal' screen is provided in Fig.5, indicating that the yard configurations, handling charges associated at the CT the penalty costs (hours for working outside normal hours) and the start and ending times for normal hours are considered as input for the SIMPORT agents so that calculations can be made.



Name: Port in India

Length: 890

Width: 1000

Number of: 15

Size: 3 +1

Handling Charge: 1000

Penalty Fee: 1500

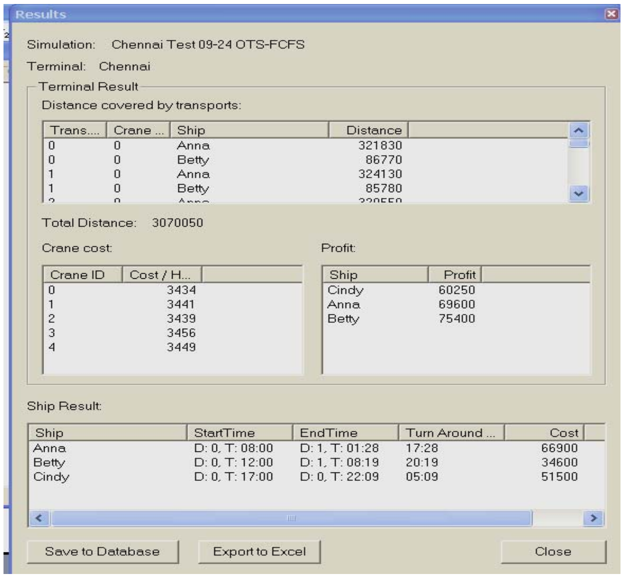
Start work hours: 0700

End work hours: 2000

Fig.5: Create Terminal GUI

5. Results of the SIMPORT Simulation Project

The managers of a CT in India provided data and layouts of their terminal for analysis. The Indian CT was encountering ship turn-around time of 3-4 days and was considering means of increasing quay crane throughput from 30 lifts per hour to 40 lifts per hour. The simulation model was used to evaluate revised layout configurations for the yard and berthing polices at the berth. The test results for a single experiment are illustrated in Fig.6, which evaluates the different types of berthing policies, sequencing policies experimented and storage management policies using data provided by the real CT in India.



Simulation: Chennai Test 09-24 OTS-FCFS

Terminal: Chennai

Terminal Result

Distance covered by transports:

Trans....	Crane ...	Ship	Distance
0	0	Anna	321830
0	0	Betty	86770
1	0	Anna	324130
1	0	Betty	85780

Total Distance: 3070050

Crane cost:

Crane ID	Cost / H...
0	3434
1	3441
2	3439
3	3456
4	3449

Profit:

Ship	Profit
Cindy	60250
Anna	69600
Betty	75400

Ship Result:

Ship	StartTime	EndTime	Turn Around ...	Cost
Anna	D: 0, T: 08:00	D: 1, T: 01:28	17:28	66900
Betty	D: 0, T: 12:00	D: 1, T: 08:19	20:19	34600
Cindy	D: 0, T: 17:00	D: 0, T: 22:09	05:09	51500

Fig.6: Screen shot of the results using the STTP policy with FIFO sequencing policy and

In Table II the results of the individual experiments are compiled into one table. The tests were conducted to analyze the relationships of stacking policies, scheduling policies, berthing policies and ship bay stowage configurations in developing improved CT performance. A list of 16 scenarios was compiled from interviews with CT managers and is simulated in SIMPORT. The total distance for each combination of policies is compared from; ship profits and ship turn around times for the arriving ships. Though SIMPORT calculates the individual crane profits and individual ship profits and costs, they are summarized in the results in Table II.

In testing the layout changes between stacking by *destination* and by *ship line*, interesting results were obtained coupled with the container ship bay configuration being either fixed or random. Meaning that the containers were randomly stowed in bays in a vessel where as fixed stowage would refer to having containers loaded into bays designated by their destination. The use of *ship line* as a storage management policy indicated that there was minimal difference in results on distance of SCs traveled, ship turn-around times and operational costs. The use of the *destination* storage management policy revealed improvements of about nearly 10% for all 16 polices which means better utilization and faster turn around time when comparing stacking by ‘ship line’. A general finding from the simulation study indicated that rearranging the yard increased efficient SC distance traveled. The results suggested positively that Berth productivity and the Yard configuration are linked, and the effect of increasing productivity of any isolated activity (e.g. lower distance traveled) must also be examined upon overall terminal operations. Continuing testing with SIMPORT on the ship bay configurations disclosed that there is a strong correlation between ship bay configurations with the other policies.

The scenario that had the fastest ship turn around time was scenario 14 at 41 hours and 10 minutes. However, the profit for the ships was reduced in that more resources were assigned in working those ships faster. The first scenario, scenario 1 had the best operating profit for the ships worked but had the third highest ship turn around time at 44 hours and 7 minutes. The lowest distances covered for the SCs was 2,698,905 meters in scenario 2 in which the ships are placed on a berth that is closest to the most worked stack in yard. This would lead to lower distances but with a potential high turn around time. The ship turn-around time in scenario 2 is 57 minutes more than the fastest time and less then one hour and 37 minutes from the average ship turn around time of 43 hours 41 minutes. In addition, the ship profits are 7.5% higher than the average profit of €206,202. A decision maker would have to consider these “trade-offs” in setting policies for the CT management personnel to use.

Table II: Test Results of CT Management Polices and Ship-Bay Stowage Configurations

Scenario	**Container Terminal Management Policies**			**Ship / Bay Stowage Config.**	**Sum of Distance Traveled by SCs in meters**	**Sum of Ship Turn - Around Times in Hours**	**Sum of Container Ship Operational Profit in Euro**
	Berthing policy	*Scheduling policy*	*Stacking policy*				
Scenario 1	BCSP	HEF	Dest.	Random	2760759	44:07:00	€ 226 500
Scenario 2	BCSP	HEF	Dest.	Fixed	2698905	42:03:00	€ 221 755
Scenario 3	BCSP	HEF	Ship line	Random	3067510	45:59:00	€ 223 000
Scenario 4	BCSP	HEF	Ship line	Fixed	3050050	44:19:00	€ 217 570
Scenario 5	BCSP	FIFO	Dest.	Random	2781045	43:51:00	€ 212 540
Scenario 6	BCSP	FIFO	Dest.	Fixed	2753205	42:45:00	€ 200 220
Scenario 7	BCSP	FIFO	Ship line	Random	3090050	44:15:00	€ 220 200
Scenario 8	BCSP	FIFO	Ship line	Fixed	3005045	43:22:00	€ 206 560
Scenario 9	STTP	HEF	Dest.	Random	2763045	42:38:00	€ 198 800
Scenario 10	STTP	HEF	Dest.	Fixed	2725450	41:28:00	€ 185 040
Scenario 11	STTP	HEF	Ship line	Random	3070050	43:07:00	€ 205 550
Scenario 12	STTP	HEF	Ship line	Fixed	2984655	42:34:00	€ 200 250
Scenario 13	STTP	FIFO	Dest.	Random	2763045	42:31:00	€ 196 800
Scenario 14	STTP	FIFO	Dest.	Fixed	2704050	41:10:00	€ 180 750
Scenario 15	STTP	FIFO	Ship line	Random	3070050	42:57:00	€ 205 250
Scenario 16	STTP	FIFO	Ship line	Fixed	2984655	42:07:00	€ 198 450

6. Conclusion and Future Work

The initial simulation experiments with SIMPORT have provided a useful example of using a multi agent system in a CT. The results seem to indicate that simulation as a backbone for a DSS can be useful for evaluating various CT management policies, e.g. berthing strategies, container yard stacking strategies, and sequencing of ships. SIMPORT suggests that the more 'informed' CT managers are, the better the choice of CT management policy. The choice of yard stack policies and berthing policies both have a strong influence on ship turn-around time and distances traveled by the SCs. The use of monetary terms has provided additional insight to the utilization and performance of the cranes, and the profits made by the various agents during the simulation. Computer simulation is suggested as an approach that may assist CT managers in making decisions without interrupting the operations and thus consequently avoiding mistakes which may be costly (cf. *Henesey et al. 2004)*.

The use of real data provided by the container terminal in India assisted greatly in setting up the experiments. The results from the SIMPORT were later communicated back to the Indian CT management, leading to a few changes in container terminal management. The most significant change being the configuration of the yard according to destination. The latest correspondence with the management at the real container terminal was positive and suggested continuing improvements with SIMPORT, e.g. situation when one of the cranes or straddle carriers is down, etc.

The use of agents in modeling and simulating the complexities associated with the CT has greatly assisted in capturing the organization and the tasks that are executed for operations. The experience with simulating the CT has assisted greatly in understanding and identifying problems from a methodological perspective.

SIMPORT currently handles the marine side flows with the yard operations and future work is to extend it to model the inland side flows in more detail. However, SIMPORT could simulate a transshipment CTs like those found in ports such as Hong Kong and Singapore, where most of the containers are discharged at the terminal for loading onto another vessel. In addition improve algorithms are needed for the agents to make better decisions. Testing of a longer time horizon with multiple ships (currently three ships are used) is considered for SIMPORT in the near future. The agents in the management system are considered to be reactive with much communication taking place between them. The next stage of the research would be to refine the management system agents to be proactive and making complex decisions. For example, the yard could be better represented by an agent in selecting yard location and stack configurations according to a list of rules. The possible extension of SIMPORT to test a market driven approach in handling containers in a CT is the aim of the research.

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Appendixes:

Appendix A. Costs in Purchasing Container Terminal Equipment and Developing Infrastructure

Container Gantry	€ 5,000,000
Mobile Crane	€ 2,500,000
Transtainer	€ 1,000,000
Straddle Carrier	€ 600,000
Reach Stacker/ Front Loader	€ 300,000
Meter of Quay Length	€ 50,000
Per Square meter of yard	€ 50

Source: MARCONSULT Performances of Container Terminals Report 2003 Genoa – June 2003. Marconsult. S.R.L.

Appendix B. Process Flow for Running a Simulation in SIMPORT