MULTI-AGENT SYSTEMS FOR CONTAINER TERMINAL MANAGEMENT

Lawrence Edward Henesey

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"I did the best I could with what I had."

~Conway Twitty

ABSTRACT

This thesis describes research concerning the application of multi-agent based simulation for evaluating container terminal management operations. The growth of containerization, i.e., transporting goods in a container, has created problems for ports and container terminals. For instance, many container terminals are reaching their capacity limits and increasingly leading to traffic and port congestion. Container terminal managers have several, often conflicting goals, such as serve a container ship as fast as possible while minimizing terminal equipment costs

The focus of the research involves the performance from the container terminal manager's perspective and how to improve the understanding of the factors of productivity and how they are related to each other. The need to manage complex systems such as container terminals requires new ways for finding solutions, e.g., by applying novel methods and technologies. The approach taken in this thesis is to model the decision makers involved in the container terminal operations and various types of terminal equipment, e.g., cranes, transporters, etc., as software agents. The general question addressed in this work is: can the performance of a container terminal be improved by using agent-based technologies?

In order to evaluate the multi-agent based systems approach, a simulation tool, called SimPort, was developed for evaluating container terminal management policies. The methods for modelling the entities in a container terminal are presented along with the simulation experiments conducted. The results indicate that certain policies can yield faster ship turn-around times and that certain stacking policies can lead to improved productivity.

Moreover, a multi-agent based simulation approach is used to evaluate a new type of Automated Guided Vehicles (AGVs) using a cassette system, and compare it to a traditional AGV system. The results suggest that the cassette-based system is more cost efficient than a traditional AGV system in certain configurations. Finally, an agent-based approach is investigated for evaluating the governance structure of the stakeholders involved in a transport corridor.

The results of the research indicate that the performance of a container terminal can be improved by using agent-based technologies. This conclusion is based upon several studies, both conceptual and concrete simulation experiments. In particular, multi-agent based simulation seems to offer container terminal management a suitable tool to control, coordinate, design, evaluate and improve productivity.

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This research that has culminated into publishing this PhD. thesis may have never been realized were it not for the cooperation, help, motivation, patience, respect, understanding, and most of all the love from many friends, colleagues, partners, and family members throughout the world. Thank you!

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Lawrence Edward Henesey
Karlshamn, Sweden

December 1, 2006

List of Papers

The presented thesis is based upon the following papers and publications that are referenced by an assigned roman number.

[I] Henesey, L.
"A Review of Decision Support Systems in Container Terminal Operations"
Submitted for journal publication.

[II] Davidsson, P., Henesey, L., Ramstedt, L., Törnquist, J., and Wernstedt, F.,
"An Analysis of Agent-Based Approaches to Transport Logistics"
Transportation Research Part C: Emerging Technologies, Vol. 13(4), pp. 255-271, Elsevier, 2005.

[III] Henesey, L., Notteboom, T., and Davidsson, P.,
"Agent-based simulation of stakeholders relations: An approach to sustainable port and terminal management"
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"Market Driven Control in Container Terminal Management"
Proceedings of the 2nd International Conference on Computer Applications and Information Technology in the Maritime Industries (COMPIT '03), Hamburg, Germany, pp. 377-386, 2003.

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"Agent Based Simulation Architecture for Evaluating Operational Policies in Transshipping Containers"
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Extended version accepted for publication in the Journal of Autonomous Agents and Multi-Agent Systems.

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"Evaluating Container Terminal Transhipment Operational Policies: An Agent-Based Simulation Approach"
Journal WSEAS Transactions on Computers Vol. 5(9), pp. 2090-2098, Sept, 2006.

[VII] Henesey, L.,
"Stakeholder Validation and Verification of SimPort"
To be submitted for publication.

[VIII] Henesey, L., Davidsson, P., and Persson, J.A.,
"Comparison and Evaluation of Two Automated Guided Vehicle Systems in the Transhipment of Containers at a Container Terminal"
To be submitted for publication. Partially based on a paper published in Proceedings of the 5th International Conference on Computer Applications and Information Technology in the Maritime Industries (COMPIT '06), pp. 54-64, Oud Poelgeest, Leiden, Netherlands, 2006.

[IX] Henesey, L. and Persson, J.A.
"Application of Transaction Costs In Analyzing Transport Corridors Using Multi-Agent-Based Simulation"
Extended version of article published in Promet Traffic & Transportation: Scientific Journal on Traffic and Transportation Research. Vol. 18(2), pp. 59-65, 2006.

Papers and publications that are related to the thesis but are not included:

[X] Henesey, L.,
"Enhancing terminal productivity through Artificial Intelligence: Multi-Agent System Approach"
Proceedings of the 26th Terminal Operators Conference (TOC-Europe 2002), Antwerp, Belgium, 2002.

[XI] Henesey, L., Wernstedt, F., and Davidsson, P.,
"A Market Based Approach to Container Port Terminal Management"
Proceedings of the 15th European Conference on Artificial Intelligence, Workshop (ECAI 2002) - Agent Technologies in Logistics, Lyon, France, 2002.

[XII] Henesey, L.,
"More than just Piers: a multi-agent system in defining organization in a seaport terminal management system"
Proceedings of the 47th Annual Conference of the International Society for the Systems Sciences (ISSS) (Special Integration Group on Systems Applications to Business and Industry), Crete, Greece, 2003.

[XIII] Henesey, L and Kerckaert, K.,
"Prospects for Short Sea Shipping"
Proceeding of 3rd Short Sea Shipping Conference: building a U.S. waterborne intermodal system. Hilton Head SC., US. pp. 103-116. 2004.

[XIV] Henesey, L., Davidsson, P., and Persson, J.A.
"Simulation of Operational Policies for Transhipment in a Container Terminal"
Proceedings of the 10th World Scientific and Engineering Academy and Society (WSEAS) Multiconference on Circuits, Systems, Communications, and Computers, July 10-15, Athens, Greece, 2006.

[XV] Henesey, L., Aslam, K., and Khurum, M.
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Proceedings of the 5th International Conference on Computer Applications and Information Technology in the Maritime Industries (COMPIT '06), Oud Poelgeest, Leiden, Netherlands, pp. 54-64, May 8-11, 2006.

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"Short Sea Shipping in the United States: Identifying the Prospects and Opportunities"
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" A Simulation Model for Analysing Terminal Management Operations"
Proceeding of the 4th International Conference on Computer Applications and Information Technology in the Maritime Industries (COMPIT '05), Hamburg, Germany, pp. 100-113, May 8-11, 2006.

[XVIII] Davidsson, P., Henesey, L., Ramstedt, L., Törnquist, J., and Wernstedt, F.,
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" A Multi Agent Based Simulator for Managing a Container Terminal"
Proceedings of the 2nd European Workshop on Multi-Agent Systems (EUMAS 2004), Barcelona, Spain, pp. 291-302, December 16 &17, 2004.

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Table of Contents

Introduction

This thesis describes research investigating the applicability of multi-agent systems technology in assisting container terminal management to improve the performance of their terminals. A distributed approach has been taken for modelling and simulating the decision making processes in order to capture local decisions made by the different actors involved in the activities of a Container Terminal (CT). The main contributions of the thesis concerns two simulation tools; one for evaluating management policies in CTs, and the second for evaluating different types of automated guided vehicles (AGVs) in a CT.

In the next section a background is provided that motivates the research. Section 2 then presents the CT management problem domain. In Section 3, agents and multi-agent based simulation are described followed by Section 4, which presents the main research question and a list of sub-questions. The methodology that was used in addressing the research questions is explained in Section 5. Section 6 summarizes the results and contributions of the thesis. Finally, in Section 7 conclusions and pointers to future research are given.

1. Background

The global growth of containerization, transporting goods in an inter-modal steel shipping container, is increasing annually at ten percent and the number of TEU (twenty-foot equivalent unit) containers have increased from 39 million in 1984 to over 356 million in 2004 [1]. In addition, vessel size for transporting containers have increased to nearly 14,000 TEU vessels, e.g. the recent launch of the M/V Emma Maersk in September, 2006 [2]. The daily operating costs of such ships can be over $65,000 [3].

The spectacular growth of globalisation and increasing container transportation have created many problems for ports leading to higher requirements on terminals, cities, and communities. Observations made during port and terminal visits confirm that many CTs are reaching their capacity limits leading to traffic and port congestion.

The repercussions of the costs associated with port congestion affects a number of actors related to CTs. Some examples of how port congestion has a negative effect on the major stakeholders in ports are:

- Shipping Lines – ship delays, extra costs, missed feeders, etc,
- Terminals – extra manpower, yard congestion, re-handling, etc.
- Trucking Companies and Railways – waiting time, loss of business.
- Shippers – longer lead times.

Increasing capacity is one way of handling congestion and bottleneck problems that constrain the performance of terminals. Capacity can be increased either by physical expansion or improved utilization of the available resources. Unfortunately, many seaport cities, especially in Europe, do not have the space to physically expand their terminals nor have the funds to build new infrastructure. Table 1 lists the eleven biggest port projects in Europe for increasing CT capacity by introducing new IT systems, terminal equipment, land expansion and training labour. The additional capacity provided by these projects is estimated at 31,2 million TEU, with over € 5 billion budgeted [1].

Table 1. Largest Port Projects for Container Terminal in Europe 2005

Port	Cost of Approval (million €)	Total Project Cost (million €)	Increased Capacity (m teu/ p.a.)	Proposed Project Start Date	Earliest Actual Operation Date
Bathside Bay	20	438	1.7	2004	2008
Cuxhaven	5	400	2.0	2006	Never?
Dibden Bay	98	876	2.1	2000	Never?
Felixstowe South	5	365	1.6	2006	2007
Hull Quay 2000/2005	10	51	.6	2000	2007
Le Havre Project 2000	25	550	4.2	2003	2006
London Gateway	36	876	3.5	2006	2008
Rotterdam Euromax	25	225	2.4	2004	2008
Rotterdam Maasvlakte II	150	1100+	6.0	2002	2012
Westerschelde	50	400	3.0	2003	2008?
Wilhelmshaven/Jade	25	800	4.1	2006	2010
Totals	**€ 449**	**€ 5081**	**31.2**		

Source: Compiled from Drewry Consultants presentation and documentation [1]

From the figures presented in Table 1, some projects such as Dibden Bay, UK and Cuxhaven, Germany, which have spent over € 100 million for planning, may not be realized for various reasons, such as environmental. The number of years from decision to realisation that it takes to physically increase CT capacity by building new terminals or extending existing ones can be between two to over ten years. Meanwhile, existing CT capacity in some regions, such as North Western Europe, have very high utilization rates for their CTs.

In Table 2 a list of the seven largest CTs and other CTs in this region shows that many of the large CTs are reaching their maximum capacity. Though the other CTs have a mean utilisation rate of 41% they are not considered by many ship lines for various reasons, such as the road and rail infrastructure, warehousing, customs organisations, sea access. The large CTs represent traditional centres of trade have developed to a point that requires additional capacity to handle increasing container traffic.

Table 2. North-West European Container Terminal Utilisation in 2004

Port	Utilisation Rate
Antwerpen	92,9%
Bremerhaven	95,5%
Felixstowe	77,1%
Hamburg	93,2%
Le Havre	89,6%
Rotterdam	92,5%
Southampton	99,3%
Other Ports in N. W. Europe	41,9%
Total for N. W. Europe	86,6%

Source: Drewry Consultants [1]

From the situations described which are afflicting CTs not only in Northern Europe but world wide, calls are made by CT managers for alternative methods in unmasking the problems that weaken CT performance. This thesis focuses on improving the performance by the efficient use of available resources through computer-based support for management decision making as well as automation. It has been argued that the ‘software’ rather than the ‘hardware’ will be the determining factor in future trends in port competition in relation to CT management [4].

2. Container Terminal Management

Since port, seaport, terminal and container terminal are terms often used interchangeably in research papers and discussions; an attempt is made to clarify the terminology. A *port* can be seen at first hand as a place to or from where goods may be shipped. The use of ports has long been associated with maritime trade and the use of ships to carry cargo. The advent of rail roads, automobiles, and airplanes associates the mode of transport using the port, i.e. airport, seaport. A *terminal* is a specialized part of the port that handles a particular type of goods, e.g. cars, containers, wood, people, etc. The situation today must reflect the change in institutional structures where port authorities are granting concessions to stevedoring companies to operate terminals (e.g. CTs) independently and competitively within the port area. The CT is the basic unit that is being studied in this thesis.

The primary aim of CT managers is to develop strategies that improve customer satisfaction and the terminal's competitive position. The main functions of the CT management are the *planning* and *controlling* of operations. CT management is often driven by tradition rather than theory, thus being conservative with respect to adopting new ideas or technologies. The management of a CT can affect the choice of ship lines to use a particular CT. Thus, it is imperative that the CT management is able to satisfy its customers, such as minimising the time that a ship spends berthed at a terminal. To shorten this time, CT managers spend special effort in increasing the productivity in terms of container crane moves per hour, which is regarded to be one measure of CT performance.

The increasing complexity of CT operations requires management to decide allocation of resources but also the sequence and timing of operations. Due to tradition and outdated practices, the management of a CT or port is often fragmented, with differing organizations handling specific tasks within the terminal. Through interviews and port visits we observed that many CT managers are often faced with these types of problems, which are further supported in research articles, e.g., Rebollo et al. [5], Gambardella et al. [6], and Frankel [7]:

- lack of planning
- not enough delegation
- ad hoc planning
- little insight in terminal operations
- lack of unity of control

The choice of organizational structure has been observed by Cullinane et al. [8] to affect the efficiency and ultimately performance of a CT. The most common structure in CT management is a ‘unity of command’, where key decisions are made by a single manager or group of terminal managers [9]. The development of specific departments leads to specialists in planning, e.g., ship planners, yard planners, and resource planners. The decisions made by CT management demands an understanding of customer service requirements, such as:

- *Performance* – fast ship service (‘turn-around’) time,
- *Reliability* – predictable performance,
- *Cost* – desired to be competitive and predictable,
- *Quality* – no waste or damage during operations, and
- *Adaptability* – capacity of CT operators to implement solutions, i.e., changes to shipping line schedules and fulfil other customer requirements.

Additionally, CT managers must understand their resource availabilities, operating costs, and other constraints, such as schedules, budgets, regulations, and the objectives of the CT [7]. The main objective for many CTs is cost leadership and terminal competitiveness. Through improving productivity, many CTs seek to gain cost leadership, since terminal costs according to Persyn [10], are significant to the total costs of shipping goods. According to Frankel [7], port costs can be in excess of 50 percent of the total costs and where 55 percent of these port related costs are the result of poor ship turn-around times and low cargo handling speeds.

Figure 1 illustrates how a CT system is viewed in this thesis; the four subsystems are distinguished when functioning together so that the effectiveness of one subsystem affects the performance of the next subsystem. The four main subsystems are:

(1) *ship-to-shore*, movement of containers from ship to berth. Quay cranes are assigned to a ship for the task of unloading and loading containers.

(2) *transfer*, bi-directional movement of containers from a berth to a stack (storage area), from one stack to another stack and from the gate to a stack. Usually trucks, Straddle Carriers or AGVs are employed in this subsystem.

(3) *storage*, stack or area where containers are transported to and then placed. Often stacking cranes or straddle carriers are used to lift containers and stack them on top of each other.

(4) *delivery / receipt*, movement of containers between stack and the 'gate' and vice-versa depending if the container is an import or an export. The gate acts as an interface for the CT with other modes of transport such as rail roads and trucks.

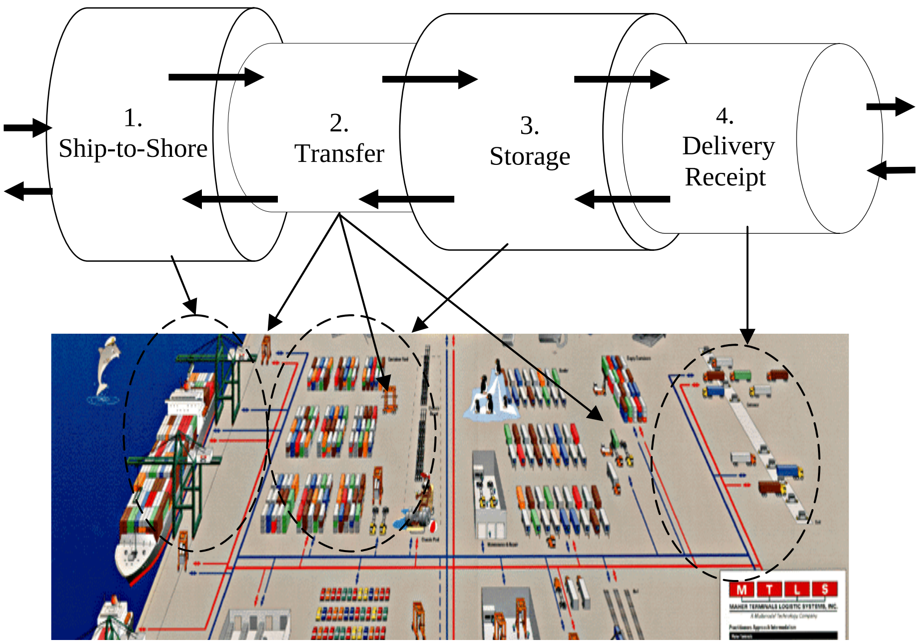

Figure 1: The Container Terminal Subsystems
(Source: permission from Justin Nortillo, Maher Terminals Logistic Systems, Inc., US)

The flows of containers, represented by the bold arrows, which go through the CT system in Figure 1, are limited by the capacity of the subsystems, which may constitute bottlenecks. The diameter of each subsystem in Figure 1 suggests its typical capacity, which in turn determines the capacity of the whole CT system. Thus, the performance of the CT depends upon a wide mix of factors affecting the individual subsystems rather than just focusing on the quay crane performance, which some managers place much importance on. Moreover, the interactions between the subsystems may affect overall performance. For instance, pre-stacking containers to be loaded onto a ship may optimize the crane operations, but may increase congestion in the transfer system and lead to more traffic in the storage system.

In addition to the traditional flows in a CT between berths and gates, there is an increasing amount of transhipment taking place world wide [11]. Transhipment is when containers are first unloaded from a ship and then loaded to another ship at the same CT. This is often caused by physical and economic constraints, e.g., larger container ships requiring more space and depth and port costs. As the ships become larger and coupled with shipping line strategies, such as ‘feedering’, shipping lines are having their larger and more expensive ships service fewer ports so that these ships can spend more time at sea generating revenue [12].

Many shipping lines are serving geographic regions by establishing one or two “main-hubs” from which they will tranship containers onto smaller ships that will “feed” them to other ports in the region. This strategy leads to more containers being transhipped at the main-hubs [12]. In a study by Ocean Shipping Consulting [11], the total transhipment throughput for Europe and the Mediterranean has increased more than 58 percent between 2000-2004 and demand will increase between 56-68 percent from to 2010. Figure 2 depicts a more traditional method of linking CTs and ports in which ships would serve each port directly.

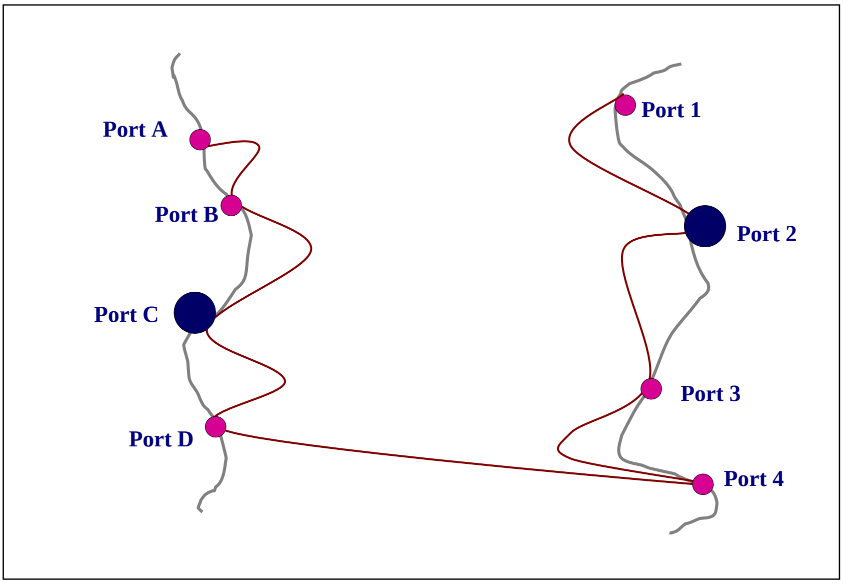

Figure 2. Traditional Maritime Link between Two Trading Regions

Many CTs and ports are becoming known as “feeder CTs” or “feeder ports” and are linked to a larger main hub CT where transhipping occurs. At the main hubs, the containers are temporarily stored waiting to be loaded on larger ships to be transported between various regions of the world. Figure 3 illustrates how the smaller ports or CTs in one region (e.g., ports A, B, and D) are feedering containers to a CT in port C. The smaller ports are linked by a connecting “main line service” between CTs in port C and port 2 with CTs in ports located in another region (e.g., ports 1, 2, 3 and 4).

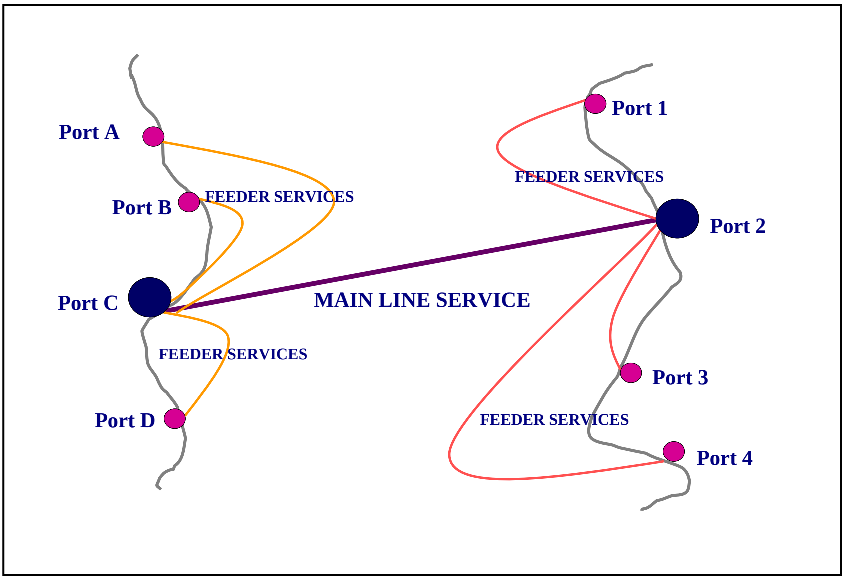

Figure 3. Feedering and Hub and Spoke Maritime Link between Two Trading Regions

As noted by Hultén, [13] there is a considerable amount of research within container management that does not consider the wider perspectives of container logistics. Similarly with CT management, most of CT research has focused on the subsystems individually with very few on the whole system or from a 'holistic' view. The introduction of CT management tools able to evaluate and identify the factors determining performance in the CT system may assist in developing more robust strategies and better management techniques.

The application of combinatorial optimization techniques has had little success in analysing and increasing the performance of CTs [14]. The complexity of the CT often requires complex models (combinatorial and non-linear), so the resulting models are extremely difficult or take too much time for solving problems [14]. Due to these reasons, isolated planning normally is normally used. The disadvantage of this approach is that it only provides approximated results and requires to be compensated by the experience of human planners, which many are becoming difficult to find or replace.

3. Agents and Multi-Agent Based Simulation

Artificial Intelligence (AI) is a discipline of science that was formally initiated in 1956 during a conference in Dartmouth, New Hampshire and the main goal of AI could be viewed as having machines or software act more like humans [15]. Since the mid to late 1970's distributed artificial intelligence (DAI) has been evolving leading to the introduction of agent technology in the 1990's for tackling problems in a distributed and autonomously manner.

3.1 What is an Agent?

In the last decade there has been increasing interest in software designs based on multi-agent systems (MAS); i.e. a range of techniques that share a common bond in that they describe systems in terms of aggregations of goal-oriented, interacting and autonomous entities, placed in a shared environment[16]. Although agents and MAS have become important metaphors in model construction there has been no consensus regarding what an agent is and what distinguishes agency from related concepts such as objects. There exist many definitions for describing software agents and we will here rely on the one made by Wooldridge [17]; "an agent is a computer system that is capable of *independent* action on behalf of its user or owner and a multi-agent system consists of a number of agents which *interact* with each other, typically by exchanging messages". In the case of MAS, several agents are interacting in a goal or task oriented coordination that can be both *cooperative* and *competitive*. The interaction between the various agents in the system provides an interesting way for solving problems.

A slightly more concrete approach to defining agents is by means of a set of properties, all or some of which an agent must posses (cf. [18], [19]):

- Autonomy: An agent is able to execute tasks with little or no intervention from other entities.
- Adaptively: An agent can adapt to future behaviour based on past experiences, i.e. can learn.
- Goal-orientation: An agent does not solely react to environmental stimuli, but may act proactively according to a set of persistent

goals. To meet these goals, an agent is able to execute plans over time.

- Mobility: An agent is able to change its location within a physical or virtual environment (e.g. a computer simulation model)
- Reactivity: An agent is able to respond to changes in its environment in a timely fashion.
- Situatedness: An agent inhabits or occupies some environment that it can sense and act upon.
- Sociality: In order to reach its goals an agent communicates and interacts with other agents in a cooperative or competitive manner

The use of agents has evolved from concepts found in object oriented programming. In object oriented programming, objects maintain their parts of code (or methods) and local control over the variables manipulated by its methods. The difference between objects and software agents is that objects are considered to be passive since their methods are invoked by external entities, whereas software agents maintain their own thread of control, localising not only code and state but their invocations [20]. Parunak suggests that agents are appropriate for applications that are characterised as *modular, decentralised, changeable, ill-structured*, and *complex* [21]. The qualities listed by Parunak for using agent technology can be identified in the CT management domain.

- Modular: Each decision maker in a CT and the resources used for executing tasks can be seen to have its own set of state variables that are distinct from the environment.
- Decentralized: A set of actors in a CT can be decomposed into stand-alone processes, each capable of doing useful things without continuous direction by the other actors/processes. This also minimizes the impact that changing one module has on the behaviour of other modules.
- Changeable: The structure of a CT is afflicted with change as that continuously new ships are entering while others are leaving, with each ship having its own unique demands and configurations.
- Ill-structured: Complete information on all the processes for managing the CT is not achievable due to the current prevailing state of

using a number of different systems that are not connected to each other.

- Complex: The CT domain is considered to be a complex system with a large number of interacting entities and uncertainties.

3.2 Multi Agent Based Simulation

Multi Agent Based Simulation (MABS) differs from other kinds of computer-based simulation in that (some of) the simulated entities are modelled and implemented in terms of agents. Similar to other micro simulation techniques, MABS attempts to model the specific behaviours of specific individuals. This is in stark contrast to typical macro simulation techniques in which the characteristics of a population are averaged together. The model in this type of simulation approach simulates the changes for the whole population by using the averaged characteristics [22]. Thus, in macro simulations, the set of individuals is viewed as a structure that can be characterized by a number of variables, whereas in micro simulations the structure is viewed as emergent from the interactions between the individuals. Parunak et al. [23] compared these approaches and pointed out their relative strengths and weaknesses. They concluded, "…agent-based modelling is most appropriate for domains characterized by a high degree of localization and distribution and dominated by discrete decision." Thus, given the characteristics of CTs, MABS seems a promising approach to simulating CTs.

4. Research Questions

The research that is presented in the thesis is based on several research questions stemming from the following general research question:

> ***How can the performance of a container terminal be improved by using agent-based technologies?***

The research has focused on issues related to performance from a CT manager's perspective. In addition, the research considers how to improve the understanding of the factors of productivity in CTs and how they are related to each other. In attempting to answer the main research question, the following more specific questions have been investigated:

RQ1: What is the state-of-the-art in research with respect to improving performance of container terminals and can this be classified into a framework?

RQ2: How can agent-based modelling be used to model the stakeholders in a container terminal environment?

RQ3: In order to increase efficiency in a CT, how can agent based technologies be used to control the terminal operations?

RQ4: How can MABS be used in evaluating CT management strategies for transhipment operations?

RQ5: How can MABS be used to compare and evaluate two different types of automated guided vehicle systems?

In addition, to get a broader perspective in understanding how the actors in a container terminal system interact with other actors within a transport corridor, to the following research question was also studied:

RQ6: How can agent-based technology be used in analyzing the transaction costs and organisational structures in a transport corridor?

5. Methodology

Methodology provides tools and techniques that researchers can use for gaining knowledge, firmer understanding and solving problems. A researcher either has a fixed aim and has to accommodate the means for getting there, or has fixed means (staff, lab, competence) and tries to find the optimal goals, given the means. At times, during the research, one must try to modify both the ends and the means. In the current research, the aim has been on improving CT performance with the available means. According to Yin [24], researchers may opt to use more than one methodology approach in answering a question. One type of strategy that was adopted in this research and employed in the thesis was the use of a triangulation strategy employing the following three methods, which combines quantitative and qualitative approaches:

- *Literature review*: A review of journals, periodicals, E.U. projects, and other research publications related to the subject area was executed during the initial phase of the research and updated throughout the research. The purpose was to obtain a firm understanding of what has been done in the CT management domain. An overview of relevant literature is provided in Paper I, together with an analysis of the current state-of-the-art in research on CTs. In Paper II agent-based technology applied to freight transportation was surveyed in order to gain a better understanding of agents and multi agent systems, and their application to problems related to those studied in this thesis.

- *Interviews*: Two types of interviews were conducted; qualitative and quantitative. The qualitative interviews were open-ended discussions with port and CT personnel that took place during port and CT visits, which assisted in Papers III, VI, V and VI. A more focused interview or survey was later conducted with selected terminal managers and terminal users to identify areas considered to be bottlenecks. The results from a questionnaire assisted in developing the software requirements for the multi agent based simulator presented in Paper V. In paper VII a series of interviews with CT managers followed by a questionnaire was conducted as a part of the validation process. The goal was to assess the credibility of the modelled entities, simulation results and most importantly, the design of the simulation model.

- *Simulation*: Simulation is a means of conducting experiments of system behaviour on models mimicking the real system with sufficient accuracy. According to Robson [25], the simulation method can be considered a good alternative strategy in implementing a case study, e.g. the development of an agent-based CT simulation tool in Paper V, VI, and VIII, and for modelling stakeholders in Paper III. An important part of simulation is modelling, e.g., of resources and their processes, which was performed in Paper IV. The operations of a CT in Paper IV were described in the context of a model for market-driven control in a CT. A distinctive characteristic of simulation as an experimental approach is to evaluate and test one or more solutions rather than providing an optimal solution as was conducted in Paper V, VI and VIII. The simulation experiments performed were strengthened by the fact that in Paper V, VI and VIII, the parameters were based on "real-world" data. A simulation model is supposed to reflect the real system behaviour by incorporating rules, procedures, and operational properties of the real system. CT components can be compared and evaluated with performance metrics to assist in decision making. Moreover, hypotheses about a CT component can be verified through simulation.

The work in this thesis is based on various fields of science and scientific theories. The main area of science has been computer science supported by various fields associated in the following disciplines: maritime economics, operations research, and logistics and transportation management. The premise for adapting a multidisciplinary approach has been the need for a better understanding of the domain and possible solutions. The advantage of such an approach when conducting research from an individual perspective is that a thorough and more complete picture of the characteristics of the domain are realized and captured. The disadvantage of this approach is that it is quite time consuming and can be difficult for an individual to grasp such a broad view of the subject. The main technological approach explored has been agent-based modelling.

6. Summary of Research Results

The nine papers included in this thesis address the research questions listed in section 4. The contribution and results of the papers and their relations to the research questions are described in this section.

In Paper I, "*A Review of Decision Support Systems in Container Terminal Operations*", the first question, RQ1 is addressed by performing an extensive literature survey of previous research relevant to studying container terminals. A classification table is formulated, which makes a distinction between planning and control decisions. The surveyed research papers are categorised according to the problem(s) that they attempt to model, solve or understand. The results of the literature survey pointed to the fact that most research was focused towards the maritime interface area of a CT and that simulation was the most widely used tool. The general focus of the literature was often on the ship turn around time with little or no consideration to the efficient employment of CT resources and how they effect the other parts of the CT. As a complex system involving many different decision makers with various objectives, it is concluded that CTs presents an environment well suited for decentralized problem solving techniques.

In Paper II, *"Analysis of Agent-Based Approaches to Transport Logistics"*, the first research question, RQ1 is studied further by exploring agent-based technology research that has been applied to the field of freight transportation and traffic. A framework was developed in order to assess the work presented. The general conclusion from the study was that agent-based approaches seem very suitable for this domain, especially for CTs but that there is a lack of verified deployed systems.

In Paper III, *"Agent-based simulation of stakeholders relations: An approach to sustainable port and terminal management"* addresses RQ2. The actual stakeholders in a CT were modelled using the MAS-CommonKADS methodology. This methodology provides a formal framework for designing software using agents. This simulation application is intended for studying elements of Stakeholders Relations Management (SRM) theory in order to model a container terminal community for analysis. Paper III describes the approach enabling decision makers to simulate various port policies and analyze the multitude of possible scenarios. In general, the MAS-CommonKADS provided a good, clear methodology for interested persons that are not involved in software development to understand and participate in the design processes. The work sheets, which were generated in using the MAS-CommonKADS methodology, assisted greatly in the development of the software requirements for the MABS simulators described in later papers.

In Paper IV, *"Market Driven Control in Container Terminal Management"*, we address RQ3 by describing how a MAS approach to the automatic planning could be implemented for efficient allocation of CT equipment. The MAS suggested in the paper is argued to provide both a dynamic yard allocation and a dynamic berth allocation, in order to reduce idle time of transport vehicles. The main goal of optimising the capacity of the terminal is investigated by suggesting the use of a market-based approach, in which agents are trading services. The work presented in the paper suggests that the MAS market-based approach offers a means for balancing the resources efficiently in order to avoid bottlenecks. It is concluded that the port capacity and throughput can be increased under certain conditions by the application of such a MAS strategy, but this still needs further support to be validated.

In Paper V, *"Agent Based Simulation Architecture for Evaluating Operational Policies in Transshipping Containers"*, we address RQ4 by proposing an architecture for a simulation model that is called SimPort. It adopts a Multi-Agent Systems approach to modelling the entities in a container terminal domain. A description of the simulation model is outlined in the paper and later the model is used to initially test twelve combinations of berth positioning, sequencing and yard stacking policies in the context of a major container terminal. The initial results indicated that by taking into account the major destinations of ship lines when arranging the container stacks it is possible to reduce the waiting time[1]. The model for simulating the CT coupled with the experience from related work in the context of a case study [26] suggested that the entities that are modelled in the simulation tool are behaving correctly and that SimPort was useful in identifying the best overall policy when evaluating policies for berth allocation.

In Paper VI, *"Evaluating Container Terminal Operational Policies: An Agent-Based Simulation Approach"*, further addresses RQ4 by using SimPort to conduct experiments for comparing the twelve transhipment policies in forty-eight scenarios in more detail than in Paper V. The scenarios differ with respect to the distribution (peak or even) and volume (high or low). The policies were evaluated with respect to a number of aspects, such as, total cost, turn-around time for ships and distances travelled by straddle carriers. The simulation results indicated, for instance that under different scenarios, the Overall Time Shortening policy combined with a Shortest Job First sequencing of arriving ships yielded a faster turn around time for ships at a lower cost when compared to other policies. Thus, the simulation results

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[1] A participating port in the study described in an earlier paper [26]. The simulation experiment results indicated means of reducing the waiting time of container ships from two to three day to less than 24 hours and thus save on terminal costs and ship operation costs.

show that an informed choice of berth assignment policy can provide better use of the available resources, e.g., by reducing turn-around time and/or distance travelled by the transport equipment.

In Paper VII, *"Stakeholder Validation and Verification of SimPort"*, regarding to RQ4, the simulator and the simulation results were presented to seven groups of CT experts, representing a combined global container handling market share in 2005 of over 60% (approximately 216 million TEU). A validation of the simulation results and the model was conducted through a questionnaire and interview. The use of agents in modelling and simulating decisions involved in CT operations seemed to provide a viable means for the managers to understand some of the problems with berthing ships. Moreover, the respondents found the simulation results to be credible and consistent with their own experiences. Often mentioned by the experts, was that the amount and type of configuration data used in the simulation tool offers much detail for accurately modelling and simulating the conditions in a CT. Additionally, the experts assisted in the verification process by ensuring that each of the entities modelled in the simulator were behaving as how they should operate in the real CT. The validation and verification processes have assisted in determining the accuracy of SimPort in representing the real system.

In Paper VIII, *"Comparison and Evaluation of Two Automated Guided Vehicle Systems in the Transshipment of Containers at a Container Terminal"*, we address RQ5 by developing an agent-based simulator for comparing and evaluating two AGV systems, one that uses cassettes for transporting containers and a traditional AGV system. The simulator tests a number of different configurations of container terminal equipment, e.g., number of AGVs and cassettes, in order to find the most efficient configuration. The simulation results indicated that there are several configurations in which the cassette-based system is more cost efficient and serves a ship faster than the traditional AGV system.

In Paper IX, *"Application of Transaction Costs in Analyzing Transport Corridors Using Multi-Agent Based Simulation"*, addresses RQ6 by proposing that transaction cost simulation modelling can be considered as an additional determinant in conducting transport corridor analysis. The application of transaction costs theory in analyzing the organisational structures and the transactions that occur, assists in indicating as to which governance structure results in higher efficiency. By extending the work by Klos [27], we present an agent-based simulation model for analysing cooperation and governance structures within a transport corridor.

7. Conclusions and Future Research

In summarising the thesis, the conclusion is that agent-based technology is a viable approach to several areas of CT management. The survey of literature indicates that there exists several opportunities for further improvement in CTs, only a couple of areas have been intensely studied by researchers. The use of MAS provides several interesting solutions to enhancing productivity as well as a means of understanding the multitude of varying problems that afflict CT management. The results of the papers presented in this thesis suggest that MAS is suitable in managing a CT, e.g.; adopting a decentralised planning view, using the MAS-CommonKADS methodology for developing a simulation tool, suggesting a market-based approach and employing a protocol called Contract-Net for coordinating the entities, modelling and simulating the entities in a CT for experimenting management polices, and a means for comparing AGV systems. We have presented agent-based technologies for managing the various systems in the CT in an integrated fashion, i.e., with simultaneous regard for the parallel processes that occur in a CT system.

The development of the simulation tool, SimPort, has provided much experience in modelling and simulating a system as complex as CT. The increasing importance of transhipment terminals in global logistics has motivated the research to modelling and simulating the sub-systems and operations involved in the transhipment of containers in a CT. An AGV simulation tool was developed using a MABS approach for comparing productivity of an AGV system employing cassettes to a traditional AGV system. The AGV simulator provided much insight and understanding in the behaviour of the AGV and cassettes when handling containers. The simulation results indicated many advantages of the AGV and cassette system in comparison to the traditional AGV system.

In addition, the experience of exploring, explaining, and defining the use of agents in a CT has generated ideas for further research. A number of research proposals have been suggested by industry and

CTs for the continuation of the research presented in this thesis such as; testing AGV systems in CTs, berth auction schemes between the quay cranes and the container yard stacks, developing an intelligent decision support system that would network with several container terminal systems. The incorporation of many of the research ideas and results presented in this thesis is envisioned to eventually lead to a full functioning simulator for testing operational policies with strategic objectives. The proposals are motivated from the current situation in today's CTs which shows a dire need for increasing capacity. The question hanging over the heads of many ports, communities and governments is: are their ports and CTs adequately prepared for the continuing growth in trade?

The development of a computer based simulator, representing intermodal transportation of containers is planned. Further development of the logic is planned as well as investigating the integration of traditional optimization techniques for berth allocation.

Ultimately, we intend to extend SimPort to model also the container logistics connections, such as road, rail and perhaps connecting other ports. We suggest that extending the MABS simulator may assist for example; in analysing various scenarios, representing different ways of operating the container transportation systems, and various handling systems. In addition, different polices and strategies for integrating terminal, shipping and logistics operations such as in short sea shipping will be analysed and compared using the simulator. Scenarios representing different levels of capacities and events, such as the economy, cost of petrol, government influence, could also be generated and analyzed. The goal is to provide a methodology and tool for decision makers so that they can understand and evaluate container terminal systems in the context of intermodal systems.

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I

Paper I

A Review of Decision Support Systems in Container Terminal Operations

Lawrence Henesey

Paper submitted for journal publication

Abstract

An overview of literature is conducted on research focusing on improving the performance of container terminals. The growth of containerization has led to numerous decision problems for container terminal management to consider in operating their container terminals more efficiently, e.g. where to place a ship along a quay, scheduling the resources to work a ship, etc. The research papers reviewed are summarized and then categorized based on the decision type, time frame, and container terminal system employed. The general conclusion from the results of the survey is that much research has been focused on the marine side interface of a container terminal, which leaves room for further research such as on the land-side interface. In addition, it seems that the use of simulation is becoming the method that is most often used to study these types of problems.

1 Introduction

The biggest impact of using containers on terminals and ports has been the need to develop special methods in terminal operations. The container terminal (CT) viewed in Henesey [1], is a system composed of four main subsystems, where each is characterized by unique operations that take place within them. The number of activities being carried in moving thousands of containers is challenging for management to co-ordinate, especially when demand can fluctuate on an hourly basis in some parts of the system to daily or weekly in others. Clearly, it is important to develop methods that ensure proper sequencing, load balancing, the optimal use of resources and result in increased service levels (e.g. faster ship turnaround time).

Modern container terminals (CTs) are not passive points of interface between sea and land transport. The CTs have become logistic centres acting as natural points of intermodal interchange. The importance of CTs to the economic and social dimensions of a community, nation, or region is significant. Better performing CTs, it is often argued to contribute in increasing trade and development of national economies [2]. At any one time, an estimated 15 million containers are currently being handled in the world and this number is projected to increase at a rate of 8.5 percent for the next ten years [3]. More interesting is the number of times that a container is handled or "lifted" by a CT crane during a year. An estimated 315 million container lifts were recorded for the year 2005 and this number is projected to increase 10 percent per annum in the future [4].

Concurrent with a growth in the number of containers handled is growth in number and size of container ships being built or on order. The Danish container shipping line, AP Møller-Maersk has built a ship that can handle 12, 500 TEU but according to Lloyd's List, may have capacity for 15,000 TEU [5]. The collected data in Figure 1 indicates that larger container ships are increasingly being built and ordered from the 5000 TEU (twenty foot equivalent unit) range to the 8000+ TEU range.

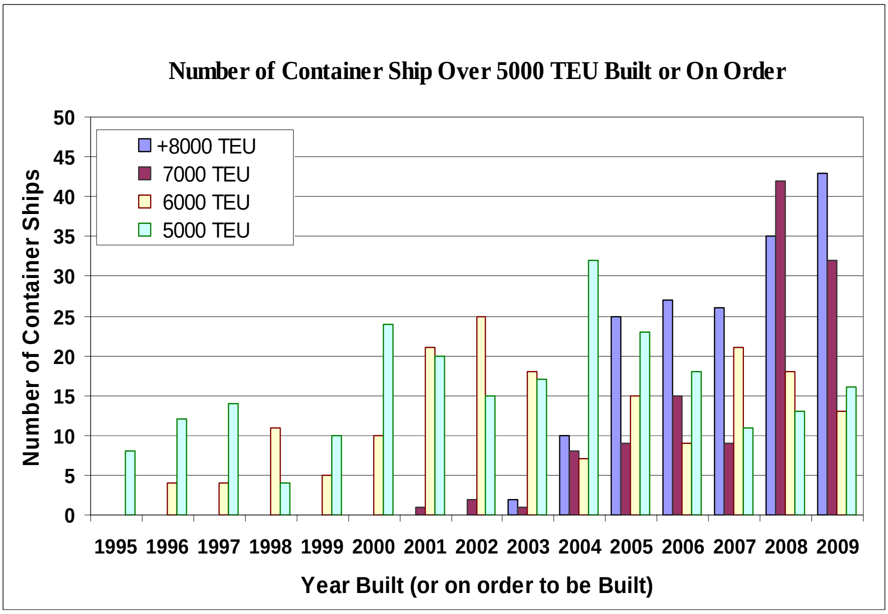

Figure 1. Number of Container Ships built or on order, 1995-2009[1]

The number of such large ships arriving at CTs increases the number of factors that must be considered, e.g. the layout of the terminal to handle large numbers of containers within a short period of time, schedule of cranes, etc. In order to meet the increasing demands to handle more containers from larger container ships, CTs will have to increase their capacity either through physical expansion, better utilization of the available resources, or implementing new methods or technologies.

The orders for ships to be built are still coming in and the data is thus far from being complete. However, the number of such giant ship that will be arriving at container terminals places additional factors that must be considered, e.g. the layout of terminal to handle over 8000+ containers within a short period time and the number of cranes to be scheduled, etc. In order to meet the increasing demands to handle more containers from larger container ships, CTs will have to increase their capacity either through physical expansion, better

[1] Data collected from various sources, e.g. BRS-Alphaliner,CI-Online, Containerisation and Lloyds List.

utilization of the available resources, or implementing new methods or technologies. Researchers and scientists have been studying various methods, solutions and techniques for assisting CTs.

In this paper an overview of published research literature was conducted in order to ascertain the “state-of-the-art” in this area. The reviewed conference papers, journal articles, technical reports and thesis were identified according to a framework (c.f. section 3 for a full description of the framework). Various scholastic and academic databases, such as the ACM digital library, COMPENDEX, ELIN@Blekinge, EMERALD, IGENTA, and an Internet search with SCIRUS search engine.

In the next section, section 2, a description of CT operating systems is described and the concepts of performance and productivity are discussed within the context of CT research. In section 3, the framework of analysis is described. The literature review is presented in a systematic fashion in accordance with the framework in section 4 and a classification table is constructed. The results of the literature review are described in section 5. Finally, in section 6 a conclusion is presented.

2 Background to Container Terminals and Concepts

Traditionally, seaports focused exclusively on the berth [6]. With the advent of containers, however, the need to integrate activities and specialized services beyond the quay has led to the development of many types of terminal operations to assist in the *planning* and *control* of CTs. CT management must consider the operating system(s) employed by the CT system when attempting to improve the planning and control decisions. Most of the research papers that were surveyed have attempted to improve the performance or the operating systems used in the ports or CTs studied. According to D´Hondt [7] and De Monie [8], the CT industry has developed four main types of operating systems, based on specific equipment used, in order to manage the flow of containers. An additional type of operating system that has been gaining much attention since its inception at Rotterdam in 1993 is the use of AGVs (automated guided vehicles) [9]. A few CTs are employing AGVs and the attention to such automation systems is increasing, c.f. Euromax in Rotterdam and CTA in Hamburg [10].

There follows brief description of the five operating systems employed in CTs:

(1) *Wheeled* (road chassis): Commonly employed in North America, in which containers are moved directly to and from the terminal on road chassis. The containers are placed on road chassis and then parked; obviously this operation system takes a lot of space due to the fact that the containers are not stacked. Although wheeled operations requires more space than other handling systems, the benefit of this system is that handling is reduced to a minimum. A picture of a wheeled system is presented in Figure 2.

Figure 2. Picture of a wheeled operation in Norfolk, US
(Source: courtesy of Virginia Port Authority, US)

(2) *Straddle Carrier (SC):* A dual task machine providing both horizontal transport and vertical stacking of the container. Stacking capacity of a SC varies; from being able to put just one container on another container to being able to build stacks containing up to five containers. A SC can operate at any location in the yard at any time and can support the high operating rates of the quay crane. One obvious advantage is that containers can be picked from the stack and placed under the gantry crane without waiting for the quay crane's movement. A picture of a SC employed in Antwerp, Belgium, is presented in Figure 3.

Figure 3. Picture of a Straddle Carrier (SC) in Antwerp, Belgium (Source: courtesy of Kalmar Industries, Sweden)

(3) *Rubber-Tyred Gantry crane (RTG):* Is a crane that travels on rubber tyres, giving it some flexibility in moving within a stacking area or moving to another location on the terminal. A picture of a RTG employed in the moving of containers at the port of Oslo, Norway is presented in Figure 4. RTGs are primarily used in the vertical movement of containers, e.g. stacking. A fleet of yard trucks is required for the horizontal transport of containers. The yard trucks share the lanes with RTGs and with trucks coming into the terminal. The need to tackle traffic congestion is important. Therefore, the RTG requires more synchronization with other equipment than other CT operating systems. According to interviewed experts, often the problems to be addressed when using this system are the yard planning, allocation of slots, deployment of RTGs and yard trucks in order to avoid traffic or port congestions.

Figure 4.Picture of RTG in Oslo, Norway
(Source: courtesy of Kalmar Industries, Sweden)

(4) *Rail-Mounted Gantry crane (RMG):* Most commonly found in large CTs such as Hong Kong, Singapore, and Rotterdam. The cranes run over rails. The RMG is very closely related to the RTG in operation, but the RMG is bound to the rails and cannot move from one stack to another as compared to the RTG. The advantages of using the RMG system are largely based on CTs with extremely large volumes of container throughput and high levels of automation, i.e. Automated Guided Vehicles (AGV) [8]. An example of a RMG is found in Figure 5; notice that the crane is quite stationary and suitable for loading and unloading containers across the stacks.

Figure 5. Picture of RMG in Genk, Belgium
(Source: courtesy of Kalmar Industries, Sweden)

(5) *Automated Guided Vehicle (AGV):* An AGV is a transport vehicle that is automated and driven by automatic control systems. Manual systems, such as wheeled and straddle carrier systems are often replaced by AGVs because of low labour costs and flexibility [9]. Ideally, the deployment of AGVs is promising for CTs that have high container throughput and operate on a 24 hour /7 day a week schedule. An example of a novel concept in AGV design is presented in Figure 6 in which cassettes are employed with AGVs in the transporting of containers inside the terminal area.

Figure 6. Picture of AGV with cassette
(Source: courtesy of TTS AB, Sweden)

The operating systems that have been described are often employed together, e.g. in the port of Gothenburg, Sweden, the SCs are used for the horizontal transfer of containers, while RTGs are employed in loading and unloading containers from rail wagons. The choice of CT operating system has an influence on the performance of a CT as well as the amount of land space required. In Table 1 a brief comparison, based on work by De Monie, [11] of the five main operating systems is presented. This information has been derived from port interviews and field studies.

Table 1. .Examples of CT operating systems and land used per annum

Operating System	**m^2 per 1000 TEU p.a.**	**Examples of operating system employed**
Wheeled operation	50000	Norfolk, Baltimore, New York/New Jersey
SC	20000	Norfolk, Antwerp, Zeebrugge, Gothenburg
RTG	12000	Antwerp, Rotterdam
RMG	8000	Kaoshiung
AGV/ASC	2500	ECT in the Netherlands (with automated stacking cranes, ASC)

The main problems in defining productivity according to Avery [12], is how to measure it and how to improve it. As stated by Peter Drucker; "*if you can't measure it, you can't manage it*" [13]. The description of CT performance and productivity used in this paper stems from a CT operators viewpoint. In the literature review, most research focuses on improving the performance of a CT. According to research by [14], terminal productivity has a strong influence in CT performance. There are several approaches used by researchers in increasing performance, e.g. use of algorithms for scheduling SCs or econometric forecasting methods to determine container terminal yard size, etc.

According to strict economic thinking, productivity can be viewed as how well an organization converts input resources (labour, resources, etc.) into goods and services. Productivity is a sound indicator for measuring CT performance [15]. Often, in improving CT productivity, management and many researchers have directed their attention to finding solutions by using a number of productivity indicators in evaluating the performance of CT management decisions. The aim of many managers has been observed from field studies cantered on finding a solution that yields a faster ship turnaround. Speed is viewed as a common measure of productivity in CTs; examples of speed are turn-around time that a ship is worked, the speed of cranes, etc. Faster turnaround times in a CT translate to a shipping line having its ship(s) sail more often leading to more earnings. In addition, other indicators that are used are:

- *Service time*: Period of time which a ship is berthed and whether it is worked or not. Thus, this includes working and non-working periods.
- *CT Capacity*: Maximum output that is generated from the input of production factors.
- *Berth Utilization*: utilized service time in relation to available service time.
- *Waiting time*: Time the ship has to wait for an available berth
- *Dwell time*: Time spent by the container in the seaport

3 Classification Framework

The research literature surveyed in this paper has contributed to methods or techniques in improving various tasks or activity found in CTs. In Figure 7, the surveyed literature is organized into a framework with four categories: CT subsystems, Decision Types, Time Frame, and Typical Issues.

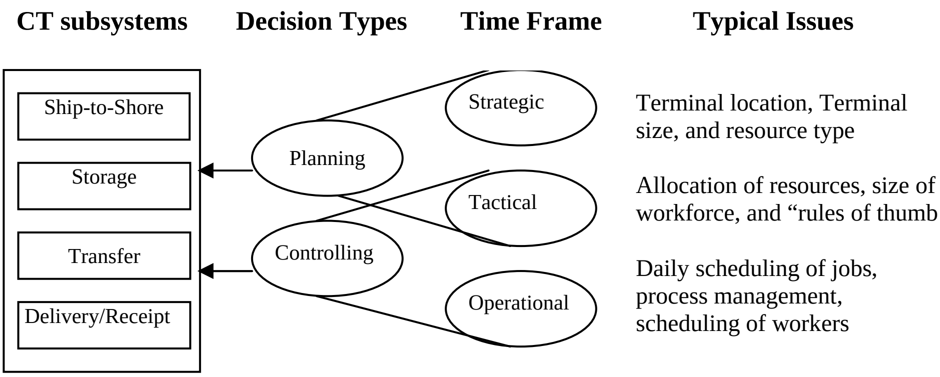

Figure 7. Derived from authors’ own work and Rushton et al. [16].

In the category of *CT subsystems*, each research paper describing a problem is classified into which subsystem(s) that it attempts to explain or solve. The main subsystems found in CTs and used in evaluating the research literature are:

- Ship-to-shore – ship loading and unloading occurs.
- Storage – containers are stacked, handled, or sorted.
- Transfer – containers are moved within the CT to another system
- Delivery and Receipt – interface to road, rail, or barge connections to the hinterland

The research literature is classified according to the *Decision Type* that is studied. The type of decision handled in the research literature, which is either *planning* or *controlling*, is considered in evaluating the literature. A planning decision is more concerned with the design and development of processes or can be described as ‘doing the right thing’

[16]. Planning can be associated with the design of the processes that must be carried out in achieving an efficiently managed CT. The aim is often to have a streamlined, operation that crosses over the boundaries of the subsystems in a CT and acting in a synchronised manner. A control decision is more directed to monitoring or controlling the process or can be described as 'doing the thing right' [16]. Control can be viewed as ensuring that levels of productivity are kept within the policy decisions made by CT management.

The *Time Frame* refers to what stage of planning is considered. The literature is categorized into strategic, tactical and operational time frames. Many of the problems that are described by researchers are considering the level of planning, i.e. strategic, tactical, or operational by using the time frame for the planning, e.g. long term (typically years), medium term (weeks), and short term (days or hours). Finally, *Typical Issues* are not used directly in the framework; it simply illustrates the types of problems that CT managers face in making a decision. In addition, this can be viewed as a background to the decision types and time frames and how they are related to the problems.

4 Literature Review

In this section, the research literature most closely associated with the CT subsystem being studied briefly summarized and classified into the following subsections: 4.1 ship-to-shore, 4.2 storage, 4.3 transfer, and 4.4 delivery and receipt. In subsection 4.5 overall CT solutions are described, in which several research papers attempt to solve the complete CT system by using simulation.

4.1 Ship to Shore System

When a ship arrives it will need to be assigned a berth along the quay. The objective of berth allocation of an arriving ship is to assign the ship to an optimum position, while minimizing costs, such as berth resources [17]. One problem that many terminal operators experience is reducing the unproductive and expensive container moves in a terminal. The number of cranes used to perform the operation varies depending on the size of the containership and the volume of containers to be handled. Each gantry crane will be served with a number of transport machinery. The transport machinery will transfer containers in the terminal to be stacked by a yard crane or they may stack the containers themselves to a certain height depending on type of transport machinery employed. The vessel planning is typically executed 24 hours before a vessel call and produces a manifest, which is based upon a list of containers to be loaded or discharged provided by the ship line. The influence of the berth allocation on the crane operations is viewed in Figure 8. The circle around the cranes in Figure 6 shows the location of cranes along the quay, at Skandia Harbour in Gothenburg, Sweden. Since the cranes are positioned on rail tracks along the length of the quay they are not able to pass each other.

Figure 8. Berth and Crane Allocation at a CT in Gothenburg, Sweden (Source: courtesy of Port of Gothenburg, Sweden)

Planning decisions for Ship to Shore Systems

A queuing network based model of ship arriving is simulated with Visual SLAM software under various scenarios in a paper by Legato and Mazza [18]. The model was tested with data from Giao Tauro. The authors focus on the berth and the allocation of berths to arriving ships. In a paper by Henesey et al. [19] they simulate and test two berth allocation polices under various conditions. The simulator is called BAMS (berth allocation management system) produces a berth schedule for a set of ships considering turnaround time and resource utilization. The berth planning problem is argued by Lim [20], and Wilson and Roach [21] and Wilson, Roach et al. [22] to be NP-Complete. The proposal by Lim, [20] is that the berth problem be transformed to a graph that represents it. A heuristic is developed that uses 6 months of historical data from the port of Singapore. The berth is sectioned into strict areas and vessel is thought not to take up more then two berths. Thus, from the viewpoint of this author, the berths are static when considering that vessels come in different sizes. The berth management in a container terminal is evaluated by Moorthy and Teo [23] by modelling it as a rectangle packing problem on a cylinder and use of a sequence pair based simulated annealing algorithm to solve the problem of home berth location. In reviewing public berths, Nishimura et al. [24] tackle the berth-planning problem by employing genetic algorithms that solve a dynamic berth allocation problem that was addressed in earlier papers by Imai et al. [25], [26] and then later in Imai et al. [27] The authors compare the Lagrangean Relaxation based heuristic algorithm with the GA. The results using the GA showed no significant improved solutions for large size problems. There is some improvement in using GA in small size problems. Nishimura et al. [28]evaluates the use of GA for the routing of trailers in a CT. In a recent paper by the same group of authors in [24-27], Imai et al. [29]evaluate the use of a GA for the stowage, loading of a container ship with the number of containers rehandled in the yard stacks. The consideration of the container ship's stability, list and trim is considered in [29] by using multi-objective integer programming and a GA.

A multi agent systems approach is investigated in vessel berth allocation that is published in a series of papers by Lokuge et al. [30-32], which incorporates multi-agents for the decision tasks and an adaptive neuro fuzzy inference system in making final decisions considered rational. The use of fuzzy logic with an improved Genetic Algorithm is proposed by Zhou and Kang [33] for CT resource allocation in serving arriving ships. The berth allocation problem is studied y Zhou et al. [34]by evaluating a heuristic based on a genetic algorithm.

In Duinkerken et al. [35] and Duinkerken [36] a simulation model is used in the planning and development of a CT. In Duinkerken et al.

[35], the simulation model is described, based on TRACES to model the yard, and marine side of a CT. In addition to planning the model with TRACES, the control of the system is communicated by a system based on SERVICES. The operations of a planned terminal are analyzed under various parameters.

A number of research papers investigate the role of simulation to preview plans. In Koh et al. [37], a CT simulator is implemented using MODSIM II.5. The simulator is an initial attempt by the authors, but they encounter a few discrepancies between their model and the real system. The simulator always produces a faster simulated turn-around time for ships because shifting activities are left out, yard crane is not scheduled but always available, and the straddle carriers are not modelled correctly according to the real world. In Tahar et al. [38] the authors develop a CT simulator implemented with ARENA simulation software to test polices of priority based berthing. The authors focus mostly on the marine side of the CT and especially on the berthing of the vessel. The yard cranes or characteristics of the yard are not considered. Historical data is used to compare the utilization of the gantry cranes and transport equipment. The authors, based on simulation, recommend a new interchange area to help reduce the maintenance on the transport equipment.

The use of simulation packages to develop models provides researchers a fast means to code and simulate the problems that they hope to understand. Alternative methods for modelling a CT are investigated by Yun and Choi [39], they assume that a CT consists of a gate, container yard and berth. The authors use an object-oriented model to develop modules and be able to model at a higher level of abstraction. The simulation program language used in developing the model is Simple++. The simulator primarily analyses different equipment to handle the loading and unloading operations of a vessel in the marine interface. Testing was done at Busan Container Terminal for one week to check validity of the simulator.

In determining how to improve the loading and unloading of ships, Goodchild and Daganzo study in [40] methods to load ships while they are being unloaded, which is called “double cycling”. They researchers test two solution algorithms and simple formula to reduce the number of operations and operating time. One formula is developed for an improved lower bound to the optimal solution. The other formula for an upper bound to the greedy algorithm is extended to include an analysis of double cycling when ships have deck hatches. The results by Goodchild and Daganzo in [40] demonstrate that double cycling can gain efficiency and crane productivity is deemed to play a pivotal point in the performance of container operations. Work by Giemsch and Jellinghaus [41] shows that the container stowage problem can be modelled as a mixed-integer programming model. The authors consider the stability of the ship by minimizing the usage of ballast water, torsion and shear forces with a global goal of minimizing container shifts while maximizing the utilization of container terminal equipment.

Control decisions for Ship to Shore Systems

Much attention has been primarily focused on the ship to shore operations or marine side interface of a CT. The first decision that a manager encounters is when a ship arrives; a decision must be made on where to position the ship on the berth and with which resources are to be assigned, e.g. cranes and transport machinery. The schedule of available resources and the available space along the quay of a terminal influence the decision making coupled with the number of container that are to be handled, which drives the service requirements.

At the operational level of a control decision in berth allocation Imai et al. [25] propose a dynamic berth allocation algorithm developed for assigning ship at public berths, which assigns berths to ships while work is in progress. The authors compare static berth allocation to dynamic berth allocation where ships arrive while work is in progress. The use of Lagrangean relaxation techniques is employed in developing an algorithm that seeks the best plan for berth allocation. The authors claim that the algorithm may assist in further decision support. The criteria that CT managers often used in determining the berth allocation for ship berths and the assignment of resources to work the ships are: number and types of containers being loaded and unloaded with respect to a ship, and the distance to the stacks in the yard.

In work by Kim and Park [42] and Ng [43], they investigate scheduling multiple cranes with given set of jobs. The goal of both papers is to assign the most expensive resource, the quay cranes, optimally to arriving ships. Kim and Park [42], propose a branch and bound method for obtaining optimal quay crane scheduling using a greedy randomized adaptive search procedure (GRASP). Ng [43], proposes a dynamic program-based heuristic to solve the quay crane scheduling problem. A branch-and-cut algorithm is proposed by Moccia et al. [44] for quay crane scheduling. The others develop a heuristic which is tested using CPLEX, which results that it outperforms the branch-and-bound algorithm on medium size instances without reducing the solution space.

The use of the stowage plans for container ships has been researched by Avriel et al. [45], where the objective is to minimize total cost of shifting of containers on a vessel calling various ports. The authors assume that shifting costs are the same at each port, which in reality often varies considerably. Other constraints such as the crane or berth resources are not considered in the simulation. Heuristic methods are deemed to be the best method since the stowage problem is NP-complete. The authors use a heuristic that they entitle a suspensory heuristic in trying to solve the berth allocation problem. A paper by Ambrosino et al. [46], propose a liner programming model that incorporates a heuristic for the preprocessing and prestowing procedure in the stowage of containers in a container ship, which they call a master bay plan problem (MBPP). The researchers have decomposed the problems by splitting the ship location into different subsets and forcing the stowage of containers within them. A validation of their method is conducted with a real terminal in Genoa, Italy.

In two papers by Wilson and Roach [21], and Wilson, Roach et al. [22], they propose a methodology developed for a generalized and a specialized placement for a container using a branch and bound algorithm and later a Tabu search. The authors focus on the number of re-handles, which they interpret to be the result of poor container stowage planning. A strategic plan assigns general containers to a specific bay. The tactical plan assigns specific containers to certain slots in the bay. Authors note that the importance of modelling how humans solve this problem contributed immensely to the methodology’s development.

In the planning for berth allocation, Imai et al. [47] use mathematical programming to load and unload containers while considering the ship stability. The paper is concerned with the ship loading sequence, which in turn creates the transport sequence from the stack to the ship. The relationships between ship stability and container re-handles that occur in the yard are compared with integer and linear programming. The integer programming is viewed to be more attractive however the computational time is long and from their view, the linear programming formulation is more practical.

In another paper, Kao and Lee [48] approach the assignment of a berth by investigating the cargo being unloaded. The authors study the situation of a bulk carrier unloading steel and devise a means of integrating two independent systems in order to reduce the ship's time at port. The problem is closely related to containerships when they are given a berth assignment that considers their discharge and proximity to stacks.

Other researchers look to improving the gantry cranes performance and other resources associated with the allocation of berth. To improve the productivity of the gantry cranes in order to reduce the turn-around time, Böse et al. [49], suggest that more efficient scheduling of the straddle carriers (SCs) is needed. A genetic algorithm (GA) is employed to find the best schedule for straddle carrier (SC). The authors argue that there are two methods to reduce turn-around time, either reorganization of the terminal or enhancements in optimization may help planners. The results of several simulations concur that the use of GA minimizes the time spent by a ship.

In Steenken et al. [50] the ship-planning problem is tackled by using combinatorial optimization. The containers are portioned according to classes of types. The author's, interestingly note that the export stacks can partially provide a sequence of containers to be loaded. The objective function is to minimize the number of loading events by scheduling straddle carriers to position containers optimally from yard to quay. The authors consider the stowage plans in the real-time execution of scheduling gantry cranes with the straddle carriers. Steenken et al. [51]conduct an literature review of container terminal operations and operations research that is quite comprehensive. An overview of AGVs (Automated Guided Vehicles) and the problems of scheduling and routing are critiqued by Ling and Wen-Jing [52], according to the problem(s) being solved, the algorithm employed, computational complexity, advantages and disadvantages of the approach. The authors do not point if all the papers surveyed are applied to CTs? A number of papers simply cover the problems of AGV and not in context with a CT. A Petri net model is investigated by Maione and Ottomanelli [53] for the transhipment operations at a CT in Taranto, Italy. The authors suggest that the Petri net model is useful in efficient allocation of CT resources and could be extended for further simulation of other CT processes.

Much research literature has focused on strategic time frames and a few on tactical frames. A paper by Thurston and Hu [54] describes the development of an agent simulation written in Java programming language for the loading and unloading of containers onto vessels. The authors focused on the quay cranes as being paramount to the total performance of a terminal. It is assumed that first all containers should be unloaded are unloaded first and those container to be loaded would be loaded after unloading has been completed. The authors provide insight on the job assignments for the straddle carriers and how their routing may be plotted. The system has been evaluated in a simulation with randomly generated data.

4.2 Storage System

The storage system or yard operations of the CT is viewed by many managers as what “steers” the overall CT performance [55]. The stacking density of the containers and the equipment employed can influence the capacity of the yard immensely. The picture in Figure 9 illustrates the processes of stacking containers at a CT yard.

Figure 9. Yard Operations at CT in Kaoshiung, Taiwan
(Source: courtesy of Evergreen America Corporation)

The yard operations are heavily interdependent upon the other operations in order to maintain good container handling performance. A properly laid-out terminal can benefit the performance of a CT by segregating containers according to various characteristics. A few container characteristics:

- port of discharge (where the container is destined)
- commodity (types of cargoes)
- shipping line (i.e. Evergreen, Hanjin, APL, etc.)
- size and type (20′ or 40′, refrigerated, dry box, etc.)

There exist three main types of storage systems: short term, long term, and specialized [17]. The short-term storage system is for containers that may be transhipped onto another containership. Long-term storage is for containers awaiting customs release or inspection. Specialized storage is reserved for the following containers: refrigerated (called reefers), empty, liquid bulk, hazardous materials, or are out of gauge. The container storage system uses stacking algorithms in assigning a space for the container till it is loaded or dispatched. Various decisions are made that influence each other, i.e. the storage segregation or stacking policy translates into increasing the workload of yard cranes and travelling distances of SCs.

Planning decisions for Storage Systems

The decisions that fall on many managers is the allocation of cranes to stacks and the scheduling of transport equipment such as trucks, straddle carriers, and AGVs. The containers are stacked under various characteristics, i.e. size of container, status of container, ownership of the container, etc. A large amount of research has focused on the constraints and the decisions that are made. The problem of solving resource allocation and scheduling of loading operations is formulated and solved hierarchically in Gambardella et al. [56]. The coupling of optimization such as a mixed integer linear program that formulates the resource allocation with simulation to test if polices are good. The simulator uses agents that map humans and resources found in the terminal. Curiously, the authors state that the stowage plan is received only a few hours before a ships arrival; while in practice it would be 24 or more hours.[2] The focus of the research is on optimized turn around time of the vessel, which is argued to be influenced by the degree of yard crane work.

In a series of paper by Kim et al. [57-59], the planning of containers is viewed from a strategic to tactical time frame. The re-marshalling or handling of containers at the stack in the yard is argued by Kim and Bae [57], to contribute to the efficiency of the loading operations. The research is focused mostly on export containers arriving in a CT and the decision as to where to place them in order to minimize their handling till they are loaded to a ship. The problem is decomposed to three sub- problem: bay matching, which matches a the bay of the ship to a target area in the yard; the move planning, which determines number of containers that are to be moved between bays; and the sequence of moves, where the sequence of container moves is determined in order to minimize the re-marshalling operation. The authors enlist dynamic programming to help solve the problem of correct stacking.

In a related paper, Kim and Hong [60], use dynamic programming to determine the optimal storage space and number of cranes to handle import containers constrained by costs. An analytical model is formulated with transfer cranes and import container yard space is

[2] This statement is based on this researcher's prior experience in the assisting of vessel operations while employed with Evergreen in Norfolk, US.

considered. The model is not validated or tested with real data. In Kim and Park [59] and Kim et al. (2000), they study the problems in handling export containers. The problem of random arriving containers and the storage area where they should be placed is formulated with a mathematical program that seeks to minimize the transfer cost from the export stack to the apron where the container shall be loaded from to a ship.

The planning of the yard configurations has prompted research to look at new technological ideas that are expensive to implement and are thus attractive for simulation. The use of certain types of equipment can be simulated to justify their expenditure. Most of the terminal equipment is quite expensive, i.e. a 'panamax' crane is reaching nearly $6,5 million while straddle carriers are listed at nearly $500,000 [61]. In a project commissioned in the US, Khoshnevis and Asef-Vaziri [62], use 3D virtual simulation to analyze the impact of implementing an automatic storage and retrieval systems on the operations of a prototype CT. The loading of the vessel is the problem that is mainly addressed in the simulation. The authors deem that automation is feasible in the simulated model but do not consider the landside part (delivery receipt system) of the terminal in the simulation. In work by Vis [63], an analysis of two types of container storage and retrieval system at a container terminal is conducted by using both simulation and analytical tools. Manned straddle carriers and automated stacking cranes are evaluated along performance measures, such as total travel time. Results from [63] indicate that automatic stacking cranes outperform straddle carriers when the stacking span width is smaller than nine containers.

Another use of simulation was used by Kia et al. [64], to simulate two ports, one in the US and the other in Australia, that verify that increased CT performance is obtainable if straddle carriers are employed with electronic devices. The simulator identifies bottlenecks during the operation that may increase vessel-waiting time. The straddle carriers have a reduced waiting time and are not caught in congestion in the yard, resulting in less crane idleness and faster vessel turn around time. The authors used Taylor II for window to build the simulator.

The application of automated stacking cranes (ASC) to be used in the simulation of a CT along with AGVs is investigated by Duinkerken et al. [36]. Various stacking strategies are simulated at the yard. The authors argue that it is the yard that is the most important part of an integrated model. The other two models developed are the quay crane and the container transfer, which are simulated with the container stacking. The simulator was tested at Rotterdam's DSL terminal. The authors later recognize in Duinkerken et al. [65] the importance of having a distributed model in simulating a CT. The distributed modelling approach is argued to improve the transparency and maintainability of a CT simulator. By decomposing an original model to small sub-models, the authors conclude that the improved structure of the container simulator is much better for analysis and maintenance.

In other related papers, Preston and Kozan [66], investigate the yard or container storage area by the use of a genetic algorithm to minimize the turnaround time of ship compared with current practices at the port of Brisbane, Australia The modelling of storage location in the yard is believed to contribute to minimizing the transfer time between the stacks to the ship. The CT is partially modelled, as the main consideration is effect of storage utilization to transfer time. Another area that is causing many terminal managers problems is the planning for empty containers. Decker et al. [67]evaluate stacking polices for a container terminal using automation. The authors consider several policies that consider the stacking of containers and work load for the stacking cranes. Stacking strategies are investigate by Kang et al. [68], study the problem of containers arriving with uncertain weights by using a simulation tool. The authors propose a simulate annealing solution that is evaluated in the simulator for developing stacking strategies

Many trade lanes are experiencing trade imbalances where more import containers are coming in and less export container are being shipped out or the situation can be reversed. A good example is the numbers of containers imported into Gothenburg, Sweden were many will be returned back to the port as empties. In Sheen and Kong [69], they suggest a Decision Support System (DSS) for empty container distribution planning. The authors focus on the commercial perspective rather then the technical in optimizing container positioning across a port or terminal. They use a network model with relaxed constraints that are minimized via heuristics. Interestingly they consider mostly the problem of positioning leased containers and empty positioning of containers in the development of the DSS supporting a region of ports.

Control decisions for Storage Systems

The objective of transferring containers from the gate to the stacks in a container yard in an operational time frame are tackled by Bash [70], who divides the problem into two levels in order to minimize the maximum turnaround time for a set of ships. The levels are dispatching of vehicles to containers and locating yard cranes, however a third level could be argued- the sequence of loading and unloading of containers that are to be handled by the gantry cranes. The use of optimization techniques is formulated to model a CT using AGVs. The objective is to analyze the performance of heuristics under varying parameters and uncertainty in AGV travelling time.

In Zhang et al. [71], they use a mixed integer program augmented with Lagrangean relation generates solutions for a terminal using RTGs (rail tired gantry cranes). In addition in Zhang et al. [71] they argue that it provides fast solutions in the executing of a dynamic crane deployment in container storage. The authors do not consider the exports arriving at the gate and focus much attention to the marine side. In Kim et al. [72], they investigated what many researchers have not considered, the practice of using the information on weight of the containers for stacking. Motivation for the paper is to minimize the expected number of container handlings. A dynamic program is developed to determine the optimal storage slot in a yard. The authors focus solely on arriving export containers and not on import or transhipment containers.

An alternative approach to optimize the container transfers often found in terminals is described by Kozan [73] to be a network model. Later the model is introduced in analyzing the determinants affecting container transfer and how the process could be improved. An optimization function is developed that seeks to minimize the sum of handling and travelling time-called throughput by the author. The model was tested at a real port in Australia and confined to testing planning problems for investment. The operations were not considered, however, the author argues that the model could be used to investigate improvements in operational methods.

The suggestion of using multi agents systems (MAS) are proposed in two papers by Rebollo et al. [74], [75] and a paper by Carrascosa et al. [76] in controlling the operations at the storage and transfer systems. They propose that agents may assist in the executing of tasks according to set goals. The authors have suggested using the MAS paradigm in order to solve the port CT management problem and specifically the automatic container allocation in order to minimize the time a ship is berthed. Various resources and entities such as RTGs, SCs, yard planners, and ship planners are mapped as agents. The use of wrapper agents is suggested for legacy systems in order to provide access to the database, along with communication with external software. A prototype is still being developed.

4.3 Transfer System

Once a container is lifted from a containership, a transport vehicle may be waiting below to move the container to location within the yard. Alternatively, depending on the operation, containers may be placed below or near the gantry crane as a temporary storage (string-piece) till a transport vehicle is able to retrieve the container and move it to the yard. The choice of transport vehicles such as yard trucks, AGVs or straddle carriers have varying advantages and disadvantages depending on the amalgamation of the CT operations. The objective that many terminal managers have is to schedule the transport vehicles while considering the order of containers to be picked. The example of a transfer system is illustrated in Figure 10.

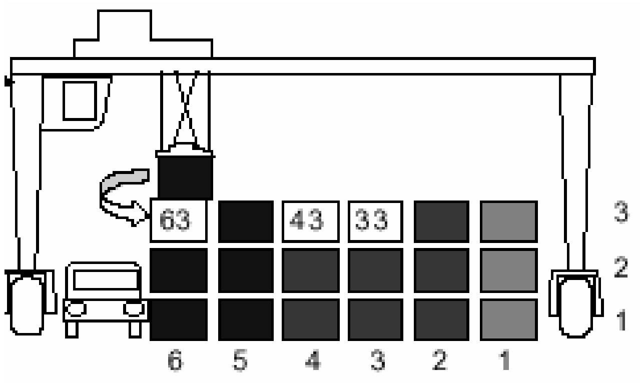

Figure 10. Example of the Pickup sequence problem

Most research in the transfer system is tightly coupled with either the ship-to-shore system operations or with the container storage system operations. Thus, the overview for *planning* and *control* decisions in the transfer system is discussed within the context of the other two related subsystems. There exist a few papers on straddle carriers negotiating their way through a container yard. However, most of this research area is more inclined towards robotics, such as AGVs then with developing tools to assist human CT workers. There has been recent work conducted by Vis et al. [77], which liner algorithms are developed to minimize the number of transport equipment required to move containers between stacks and quay crane under a time-window constraint. They researchers compare their simulated results with their analytical results and conclude that the simulation results benefit from the analytical model. Regarding to AGV systems, one of the most important problems that needs to be considered when employing such systems in a CT is the issue of "deadlock". Research by [78] and [79] both present methods for guaranteeing that the AGVs will be deadlock-free during the operations. The dispatching strategies of AGVs are studied by Grunow et al [80] in which they develop a heuristic that outperforms other traditional dispatching strategies. The agent based approach is studied in the management of AGVs in a CT by Hoshino et al. [81]in which the entities are modelled as agents for comparing AGVs with RTGs. The results indicate that certain configurations of AGVs and RTGs will increase the CT performances.

4.4 Delivery and Receipt System

The gate operations of a CT serve as the land interface to other modes of transport either rail or trucks. The gate consists of mainly two processes that link it with the yard operations. The first process is when arriving containers are checked and inspected. Each container has its information, which identifies its contents, owner, and directs its movements, known as a bill-of-lading. Once cleared, the import container is assigned to parking area where a transport vehicle may lift the container and place it in a stack. The second process is when a container is leaving the CT. The road or rail carrier that is taking the container out of the CT must clear documentation and security procedures. An export container is then removed from a stack and carried by a transport vehicle to the either the parking area for trucks or to the rail interface to be place on a rail wagon.

A majority of the papers that consider the problems of delivery or receipt of container have coupled the problem with the stacking or storage of containers in the yard. Little research has been focused in the delivery and receipt subsystem of CTs, which is exceedingly becoming important. The example of truck drivers in the US waiting up to three hours to pick or deliver a container have fuelled the trucking strikes that have erupted in the west coast US. The CSI, Container Security Initiative has prompted many terminals to develop security systems at the gate to identify the truck driver, the truck, and the cargo [61]. Some examples of gate security have been implemented in ports such as Rotterdam, Singapore, and New York. Regarding to control decisions, many terminal managers will go by "gut-feeling" and open a certain amount of lanes at a gate varying times of the day. Most of the gates are open on weekdays during business hours. A few proponents have questioned the operational hours of the gate in that often they contribute to the congestions and traffic outside the terminal. A few terminal and ports have instituted "time-windows" or appointments, i.e. Hong Kong. However there is very little research in this area.

Planning for Delivery and Receipt Systems

In the one paper that focused mostly on the problem of the delivery and receipt of containers at the gate, Sideris, et al. [82] argue that forecasting that is based on online information of container positioning and movements offers clear advantages to the daily operations. Trials were conducted at Maher Terminals in US and the observations were positive [82]. An automated procedure is mentioned but is not detailed as to how it is using the information of incoming containers to create a forecast. More research in this area is required in this area. Interestingly, many terminals are not aware of what is coming in their gate considering that they have dispatched containers under booking numbers? The booking numbers identify that a shipper will be shipping a good in a container type for a particular ship arriving on a particular said date. Most terminals do not look to this information for planning or scheduling their staff or resources. Information on the arrival and departing distribution of containers can help terminal operators manage capacity and minimize 'dwell time'. As the loading date for a ship draws near, the amount of containers for export increases. In the import side, the numbers of containers that are stored in the CT begin to decrease.

4.5 Complete Container Terminals and Simulation

Simulation using computers coupled with visualization is often associated with games. However, in Bockstael-Blok et al. [83], they support the design of an Inland Container Terminal through visualization, simulation, and gaming. The planning and designing of a terminal uses visualization-simulation tools in inter-organizational decision-making. The implementation of a game where various stakeholders could interact and negotiate in determining the location and design of an inland CT is argued by the authors to generate a better understanding for non-experts. The question raised, is if such a tool is an adequate representation of the real system?

Often simulation is used where there is no previous data to work with, such as the building of a new terminal or port. In Hartmann [84] generating scenarios for simulation and optimization of CT is argued to benefit the development of port and can assist in improving the performance. The proposal is that certain parameters are important to be included in the model and an algorithm is computing scenarios based on those parameters. The model is quite general, as it does not include the position of containers in the yard or vessels. The interest is mostly on the arrival of containers and not on departures or the handling.

One of the earliest papers on computer simulation for marine terminal planning is by Carpenter and Ward [85]. In Carpenter and Ward [85], a terminal model was developed with SIMAN/CINEMA, a discrete-event simulation language to simulate an actual terminal. The justification for use of simulation is supported by the results in the simulation project. A running debate at the terminal was that the current layout was unproductive, but the results of the simulation aided the terminal from expending several million dollars for unnecessary improvements. Another article that the authors collaborated on, Gibson et al. [86] proposes that simulation can offer a flexible traffic-planning model. The authors seek to model the whole port and not individual terminals. Various software simulation packages were employed in order to analyze travel demand and traffic operations of arriving trucks. Much attention and focus is on the landside traffic problems and not on the operations with in the terminals or ports.

On the development of a computer system to simulate port operations considering priorities, Holguín-Veras, and Walton [87], use a simulator to simulate the priorities of port CT. The simulator is written in FORTRAN with two modules, one called PRIOR used to asses the performance of a set of priorities and the other called ECON that process the PRIOR output to produce economic indicators of performance. The performances of the container's priority in relation to the terminal operations offer a novel way of thinking. Instead of thinking from a network centric viewpoint, the container centric provides an alternative to conducting operations considering service differentiation.

In building a CT simulator, much thought has to be put in deciding the parameters and what is to be simulated. The operative requirements and advances for the new generation simulators in multimodal CTs is tackled by Bruzzone et al. [88], in which the requirements for developing a simulator are analyzed and assessed from both academia and industry. The authors argue that it is necessary to use several models instead of one general model of a CT. The simulation approach is argued to be the best method in modelling and analyzing. In Ryan [89], she argues that simulation is a proper tool for analyzing cargo handling in ports. The two concepts that are discussed and simulated are large ships and fast ships. The author acknowledges that capacity at the yard is sensitive to the number of container being discharged. The agile port concept is introduced and provides analysis from a strategic time frame. In considering the validation of container terminal simulation, Rida et al. [90] propose a simulation tool which is calibrated and validated in the context of a container terminal in Casablanca, Morocco. The authors attempt to improve the management practices by calibrating the system requirements for the simulator, which was produced in an earlier paper that focused on the simulation model by Rida et al. [91].

Simulation of port resources and operations are the most researched area. There is interest in the social simulation of organizations. In a paper by Gambardella et al. [92], they use simulation to understand

and evaluate the socio-economical dimensions of the management of a terminal. The application of the PLATFORM project is presented. The simulation of impacts of varying technologies and policies is weighed with cost benefit analysis (favoured by industry) and multi criteria analysis (policy makers). The project is based on three simulation modules, road network, terminal, and rail network. The research is related to port CTs as they handle many of the same types of operations and have similar constraints. Three scenarios are analyzed in the simulation. The project uses Net Present Value (NPV) to determine choice of scenario. In a related paper where the authors collaborated on, Mastrolilli et al. [93], the authors use simulation for policy evaluation, planning and decision support in an intermodal CT. The use of agents is used in a simulator that evaluates policies or decision taken from information. The simulator is used to analyze resource allocation and loading/unloading operational policies. The output of the decisions influences the flow of containers from the stacks to be loaded on the ship. The simulator is validated and calibrated from two weeks of data at a CT in La Spezia, Italy. Short discussion on the simulator and how the agents are designed as the focus of the paper is to evaluate policies in an (port) intermodal CT. Another paper, which uses data from La Spezia CT, by Parola and Sciomachen [94] investigates the performance of the port system network by modelling the ship berthing, truck gate interface and the import and export flows of containers using the Witness software program.

The use of agent-oriented technology is explored by Lee et al. [95], in the design of simulation system for port resources. They analyze the port operations via agent-based simulation for the planning and management of the CT. The researchers simulated the PECT terminal in Busan, Korea by testing various policies with physical and logical agents. The agent based simulator results indicated that the stronger the partnership relationships between shipper agents and CT operator agents, the faster the handling of containers. The study was primarily focused on the ship-to-shore system and the transfer system. Agent based simulation has been suggested to the CT by Henesey et al. [96], in which the actors involved in the container terminal are simulated with the use of design methodology called MAS-CommonKADS and applied to stake holders management theory. The methodology seems to be adequate in developing simulation studies of port or terminal actors. The development of an agent based tool by Henesey et al. [97]is used for simulating CT management policies and evaluating them with performance metrics. The simulation results indicate that certain policies should be considered under various conditions.

The use of simulation is investigated by Gambardella et al. [98] in the intermodal CT operations in which a combination of operations research techniques with simulation using agents in a hierarchical order is applied. The problems focused by Gambardella et al. [98] are the scheduling, loading, and unloading operations. The models of the intermodal terminal are based upon complex mixed integer linear program. Decision support for terminal management is divided into three modules: forecasting, planning, and simulation. The last module, simulation, uses agents that act as an agent simulator test bed to check for validity and robustness of policy. In a later paper by Zaffalon et al. [99], they investigate the scheduling for operations and the allocation of resources generated by optimization algorithms and later evaluated through simulation. The authors focus on the loading and unloading and not on the landside or yard operations.

The use of simulation in CTs has not only been confined to industry and academia, but to defence related issues in the United States of America. A series of papers by [100-104] have researched various questions that challenge military commanders and decision makers. The problems generally investigated by simulation are the integration of a commercial port for military purposes. The researchers have developed a military oriented port simulator called PORTSIM. The researchers have explored the strategies for re-configurable port models and how to integrate them with military-oriented port operations.

The collected literature is summarized and placed into a classification framework, described earlier from Figure 1, is presented in Table 1. The literature is identified by the author(s) and then inserted in the table according the categories in the framework (see pp. 42-43).

Table 2. Classification table of the reviewed research literature

CT	Control		Planning
System	**Operational**	**Tactical**	**Strategic**
Ship to Shore	(Ambrosino et al. 2004) (Avriel et al. 1998) (Böse 2000) (Henesey et al. 2003a) (Kim and Park 2004) (Ling and Wen-Jing 1999) (Moccia et al. 2006) (Ng 2005) (Steenken 2001) (Wilson and Roach 2000) (Wilson et al. 2001)	(Imai 2001) (Imai et al. 2002) (Maione and Ottomanelli 2005) (Nishimura 2001)	(Bockstael-Blok et al. 2002) (Bruzzone 1999) (Carpenter and Ward 1990) (Duinkerken 2000) (Duinkerken 2001) (Duinkerken et al. 2002) (Gambardella et al. 1998) (Gambardella et al. 2000) (Gibson et al. 1992) (Giemsch and Jellinghaus 2003) (Goodchild and Daganzo 2005) (Hartmann 2002) (Henesey et al. 2003b) (Henesey 2004) (Henesey et al 2006) (Holguín-Veras and Watson 1996) (Imai et al. 2002) (Imai et al 2006) (Kao 1996) (Kia 2002) (Koh et al. 1994) (Lakuge and Alahakoon 2004a) (Lakuge et al 2004) (Lakuge and Alahakoon 2004b) (Leathrum 1997) (Leathrum 2000) (Leathrum and Frith 2000) (Lee et al. 2002) (Legato 2001) (Lim 1998) (Mastrolilli 1998) (Moorthy and Teo 2006) (Nevins 1995) (Nevins 1998) (Nishimura et al. 2001) (Nishimura et al. 2005) (Rida et al 2003) (Rida et al 2004a) (Ryan 1998) (Tahar 2000) (Thurston and Hu 2002) (Yun and Choi 1999) (Zaffalon 1998) (Zhao and Kang 2006)

Transfer	(Henesey et al 2003a) (Vis et al. 2005) (Zhang 2001)	(Gambardella et al. 1996) (Grunow et al. 2006) (Kim 2000) (Kim and Park 2002) (Kim et al. 2006) (Lehman et al. 2006)	(Bockstael-Blok et al. 2002) (Bruzzone 1999) (Carpenter and Ward 1990) (Duinkerken 2000) (Duinkerken 2001) (Duinkerken et al. 2002) (Gambardella et al. 2000) (Gibson et al. 1992) (Hartmann 2002) (Henesey et al. 2003b) (Henesey et al 2006) (Holguín-Veras and Watson 1996) (Hoshino et al 2006) (Imai et al 2006) (Kia 2002) (Khoshnevis and Asef-Vaziri 2000) (Kozan 2000) (Leathrum 1997) (Leathrum 2000) (Leathrum and Frith 2000) (Lee et al. 2002) (Mastrolilli M. 1998) (Nevins 1995) (Nevins 1998) (Nishimura et al. 2005) (Rida et al 2003) (Rida et al 2004) (Ryan 1998) (Tahar 2000) (Vis 2006) (Zhao and Kang 2006)
Storage	(Bish 2003) (Carrascosa et al. 2001) (Henesey et al. 2003a) (Kozan 2000) (Rebollo et al. 2000) (Rebollo et al. 2001) (Zhang 2001) (Zhang 2002)	(Dekker et al. 2006) (Gambardella et al. 1996) (Gambardella 2001) (Kim and Bae 1998) (Kim and Hong 1998) (Kim et al. 2000) (Kim and Kim 2002) (Kim and Park 2002)	(Bockstael-Blok et al. 2002) (Bruzzone 1999) (Carpenter and Ward 1990) (Gambardella et al. 2000) (Gambardella 2001) (Gibson et al. 1992) (Hartmann 2002) (Henesey 2003b) (Henesey et al 2006) (Holguín-Veras and Watson 1996) (Hoshino et al 2006) (Imai et al 2006) (Kim and Kim 2002) (Kim and Park 2002) (Khoshnevis and Asef-Vaziri 2000) (Kia 2002) (Preston and Kozan 2001)

			(Kozan and Preston 1999) (Leathrum 1997) (Leathrum 2000) (Leathrum and Frith 2000) (Lee et al. 2002) (Mastrolilli M. 1998) (Nevins 1995) (Nevins 1998) (Nishimura et al. 2005) (Rida et al 2003) (Rida et al 2004) (Ryan 1998) (Shen and Khoong 1995) (Tahar 2000) (Vis 2006)
Delivery and Receipt	(Henesey et al. 2003a)	(Sideris et al. 2002)	(Bockstael-Blok et al. 2002) (Bruzzone 1999) (Carpenter and Ward 1990) (Gambardella et al. 2000) (Gibson et al. 1992) (Hartmann 2002) (Henesey 2003b) (Holguín-Veras and Watson 1996) (Kia 2002) (Leathrum 1997) (Leathrum 2000) (Leathrum and Frith 2000) (Lee et al. 2002) (Mastrolilli M. 1998) (Nevins 1995) (Nevins 1998 (Rida et al 2003) (Rida et al 2004) (Ryan 1998)

5 Results of the Overview

A graph indicating the level of research concentration is presented in Figure 11 from the data in Table 2. The majority of the research, 75,8 percent or forty-four papers have mostly focused on strategic time horizon of the ship-to-shore interface of the CT. Perhaps this is due to the general focus on ship-turn around time in improving performance of a CT. The numbers of research papers that study operational time horizon are ten and four papers considering the tactical time horizon in the ship-to-shore interface. The transfer system in the CT is rather difficult to identify in that often it is considered by many researchers when studying the other terminal processes, e.g. delivery and receipt, ship-to-shore, and storage. The majority of the transfer system papers, about thirty one papers or 77,5 percent of the papers were identified as focusing from a strategic time horizon. The number of papers focusing from an operational time horizon was identified as three papers and focusing on the tactical time horizon was six papers.

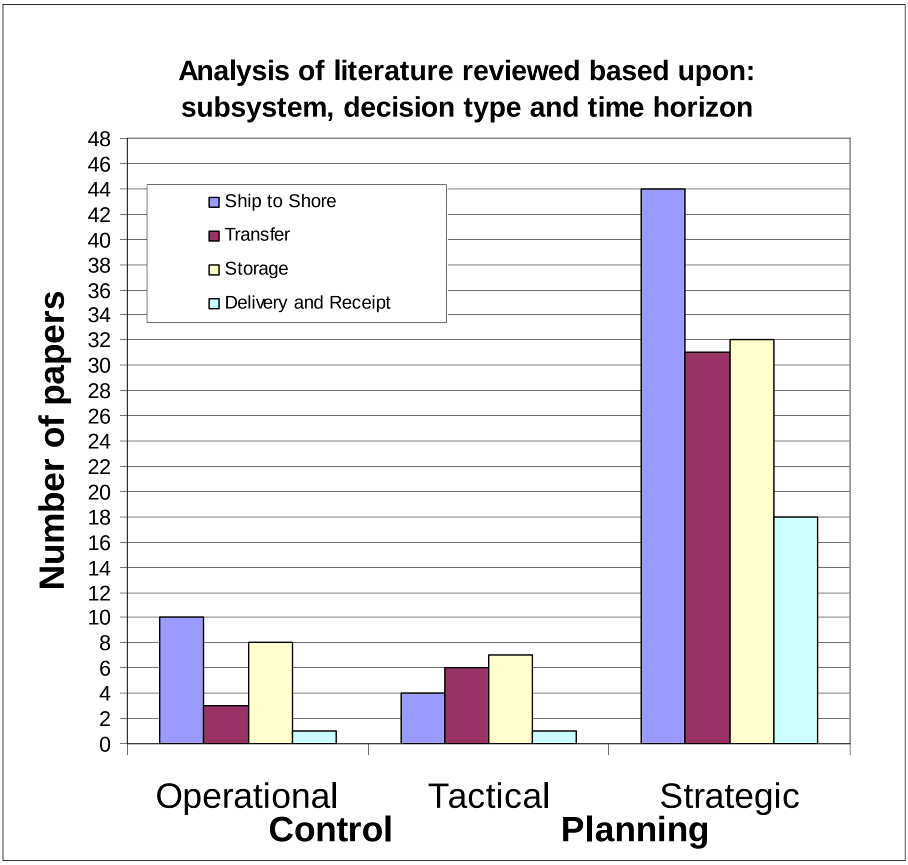

Figure 11. Analysis of Reviewed Research Publications

The storage system in the CT was an area that had many papers, which approximately 68 percent had a strategic time horizon focus or thirty two papers. Eight papers were found to have an operational time horizon perspective and seven had a tactical time horizon focus.

The delivery and receipt system of CTs had the least papers published in which of the twenty papers reviewed, one paper focuses exclusively on an operational time frame and another paper focused on the tactical time frame. The remaining eighteen papers studied the delivery and receipt problem in combination of other system, e.g. with storage systems from a strategic time frame. Clearly, this is an area for further research and development of new ideas. The reviewed literature indicates that 76% of the papers are studying CTs from a strategic time frame, while 11% are studied from a tactical time frame, and the remaining 14% are from an operational time frame. Planning decisions are observed to be more researched then control decisions in CTs.

.According to Ojala [105], the main methods for modelling ports planning and analysis, are: *econometric*, *analytic* (considers optimization to be under this category), and *simulation*. Though there is a significant amount of analytic and econometric methods used to study the problems in CT, simulation was found to be the most commonly used method employed in the literature review. Optimization and the use of econometrics are viewed to be suitable in problems that are well structured and not complex.

The nature of many problems affecting CTs is complex and ill-structured. Most of the recent research papers point to the adoption of the simulation method in studying the problems. Port and container management has been argued by various researchers such as [106], [17], [107], [108], [109], [110], [96], and [111], to be complex systems that are very difficult to model and analyze. The proposal has been the application of systems theory in helping to understand the relationships in the domain (system).

6 Conclusions

The number of papers that are appearing in scientific journals and conferences is rising and the diverse fields of science that are being represented is growing, e.g. economics, mathematics, geography, and computer science. This supports the notion that studying CTs can be done through a multi-disciplinary field of research. Many interesting approaches in order to understand and analyze CTs have been offered by researchers. The incorporation of theoretical frameworks, such as systems theory, network theory, and systems dynamics has been proposed by [106], [109, 111, 112] and [108] to provide analytical tools that help in making decisions when their exists high levels of uncertainty.

Many of the papers focused on just one or two systems in a CT. Perhaps a more holistic view of studying CT from a system perspective may provide a better means of understanding the problems. For instance the large amount of research towards ship turn-around-time may not be justified if problems in the storage system are not properly addressed. The example of customs procedures that take a long amount of time may increase the 'dwell time' for the container and impacting CT capacity and performance. Thus, if a container has to dwell for a long time in a storage system then the speed of physically handling the container at the ship-to-shore system has lead to no benefit to the whole CT system.

The use of simulation continues to offer many tantalizing areas to study and problems to solve related to CTs, such as studying the global movement of containers in a CT. The objective to simulate and manage a CT completely with all systems coupled together has been done but not at a detailed level. Also, the idea of integrating the various systems does not seem to be an elusive idea but may fast become a reality in the future development of *intelligent* decision support systems.

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II

Paper II

An Analysis of Agent-Based Approaches to Transport Logistics

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Abstract

This paper provides a survey of existing research on agent-based approaches to transportation and traffic management. A framework for describing and assessing this work will be presented and systematically applied. We are mainly adopting a logistical perspective, thus focusing on freight transportation. However, when relevant, work of traffic and transport of people will be considered. A general conclusion from our study is that agent-based approaches seem very suitable for this domain, but that this still needs to be verified by more deployed system.

1 Introduction

The research area of agent technology continues to yield techniques, tools, and methods that have been applied or could be applied to the area of traffic and transportation management. The aim of this paper is to present a consistent view of the research efforts made in this area.
We are mainly adopting a logistical perspective, thus focusing on transportation rather than traffic, and on freight rather than people. In particular, we will not survey the extensive work on agent-based modeling of driver and commuter behavior. Also we will not consider approaches to supply-chain management.

In the next section, the areas where agent technology may be useful will be identified. We then present a framework that will be used to classify and assess the research in the area. This is followed by a systematic survey of the work found in the literature. Finally, we analyze our findings and present some conclusions.

2 Background

The development of distributed and heterogeneous systems, such as software for automation of, and decision support for logistics management, poses significant challenges for system developers. *Agent technology* [73], [75] aims to provide new concepts and abstractions to facilitate the design and implementation of systems of this kind. Parunak [51] lists the following characteristics for an ideal application of agent technology:

- *Modular*, in the sense that each entity has a well-defined set of state variables that is distinct from those of its environment and that the interface to the environment can be clearly identified.
- *Decentralized*, in the sense that the application can be decomposed into stand-alone software processes capable of performing useful tasks without continuous direction from some other software process.
- *Changeable*, in the sense that the structure of the application may change quickly and frequently.

- *Ill-structured*, in the sense that all information about the application is not available when the system is being designed.
- *Complex*, in the sense that the system exhibits a large number of different behaviours which may interact in sophisticated ways.

As most transport logistics applications actually fit Parunak's characterisation rather well, this would suggest that agent technology indeed is a promising approach for this area. However, it is not suitable for all applications. For instance, in applications that are monolithic, centralized, static, well-structured, and simple, agent technology will probably not provide any added value, only unnecessary complexity.

3 Evaluation framework

For each paper surveyed we describe the problem studied, the approach taken to solve it, and assess the results.

3.1 Problem description

Each problem description includes the following three parts: the domain studied, the mode of transportation, and the time horizon considered.

3.1.1 *Domain*

We have chosen to divide the problem descriptions into three domains: *transport*, *traffic* and *terminal*. A transport is an activity where something is moved between point A and B by one or several modes of transport. Problem areas that fall under the category transport are e.g. route planning, fleet management, different sorts of scheduling, i.e., functionalities that takes place to support transportation.

While transport refers to the movement of cargo from one point to another, traffic refers to the flow of different transports within a network. One train set is thus a transport, or part of a transport, that takes part in the train traffic flow. Hence, a transport can be part of several traffic networks (air, waterborne, road, rail,) and a traffic network constitutes of several transports. Typical traffic activities are traffic flow scheduling such as railway slot allocation, air traffic management, and railway traffic management.

Within for example a transport chain where the cargo is transported by truck, rail, ship and truck again, there are interfaces between the different modes. These interfaces represent nodes for re-loading and are referred to as terminals. Terminals can be any fixed place where the cargo is handled and require access to different kinds of resources. Typical terminal activities are resource allocation and scheduling of cranes, forklifts and parts of a facility.

3.1.2 *Transport mode*

There are five basic modes of transportation: *road, rail, air, water,* and *pipeline* [64]. Although the use of pipelines often offers the cheapest method in transporting bulk fluids in long distances, we will in this paper not regard this modality.

The water transport via sailing vessels offers one of the most used and less costly means of transporting bulk goods. The use of rail is often associated with bulk items transported less costly than road to far distant markets. The flexibility and often-inevitable use of road for the beginning or final transport mode in a transportation chain makes this the most often used form of transport. Road transport is often associated with faster delivery in short distances and is attractive to shippers and customers that demand choice and flexibility in scheduling. Finally, air transport mode offers the fastest means of transport and usually the most expensive. This mode is usually reserved for high-valued goods that need to be transported across large distances. The use of air is also considered in short supply times, as in the case of disaster relief.

All freight transport modes can include, for example, fleet management techniques, route and maintenance planning, on-board loading/unloading techniques and on-board computers. In all cases, the emphasis will be on the impact on organizational costs and service levels. Usually in freight logistics, transportation represents the most important single element in logistics costs for most firms [5]. Transportation is a key decision area within logistics due to, on average, a higher percentage of logistics costs associated with this activity than any other logistics activity [5]. The selection of which mode of transport is to be used is dependent on several factors associated with the type of cargo/goods, e.g., requirements on speed, handling, costs, distance, flexibility etc.

Intermodal transportation, refers to "movement of goods in one and the same loading unit or vehicle that uses successively several modes of transport without handling of the goods themselves in changing modes" according to the definition of The European Conference of Ministers of Transport [24]. The definition is valid also for personal travelling that includes two or more different modes of transportation. One of the primary challenges in intermodal transport management is to coordinate several inter-dependent activities within the transport as well as the communication between the multiple actors involved.

3.1.3 *Time horizon*

Historically, the term logistics referred mainly to issues regarding technical and physical flows of products on an *operational* level. Today, the term includes both strategic and tactical issues beside the operational ones and includes the information flow connected to the physical flow. Therefore, the applications and concepts studied and presented are divided into levels of time perspective; *strategic*, *tactical* and *operational* level of decision-making. This is an established classification that is widely used. It can also be seen as a hierarchy in decision time [61]. We will here by *time horizon* refer to at what stage in the decision-making process the application is used, or is intended to be used. There are two dimensions often distinguished, the level of decision-making and its time frame. There is no definite line of separation, but strategic decision-making typically involves long-term decisions concerning determining what to do, while tactical deals with medium-term issues of setting up an action-list, and operational how to conduct the work set out in more specific terms, i.e. short term issues [61]. The time horizon for these levels is highly domain dependent.

In this study we also include the execution of tasks and real-time controlling functionalities within the operational decision-making. For a transport operator, as an example, a strategic issue to address would be where to locate distribution centres, while a tactical issue would be to tailor the vehicle fleet to satisfy the customer demands, and the operational level would involve scheduling of each and every transport and the controlling function with monitoring and ad-hoc planning if necessary.

As can be seen there is no established definition on time frame or content in the different planning hierarchy, and it is highly dependent on what type of business that is addressed.

3.2 Approach

Each approach is described by the following three parts: the intended usage of the agent system, the type of agents used, and the type of coordination chosen.

3.2.1 *Usage*

The applications studied can be classified, according to this paper, as either to serve as an automation system, or a decision-support system. An *automation* system can be defined as "having a self-acting mechanism that performs a required act at a predetermined time or in response to certain conditions" [46]. In this context it refers to a system's ability to act upon its decisions, i.e. it has a direct influence on the controlled environment and there is no human involved. On the contrary, a *decision-support system*, DSS, has only at most an indirect impact on the decision-making. A DSS is a system that provides output of some specified type to support the decision process for the user. The user, i.e. the decision-maker, takes the suggested decision(s) into consideration, and then acts. Thus, the final decision is made by a person, not the software system.

3.2.2 *Coordination (control, structure and attitude)*

Researchers in many fields including computer science, economy, and psychology have studied the area of coordination, which can be viewed as "managing the interdependencies among activities" [45]. In any environment where software agents participate, the agents need to engage in cooperative and/or competitive tasks to effectively achieve their design objectives. From the multi-agent systems perspective coordination is a process in which agents engage in order to ensure that a community of individual agents acts in a coherent manner [48]. Coordination techniques are classified here according to the three dimensions control, structure and attitude.

We capture the authority relationships between agents in the dimension of *control*, which is either centralized or distributed (decentralized). The *MAS structure* corresponds to the set of agents constituting the MAS, their roles, and the communication paths between agents. The structure is either predetermined, i.e., static (the set of agents or their roles do not change during the execution), or is changing dynamically. Finally, the *agent attitude* dimension captures the behavior of agents, which is classified as either benevolent (cooperative), i.e., they will comply with social laws and global goals, or selfish (competitive), where the agents' individual goals, e.g., in a market-based economy, will govern their behavior.

3.3 Results

The main classification of the result of the approaches will be in terms of maturity of the research. However, we will also try to assess the performance and the limitations of the approaches.

3.3.1 *Maturity*

Agent applications can have varying degree of maturity, i.e., how complete and validated an application is. According to Parunak [52], the description of the maturity of an agent application helps the users to assess how much work that remains to carry out the implementation of the agent application. Furthermore, Parunak has suggested a number of degrees of maturity which formed the basis for our refined classification.

The lowest degree of maturity in the classification is *conceptual proposal*. Here the idea or the principles of the proposed application is described with its general characteristics, e.g. if the model is simple or complex. In the literature the term *conceptual model* is quite well-established and well-defined. However, we prefer the more open term conceptual proposal since it otherwise could be more difficult to fit in all applications according to the classification.

The next level in the classification is *simulation experiments*. Here the application has been tested in a simulation environment. The data used in the simulated experiment can either be real data, i.e. taken from existing systems in the real world, or data that is not real, i.e. artificial, synthetic or generated. Further, the type of data has been divided into limited/partial or full-scale data. The full-scale data represents data for a whole system, while the limited/partial data only covers parts of the system.

Field experiment indicates that experiment with the application has been conducted in the environment where the application is supposed to be applied. As in the simulated experiment, the field experiment is also divided into limited/partial and full-scale. The final level, *deployed system*, indicates that the system has been implemented in the real world and also has been or is in use. This is the most mature type of agent applications.

3.3.2 Evaluation comparison

If a new approach is developed to solve a problem which has been solved previously using other approaches, the new approach should be compared to those existing approaches. Such an evaluation could be either *qualitative*, by comparing the characteristics of the approaches, or *quantitative*, by different types of experiments.

3.4 Summary of framework

Table 1 on the next page summarizes the framework for describing and assessing the agent-based approaches to logistics. The Appendix provides a table listing the published work in the area of agent-based approached to transport logistics that we have encountered is classified according to this framework. The papers in the table are first sorted according to domain and then according to mode of transportation. In the case where several papers have been published regarding the same project, we have chosen the most recent publication and/or the most widely available.

Table 1. Classification framework

	Aspect	**Categories**
Problem description	Domain	1. Transport 2. Traffic 3. Terminal
	Transport mode	1. Air 2. Rail 3. Road 4. Sea 5. Intermodal
	Time horizon	1. Operational 2. Tactical 3. Strategical
Approach	Usage	1. Automation system 2. Decision support system
	Control	1. Centralized 2. Distributed
	MAS structure	1. Static 2. Dynamic
	Agent attitude	1. Benevolent 2. Selfish

Results	Maturity	1. Conceptual proposal 2. Simulation experiment 2.1. artificial data 2.1.1. limited 2.1.2. full-scale 2.2. real data 2.2.1. limited 2.2.2. full-scale 3. Field experiment 3.1. limited 3.2. full-scale 4. Deployed system
	Evaluation comparison	1. None 2. Qualitative 3. Quantitative

4 Analysis of Survey

The survey shows that agent technology has been applied to many different problem areas within transport logistics. Often these agent approaches are distributed and very complex by nature, such as: planning and scheduling, fleet management, transport scheduling, traffic management, and traffic control. In the work reviewed, there was an even distribution between the three domains (transport, traffic, and terminal), whereas the modes of transportation were dominated by air, road and intermodal. It is worth noting that very little work has been done studying strategic decision making. In addition, only a few of the publications concerning air and rail deal with transport-centered issues. In Figure 1, the distribution of modal focus over the domains can be seen. Figure 2 shows the number of applications per mode that have addressed strategic, tactical and/or operational aspects.

Most of the *rail*-related publications address problems of allocating slots for the railway network, i.e., timetabling. This is a problem seldom found within the other modes of transport besides air traffic (even though railway slot allocation differs significantly from air traffic slot allocation). Market-based approaches [19] have appealed to several of the researchers, where the coordination mechanism is very similar to the negotiation that takes place in practice. In addition, some publications study resource allocation for specific rail transports, but these problems are not modal-specific to the same extent as the slot allocation problem. Several of the approaches have been evaluated experimentally, but no deployed system has been found. Methods that are alternative to agent technology for these kinds of problems are often centralized optimization and simulation technologies.

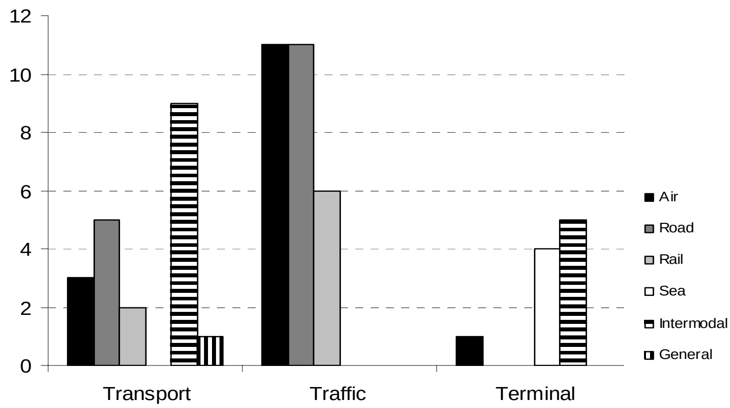

Figure 1. Problem description: Distribution of domain and transport mode.

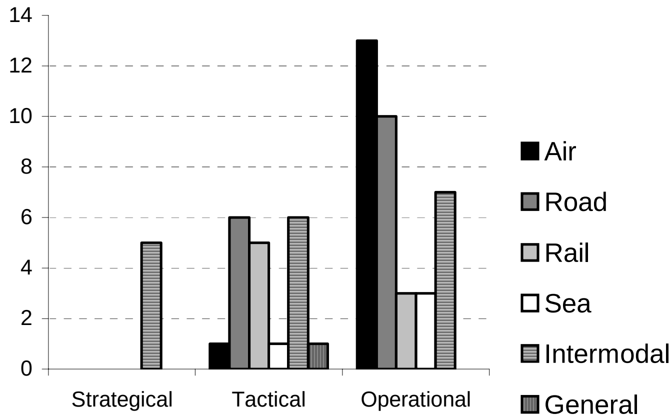

Figure 2. Problem description: Distribution of transportation mode and time horizon.

Regarding the publications that relate to *air* traffic and transportation, the studies on air traffic management is dominating and agent technology seems to have been applied to this problem area for more than a decade. The main topic addressed is distributed air traffic management using free flight, i.e., the aircrafts are allowed to choose their speed and path in real-time and air traffic restrictions are only applied when air space separation is required. Just one application focusing on airport slot allocation for a tactical setting has been found, which is surprising as many railway scheduling applications exist. Only a few publications in the air domain deal with transport related issues.

In the papers on *road transports*, most of the problems concern transport scheduling, i.e., allocating transport tasks to vehicles. The approaches are distributed and include negotiation in various manners, such as the contract net protocol, and sometimes they are market-based. However, also Multi Agent Based Simulation (MABS) is used in some applications. The agents in these applications represent different roles, e.g., a company, a truck, a customer etc. The transport applications are on a tactical level and the purpose is most often to serve as a DSS to a transport operator since the problem is complex and need some human supervision before the final transport task allocation. Alternative methods to agent technology in road transport are classical mathematical methods, and operations research.

In the *road traffic* domain most of the problems concern traffic management and control to deal with for example congestion of the roads. The applications are designed to inform drivers about the traffic situation and give recommendations, regulate the traffic with signals and messages, and so on. A couple of the applications deal with public transport management where the actual status of the vehicles is compared to the planned status, e.g. a timetable. The majority of the systems are on the operational level and most of the applications function as a DSS, but some are designed to serve as automation systems. Alternative methods mentioned in the papers, are evolutionary algorithms, knowledge-based systems, neural networks, and fuzzy theory.

Concerning the *sea* mode of transportation, most application of agents have been trying to increase the efficiency of the container terminal operations. Many papers tend to focus specifically at the marine-side interface whilst disregarding the other processes in the terminal that determine overall terminal performance, e.g., the stacking of containers. The terminals are characterized as complex and dynamic systems and researchers find the relationships between the many actors involved having both common and conflicting goals, in which vast amounts of information are not processed adequately to encourage the use of agents. Several papers focus exclusively on the operational processes of communication between the gantry cranes and the straddle carriers in order to reduce idle time and the number of times that a container is handled, whereas a couple of papers deal with tactical and strategic decisions. Unfortunately, the majority of the papers reviewed do not state clearly the type of agent approaches used or how their agents are able to communicate and make decisions. Interestingly, within the sea mode of transportation, most research has focused primarily on the terminal domain with very few papers considering the traffic and transport domains.

Of the reviewed publications regarding *intermodal* transportation, primarily the combination of road and rail has been considered. The problems studied are usually to coordinate several tasks for a specific transport, such as slot request, terminal handling and allocating transport services. The approach is typically to identify a set of different roles, similar to the real-world functions, and allocate agents for each of these. Although only a few publications were found, the work in this area seems to be extensive at the moment and rapidly developing. Some alternative methods for these problems are discrete-event simulation and optimization. In practice, however, they are more often dealt with in an ad-hoc manner with a mix of human-intervention and spread-sheet analysis. For this domain, as for the other domains, the benefits of using agent-based approaches are not explicitly discussed.

The main reasons mentioned in the papers for adopting an agent-based approach are: facilitates distributed control, ability to cope with partial and noisy data, and ability to model complex problems. Although the ability to distribute control is the most cited reason, it is interesting to note that 30% of the projects surveyed make use of centralized control. Also, only half of the applications utilize the possibility of dynamic MAS structures, which is an often cited strength of agent technology. A majority of the work (64%) concerns the use of agent technology in decision support systems. Figures 3 and 4 illustrate the distribution of the approaches taken for decision support systems and automation systems respectively (two systems are both decision support and automation systems).

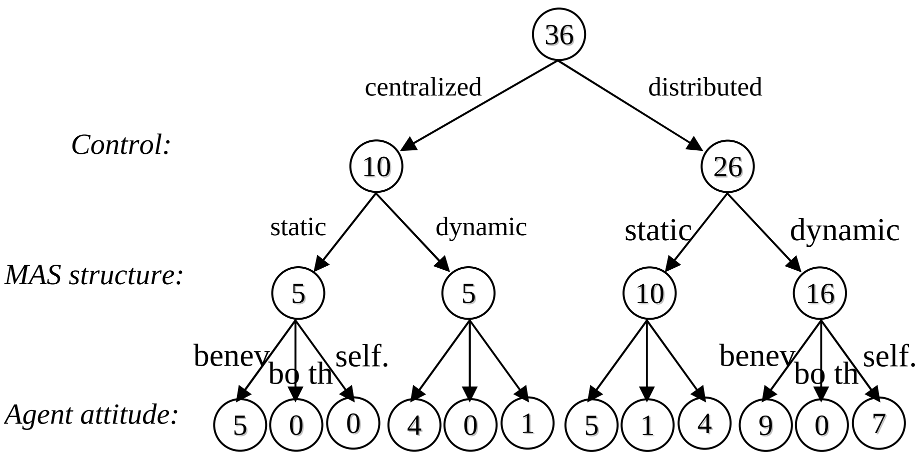

Figure 3. Number of approaches to decision support systems.

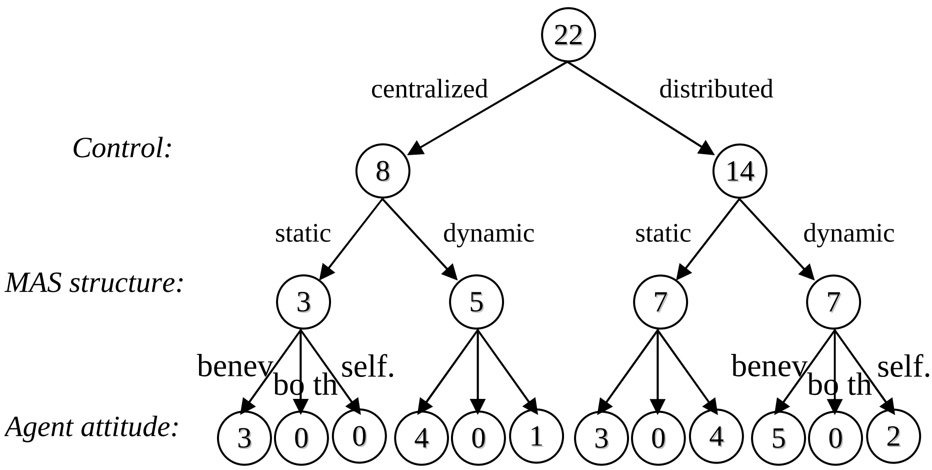

Figure 4. Number of approaches to automation systems.

Regarding the maturity, the vast majority of the approaches surveyed have just reached the level of conceptual proposal (30%) or simulation with limited or artificial data (53%). An obvious danger with simulation experiments based on artificial or partial data is that abstractions are made that simplifies the problem to a point where the results are not relevant for real-world problems. The table below illustrates how the maturity of the projects has developed through the years, i.e. presenting the number of projects found per year and maturity level. The most recent publication found for each project is included. As can be seen, only one deployed system could be found.

Table 2. Results: Maturity level over the years.

Maturity	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
1				1		1	1			2	5	7		
2.1.1	1							1		3	3	1	3	1
2.1.2				1							1			1
2.2.1		1			1			5	1	2	1	1	1	
2.2.2	1						1			1	2	1		
3.1									2			1		
3.2														
4											1			

In two thirds of the approaches surveyed, agents are applied to solve problems without considering current or alternative approaches to solve these problems. Of those that actually are making comparisons, the majority make only qualitative comparisons. The alternative approaches regarded in the papers are, e.g., for traffic management: evolutionary algorithms, knowledge-based systems, neural networks, fuzzy systems; and for transport scheduling: classical mathematical and operations research methods, i.e., mainly centralized approaches. In Table 3, the number of approaches per evaluation and maturity level is presented.

Table 3. Results: Maturity and evaluation level.

Maturity	Evaluation comparison			
	None	Qualitative	Quantitative	Both
Conceptual approach	15	2		
Partial scale simulation with fictive data	9	1	2	1
Full scale simulation with fictive data		2	1	
Partial scale simulation with real data	8	3		2
Full scale simulation with real data	2	1	2	1
Field experiment limited scale	2	1		
Field experiment full scale				
Deployed system				1
Total	**36**	**10**	**5**	**5**

5 Conclusions

While producing the survey we have identified a number of positive aspects of the current state of agent-based approaches to logistics:

- Many different approaches have been suggested and investigated.
- Many of the logistics problems that have been studied have characteristics that closely match those of an ideal agent technology application very well.
- Especially in the areas of air and road traffic management agent technology seems to have contributed significantly to the advancement of state-of-the-art.

However, there are also some things that can be improved:

- The maturity of the research; few fielded experiments have been performed and very few deployed systems could be found.
- The suggested agent-based approaches are often not evaluated properly; comparisons with existing techniques and systems are rare. Both qualitative assessments explaining the pros and cons of agent technology compared to the existing solutions, and quantitative comparisons to these solutions based on experiments, are desired.

- Some problem areas seem under-studied, e.g., the applicability of agent technology to strategic decision-making within transportation logistics.

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Appendix Survey results

	Problem Description			**Approach**				**Results**	
Paper	*Domain*	*Mode*	*Time horizon*	*Usage*	*Control*	*MAS structure*	*Agent Attitude*	*Maturity*	*Evaluation Comparison*
[12]	Transport	Air	Oper.	Auto	Centr.	Dyna.	both	1	None
[53]	Transport	all	Tact.	DSS	Distr.	Dyna.	Selfish	2.2.1	both
[77]	Transport	Air	Tact.	DSS	Distr.	Static	Benev.	3.1	Qualit.
[15]	Transport	Rail	Tact.	DSS	Centr.	Static	Benev.	2.2.1	None
[62]	Transport	Rail	Tact.	DSS	Centr.	Static	Benev.	1	None
[9]	Transport	Road	Tact.	DSS	Distr.	Dyna.	Benev.	1	Qualit.
[29]	Transport	Road	Tact.	DSS	Distr.	Dyna.	Benev.	2.1.1	both
[41]	Transport	Road	Tact.	DSS	Distr.	Dyna.	Selfish	2.2.1	both
[58]	Transport	Road	Tact.	Auto	Distr.	Dyna.	Selfish	2.2.1	Qualit.
[59}	Transport	Road	Tact.	DSS	Distr.	Dyna.	Benev.	2.1.2	Qualit.
[11]	Transport	Intermod.	Oper.	Auto	Distr.	Static	Selfish	2.1.1	None
[13]	Transport	Intermod.	Oper.	DSS	Distr.	Dyna.	Selfish	2.2.1	None
[23]	Transport	Intermod.	Tact. & Oper.	DSS	Distr.	Static	Selfish	1	None
[31]	Transport	Intermod.	Tact. & Oper.	DSS	Distr.	Dyna.	Selfish	2.2.1	None
[54]	Transport	Intermod.	Strat.	DSS	Distr.	Dyna.	Benev.	1	None
[6]	Transport	Intermod.	Strat.	DSS	Distr.	Static	both	2.1.1	None
[1]	Transport	Intermod.	Strat. & Tact.	DSS	Distr.	Dyna.	Benev.	1	None
[76]	Transport	Intermod.	all	Auto	Distr.	Dyna.	Benev.	2.2.1	None
[14]	Transport Terminal	Air	Oper.	Auto	Centr.	Dyna.	Benev.	3.1	None
[56,57]	Transport Terminal	Intermod.	Tact.	DSS	Centr.	Dyna.	Selfish	2.2.1	None
[3]	Traffic	Air	Oper.	Auto	Distr.	Dyna.	Benev.	2.1.1	None
[16]	Traffic	Air	Oper.	both	Centr.	Dyna.	Benev.	2.1.1	Quant.
[27,28]	Traffic	Air	Oper.	Auto	Distr.	Dyna.	Selfish	2.1.2	Quant.
[39]	Traffic	Air	Oper.	DSS	Distr.	Dyna.	Benev	1	None
[42,65]	Traffic	Air	Oper.	DSS	Distr.	Dyna.	Selfish	1	None
[44]	Traffic	Air	Oper.	DSS	Centr.	Dyna.	Benev.	2.2.2	None

	Problem Description			Approach				Results	
Paper	*Domain*	*Mode*	*Time horizon*	*Usage*	*Control*	*MAS structure*	*Agent Attitude*	*Maturity*	*Evaluation Comparison*
[47]	Traffic	Air	Oper.	DSS	Centr.	Dyna.	Benev.	1	None
[49]	Traffic	Air	Oper.	Auto	Centr.	Dyna.	Benev.	2.1.1	None
[73]	Traffic	Air	Oper.	DSS	Distr.	Dyna.	Selfish	2.1.1	None
[69]	Traffic	Air	Oper.	Auto	Distr.	Static	Selfish	2.1.1.	None
[70,71]	Traffic	Air	Oper.	DSS	Distr.	Dyna.	Selfish	1	Qualit.
[7,8]	Traffic	Rail	Tact.	DSS	Centr.	Static	Benev.	2.2.1	None
[10]	Traffic	Rail	Tact.	DSS	Distr.	Static	Selfish	2.2.1	None
[20]	Traffic	Rail	Oper.	DSS	Centr.	Dyna.	Benev.	2.2.1	Qualit.
[25]	Traffic	Rail	Oper.	DSS	Distr.	Dyna.	Benev.	1	None
[50]	Traffic	Rail	Tact.	Auto	Distr.	Static	Selfish	2.1.1	Quant.
[66]	Traffic	Rail	Oper.	DSS	Distr.	Static	Benev.	1	None
[26]	Traffic	Road	Oper.	DSS	Distr.	Dyna.	Benev.	2.1.1	None
[38] InTRYS	Traffic	Road	Oper.	DSS	Centr.	Static	Benev.	4	both
[38] TRYSA$_2$	Traffic	Road	Oper.	DSS	Distr.	Static	Selfish	2.2.2	both
[18]	Traffic	Road	Oper.	Auto	Distr.	Static	Benev.	2.2.2	Quant.
[2]	Traffic	Road	Oper.	both	Distr.	Dyna.	Benev.	2.1.2	Qualit.
[4]	Traffic	Road	Oper.	DSS	Distr.	Static	Selfish	2.2.1	Qualit.
[30]	Traffic	Road	Oper.	Auto	Centr.	Static	Benev.	2.2.1	None
[34]	Traffic	Road	Oper.	DSS	Distr.	Static	Benev.	3.1	None
[67]	Traffic	Road	Oper.	Auto	Distr.	Dyna.	Benev.	2.1.1	Qualit.
[68]	Traffic	Road	Tact.	Auto	Distr.	Static	Selfish	1	None
[35]	Terminal	Road	Oper.	Auto	Distr.	Dyna.	Benev.	2.2.2	None
[40]	Terminal	Sea	Oper.	Auto	Centr.	Static	Benev.	1	None
[43,75]	Terminal	Sea	Tact.	DSS	Centr.	Static	Benev.	2.1.1	None
[17,55]	Terminal	Sea	Oper.	Auto	Centr.	Static	Benev.	1	None
[64]	Terminal	Sea	Oper.	Auto	Distr.	Static	Benev.	2.1.1	None
[21,22]	Terminal	Intermod.	Oper.	Auto	Centr.	Dyna.	Benev.	2.2.2	Quant.
[32,33]	Terminal	Intermod.	Tact.	DSS	Distr.	Static	Benev.	2.2.2	Qualit.
[36]	Terminal	Intermod.	Strat.	DSS	Distr.	Static	Selfish	1	None
[37]	Terminal	Intermod.	Oper.	Auto	Distr.	Static	Benev.	1	None

Paper III

Agent-based simulation of stakeholders relations: An approach to sustainable port and terminal management

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III

Abstract

Port management is often faced with many vexing problems that are complex and difficult to define. Port policies are in some cases formed from idealized perspectives and market factors, with very little attention or understanding to stakeholder strategies. Stakeholder Relations Management provides port management a means to consider stakeholders' interests in issues related to sustainable port development and management. Decision makers in port management have very few means of evaluating the stakeholder relationships and entities involved with port systems. This lack of information often results in ad hoc positions of port managers vis-à-vis stakeholders in the port community.

Simulation tools, in particular those using the Multi Agent Based Simulation approach, may help to structure and better understand the relationships within complex organizations. The MABS approach has been applied to other areas of policymaking and could be used to evaluate Stakeholder Relations Management by modeling and simulating the different stakeholders in a port system. This paper aims to describe an approach (supported with MAS-CommonKADS) enabling decision makers to simulate various port policies and analyze the multitude of "what if" scenarios. The development of a state-of-the-art, MABS of SRM would be the basis for a decision-support system. The results of the simulation rather than guarantee an optimum policy solution, would offer decision makers the ability to view the structure of a port system and the functions that the stakeholders have under various "what if" analyses.

1. Introduction

> *"Increasingly, competition is not between companies but rather between whole networks, with the prize going to the company that has built the best network. The operating concept is simple: build a good network of relationships with key stakeholders, and profits will follow." (Kotler, 2001)*

An IAPH report of the Combined Transport and Distribution Committee published in 1996 stated that a modern port is to be regarded as a function in a logistics system (IAPH, 1996). Ports find themselves embedded in ever changing logistics systems and networks. The globalising market place, with powerful and relatively footloose players, extensive business networks and complex logistics systems have a dramatic impact on the *raison d'être* of seaports. The logistics environment and the related risks and harms for the local community create a high degree of uncertainty and leaves port managers puzzled with the question how to respond effectively to market dynamics and to local community issues.

The port system is a complex system with many internal and external actors that are considered in this paper to be stakeholders in a port community, each with their own interests and objectives. However, according to a survey conducted by the European Sea Ports Organisation, only 17% of ports involved local communities and stakeholders in port development plans (Brooke, 2002). The use of networks as a metaphor has been used widely in scientific literature to describe the processes, activities, and relationships in ports and terminals (Gambardella et al., 1998, Frankel, 1987, Kia et al., 2000, and Notteboom and Winkelmans, 2002). The society or community view of a port or terminal may yield a richer detail of the inner workings of the structure and provide insight to the relationships between actors or stakeholders. In order to analyze the port community, an agent-based model will be used. The agent paradigm has been successful in modeling other societies or communities in varying fields of scientific research (see Bernard, 1999, Barton, 2000, and Downing, 2000). In building an agent based model to simulate stakeholder relationship management policies, a methodology known as the MAS-CommonKADS is employed in extracting and modeling knowledge on the port or terminal society.

The modeling and simulation of real systems, using terminals or ports, with the introduction of software agents has emerged as an interesting research area. Systems of this kind can be found in the transportation area with particular focus on traffic, logistics, supply-chain management, and physical distribution (Gambardella et al, 1998, Funk et al., 1998, Ljungberg and Lucas, 1992, Rebollo et al., 1999, Shinha Ray et al, 2003, Thurston and Hu, 2002, and Zhu and Bos, 1999). Most of these studies addressed pure operational issues such as the optimal use of available container handling equipment within a terminal. The use of modeling and simulation techniques to support policy decisions with respect to port functioning and port development, however, is a relatively little explored area of research.

The development of a MABS by using the MAS-CommonKADS provides a state-of-the-art technique in assisting port managers and decision makers to model and simulate port policies that may run to thousands of interactions amongst stakeholders. The use of MABS with Stakeholder Relations Management (SRM) constitutes a *multi-disciplinary* approach that includes maritime economics, distributed artificial intelligence, and stakeholder relations management in order to analyze the interests of various *stakeholders and their interplay and competition within ports.*

Port planning and the management of ports have often relied on various economic forecasting and econometric methods to guide port development policy. The introduction of stakeholder relation's management offers policy makers, port operators, and decision makers a framework to analyze the various stakeholder relationships and how they are directly or indirectly involved in port activities and port development. We argue that relationships and behaviors of stakeholders can be successfully captured by the models that are found in the framework of MAS-CommonKADS (i.e., agent model, task model, and communication model). After the model of the stakeholders, represented by software agents, has been designed we can implement the MABS.

The outline of this paper is to introduce the subject of stakeholder relations management in port activities, which is the basis for conceptualizing a model to simulate the stakeholders in the port community. The MAS-CommonKADS methodology will be explained and how it is used in developing a multi-agent model of the container terminal community. To better grasp the essence of the MAS-CommonKADS methodology we deliberately focus on the container terminal community instead of on an entire port system with its multitude of stakeholders. A description of a prototype that is currently being built is followed by a discussion of future work and a conclusion.

2. Stakeholders Relation Management

2.1. The port community and the concept of 'stakeholders'

The success of a port is not only determined by infrastructure, superstructure and related output performances. It is increasingly being determined by the way the port manager succeeds in directing the interactions between different stakeholders towards a common objective as described by the mission statement. The concept of 'stakeholders' has become a key term in any port management strategy.

A stakeholder is any individual or group having interest or being affected by the port. A port both technologically and economically is in fact a node for contacts and contracts, whereby every stakeholder is driven by his/her own interests and priorities. Ports are associations where a multitude of individuals and interests (should) collaborate for the creation and distribution of wealth. Hence, the value creation process in ports is dependent upon the support of the different stakeholders groups. Each group of stakeholders however merits consideration for its own sake.

Following the broad view on stakeholders and taking the viewpoint of a landlord port authority, Notteboom & Winkelmans (2002) have identified four main stakeholder groups in a port community:

1. *The internal stakeholders*. They are part of the comprehensive port authority organization (port managers, employees, board members, unions and shareholders).

2. *The external stakeholders (economic/contractual)*. This group includes in situ and ex situ economic players. The in situ group consists of the different port companies and supporting industries that invest directly in the port area and who generate value-added and em-

ployment by doing so. The ex situ group would consist of industries located in the foreland and hinterland. A port also is a cluster of strongly intertwined economic activities with linkages to economic activities outside the port perimeter. Each economic/contractual stakeholder in the port community can be brought into relation with one or more entities/functions within this economic cluster. Some of these companies are mainly involved in physical transport operations linked to cargo flows (e.g. terminal operators and stevedoring companies - including the carrier/terminal operator in case of dedicated terminals). Others solely offer logistical organization services (e.g. forwarding agencies, shipping agencies, etc.). Industrial companies in the port area (e.g. power plants, chemical companies, assembly plants,), supporting industries (e.g. ship repair, inspection services, etc.) and port labor pools also belong to the group of the first order economic stakeholders. Other economic stakeholder groups include port customers, trading companies and importers/exporters. They are less directly involved than the in situ economic groups, as they normally do not invest directly in the port. Nevertheless they follow the port evolution carefully, because port activity can influence their business results. Moreover, they exert strong demand-pull forces on port service suppliers and as such 'dictate' the market requirements to which the port community has to reply.

3. *Legislation and public policy stakeholders.* This group not only includes government departments responsible for transport and economic affairs on a local, regional, national and supranational level, but also environmental departments and spatial planning authorities on the various geographical decision levels.

4. *Community stakeholders.* Include community groups or civil society organizations, the general public, the press, and other non-market players. They are concerned about the port's evolution, i.e. mainly about its expansion programs, for reasons of well-being. They may experience actual or potential harms or benefits as a result of port action or inaction. It is possible that some community stakeholders may be unaware of their relationship to the port until a specific event - favorable or unfavorable - draws their attention. Figure 1

on the following page summarizes the various stakeholders of a port community identified by the authors.

Given the large number of stakeholders, port management is a complex matter. Port managers should acknowledge and whenever possible actively monitor the concerns of all legitimate stakeholders, i.e. they should take the interests of certain stakeholders appropriately into account in decision-making and operations. In taking particular decisions and actions, port managers should give primary consideration to the interests of those stakeholders who are most intimately and critically involved.

This balancing exercise is far from easy, given the latent danger of a struggle between port management objectives as a function of group interests. The underlying common interest of stakeholders of any port is the port's survival, but it is too simplistic to assume that all parties accept that the main port development objective is 'to provide port facilities and operating systems in the national interest at the lowest combined cost to the port and port users' (UNCTAD, 1985:27). Conflicts of interests among different stakeholders may overshadow the community of interests. The objectives of environmental pressure groups are often conflicting with that of the port authority: for the one the less expansion the better, for the other almost continuous extension is required to cope with market opportunities in the foreland-hinterland continuum. The central government usually pursues socio-economic objectives through an active seaport policy. This policy is aimed at increasing the societal value-added of the national seaport system. The central government objectives may conflict with or at least diverge from objectives of the port authority. The objectives of the port industries and operators usually relate to traditional micro-economic goals such as a mix of shareholder value, maximization of profits, growth, increase in market share, productivity, etc.

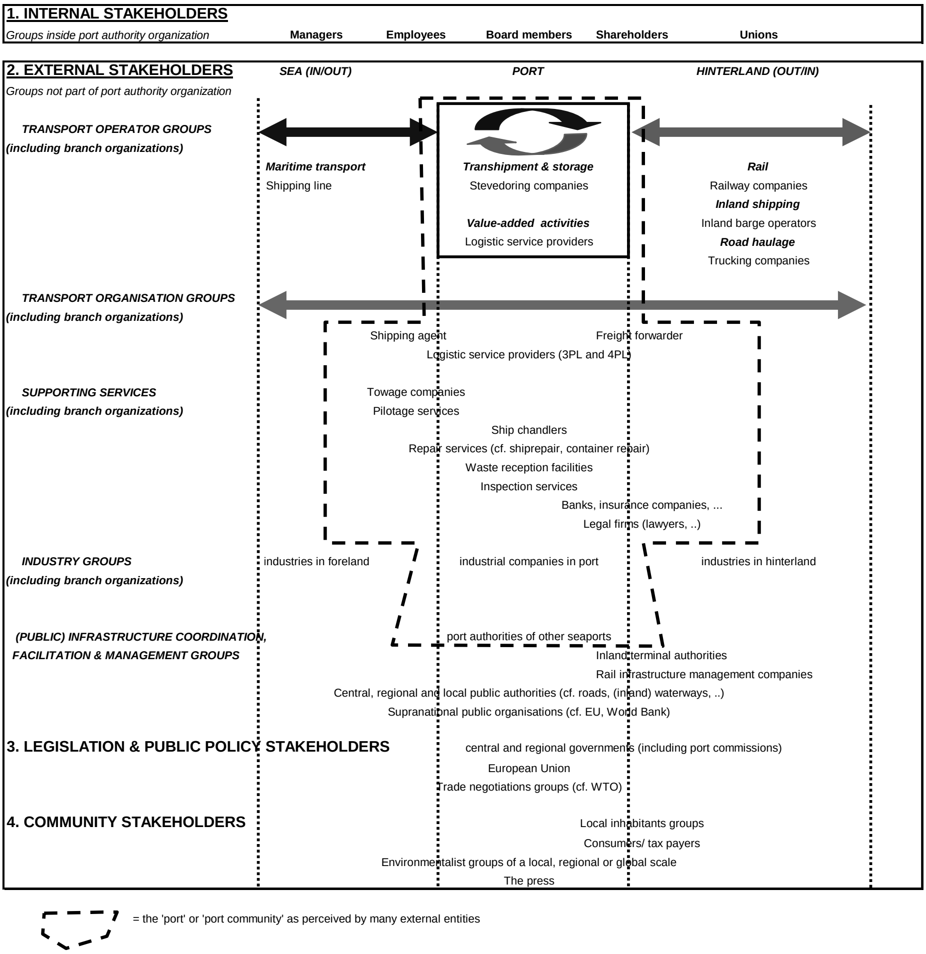

Figure 1. The Port Community Stakeholders according to the Authors of this paper

2.2. Structuring relationships between and within stakeholder groups

Two forms of interaction characterize the inter-organizational relationships among stakeholders: *physical* (i.e. related to the physical transfer of cargo) and *incorporeal* (Martin & Thomas, 2001). The latter type of interactions consists of contractual, supervisory or information based exchanges. The interactions between port authorities and the first order port players are mainly of an incorporeal kind. For instance, port companies involved in physical operations are linked to the port authority via concession agreements (esp. in case of landlord port authority).

There are several concerns that shape the relationships between and within stakeholder groups (Notteboom and Winkelmans 2002):

- distributional concerns, i.e. issues related to the distribution of costs and benefits among stakeholders, the trade-offs (e.g. between economic, ecological and the social value of ports) and the creation of win-win situations
- efficiency concerns, i.e. maximum output generation with a minimum of inputs
- behavioral concerns, e.g. related to cheating behavior, opportunism and bounded rationality. For instance, local pressure groups often defend their local interests in such a fierce way that the individual well being of a few people is becoming an even bigger driving force than the well being of the greater community.

These aspects do not only play a role in formal contracting among stakeholders, but also in less formal situations of stakeholder interaction.

Port managers need a better understanding of the relationships between and within different stakeholders groups as well as of the divergence/convergence of objectives and concerns among stakeholders. In most port organizations such an exercise is not done in an explicit way. Port managers typically take account of the behavior and perceived objectives of the different stakeholders, but they seldom have a good overall picture of the underlying dynamics that shape stakeholders relations. As a result, stakeholder relations management in ports typically is of an *ad hoc* nature and does not rely on any kind of framework that could help to assess possible action/reaction patterns in stakeholder relations.

2.3. Objective struggle and stakeholders relations in the container terminal community

The container terminal (CT) community consists of many market players and non-market players. The CT community is in fact a subset of the larger port community. The actors that are located in the CT community are found in Figure 2. The *physical* inter-organizational relationships between actors in the CT community are mainly of an operational nature i.e. related to the cargo handling itself. The *incorporeal* inter-organizational relationships between actors in the CT community are between organizations such as customs and port authority.

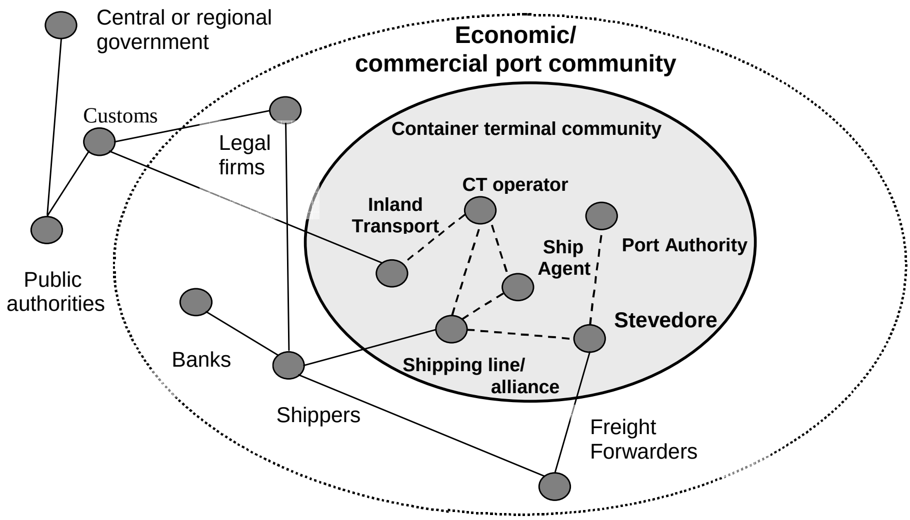

Figure 2. The container terminal community and its stakeholders

The relationships between and within stakeholder groups in the CT community are shaped by mutual concerns and converging/diverging objectives. Congestion and increasing cargo dwell times is a common scene in many of the world's ports. Government authorities such as customs and health may delay containers from reaching their destinations due to inspections. Shipping lines are unconcerned if there is a poor terminal productivity, as long as their vessel sails on time. Terminal operators are trying to reduce or stabilize the cost per TON/TEU (twenty-foot equivalent unit: container) handled and thus maximize profit. Ports and terminal operators are also cognizant of the coming changes and perhaps threats if they do not keep up with the pace of change. Ports such as Antwerp, Rotterdam, and Hamburg are expanding their terminals or creating new terminals to accommodate the projected rise in number of containers. The CT investment in Europe (1999-2001) was approximately 208 million Euros (Wiegmans et al., 2002). It is evident ports are seeking better ways in improving their productivity and offering logistical solutions to shippers of cargo. No longer are ports handling just cargo, but more and more they are becoming *"information handlers"* (Henesey, 2002).

Efficiency concerns are vital here. However, behavioral aspects can have an impact on the efficiency objective. For instance, human behavior might impede terminal operators from achieving an optimal terminal system configuration. Incorrect or incomplete information results in bounded rationality in terminal operators' terminal configuration, leading to sub-optimal decisions. Secondly, oppor-tunistic behavior of economic actors or informal commitments to individuals or companies might lead to non-cost minimizing decisions. Thirdly, terminal operators might stick to a specific configuration as they assume that the mental efforts (inertia) and transactions costs linked to changes in the terminal configuration will not outweigh the extra costs of the current non-optimal solution.

Due to increases in speed, volume, and behavioral influences, the operations of a CT requires a better regulating systems approach. One area where terminal operators are experiencing problems is reducing the unproductive and expensive container moves in a terminal. Software technologies such as agents may be able to assist terminals in increasing capacity and performance without spending large investments on terminal expansion and equipment. The "software" rather than the "hardware" of port development will be the determining factor in future trends in port competition vis-à-vis terminal management (Winkelmans and Van de Voorde 2002).

3. Multi Agent Based Simulation

In Distributed Artificial Intelligence lies a new paradigm, a converging technology called agent or Multi-Agent Systems (MAS). Agents can be seen as a system capable of interacting independently and effectively within its environment in order to accomplish given or self-generating task(s) (Davidsson 1996). The main characteristics of agents are autonomy, pro-activity, coordination, and communication. This approach facilitates in designing a distributed model of the CT, where agents carry out the processes and tasks. By having more than one agent, the model becomes a MAS, which leads to more complex issues, such as how are the agents to communicate or work together in order to fulfill task(s) or goal(s). Development in this area has led to a number of agent-oriented technologies such as multi-agent based simulation (MABS).

MABS differs from other kinds of computer-based simulation in that (some of) the simulated entities are modeled and implemented in terms of agents. As MABS, and other micro simulation techniques, explicitly attempts to model specific behaviors of specific individuals, it may be contrasted to macro simulation techniques that are typically based on mathematical models where the characteristics of a population are averaged together and the model attempts to simulate changes in these averaged characteristics for the whole population. Thus, in macro simulations, the set of individuals is viewed as a structure that can be characterized by a number of variables, whereas in micro simulations the structure is viewed as emergent from the interactions between the individuals. Parunak et al. (1998) recently compared these approaches and pointed out their relative strengths and weaknesses. They concluded, "…agent-based modeling is most appropriate for domains characterized by a high degree of localization and distribution and dominated by discrete decision. Equation-based modeling is most naturally applied to systems that can be modeled centrally, and in which the dynamics are dominated by physical laws rather than information processing."

If we compare MABS to traditional simulation approaches, e.g., Discrete Event Simulation (DES), we find that it has several advantages. It supports structure preserving modeling and implementation of the simulated reality. That is, there is a close match between the entities of the reality, the entities of the model, and the entities of the simulation software. This simplifies both the design and the implementation of the software, and typically results in well-structured software. In addition, MABS has the following important advantages compared to more traditional DES techniques (Davidsson 2000):

- It supports modeling and implementation of pro-active behavior, which is important when simulating human decision-makers that are able to take initiatives and act without external stimuli.
- Since each agent typically is implemented as a separate process and is able to communicate with any other agent using a common language, it is possible to add or remove agents during a simulation without interruption. And, as a consequence of this and the structure preserving mapping between the simulation software and the reality, it is even possible to swap an agent for the corresponding simulated entity, e.g., a real person during a simulation. This enables extremely dynamical simulation scenarios.
- It is possible to program (or at least specify) the simulation model and software on a very high level, e.g., in terms of beliefs, intentions, etc., making it easier for non-programmers to understand and even participate in the software development process.
- It supports distributed computation in a very natural way. Since each agent is typically implemented as a separate piece of software corresponding to a computational process (or a thread), it is straightforward to let different agents run on different machines. This allows for better performance and scalability.

From this we conclude, and have been argued by Downing et al. (2000) and others, that the MABS approach seems very promising for simulating stakeholder interactions such as in a seaport environment. In addition, a number of researchers have argued that the use of MAS as a metaphor in container and/or intermodal terminals is valid and supported by previous research (Gambardella, et al., 1998, Zhu and

Bos, 1999, Funk et al., 1998, Henesey et al., 2002, Thurston and Hu, 2002, and Sinha-Ray et al., 2003).

We will here model the CT community using MABS, where a software agent represents a physical stakeholder. In a MABS different agents may have different roles and also individual goals. The use of agents representing the various organizations or actors may provide alternative solutions in order to optimize the resources in the total terminal operations process.

The execution of the MABS may result in behavior or patterns that are interesting for analysis. This resulting or emerging behavior of the various agents modeled at a micro level and than simulated on a macro level would facilitate in better understanding of the complex interactions of the modeled agents. This understanding undeniably would contribute to a more structured approach on stakeholder relations management. There do exist other micro-modeling simulating strategies, however these strategies only model the entity at the micro level only, where as MABS allows the entities to interact and allow researchers to observe the behavior under complexity.

4. MAS-CommonKADS

Many methodologies exist for developing MAS (see Grüer et al., (2002) for short survey and description on formal frameworks for MAS analysis and design). Methodologies usually consist of models and rules that help to formalize the understanding of the system being analyzed. By using a formal approach to modeling, it allows the implementation of a system to be built more robustly.

According to Wooldridge (2002), there are basically two types of MAS methodologies, which can be used for analyzing and designing an agent-based system:

- methodologies that are rooted in object-oriented development; and
- methodologies adapted from knowledge engineering or other techniques.

The MAS-CommonKADS is a methodology adapted from Knowledge Engineering that we have used in designing the software agents by eliciting information from the physical (human) stakeholders. We considered using the MAS-CommonKADS because:

- applications of MAS-CommonKADS have been successful in various related areas such as the flight reservations systems (Arenas and Barrera-Sanabria 2002) and the steel roll-mill (Iglesias et al. 1998); and
- previous experience in using CommonKADS to model port knowledge in Karlshamn, Sweden, assisted in understanding the port operations.

Alternative methodologies were considered, such as the Gaia design model developed by Wooldridge (2002). However the Gaia model is primarily an analysis method.

The MAS-CommonKADS is an extension of CommonKADS, which is a formal methodology for the development of knowledge-based systems (KBS) and designing software to build such systems (Schrieber et al. (2001). The extension of the CommonKADS with Multi Agent Systems has largely been the result of work done by Iglesias et al. (1998) and Arenas and Barrera-Sanabria, (2002). According to Iglesias et al. (1998) the potential benefits for using MAS-CommonKADS are:

- The decisions on the selection of a multi-agent platform and architecture for each agent are documented.
- The design model collects the information of the previously developed models and details how these requirements can be achieved.
- The design model for MAS determines the common resources and needs of the agents and designs a common infrastructure managed by network agents. This facilitates in the design.

The MAS-CommonKADS, similar to the CommonKADS methodology, incorporates seven individual models that assist in eliciting tacit knowledge. Each model consists of entities to be modeled and relationships between the entities (Iglesias et al., 1998). The relationships between the seven models are described in Figure 3. The seven models:

- *Agent model* describes the characteristics of each agent.

- *Task model* decomposes and describes the tasks required for an agent. Also, determines what the goal(s) are.
- *Expertise model* (Knowledge) describes the knowledge needed by the agents to achieve their goals
- *Organization model* describes the structural relationships between agents (software agents and/or human agents);
- *Coordination model* is a descriptive model of the interactions and protocols between agents and describes the dynamic relationships between software agents
- *Communication model* focuses on modeling the dialogue between agents and describes the dynamic relationships between human agents and their respective personal assistant software agents
- *Design model* refines the previous models and determines the most suitable agent architecture for each agent, and the requirements of the agent network.

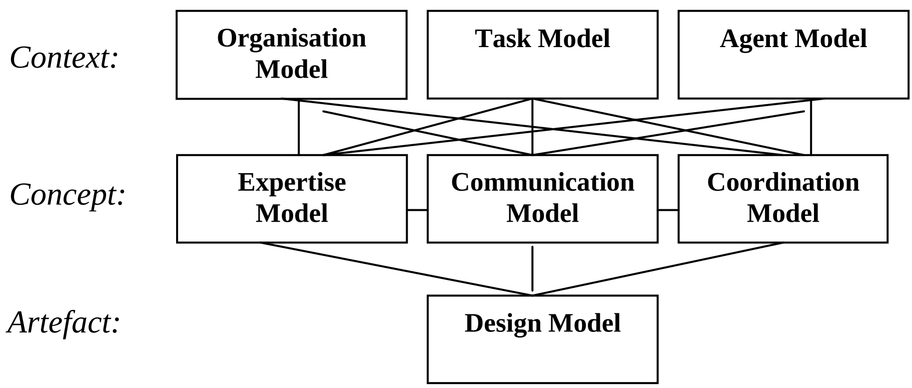

Figure 3. The MAS-CommonKADS model.

The overall MAS-CommonKADS methodology for multi-agent systems development, according to Iglesias et al. (1998) follows these phases:

- *Conceptualization.* Elicitation task to obtain a first description of the problem and determination of use cases which can help to understand informal requirements Potts et al. (1994 cited Iglesias 1998, p. 2) and to test the system.

- *Analysis.* Determination of the requirements of the system starting from the problem statement. During this phase the following models are developed: *Organization Model, Task Model, Agent Model, Communication Model, Coordination Model and Expertise Model.*
- *Design.* Here is determined how the requirements of the analysis phase can be achieved by the developing of the *Design Model*. It is determined the architecture of both the global multi-agent network and each agent.
- *Coding* and *testing* of each agent
- *Integration.* The overall system is tested.
- *Operation* and *maintenance.*

In what follows, particular attention is focused on the *Agent Model, Task Model, and Organization Model* in order to successfully simulate the stakeholders' relations contextual environment.

5. Terminal Community Model

We have completed the conceptualization phase and are currently in the analysis phase. The model of the container terminal community is populated by many agents (stakeholders) that possess individual goals (set of functions that are specified). The trade-offs that may occur in reaching a desired state can be reviewed through simulation experiments. Through using the MAS-CommonKADS, the set or ranges of parameters can be assessed while the simulation provides a means to evaluate many different alternatives, i.e. supporting stakeholder relations management.

5.1 Conceptualization

The knowledge of the port domain was obtained via interviews with various port managers in Europe, North America and in South Africa. The experience of one of the authors in working in terminal operations with Evergreen has provided additional help in understanding the port system. Through the information and data collected, scenarios were developed and stakeholder roles were identified. From the scenarios, the context of the port system is developed and is eventually refined via the use of the models in MAS-CommonKADS.

5.2 Analysis

The analysis phase assists in the development of requirements specification. The work sheets and templates of the MAS-CommonKADS methodology assisted in the mapping of the physical stakeholders to agents for the port simulator. Since we will develop a simulator (where stakeholders/agents exist apriori), this task is more straightforward than if, for instance, a control system was to be developed. That is, the task is to *identify* them rather than *inventing* them. The *Organization Model, Agent Model, Task Model* each will be individually discussed below, whereas the *Coordination Model, Communication Model and Expert Model* are only briefly discussed.

5.2.1 Organization Model

The *organization model* provides through five worksheets, a structured view of the *static* relationships and ties between the agents (stakeholders) and their environment in a systematic approach. The *organization model* assists in analyzing the organization in locating bottlenecks, problems, and potential solutions. The model is viewed as an important first step in the developing the context of the CT environment. Most of the hierarchical processes found in a CT often differ from other CTs, e.g. the port of Karlshamn has a flat hierarchy separated between administration and operations. The feasibility of structuring the organization is ascertained by looking at organization from a knowledge orientation point of view. The model provides information on the organizations work processes and assists in identifying the impact of implementing a MAS. The information or data obtained in the *organization model* contributes to the building of the *task model* and *agent model.* In addition, the organization model elicits organizational information that includes: culture, mission, strategy, problems, opportunities, and knowledge assets. An overview of the organization model is described in Figure 4.

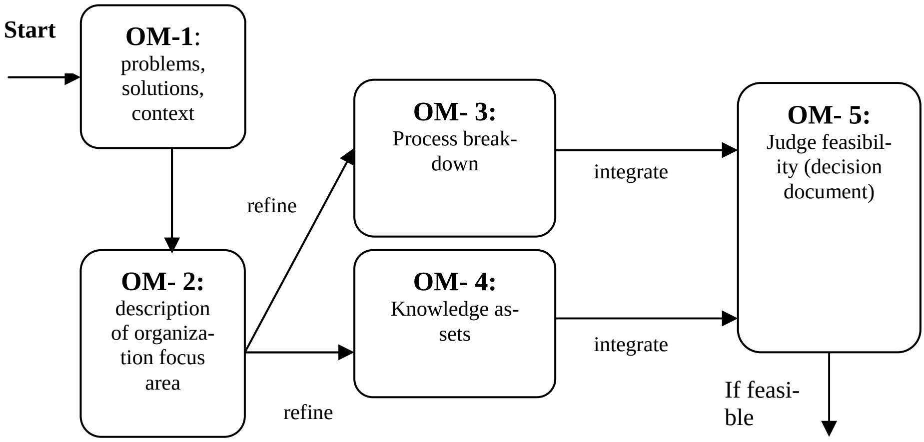

Figure 4. Overview of Organization Model Worksheets from Schreiber et al. (2001)

5.2.2 Agent Model

The *Agent Model* worksheets assist in collecting particular characteristics of the agents, e.g. the Yard planner in a CT would not control the arrival of trucks to the gate or allocation of gantry cranes to a vessel. The example of the agent model for the ship planner is described in Table 1. From the list of stakeholders found in Figure 1, we were able to identify the following stakeholders to be considered for the CT model:

- *Ship planner's* main task is to conduct calculations that lead to producing a load lists. The load list assists in correctly and efficiently loading and unloading a ship according to various parameters and constraints. The planner may request additional equipment.
- *Port Captain* is concerned with optimal allocation of fixed capital, such as the berth and cranes to the customer (ships and cargo).
- *Yard planner* manages the physical stacks of cranes according to various policies.
- *Stevedore* is focused on the physical handling and providing the service as demanded by the ship agent.
- *Port Authority* maximize throughput, quality of service, and return on capital invested while seeking to minimize vessel time in port.

- *Ship Agent* seeks to minimize port user costs on behalf of the ship owner.
- *Shipping Line or Alliance* is interested at maximizing net profits, operating at least cost
- *Inland Transport operator* is concerned with providing quality service, low costs, maximizing return and profits while minimizing costs.

Table 1. Agent Model of Ship Planner

Agent Model	**Agent Worksheet AM-1**
Name	1. Ship planner
Organization	2. Centralized-command hierarchical systems
Involved in	3. Producing work schemes, planning of loading and discharge of vessels. Involved with information analysis and calculations
Communicates with	4. Stevedore, Ship Agent, Ship Line, and with Yard Planner
Knowledge	5. Algorithms to sort and load
Other competencies	6. Print, distribute, and retrieve information
Responsibilities and Constraints	7. Responsibilities: produce an "error free" load list that minimizes the handling required by the terminal. 8. Constraints: quality of information entered, Amount of information entered, up-to-date rules.

5.2.3 Task Model

The *task model* assists in locating which objects are to be utilized or handled in the CT for executing a specific task. The degree and manner that the tasks are executed and the effects that a particular task may have on another task or tasks are identified and listed in Table 2. As mentioned by Iglesias et al (1998), the advantages of documenting the tasks and activities of the organization assist in the management of changes in the organization. The model assists in analyzing the resources, competencies, performance demands and other conditions in carrying out the main business function, i.e. handling cargo or containers.

Table 2. Task Model for Loading a Vessel

Task Model	**Task Analysis Worksheet TM-1**	
Task	Cf OM-3	Loading
Organisation	Cf OM-2	Vessel Operations in a CT
Goal and Value		To load a vessel with less moves as possible. Using "Quality" (i.e. fast, complete, and correct), information. **Codify experience** Value is faster turn-around time for vessel and less costs for loading.
Dependency and Flow	1.preceding tasks 2. follow-up tasks	Input: **tasks 1,2** (receive information of container) **task 4** (place it at its best position at vessel. Output: Print or send a schematic diagram *(Manifest*) of what and where each container is to be loaded.
Objects handled	Input objects Output objects Internal objects	Information (B/L or TIR) Scheme-Manifest. Vessel "worked" Reports, load list, customs docs.
Timing and Control	Frequency, Duration Control Constraints and Conditions	Frequency: 24 hours 7 days a week. Duration: 1 hour Constraints: Security and Safety. Tasks 1, 2, 3, are preconditions. Conditions are time, moves, rules for stowage, Post conditions are a Manifest that shows a well planned and loaded vessel Less moves and having a faster turn around is the objective
Agents	OM2: People, System Resources; Om-3: Performed by	Computer to help plan, (ship planners) print out plan for distribution to the stevedores (varies between 5 to 7 members). Personal (ship planner and yard planner) key in and monitor the plan.

Knowledge and Competence	Cf.OM-4	Vessels ops (ship planner) the loading Knowledge of computer, constraints, scheme of vessel, what are the rules for each container? Ports of destination? Weights? Hazardous Y/N, proper documentation
Resources	Detailing of OM-2	Computer systems, staff equipment (cranes & container fork lift)
Quality and Performance	Measures	Each unit has its own set goals.

5.2.4 Other Models

The *communication model* includes interactions between stakeholders that may be involved in a task, e.g. the *Port Captain* agent and other agents (ship planner, stevedore, ship agent, etc.) involved in scheduling operations for a vessel in a CT. The communication transactions between the stakeholders are labeled and modeled. The *coordination model* uses templates similar to those of the *communication model*, but taking into consideration human factors such as facilities for understanding the recommendations given by the system. The templates assist in understanding the coordination process within the terminal, e.g. straddle carriers may be bounded to a single gantry crane and can not feed containers to another gantry crane working on the same ship. The *expertise model* is split into the development of the application knowledge and the definition of the problem solving method (Schreiber et al. 2001). In order to develop the application knowledge, we determine the domain knowledge, which defines the ontology and models of the domain; the task knowledge, which specifies the knowledge needed by a task to reach its goals; and the inference knowledge, which represents the inference steps needed to solve a task.

6. Simulator Software

The CT simulator is composed of two systems, the *stakeholder agents* and *physical environment.* The stakeholder agents system is where decisions are made and information is generated, i.e. ship planning, berth assignments, and ship line schedules. From the interactions between the stakeholder agents, appropriate decisions are made and sent to the CT simulator located in the physical environment. The physical environment generates information from the simulations that is sent to the stakeholder agents. The communication between the two systems is built on Java programming language using the Remote Method Invocation (RMI) facility and facilitates what the two systems require, namely sending information (objects) to each other. A diagram of the prototype of the CT system is shown in Figure 7 and is being developed partially from a case study of a terminal in Sweden.

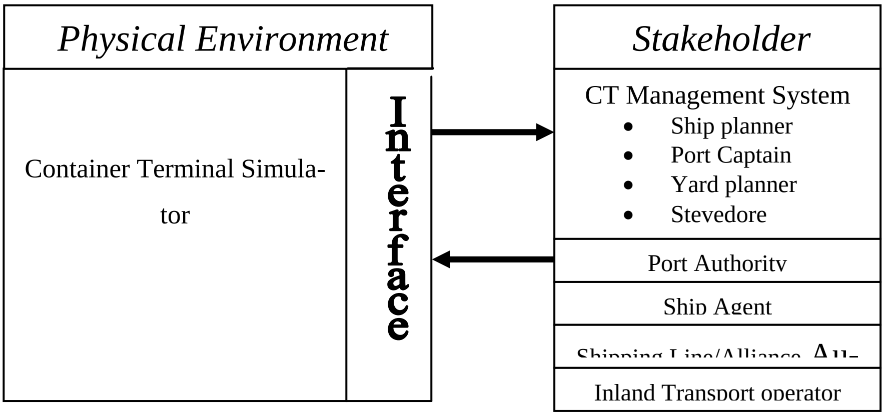

Figure 7. The architecture of the prototype simulator

The environment of the model is not fully designed from the worksheets. The berthing and loading/unloading operations have been modeled and simulated. The modeling of the stakeholder agents has been designed but not fully implemented; only the ship planner and port captain are functional.

7. Conclusion and Future Work

So far, the methodology has assisted in providing the tools to help design the CT system simulator. The information collected from the various worksheets in MAS-CommonKADS is quite formal and often repetitive. We feel that with more experience in using the methodology, some of the worksheets may be omitted or combined with other worksheets. The MAS-CommonKADS worksheets place much emphasis on the structuring of the information and may slow the work process on the building of the CT simulator. The container terminal domain provides an interesting area to model stakeholders with agents. The application of the MAS-CommonKADS methodology provides in general, a robust method in designing the software to simulate from different models. We argue that the methodology provides the backbone on which state-of-the-art simulation software can be developed in order to conduct agent-based simulation on stakeholder relations in a container terminal. The software process uses both the risk-driven approach with the component-based approach. After every cycle in MAS-CommonKADS, the models are evaluated and analyzed before continuing forward in order to reduce any perceived risks in developing the tool (agent-based simulator).

In general, the MAS-CommonKADS provided a good, clear methodology for those that are not involved in software development to understand and participate in the design processes. The method-ology assists practitioners from other fields of science, i.e. economics, in building a MABS. We have presented the initial steps in developing a MABS of SRM. The goal is to develop a MABS that can be used for evaluating policies for port terminal systems from stakeholders' perspectives. The plan is to conduct a more thorough analysis of a major container terminal.

The concepts underlying the CT community model can also be employed to analyze stakeholder's relations on a broader scale, i.e. the port community as a whole. As such the MAS-CommonKADS provides a powerful tool to structure stakeholder relations and as such is helpful when developing a more structured stakeholder relations management.

8. Acknowledgements

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Paper IV

Market-Driven Control in Container Terminal Management

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IV

Abstract

The steady, global increase in number of containers and the size of vessels able to carry containers is adding pressure to seaports and terminals to increase capacity. The alternative solution to increasing capacity other than physical expansion is via increased terminal performance so that containers are loaded, discharged, stored, and dispatched efficiently whilst optimizing available resources. The automatic planning of the operations of a container terminal via market-based allocation of resources may greatly benefit the container terminal in satisfying its objectives and meeting its goals. The proposal is that a Multi-Agent System approach would offer port or terminal managers a suitable tool to plan, coordinate, and manage the container terminal domain. There exists a variety of inputs and outputs, actors, intrinsic characteristics and a large number of combinations of factors influencing the output that makes it quite difficult to conduct analysis. In the suggested approach, the Multi-Agent System will plan and co-ordinate the processes within the terminal by mapping the objects and resources that are used in the terminal. The agents will be searching, coordinating, communicating, and negotiating with other agents via a market-based mechanism, a series of auctions, in order to complete their specified goal.

1. Introduction

Seaports are important nodes in international shipping. The transfer of goods from one mode of transport to another model has been the primary function of seaports and more specifically, terminals. It is important to note that terminals are parts of a port where specialized cargoes are handled, e.g. passengers, autos, containers and oil. Ports are more than just piers. More than 90% of international cargo is moving between ports, *Winklemans (2002).* Of this increasingly growing trend, containerization has become the dominant method of moving unitized cargo in the world with many adverse effects such as the requirement for increasing space and causing congestion. This paper will pay particular attention to container seaports and container terminals. The needs for higher operational productivity, faster exchange of information, and speedier vessel turn-around times are just a few of many critical factors that are currently pressing port's nodal position within logistics systems and supply chains. Logistics chains are stretching across continents where production may be in one continent and the market in another. Cargoes and shipments from all over the world have been increasing exponentially. However, seaports have not kept with the pace that economic development has been growing. In fact, many seaports are experiencing difficulties. There exist many bottlenecks in terms of information and physical status of the cargo leading to low productivity within the terminal. There are many obstacles in increasing terminal capacity through expansion, *Notteboom and Winkelmans (2002).*

In container terminals, the management of container terminal systems (CTS) is a decentralized, poorly structured, complex, and changeable problem domain, *Gambardella et al. (1998), Rebollo et al. (2000).* It is important that the definition of *terminal operation system* be explained in that it is an operating system managing the flow of cargo through the terminal, ensuring and that the cargo all go to the right places and that the cargo movements are handled in the most efficient manner. Unfortunately, the few "off the shelf" programs that are available (i.e. NAVIS, based in Oakland, California and COSMOS NV. of Antwerp, Belgium) are designed for specific functions and not covering the total terminal operating system. The proposal to use Market Driven control implemented as a Multi-Agent System (MAS) in container management would provide control over the various sub systems found in a CT by decentralizing the problem solving tasks to the local area agents.

The MAS approach is considered as a viable approach to CT management due to the complexity in finding a solution, because performance of terminals are determined by a variety of inputs, outputs, actors, intrinsic characteristics and external influences, *Persyn (1999).* Both for the CT operators and the vessel operators it is paramount to minimize "*turn-around time*", i.e. the loading and discharging of containers should be done as quickly as possible. According to *Rebollo et al. (2000), a*n average container liner spends 60% of its time in port and has a cost of $1000 per hour or more. To shorten the time spent by vessels, terminal operators need to spend special emphasis in resource allocation. According to *Kia et al (1999), the r*eceipt of information before vessel berths is important in the planning of terminal operations, in order to reduce the $45000 stay of a third generation containership or $65000 of a large vessel at port. The terminal operators are obliged to provide a service that involves much more than crane moves per hour. In the CTs there exist four main subsystems and several processes that have a direct effect on each other and on the system as a whole. The MAS approach to the management of containers would allow each agent to find the container destinations through the array of subsystems that make up the CTS. By introducing auctions, agents will bid based on criteria and goals set before each auction, the agents would negotiate and bid their way through the series of subsystems found in CTS.

The use of Artificial Intelligence (AI) techniques to support port or terminal management has already taken root in some parts of the world. For instance, a family of ten expert systems assists the port of Singapore to plan the optimal use of the port resources, which serve 800 vessels daily, reduces the stay in the port from days to hours, *Turban and Aronson (1998)*. A number of uses exist where agents have been applied to related areas as air traffic control, *Ljungberg and Lucas (1992)* and recently to SouthWest Air Cargo operations, *Wakefield (2001).*

In the next section we describe briefly the principles of container port terminals. This is followed by an overview of related research and then a section presenting the suggested approach. Finally, we provide conclusion and pointers to future work.

2. Problem Description

Currently, there exists an estimated 15 million containers and this figure is projected to continue increasing for the next 10 years at 8.5%, *Containerisation (2002).* Ship lines are aware of this growth as can be seen by the huge investments in yard construction of very large container ships that can transverse the oceans at 25 knots, whilst laden with 6000 or more containers. Ports and terminal operators are also cognizant of the coming changes and perhaps threats if they do not keep up with the pace of change. Ports such as Antwerp, Rotterdam, and Hamburg are expanding their terminals or creating new terminals to accommodate the projected rise in number of containers. The planned CT investment in Europe (1999-2001) is approximately 208 million Euros, *Weigmans et al. (2002).* Due to increases in speed and volume, the operations of a CT require a better regulating systems approach. One area where terminal operators are experiencing problems is reducing the unproductive and expensive container moves in a terminal. Technology such as agents may be able to assist terminals in increasing capacity and performance without spending large investments on terminal expansion and equipment. The “software” rather than the “hardware” of port development will be the determining factor in future trends in port competition vis-à-vis terminal management, *Winklemans (2002).* The CT is viewed not as a passive point of interface between sea and land transport, used by ships and cargo as the natural point of intermodal interchange. They have become logistic centers acting as 'nodal points' in a global transport system.

Congestion and increasing cargo dwell times is a common scene in many of the world’s ports. Government authorities such as customs and health may delay containers from reaching their destinations due to inspections. Shipping lines are unconcerned if there is a poor terminal productivity, as long as their vessel sails on time. Terminal operators are trying to reduce or stabilize the cost per TON/TEU (twenty-foot equivalent unit: container) handled and thus maximize profit. The aim is to efficiently use the resources available during the operating time that the vessel is occupying the berth. Complications in port systems arise in having the various computer systems work together. Currently, ports are seeking better ways in improving their productivity and offering logistical solutions to shippers of cargo. No longer are ports handling just cargo, but more and more they are becoming *"information handlers", Henesey, (2002).*

We will consider CTs that are at least handling over 50,000 TEU per annum. It has been researched that after 50,000 TEU per annum a terminal requires an Information System to help manage, *Jeffery (1999).* In building a model of the system, a set of operations is taken from the various sub-systems that exist within the terminal domain. In Figure 1, the four main subsystems/operations in a CTS are illustrated; (1) ship-to-shore, (2) transfer, (3) storage, and (4) delivery/receipt. The two subsystems that are constantly plagued with congestion and bottlenecks are the (2) transfer system and the (4) delivery and receipt area (also known as the "gate"). The optimization of the vessel turn around (time spent in port) is viewed by much research as being paramount to a port's performance and competitive advantage. We propose that a Market Driven control would provide faster discharge and loading of containers and increased productivity through faster turnaround of containers through the CTS as the primary goals.

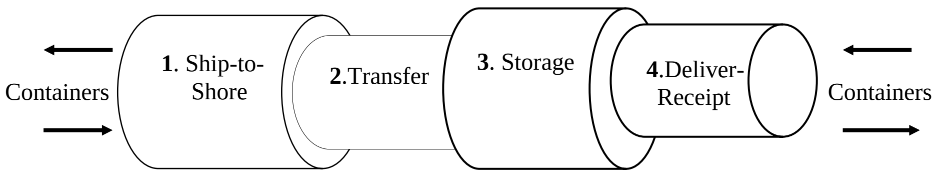

Figure 1. A container terminal system and the four main subsystems

2.1. Ship to Shore System

Also synonymously used as the maritime interface in that this area is where cranes handle vessels. One area where terminal operators are experiencing problems is reducing the unproductive and expensive container moves in a terminal. The number of cranes used to perform the operation varies depending on the size of the containership and the volume of containers to be handled. Usually, every gantry crane will be served with a fixed number of transport machinery, which transfer the containers in the terminal and can stack them to a certain height depending on the type of transport machinery employed. The vessel planning is typically executed 24 hours before a vessel call and produces a manifest, list of containers to be loaded or discharged is provided by the ship line.

2.2. Berth Planning System

According to Nicolaou in *Frankel, (1987, t*he objective of berth planning by evaluation of congestion and cost as suggested is "to arrive at an optimum port capacity while incurring minimum capital cost". Each containership that arrives at a terminal will be assigned a berth, a location where a vessel can dock in the terminal. The characteristics of a container berth are the length, depth, equipment (i.e. cranes), handling capacity, and service facilities.

2.3. Transfer System

Containers are moved from berth to the storage area to be stacked or placed in an area for dispatch or containers from the stack are delivered to the gantry crane at the berth to be loaded on a vessel. The import container information such as its number, weight, seal number, and other information are recorded along with the location identification to a central database, such as a yard system in the terminal. Depending on the operations, either yard tractors, front loaders, or straddle carriers are employed as transport in this operation. The type of transport employed has a direct relation to the layout of the yard, operations of the terminal, and how the stacking is executed. The export containers are transferred from a location in a stack, thus notifying a yard system that the location is free and will be given to a gantry crane to be loaded on a vessel.

2.4. Container Storage System

There exist three main types of storage systems: short term, long term, and specialized, *Frankel, (1987).* The short-term storage system is for containers that may be transshipped onto another containership. Long-term storage is for containers awaiting customs release or inspection. Specialized storage is reserved for the following containers: refrigerated (called reefers), empty, liquid bulk, hazardous materials, or are out of gauge. Transtainers (either RTG-rubber tired gantry cranes or RMG- rail mounted gantry cranes) are usually employed in the sorting and management of containers in the terminal. The container storage system uses stacking algorithms in assigning a space for the container till it is loaded or dispatched.

2.5. Delivery and Receipt System

The interface to other modes of transport lies in this system. The managing of the gate is to obtain information of containers coming into the terminal so as to be properly physically handled before ship arrival and to release import containers before the arrival of trucks or rail. Controlling this access to the terminal is important in that it affects other parts of the container terminal system. The data collected for example are; container number, weight, port of destination, IMO number if hazardous, reefer, shipper, ship line, and seal number are used in deciding where to place containers for storage and later for loading.

3. Related Work in Agent Oriented Approaches to Container Terminals:

The planning for port optimization and control has been traditionally been dominated by researchers in the field of Econometrics and Operations Research. In the field of Artificial Intelligence there have been several papers written that incorporate the use of agent-oriented technology (AOT) such as MAS in the CT domain.

Buchheit et al (1992) have modeled a multi-agent scenario that considers parts of a terminal by using a developed platform called MARS for several shipping companies where the transportation firms carry out transportation orders dynamically and the complexity of orders may exceed capacities of a single company. Cooperation between firms is required in order to achieve goal(s) in satisfactory means. The common use of shared resources, e.g. ships and trains requires coordination between many firms. Only a partial container terminal system is viewed.

Degano and Pellegrino (2002) apply agents in operating cycles called export, import, and transshipment in an intermodal container terminal. The dispatching of containers and the stacking or storage of containers is touched upon in the research. Petri nets are used to assist in fault diagnosis and recovery. Their monitoring system uses agents that detect disturbances to a Daily Process Plan. The agents are able to perform diagnosis, and decisions in a simulation that has been validated with historical data from Voltri Terminal Europa in Genoa, Italy.

Gambardella et al. (1998) investigated the intermodal container terminal in a number of papers where a combination of OR techniques with simulation using agents in a hierarchical order is applied. The problems focused are the scheduling, loading, and unloading operations. The models of the intermodal terminal are based upon complex mixed integer linear program. Decision support for terminal management is divided into three modules: forecasting, planning, and simulation. The last module, simulation, uses agents that act as an agent simulator test bed to check for validity and robustness of policy.

Rebollo, et al. (2000) have suggested the multi agent system paradigm in a few papers in order to solve the port container terminal management problem and specifically the automatic container allocation in order to minimize the time a ship is berthed. Various resources and entities such as trainstainers, yard planners, and ship planners are mapped as agents. The use of wrapper agents is suggested for legacy systems in order to provide access to the database, along with communication with external software. A prototype is still being developed.

Thurston and Hu (2002) have developed an agent simulation written in Java programming language on the loading and unloading of containers onto vessels, also known in this paper as the ship-to-shore system. The authors focus on the quay cranes as being paramount to the total performance of a terminal. It is assumed that all containers should be unloaded first and would be loaded after unloading has been completed. The authors provide insight on the job assignments for the straddle carriers and how their routing may be plotted. The system has been evaluated in a simulation with randomly generated data.

Lee et al., (2002) analyze the port operations via agent-based simulation for the planning and management of the CT. As with *Thurston and Hu (2002)*, they have focused on the berth allocation and the crane policies. The researchers simulated the PECT terminal in Busan, Korea by testing various policies with physical and logical agents. The agent based simulator results indicated that the stronger the relationships between shipper agents and CT operator agents, the faster the handling of containers. The study was primarily focused on the ship-to-shore system and the transfer system.

The Market Driven control to container management is viewed as a possible holistic solution to the container terminal system through decentralized problem solving within the sub systems of the CT leading to a global solution. In the next chapter the subsystems of the CT are defined and the conceptual model that is currently being developed is discussed.

4. Market-Based Control

In the next chapter, we will describe a market-based approach to CT management. The motivation of using market-based control is formulated from auction theory in economics where system wide costs are minimized, bidding agents will bid according to their true values, and auctions offer a specifically short-term contract that ignores long-term implications. Much interest has been garnered in the use of market mechanisms in AI. Perhaps the interest in the Internet has swelled such interest in the form of electronic markets and even auctions, *Sandholm, (1999).* A large informal body of knowledge on auctions has been in existence for centuries, and a more formal, game theoretic analysis of auctions began in the 1960's with the pioneering work of *Vickery, (1961).* Market-based control is viewed as a paradigm for controlling complex systems that are difficult to control or maintain. In this paper, we consider the port terminal domain to be a complex system and difficult to be structured quantitatively. The fundamental properties of such complex systems consist of the following notions, *Gosh and Lee (2000)*:

1. Entity: characterized in the CT domain as resources, such as gantry cranes, straddle carriers, lorries, and ships having consistent behavior that does not deviate, i.e. straddle carrier will not change roles with gantry crane.

2. Asynchronous behavior of the entities: various entities on the CT, such as gantry cranes, straddle carriers, lorries, and, ships

are encapsulated with unique behavior described by functionality and timing.

3. Asynchronous interactions between the entities: not all the resources in the CT have the knowledge to execute a task, thus the sharing of information is necessary to carry out jobs, i.e. the straddle carrier can not load container in the vessel only the crane can and the crane can not travel to the yard similar to a straddle carrier.

4. Concurrent execution of the entities: simultaneous occurrences of lorries, trains, and vessels entering and leaving a CT with varying number of containers.

5. Connectivity between the entities: the sharing of data, information amongst the resources in the CT constitutes connectivity.

Market-Based control has been proved to be a suitable tool for complex resource and task allocation applications, *Bredin at al. (1998).* It is interesting that markets are not initially perceived as a means to control a system. In the market-based system, the agents are provided with individual goals and through their interactions with other agents in an auction, a control of the CT system is achieved. Since the CT "owns" the agents, there is no security threat from agents acting selfish or behaving greedy. For the market to function we assume that agents will not bid more than they can and that agents will honor agreements. The view is that agents should act benevolently in that agents will not cheat or lie, but will buy or sell when they can. The agents in the CT system view resources, i.e. time and containers as assets that can be bought and sold. The auctions protocols currently being considered for the prototype for the various resources within the CT are proposed to be a Market-Driven Contract Net, *Clearwater (1996).* Where a task would be generated as request for bid (RFB) and broadcasted to all resource agents. The resource agents would make bids according to their cost (based on position, time and operating cost) to carry out or execute the RFB (task).

5. Multi-Agent System for Container Port Terminal Planning

In this section we present our suggested approach to a market based system for allocation and dispatch of containers within a CT. The system is primarily used for creation of work orders, container yard allocation and berth planning. The system uses the agent and multi-agent system metaphors in that the mapping of functionality in the container port terminal is made in terms of agents. The system will make use of auctions where agents are free to bid and raise their bid until no other agent is willing to bid any longer. The auction setting depends on the value that each agent places on an activity. A setting that could be utilized is the correlated value auction, *Weiss (1999)*, each agent bidding is dependent on its preference and the value that other agents may have for handling the task. In Figure 2, we show the main flow of resources traversing the system as well as the four different types of global agents inhabiting the system:

The *ship agent* is instantiated upon the planning of an arriving vessel. The agent will, before the final decision of the berth location, interact with the berth agents to decide where the most cost beneficial berthing can be achieved. The agent gains revenue when discharging/selling containers to the terminal and has expenses for the loading/buying of containers.

The *berth agent* is responsible for the allocation of resources at a dynamically changing part of the quay. It will upon request calculate the current price for the berthing of a ship with an indicated loading manifest (list of containers). The berth agent calculates the price by issuing requests for crane resources, container transportation and container storage.

The y*ard agent* is responsible for a dynamically changing storage space in the terminal. The agent will on requests for container storage, respond with a bid by calculating the value of the specific container, e.g., is there already containers in the dedicated storage with similar destination data, is there any space available and is it allowed to store the container at that space? Other impacts on the agent bids are the expenses related to transportation of the container and the subsequent need for transtainers to lift the container into place. The agent will during loading sequences of ships demand revenue for the dispatch of containers from the storage area. The agent will also request revenue for the dispatch of containers to the gate.

The *gate agent* is a logical wrapper to the physical gate. The gate agent allocates containers to the terminal storage by awarding the containers to yard agents and requests stored containers when dispatching containers to land transportation.

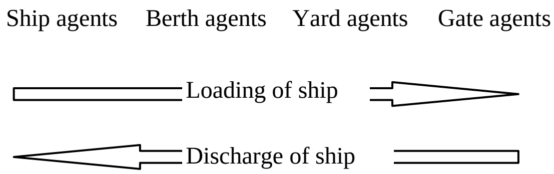

Figure 2. The direction of the revenue flow during loading and discharge of a ship.

In addition to the agents mentioned above there are three other types of agents that are used by the global agents as utility agents:

The *crane agent* is a mapping of a crane (typically a gantry crane) for the loading and discharging of a ship. The agent is concerned with the optimal usage of the crane in that it will try to minimize the number of location shifts in relation to the maximum utilization of time. This agent is one-sided in the auctions in that it will always sell its service and its costs will be based on its operating running cost.

The *transtainer agent* is a mapping of a crane used for the movement of containers within a yard. The agent is mainly concerned with optimization of the allocation of containers within a designated space. Typically it will make use of queuing theory, stacking algorithms and other existing techniques for positioning the containers so that a minimum of subsequent handling is necessary.

The *transport agent* is a mapping of a transportation vehicle. The main goal is to utilize the vehicle as optimal as possible both for allocation as well as for dispatch of containers. The utility function for the transportation agent is the degree of occupancy in relation to the distance to travel. The transport agent is one-sided in that they are always selling their service and not buying in the auctions.

The system architecture mainly supports the following activities:

Allocation of incoming containers to the terminal yard (see Figure 3). A gate agent will on receipt of a container initialize an auction and request the yard agents to bid on the specific container. The yard agent has to take into consideration the cost and availability of transtainers and transportation as well as the likelihood that it later can sell this particular container at a higher price. The gate agent awards the container to the yard agent presenting the best bid.

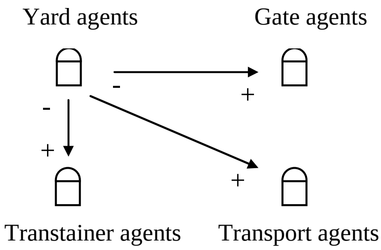

Figure 3. The yard agent has a handling cost for receiving a container.

Dispatch of containers from the terminal yard to ships (see Figure 4). A ship agent will make a request for a price for the loading of a set of containers at a specific berth. The corresponding berth agent will calculate the price by issuing a request for the containers to the yard agents. The yard agents will indicate a price as well as availability (depending on the transtainers) if the container is stored within its area. The berth agent then requests a price for transportation and cranes. Depending on the availability of a load order list, the exact sequence of containers is used when calculating the price, otherwise the availability, distance and occupancy determines the price. The final decision on which berth the ship will use depends on the lowest price presented by a berth.

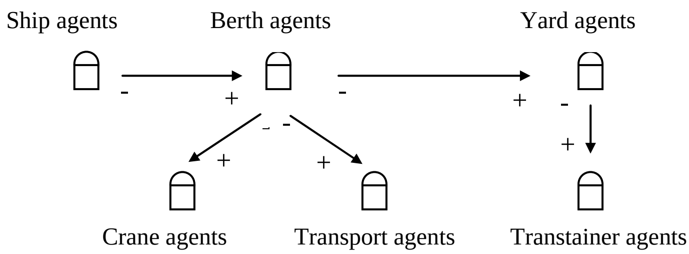

Figure 4. The berth agent has cost for making the containers available for loading onto a ship.

Allocation of the yard with containers discharged from a ship (see Figure 5). A ship agent will make a request for discharging a container to the berth agent. The berth agent then initializes an auction and requests the yard agents to bid on the specific container. The berth agent will also have to request operations from the crane agents to lift the container off from the ship. The crane agents will sell their service to the berth based upon their operating costs, thus crane will acquire income.

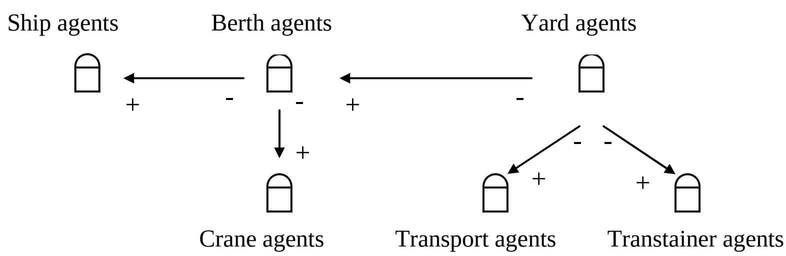

Figure 5. The yard agent has a cost for receiving a container

Dispatch of containers from the terminal yard to land transportation (see Figure 6). The gate agent will make a request to the yard agents for a container upon demand from a land transportation source. The gate agent will also have to initialize an auction to receive bids for transportation from the yard to the gate.

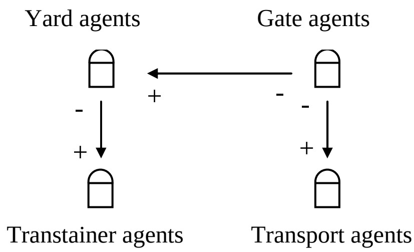

Figure 6. The gate agent has expenses for making a container available for dispatch from the terminal

Reallocation of containers after final decision of berth. The ship agent will continuously interact with berth agents to determine the current price for an actual berthing. After the final decision of berth, the yard agents can start buying and selling containers among them if the cost or price of shifting is beneficial to the yard agents. Optimally, the containers are already stacked close to the awarded berth but the shifting of one or two containers may improve turn-around time for the ships.

6. Conclusion and Future Work

Research in applying MAS approaches in container terminal planning and management issues has been gaining popularity due to the complexities in solving the problems. Researchers have proposed varying methods in applying MAS in CT. We have suggested a multi-agent architecture based on a market-based approach. This is our initial approach towards a holistic solution to a very complex domain. The MAS approach to the automatic planning will generate several work schemes. Furthermore, the planning will assist terminal management when executing decisions from the work schemes.

The system is to provide dynamic yard allocation, dynamic berth allocation, and will reduce idle time of transport vehicles. Furthermore, the main goal is to optimize the capacity of the terminal, which is measured by four main performance indicators: measures of production (e.g. traffic or throughput); measures of productivity (e.g. crane moves /hour); measures of utilization (berth occupancy) and measures of level of service (ship turnaround time). Some questions that concern CT performance are length of time to move equipment and supplies through the CT, what and where are the potential bottlenecks and limited resources to movement through the CT, why are operations not completed by the required time, what are the implications if certain seaport resources are constrained or available? What are the port throughput capability given explicit assumptions on assets, resources and scenarios?

We are currently developing a CT simulator that will be used to evaluate the market-based approach. The simulator will run scenarios where the interactions between the agents within the system will follow the information patterns that are generated and executed by physical moves, i.e., the system will map the flow of an actual container terminal.

The suggested approach needs to be concretized in several aspects, e.g., which auction protocols should be used, and how is the update of information to be achieved. Furthermore, the system needs to be validated and evaluated.

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Paper V

Agent Based Simulation Architecture for Evaluating Operational Policies in Transshipping Containers

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V

Abstract

An agent based simulator for evaluating operational policies in the transshipment of containers in a container terminal is described. The simulation tool, called SimPort, is a decentralized approach to simulating managers and entities in a container terminal. We use real data from a container terminal, for evaluating eight transshipment policies. The simulation results indicate that good choices of yard stacking and berthing position polices can lead to faster ship turn-around times, for instance, the Overall Time Shortening policy offers a lower cost and when combined with a Shortest Job First sequencing of arriving ships on average yielded a faster ship turn around time. The results also indicated, with respect to the studied performance measures that Stacking by Destination is a good choice of policy.

1. Introduction

The growth in the use of containers for transporting goods has been profound from 39 million containers handled in 1980 to over 356 million in 2004 and the annual growth rate is projected at 10 percent till 2020 [1]. Parallel with the increasing demands for transporting cargo in containers is the increasing importance in improving container terminal (CT) operations. As the primary function of CTs is to provide for efficient, low-cost, inter- and intramodal transfer, inspection, storage, form change, and control of cargo, the CT must be able to effectively act as an integral part of transport chain from origin to destination [2]. According to Frankel [2], port costs can be in excess of 50 percent of the total transportation costs of which 55 percent of these port related costs are the result of poor ship turn-around times and low cargo handling speeds. The increasing demands on CTs is placing pressure on the management of CTs in finding ways to increase capacity and offer more efficient ship handling operations. From Frankel [2] we can infer that CTs can influence the physical constraints on the size and type of ships that can be served, number of containers that can be handled, berth utilization determined by service time and ship operating costs. Research by De Monie [3], has identified several key parameters of CT capacity that can be improved through computerized planning, control and maintenance systems such as: berthing arriving ships, scheduling the ship-to-shore handling, coordinating the terminal transfer, and managing the stacking/un-stacking of containers in the yard.

There has been much research in CT effectiveness, capacity and technology. A literature survey overview on transshipment operations has been provided by Vis and Koster [4] and Meersmans and Dekker [5] followed by a rather comprehensive survey on container terminal logistics by Steenken et al. [6]. A classification of container terminal operations is provided by Henesey [7], which concludes that simulation models have been used extensively in understanding the behavior, experimenting and testing conditions and scenarios due to the cost and complexity of the CT domain. A number of simulators and simulation models have been developed in studying CTs and they differ widely in objectives, complexity and details, but all suggest or propose a centralized system for scheduling or controlling [8]. The distributed systems approach has been investigated by a number of papers in solving scheduling or control problems in CTs by using agent technology, such as [9-16]. However, these papers have mostly focused on techniques for automating or controlling the operations in a CT. This paper presents a multi-agent based simulator called SimPort (Simulated container Port) that is developed, as part of an IDSS (Intelligent Decision Support System) assisting human CT managers in the decision making process for transshipment operations in a CT.

The remainder of the paper is organized as follows; in section 2 a general description of the transshipment processes in a CT is presented. In section 3, a research question is formulated and the methodology is described. The SimPort model is explained in section 4. In section 5, a description of a simulation test and the initial results are presented. In section 6, a conclusion with pointers for future work is presented.

2. Description of Container Terminal Transshipment Operations

Many shipping companies are trying to serve a geographic region, such as Europe, by establishing two or three main hubs from which smaller container ships will "feed" containers to and from other ports or CTs in the region. This 'hub and spoke' method of servicing shipping line customers is similar to that used by the airline industry in transporting people in smaller aircraft from a region via large international airports connecting with often larger airplanes to distant destinations or offering many destinations. The amount of transshipping is increasing and according to a study by OCS, [17] total transshipment throughput for Europe and the Mediterranean has increased by 58 per cent over 2000-2004 to 22.5 million TEU (Twenty-foot Equivalent Unit). Many CTs are fast becoming known as transshipment terminals in which they will be linked with 'feeder' ships and the containers from various ports and CTs are consolidated for loading on larger ships for transporting to another region. Specialized transshipment CTs that have been developed as a consequence to the large flow of containers being transshipped are for example; Malta, Gioia Tauro, Salalah, Algeciras, Singapore, Hong Kong, and Shanghai [18].

In managing the CT, the transshipment operations in moving containers can be divided into four sub-processes: *ship arrival, loading /unloading, horizontal transport* and *yard stacking / unstacking* [4]. The four sub-processes in transshipment operations are described as follows:

Ship Arrival - The arrival of a ship requires CT management to locate a berth position so that it can moor along the quay and a service time to schedule operations. This decision on choice of a berth policy has an impact on other decisions in the ship operations. The berth 'policy' is often formulated from choosing a sequence policy and a positioning policy. Basic questions are *when* and *where* to place an arriving ship.

Loading and Unloading - The loading and unloading sub-processes requires operational decisions by the CT management in allocating Quay Cranes (QC) and transport equipment such as Straddle Carriers (SC) or trucks and labor. Usually, the allocation of these resources is conducted in parallel with the ship arrival process. The container stowage planning in a ship is a rather complex problem to solve and has been recently been studied by Kemp et al. [19], to take more 10^{27}years to evaluate all possible optimal configurations for a 2,000 TEU ship. Obviously, we need quicker solutions for loading and unloading a container ship.

Horizontal Transport - An objective that many CT managers share is trying to keep the assigned QCs from being idle or avoiding interruption during operations so as to quickly service a ship. The availability, allocation and efficient use of terminal transport are very important to ensure that the QCs are productive. In [20] mentions that many CT managers view the interface between the QCs and the yard to be a problem. Some problems in the horizontal transport process are: load sequence, routing, pickup sequencing and coordination with QCs.

Yard Stack / Stack on Quay - Containers are usually sorted using a stacking policy which may consider, for example; type (export or import), and size (i.e. 40′ foot or 20′ foot), destination, or by shipping line that owns the container, etc. Ideally, in transshipment operations the ship that is unloading the containers to be loaded by another ship will be serviced at the same time with the other ship in order to avoid problems of stacking containers. This scenario offers a faster service. However, in reality the containers must often 'dwell' or be placed in a yard stack for a period of time while waiting to be loaded onto another arriving ship. Some problems or decisions affecting this process are: stacking density; yard stack configuration; container allocation to a stack according to rules of "polices"; and dwell times.

3. Research Questions and Methodology

In this paper, we pose the following research question; "how could simulation be used to study the impact of the different policies for sequencing of arriving ships, berthing policies, and container stacking on the performance of transshipment operations at a CT?"

The research question stemmed from discussions with CT managers and the results from the reviewed literature [7]. There often appeared to be a gap in understanding the complexity of the decisions by the CT managers in the management of a CT, such as berth assignment, from both theoretical perspectives and from industry practice. Often mentioned, is that existing tools are too cumbersome, do not accurately model the CT, are too expensive and not fast. In addition, some CT experts confided that berth allocation was conducted mostly by middle managers, who did not possess enough information in making the berth assignment decision.

We considered a simulation technique called Multi Agent Based Simulation (MABS) that is suggested by [21] to be applicable to domains that are distributed, complex, and heterogeneous. Before considering using simulation, such as MABS, we first considered other methods for experimenting such as: analytical models in econometrics; mathematics, and optimization. However, CTs possess many characteristics listed by [22] that are be deemed suitable for considering simulation such as: random variables, large number of parameters, non-linear functions and behavior of a dynamic system.

Simulation in general can be used to study the dynamics of complex systems and how the various components of the system interact with each other [22].

The choice on using MABS specifically is based in the versatility in simulating complex systems and perceived easiness from which modeling a CT can handle different levels of representation, such as real human managers in a management system. Paranak et al. [23] recently compared macro simulation and micro simulation approaches and pointed out their relative strengths and weaknesses. They concluded, "…agent-based modeling is most appropriate for domains characterized by a high degree of localization and distribution and dominated by discrete decision. Equation-based modeling is most naturally applied to systems that can be modeled centrally, and in which the dynamics are dominated by physical laws rather than information processing." As a CT has a high degree of localization and distribution and is dominated by discrete decision, we found agent-based modeling a promising approach worthy to investigate.

4. SimPort Architecture

Using a knowledge engineering methodology known as MAS-commonKADS, we model the CT managers into a management system by identifying the following: their tasks, how they are organized, methods for communication and coordination mechanisms [24]. The management system simulator is based on the following managers that are modeled as agents: *port captain, ship agent, stevedore,* and *terminal manager.* Additional agents, which are modeled in the CT simulator, are the QCs and the SCs. The management model of the CT manager agents is illustrated in Figure 1, which show how the agents are organized hierarchically, communicating and coordinating, represented by arrows, and interacting with the CT simulator by sending actions and receiving observations.

The agents make decisions based on information in the messages they receive from each other. The intelligence level of the agents, such as stevedore, ship and crane agents can be considered reactive in that a specific action in the CT is executed upon a certain message. The major advantage in using reactive agents, according to Wooldridge [21], "*is that overall behaviour emerges from the interactions of the component behaviours when the agent is placed in its environment*". The interaction between the agents is summarized in Fig. 2, which adopts a pseudo AUML (Agent Unified Modeling Language) sequence diagram. The agent's goals are only implicitly represented by the rules describing the reactive behavior, illustrated in Fig. 2, for the following agents in SimPort:

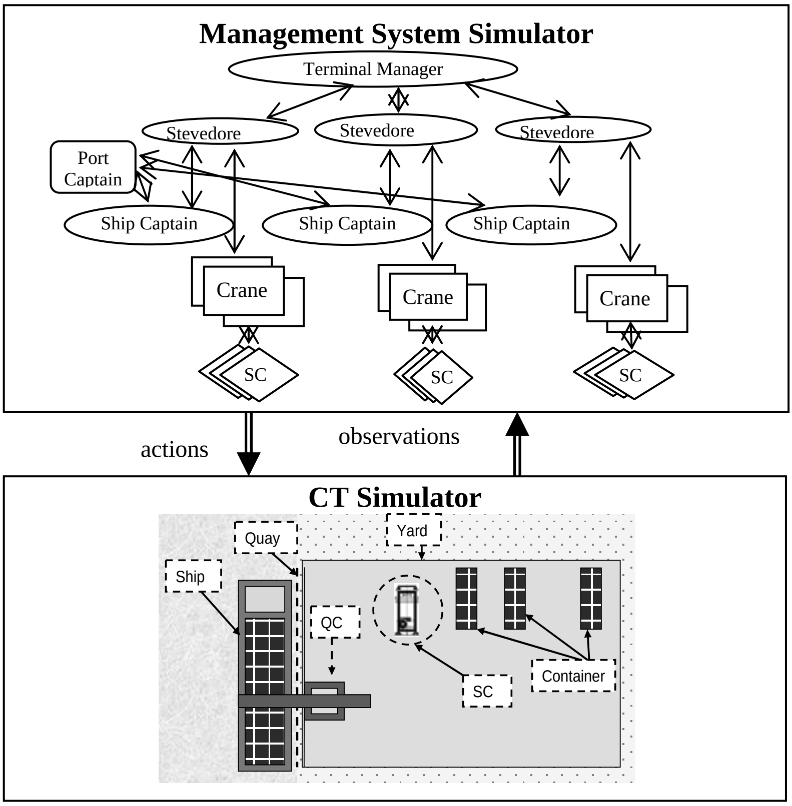

Figure.1. Simplified view of the SIMPORT Architecture

Port Captain Agent; is constantly during a 24 hour period searching for arriving ships during the next 24 hour period. Based on the ship's estimated arrival time, number of containers and size of ship, the port captain creates a *ship slot* which decides the order the arriving ships will be served according to a sequence policy, e.g., First In First Out (FIFO), Highest Earning First (HEF), which implies a ship with the most containers to be handled by a CT, and Shortest Job First (SJB).

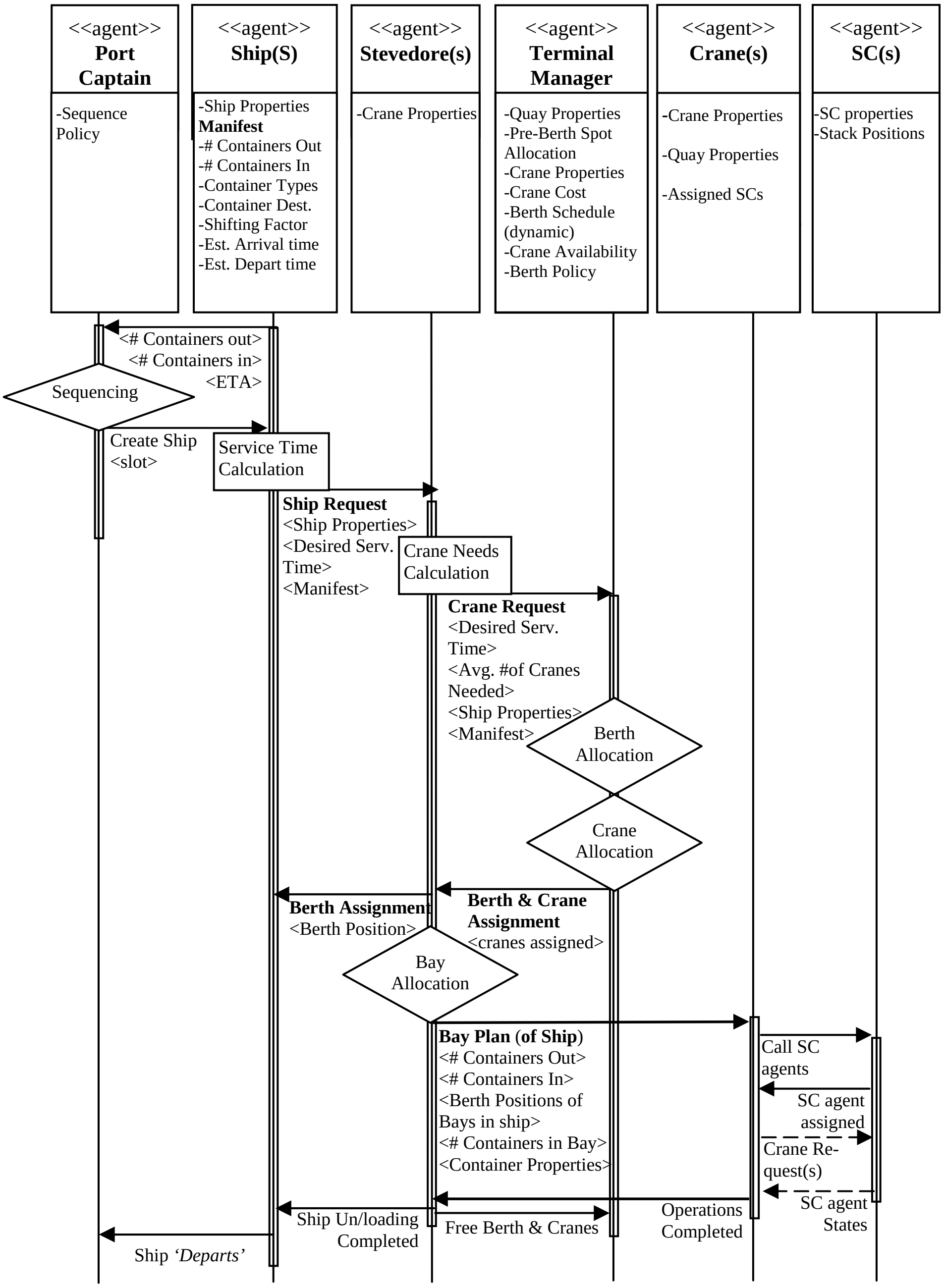

Figure 2. AUML Sequence Diagram of Agents in SimPort

Ship agent is created to represent each arriving ship to the CT. The ship agent will possess the following information:

– Ship Properties:
  1. Desired service time (t_i^{serv}) is based on the schedule, from the shipping line perspective, listing estimated arrival time (t_i^{arriv}) and estimated departure time (t_i^{dep}).
  2. Length of ship in meters (l_i).
  3. Type of ship (v_i) which is regular, panamax or post panamax,
  4. The shipping line that owns the ship.
  5. The number of bays in the ship (j_i).
  6. The hourly operating cost.

– For each bay, the 'manifest' provides the following data; number of containers, and for each container type (whether a 40′, 20′, Refrigerated or Hazardous), destination (from which we can infer it to be either an Export or Import container) and shipping line (containers on board the ship may belong to other shipping lines and this will affect in stack assignment).

When the ship is to be served, the ship agent sends its 'ship request' or desired service time, t_i^{serv} , which can be considered a duration of service, to the stevedore agent, which is computed in the following way (where t_i^{wait} is the waiting time):

$$t_i^{serv} = t_i^{dep} - t_i^{arriv} - t_i^{wait} \quad \textbf{(1)}$$

Stevedore agent will try to satisfy each ship agent's request, i.e., to be served in less time than the t_i^{serv}. It will request quay cranes from the terminal agent that can handle the ship type, v_i and a position of the cranes in order to serve the bays in a ship while trying to meet the estimated desired service time. The crane request is based on a calculation of the average number of cranes needed to work the ship. For example, if the number of containers to be loaded/unloaded, C_i is 400 and the desired service time corresponds to 4 hours and the average capacity of the cranes, Q^s, is 25 moves per hour, then the number of cranes requested, Q is 4. (The reason for using the average capacity is to mirror the actual computations performed by actual stevedores.) The general formula used is:

$$Q = C_i / (Q^s * t_i^{serv}) \quad \textbf{(2)}$$

The second task of the Stevedore agent is to allocate the cranes provided by the Terminal manager agent to the different bays of the ship. It receives information from the ship agent regarding the number of containers in the bays, number of bays in the ship and the characteristics of the containers (size, type, destination and shipping line). The bay allocation is done by assigning cranes to work an average number of containers (both load and unload) for all bays in a ship.

Terminal Manager agent performs two tasks, allocation of berth points to a ship and allocating cranes to service a ship. It receives information from the stevedore agent on ship length (l_i) and will assign a sequence of berth points (b_i) along the quay that the ship will occupy, which will include the spacing between two ships. From the 'request' sent by a stevedore agent, one for each ship, the terminal manager will allocate available cranes that can handle a ship type. Crane allocation is determined by crane type(s) that can work a ship type, v_i and their distance to the berth spot. The number of cranes is limited and this may cause ships to either have slower service times or even wait. Cranes are assigned by the average number of crane moves per hour Q^s, and dividing to the number of containers, C_i to be worked for ship v_i.

The berth positions used by the terminal manager for the arriving ships will be determined by a *berth positioning policy*. From interviews with CT managers and collected data, two types of *berth positioning policies* have been identified that are actually used; Berth Closest To the Stack (BCTS) policy and Overall Time Shortening (OTS) policy.

The BCTS policy's objective is to place a ship closest to a 'target' stack which is the stack that will be the most visited by the SCs during the operations. That is, the one that has the largest sum of (i) containers to be stored and (ii) containers to be fetched. The BCTS will wait if a berth is occupied by another ship until that berth, which is closest to the stack, is available. The OTS policy, on the other hand, tries to place the ships to berth positions in order to minimize the total ship turn-around-time for all arriving ships in a scheduled period of time. In determining the berth position for an arriving ship the OTS policy is considering 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* includes time left in serving another ship that is occupying a part of the quay. The estimation of the *Service Time* is based on the number of SCs employed, the routes covered by SCs and their average speed. The estimated 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 estimated *Service Time* and *Waiting Time*, i.e. the turn-around time of the OTS policy will place a ship wherever the shortest estimated ship turn-around-time is achieved.

Quay Crane (QC) agents are coordinated by a stevedore agent during operations. It receives a list from the stevedore agent which states all containers that should be unloaded/loaded from/to each bay. Based on this list, the Crane agent will react by calling its assigned SC agents and based on their replies, select the SC agent most appropriate to pick up a particular container based on a) availability (idle/busy) and b) the distance between the SC and the container. The general objective for the crane agents is to load/unload containers as fast as possible and use the SCs to move the containers to and from the stacks in the most efficient way possible.

Straddle Carrier (SC) agents are reacting to requests from their assigned Crane agent; an assumption based upon observations of real CTs where a number of transporters typically are 'bounded' to a specific crane. The SC agents have a map of the CT and their goal is just to satisfy the request of its crane agent. SC agents will send their state to the Crane agent. For example, if the stack that the SC has been assigned to place a container in is full, the SC will go to the closest available stack. The SC move along one-way paths for safety reasons. The SC agents calculate the distance from the top left corner of a stack to the position of the crane working a ship's bay located at the berth point along the quay. Distance of the stacks may have an influence on the handling rate of the QCs working a ship.

A SC agent determines its next destination through communication with the crane agent. The SC moves to a position in the yard that is generated by communication with the crane agent and subsequently establishes its next position by communicating back to crane agents that it has reached its assigned destination and is waiting for another task. The SC agent's function is to provide specific yard destinations rather than the container processing sequence. The model contains rules which determine an appropriate yard location based on current status of the stacks and stacking policy, and attributes of the SC agent.

5. Initial Experiment

A real CT was having problems in serving arriving ships leading to ship waiting times on average three days. The SimPort model was used to evaluate revised stacking configurations for the yard and the transshipment operational policies.

5.1 Experiment Setup

The managers at the CT provided data and layouts of their terminal for analysis. The following entities of the CT terminal were modeled in SimPort:

- *Terminal*: Length and width (meters), e.g., 900 m x 1000 m; Operating hours, e.g., 07:00 – 20:00 from Monday to Friday; The terminal handling charge (THC), a cost paid by the shipping lines for handling each container unit (100 dollars per container); A "penalty" cost, an extra cost for handling containers out of operating hours (150 dollars per container); *A yard;* and A *quay.*
- *Yard Stacks*: Length of the Yard is 1000 meters and width 890 meters. Six large stacks that can store 180 containers each are created in the SimPort model using data from the real CT. The yard stacks temporarily store containers based upon export or import status. All stacks are assigned to a number of "ports of destinations", which are based on six different import and export destinations.
- *Quay length*: The length of the quay that is able to serve docked container ships is tested at 890 meters and the width of the terminal yard is 1000 meters to reflect the actual CT. Four berths are configured with a fixed length of 200 meters along the quay. Additionally, the distance between ships worked at the quay is 20 meters and 5 cranes are assigned to the quay.
- *Quay Cranes*: Five QCs are assigned to work ships along a quay at the CT with a handling rate of 25 container moves per hour.

- *Straddle Carriers*: Twenty SCs are employed during operations; four SCs are assigned to each crane. The SCs have a capacity of lifting one container over three and are set with a maximum speed of 30 km/h.
- *Sequence of arriving ships:* The data was provided by CT managers at the real CT for developing the scenarios, the arrival time intervals of three container ships (each 200m long) and the total number of containers for the 3 ships is 1100 for export and 1000 for import, which are identified as either reefer (5%), hazard (5%), and standard 40 foot containers (90%). In addition, each container is loaded (exported) or unloaded (imported) to/from a specific bay located on a ship. The arrival times for all 3 ships were randomly generated between 07:00 and 12:00.
- *Berth Policies*: The berth positioning polices tested are the BCTS and OTS. Polices tested for sequencing arriving ships are FIFO, HEF, and SJB. Two container stacking polices are tested, stack by Ship and stack by Line.

The output from the SimPort will be a berth assignment plan for scheduling, which includes the sequencing of arriving ships and the berth position that they will occupy along the quay. Terminal equipment will be assigned, e.g., QCs and SCs, to work ships. Terminal handling costs charged by the CT in handling a TEU are provided. Finally, to compare performance levels of the various operational policies used, the following measures of performance are defined:

- *Total Distance* – Total distances traveled for all the SCs used to serve the QCs for all three ships.
- *Average Ship Turn-Around Time* – Average time for turning-around a ship in a schedule (departure time – arrival time).
- *Average Waiting Time* – Average *Waiting Time* for a ship in a schedule.
- *Total Costs* – Total costs for serving all ships computed from the number of hours that each ship is berthed multiplied with its hourly operating cost plus the THC (Terminal Handling Cost) that is assessed for each container handled for each ship.

5.2 Initial Experiment Results

The simulation results to evaluate policy combinations for a particular CT are presented in Table 1, which presents the averages from 10 simulation runs.

Table 1. Simulation results from initial experiment.

Simulation Policy:	Stacking by Shipping line					
	BCTS			OTS		
	FIFO	HEF	SJB	FIFO	HEF	SJB
Total distance (meters):	213460	219887	208806	239820	240115	238331
Average Ship Turn Around Time:	10:38	10:55	10:21	7:22	7:25	7:17
Average Waiting Time:	03:30	03:48	03:16	00:21	00:25	00:17
Total Costs (€):	187500	200500	187500	150700	151010	149600
Simulation Policy:	**Stacking by Destination**					
	BCTS			**OTS**		
	FIFO	**HEF**	**SJB**	**FIFO**	**HEF**	**SJB**
Total distance (meters):	205250	211430	200775	227333	229720	225875
Average Ship Turn Around Time:	10:20	10:37	10:04	7:13	7:10	7:07
Average Waiting Time:	3:23	3:41	3:10	0:13	0:10	0:07
Total Costs (€):	184500	194000	184500	148200	149300	147600

Total Distance — the shortest distances traveled by the SCs on average were found to be when applying the BCTS with the SJB policy; 208806 for stacking by Ship and 200775 for stacking by Destination. Within the OTS position policy, there are slight differences in distances traveled, which indicated that the HEF will yield the longest distances followed by FIFO and SJB. In comparing stacking policies, the stack by distance yielded the shortest distances compared to stack by line. The shortest distance recorded for OTS was when simulating with the SJB sequence policy, which yielded a distance of 225875.

Average Ship Turn-Around Time — average ship turn around per ship was found to be faster when using the OTS policy with an average of 7:21 hours for stacking by line and 7:10 for stacking by destination. The BCTS policy yielded an average ship turn around of 10:38 hours for stacking by line and 10:20 for stacking by line. The ship turn around time was faster when simulating with the SJB sequencing policy for both position policies.

Average Waiting Time — average waiting times are longer, when comparing position policies, in the BCTS are 3:31 hours (for all three sequence policies) with stacking by line and 3:25 for stacking by destination. The OTS had shorter waiting times averaging: 21 minutes for stack by line and: 10 minutes for stack by destination. Within the position polices the fastest waiting times are recorded when simulating with the SJB policy. In comparing the average waiting times between stacking policies, the stack by Line on average had a longer waiting time.

Total Costs — lowest cost for ships was recorded when simulating the OTS policy. The costs are lower in OTS since the turn-around time is lower then the BCTS, which influences the hourly operating costs of the ships. In comparing within the OTS, the sequence policies suggest that there is slight influence. The SJB policy in combination with the OTS suggests the lowest cost for the ships. The BCTS policy results indicated that the sequence policies, FIFO and SJB, were the same and the HEF is the most expensive. Stack by Destination on average was lower then stack by Line by € 2,100 when using the BCTS policy and € 4,167 for the OTS policy.

6. Conclusion and Future Work

The results from the experiments answered the main research question that was presented; what is the impact of the different policies for sequencing, berthing, and stacking on the performance of CTs? The objective of using a MABS such as SimPort was to analyze which CT management policies could be best considered in relation to: ship arrival patterns, number of containers to be handled during a time period, changes in container stack layout in the yard and berth. In analyzing the question, the SimPort has proven able to reflect many of these types of changes into the model for simulation.

The agent-based manager system which assigns berth schedules from the various management policies has indicated that some policies have faster ship turn-around times and lower distances traveled by SCs over other polices for certain scenarios. In addition, other performances were revealed in choice of policy such as lower costs for ships depending on the scenario; distribution of arriving ships, number of containers to be handled, characteristics of the containers and yard stacking policies.

The initial experiments could be extended to simulate a larger number of ships, a longer period of time and perhaps use more stacking positions. Future plans are to further develop SimPort in order to evaluate IPSI® AGVs (Automated Guided Vehicles) [25] coordination in a CT. Additional logic for the manager agents could be used for enhancing the decisions made. An optimizer for calculating the best berth position would offer further benefits to the simulation model. Often mentioned by CT managers is to incorporate economic or cost indicators into the simulation, such as cost per hours for groups employed to work a ship, cost for fuel consumed by SCs, number of containers handled during a specific period and profit or loss made.

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Paper VI

Evaluating Container Terminal Transhipment Operational Policies: An Agent-Based Simulation Approach

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VI

Abstract

The problem of analysing operational policies for transhipping containers in a port container terminal is studied using an agent-based simulation approach. The decision makers involved in transhipment operations, i.e., the terminal manager, the port captain, the stevedores and the ship captains, as well as some of the operators of the physical resources, such as cranes and straddle carriers, are modelled as agents. A simulator, called SimPort, has been developed to illustrate the viability of this approach. To exemplify its usage, it has been configured based on real data from container terminals and used for comparing eight operational policies in several scenarios. The policies concern the sequencing of ships, berth allocation, and stacking rule. The policies are evaluated with respect to a number of aspects, such as, turn-around time for ships and travelled distance of straddle carriers.

Key-Words: - Container Terminal, Agent-Based Simulation, Transhipment Operations, Berth Allocation,

1. Introduction

The number of Twenty-foot Equivalent Unit containers (TEUs) shipped world-wide has increased from 39 million in 1980 to 356 million in 2004 and growth is still projected at an annual growth rate of 10% till 2020 [1]. Ports and container terminals (CTs) are trying to meet increasing demand by creating additional capacity. According to Drewry consultants, the cost for planning for container terminals in Northern Europe for 2004 is €549 million with total project costs reaching €6081 million [1, 2]. Many of the solutions considered can be classified as either physical expansion or increasing terminal performance. Some types of physical expansion solutions are purchase of new or additional equipment, hiring more labour, development and purchase of IT systems. Solutions that can be classified as increasing terminal performance may include the use of optimisation and simulation technologies to use the available resources more efficiently.

There has been much research on improving CT effectiveness, e.g., [3, 4, 5]. Henesey [6] concludes that simulation models have been used extensively in understanding the behaviour, experimenting and testing conditions and scenarios due to the cost and complexity of the CT domain. A number of simulators and simulation models have been developed in studying CTs and they differ widely in objectives, complexity and details, but all suggest or propose a centralized system for scheduling or controlling [7]. Although a distributed approach has been investigated by a number of researchers using agent technology, such as [8-15], most of the work has focused on techniques for automating or controlling the operations in a CT. This paper presents a multi-agent based simulation (MABS) approach to evaluating different operational policies for increasing terminal performance. A simulator, called SimPort, has been developed to show the viability of this approach. The agent based approach offers the power of modelling the decision making processes of different actors. An application that may benefit in using an agent based approach is the operations of transhipping containers in a CT.

The remainder of the paper is organized in the following way; first a general description of the CT transhipment processes is provided, then the agent-based simulator is presented. The design of the experiments is explained in section 4 which is followed by a description of the results that are analyzed and discussed. Finally, some conclusions are presented together with pointers to future work.

2. Container Terminal Description

Container handling activities in CT are shown to be dependent on various related subsystems [16]. The managers involved are generally referred to as terminal managers, ship planners, yard planners, ship line agents, and resource planners. To satisfy the management goals for all the managers is difficult because they often have *conflicting* interests, i.e. the discharging of containers at a fast rate may lead to sub-optimal conditions for the stacking and positioning of containers in the yard. Ideally, the owners of arriving ships would like to ensure that when their ships arrive to a CT the berths are empty so there are no delays. On the other hand, CT management would like to reduce the capital outlay so that berths are always utilized. Sometimes one ship line can become dominant and its demands can take excessive importance, e.g. one ship requiring preferential service. The management of a CT can be a complex problem for CT managers to solve because of the following reasons: performance is determined by a variety of inputs and outputs; the size and number of actors often having conflicting objectives; intrinsic characteristics of the CT; and uncertain external influences such as government or international policies, weather, politics, etc. The processes involved in the transhipment of containers can be divided into sub-processes [3] and [17]. Some of these sub-processes are identified and the forms of decision making required for the CT management to consider are illustrated in Figure 1.

Ship arrival requires the CT management to locate a berth position and a service time to schedule operations. Choice of berth policy has an impact on other decisions in the ship operations. The berth policy is composed of a sequencing policy and a positioning policy. The loading and unloading sub-processes would require an operational decision by the CT management in allocating quay cranes (QC) and straddle carriers (SC). The CT management goals, which can vary, influence the decisions in both the QC allocation and the SC allocation. Usually, the allocation of these resources is conducted in parallel. The operations concerning container stacking in the yard is influenced by the stacking policy used by the CT management.

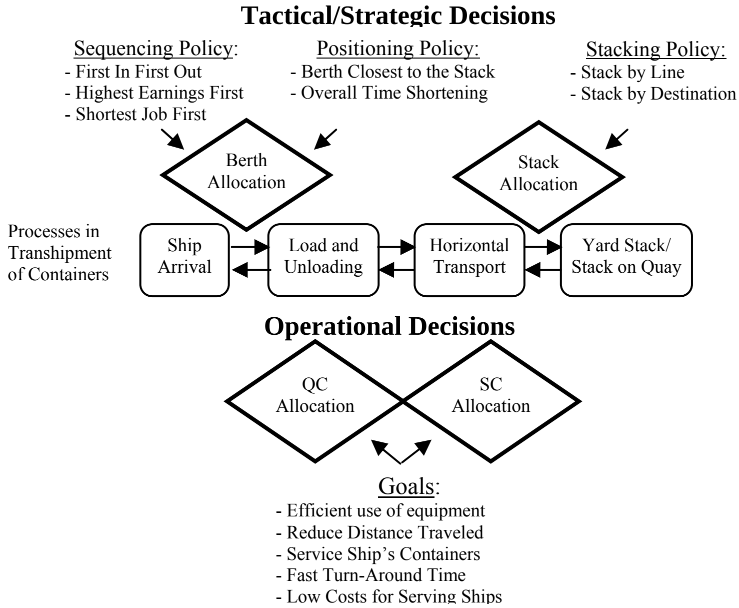

Figure 1. Decision Types & Policies for a Simulated CT

The containers are usually stacked using a stacking policy which considers; type (export or import), size (a 40'foot or 20'foot), destination, or by ship line that owns the container. The positioning policy and the stacking policy are viewed as either tactical or strategic depending on how flexible the CT can configure the berths and stacks. The flow of containers is bi-directional, which means that the containers are placed into stacks and then pulled out. Ideally, in transhipment operations the containers unloaded from one ship should directly be loaded on another ship in order to avoid the problems of stacking containers and thus provide a faster service.. However, in reality the containers must often 'dwell' or be placed in a yard stack for a period waiting to be loaded onto another ship.

Often mentioned by CT managers during port visits is that existing tools for simulation of CT transhipment policies, are too cumbersome, do not accurately model the CT, are too expensive and not fast. In addition, some CT experts confided that berth allocation was conducted mostly by middle managers, whom did not possess enough information in making the berth assignment decision.

In this paper we study how MABS can be used to analyze the impact of the different policies for sequencing and berthing on the performance of CTs under various conditions.

3. SimPort Simulation Model

SimPort consists of two parts, the CT simulator that models the physical entities in the CT and a management simulator that models the actual decision makers.

3.1 The Container Terminal Model

The relevant entities of a CT terminal described previously are modelled in the following way (entities are marked in italic font):

Terminal: Length and width (meters); Operating hours, e.g., 07:00 – 18:00 from Monday to Friday; The terminal handling charge (THC), a cost paid by the ship lines for handling each container unit (dollars per container); A "penalty" cost, an extra cost for handling containers out of operating hours (dollars per container); *A yard;* and *A quay.*

Yard: Length and width (m); *A set of stacks* and *A set of paths.*

Stacks: Length and width (m); Maximal height (m); Position (x,y); Ship line or destination (*optional*); and *A set of containers* (*variable*).

Quay; Length and width (m);The position of the berth points along the quay that can be assigned to arriving ships (x,y); Minimal distance between ships being worked at the quay (m); and *A set of quay cranes.*

Quay cranes: Type of crane (regular, panamax, or postpanamax); Capacity (container moves per hour); *A set of straddle carriers* (always three); and *A buffer* (with room for three containers); and Crane speed.

Straddle carriers: Capacity (how many containers can it stack on top of each other); Position (x,y) (*variable*); and Maximum Speed (m/s).

Ships; Name; Type (regular, panamax or postpanamax); Length (m); Owner (Ship line); Cost of operation (dollars per hour); *A set of bays;* Estimated arrival time; Desired departure time; and Position (x,y) (*variable*).

Bays: *A set of containers* (*variable*); A list of the containers to be loaded (*variable*); A list of the containers to be unloaded (*variable*); Capacity (number of containers); and Shifting factor (the percentage of moves that made by a crane for reshuffling containers which do not result in a container being loaded/unloaded).

Containers: Type (TEU, FEU, hazardous, or refrigerated); Owner (Ship line); and Destination.

The berth points in SimPort are segmented in increments of 1 meter. Once a ship is berthed it will remain berthed until the operations are completed, which in practice is valid since the cost of interrupting or moving a ship during operations is expensive. When ship i is docked at berth point b and at time t, the ship will occupy so that means not other ships can use berth points between b-10 and $b + l_i + 10$, from time t to $t + (t^{serv})$, where l_i is the length of the ship and t^{serv} is the service time. As in a real CT, in the modelled CT, cranes can not pass one over the other since they are fixed along tracks. The yard of the CT has stacks for container storage. Stacks store containers under various management policies such as; if they have the same destination, ship line and are the same type, etc.

3.2 The Management Model

By using a knowledge engineering methodology known as MAS-commonKADS, we modelled the CT managers as a set of agents by identifying the following: their tasks, how they are organized, methods for communication and coordination mechanisms [14]. The management simulator is based on the following managers that are modelled as agents: port captain, stevedore, ship agent, and terminal manager. In addition, the quay cranes and the straddle carriers are modelled as agents. The agents make their decisions based on the information in the messages they receive.

3.2.1 Port Captain Agent

The port captain agent is constantly, once each day, searching for ships arriving to port during the next 24 hour period. Based on their estimated arrival time (and sometimes size), the port captain decides in which order the ships will be served according to a sequence policy.

In this work we focus on three sequencing policies; First In First Out (FIFO), Highest Earning First (HEF) and Shortest Job First (SJB). FIFO serves the ships mainly according to the estimated time of arrival (ETA). Should the arriving ship deviate over 2 hours from its expected ETA another arriving ship (that is arriving on time) may take its place. HEF sequence the ships according to the number of containers to be handled (given that there is a conflict, otherwise according to FIFO). The more containers handled, the higher the earnings are for the terminal in serving the ship. The order is determined from a list of ships that are expected to arrive during a 24 hour period. Similarly, SJB assigns a ship from a schedule of ships that are to arrive during a 24 hour period to a berth according to the fastest service time required to turn-around a ship based on amount of containers to be handled.

3.2.2 Ship Agent

A unique agent represents each ship (i) arriving to the CT. The ship agent will possess the following information:

— Length of ship in meters (l_i).

— Type of ship (v_i) which is regular, panamax or post panamax,

— Desired service time (t_i^{serv}) is based on the schedule, from the ship line perspective, listing estimated arrival time (t_i^{arriv}) and estimated departure time (t_i^{dep}).

— The Ship line that owns the ship

— The number of bays in the ship (j_i).

— For each bay, the 'manifest' provides the following data; number of containers, and for each container type (whether a 40′, 20′, Refrigerated or Hazardous), destination (from which we can infer it to be either an Export or Import container) and ship line (containers on board the ship may belong to other ship lines and this will affect in stack assignment).

— The hourly operating cost.

When the ship is to be served, the ship agent sends its desired service time, t_i^{serv} to the stevedore agent, which is computed in the following way (where t_i^{wait} is the estimated waiting time);

$$t_i^{serv} = t_i^{dep} - t_i^{arriv} - t_i^{wait} \qquad (1)$$

3.2.3 Stevedore Agent

The Stevedore agent will try to satisfy each ship agent's request, i.e., to be served within t_i^{serv}. It will request quay cranes from the terminal agent that can handle the ship type, v_i and a position of the cranes in order to serve the bays in a ship while trying to meet the estimated desired service time. The crane request is based on a calculation of the average number of cranes needed to work the ship. For example, if the number of containers to be loaded/unloaded, C_i is 400 and the desired service time corresponds to 4 hours and the average capacity of the cranes, Q^s, is 25 moves per hour, then the number of cranes requested, Q is 4. (The reason for using the average capacity is to mirror the actual computations performed by actual stevedores.) The general formula used is:

$$Q = C_i / (Q^s * t_i^{serv}) \qquad (2)$$

The second task of the Stevedore agent is to allocate the cranes provided by the Terminal manager agent to the different bays of the ship. It receives information from the ship agent regarding the number of containers in the bays, number of bays in the ship and the characteristics of the containers (size, type, destination and ship line). The bay allocation is done by assigning cranes to work an average number of containers (both load and unload) for all bays in a ship.

3.2.4 Terminal Manager Agent

The Terminal manager agent performs two tasks, allocation of berth points to a ship and allocating cranes to service a ship. It receives information from the stevedore agent on ship length (l_i) and will assign a sequence of berth points (b_i) along the quay that the ship will occupy, which will include the spacing between two ships. From the 'request' sent by a stevedore agent, one for each ship, the terminal manager will allocate available cranes that can handle a ship type. Crane allocation is determined by crane type(s) that can work a ship type, v_i and their distance to the berth spot. The number of cranes is limited and this may cause ships to either have slower service times or even wait.

The berth positions used by the terminal manger for the arriving ships will be determined by a *berth positioning policy*. From interviews with CT managers and collected data, two types of *berth positioning policies* have been identified that are actually used; Berth Closest To the Stack (BCTS) policy and Overall Time Shortening (OTS) policy.

The BCTS policy's objective is to place a ship closest to a 'target' stack which is the stack that will be the most visited by the SCs during the operations. That is, the one that has the largest sum of (i) containers to be stored and (ii) containers to be fetched. The BCTS will wait if a berth is occupied by another ship until that berth, which is closest to the stack, is available. The OTS policy, on the other hand, tries to place the ships to berth positions in order to minimize the total ship turn-around-time for all arriving ships in a scheduled period of time. In determining the berth position for an arriving ship the OTS policy is considering 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* includes time left in serving another ship that is occupying a part of the quay. The estimation of the *Service Time* is based on the number of SCs employed, the routes covered by SCs and their average speed. The estimated sums of all the routes travelled by each SC are totalled to provide the distance being covered by the SCs for each ship. From the sum of the estimated *Service Time* and *Waiting Time*, i.e. the turn-around time of the OTS policy will place a ship wherever the shortest estimated ship turn-around-time is achieved.

3.2.5 Crane Agent

The crane agents are coordinated by a stevedore agent during operations. It receives a list from the stevedore agent which states all containers that should be unloaded/loaded from/to each bay. Based on this list, the Crane agent, will react by calling its three SC agents and based on their replies, select the SC agent most appropriate to pick up a particular container based on a) availability (idle/busy) and b) that the distance between the SC and the container. The general objective for the crane agents is to load/unload containers as fast as possible and use the SCs to move the containers to and from the stacks in the most efficient way possible.

3.2.6 Straddle Carrier (SC) Agent

The SC agents are reacting to requests from their assigned crane agent; an assumption based upon observations of real CTs where a number of transporters typically are 'bounded' to a specific crane. The SC agents have a map of the CT and their goal is just to satisfy the request of its crane agent.

If the stack that it has been ordered to put a container is full, the SC instead will go to the closest available stack. The SC agents move along one-way paths for safety reasons. The SC agents calculate the distance from the top left corner of a stack to the position of the crane working a ship's bay located at the berth point along the quay.

A SC agent determines its next destination through communication with the crane agent. The SC agent moves to a position in the yard that is generated by communication with the crane agent and subsequently establishes its next position by communicating back to crane agents that it has reached its assigned destination and is waiting for another task. The SC agent's function is to provide specific yard destinations rather than the container processing sequence. The model contains rules which determine an appropriate yard location based on current status of the stacks and stacking policy, and attributes of the SC agent.

4 Design of Simulation Experiments

Simulated scenario runs are performed on a model of a real CT located in Northern Europe that has a throughput capacity of 500,000 containers per year with the current operational equipment. In the layout of the CT presented in Fig. 2, the stacks, the berths, and the SC paths were considered in the model. As we focus on transhipment operations, the inland interface of the CT, i.e., the rail connection and the gate for truck interchange, were not modelled. Two stacking policies that have been identified from port interviews are tested, which are; stack by Ship Line and stack by Destination. Stack by Ship Line will assign containers to a stack in the yard according to the Ship Line that owns it. Stack by Destination implies that containers are assigned to stacks according to the port of destination. In the modelled terminal export stacks, import stacks and stacks for hazardous and refrigerated containers are considered. The spacing between stacks is 40 meters and the length of the stacks is 150 meters and the width is 50 meters. Each stack has a storage capacity of 180 containers (2 x TEU or 1 x 40′). The x and y coordinates of the top left corner of the stacks are used for positioning the stack in the yard and are used by the SCs for determining distances to the stacks in the yard. The SCs follow a one- way direction for safety reasons. In the layout, there are five quay cranes (QC) that are assigned to work ships along a quay. There are three SC assigned to each QC. Three of the QCs are normal sized with an average handling rate of 30 container moves per hour. The other two cranes are much larger so as to handle ships that are too wide to cross the panama canal, which are called post-panamax. The handling rates of the two ‘post-panamax’ cranes are averaging 40 containers moves per hour.

The quay has a length of 800 meters with a spacing of 20 meters between ships. There are 800 position points (range from 1 meter to 800 meters) that can be used to assign an arriving ship. The import container stacks are mostly located in the rear of the yard. The export container stacks are located closer to the cranes and berths. The hazardous container stacks located in the middle of the yard. Finally, there are 15 terminal transporters (SCs) that are assigned to the 5 QCs, that is 3 SCs per QC.

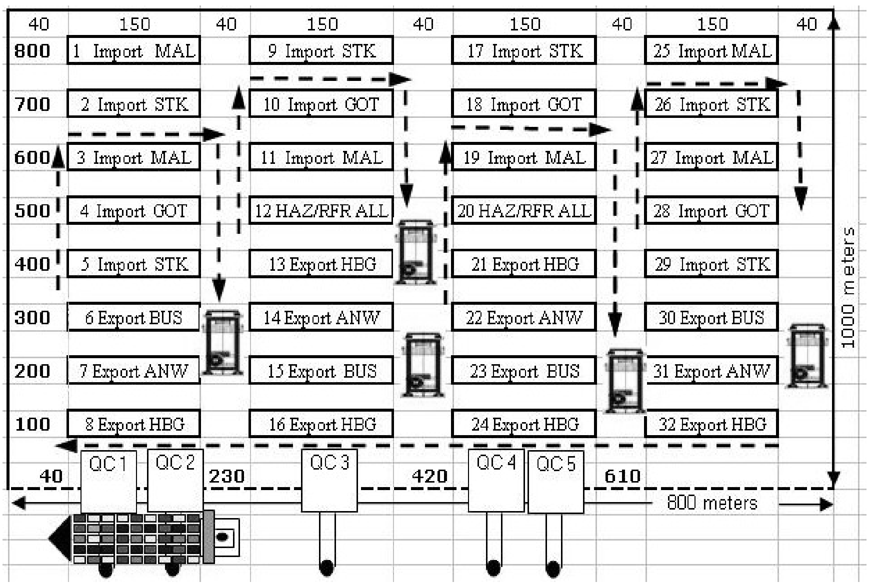

Figure 2. Simulated CT Layout

4.1 Scenarios

For the simulation experiments, two sets of ships were generated for two levels of berth utilization for arriving ships, Low and High. The Low volume represents a schedule of ships with a number of containers to be handled for the week to be set at 5,000 containers with 14 ships representing an average load of 50% of the maximum that the CT can handle physically. A High volume of ships is a schedule of ships with 7,000 containers and 21 ships, representing an average load of 70% that can be handled at the CT. The schedules of ships were generated with a distribution of ships during the schedules that can be considered to be Peak or Even. A Peak distribution implies that there will be at least two peak arrival days during a time period and an even distribution represents a number of arriving ships scheduled to arrive during a time period without peak or 'low' arrival days. Altogether four variants of schedules were considered; Peak and Low volume, Peak and High volume, Even and Low volume and Even and High volume.

4.2 Performance Indicators

The main production measures in a real CT are mostly based on ship productivity, which is container moves/ship-hour at berth. The SimPort model is designed to evaluate proposed policies for yard layouts, sequence of ships, berthing assignments (sequence and positioning) and container handling strategies. To compare proposed alternatives for a given terminal, the following measures of performance are defined:

– Total Distance Traveled by SCs (m): Total distances travelled in meters for each of the SCs used to serve cranes assigned to ships in a schedule.

– Average Turn-Around Time: Average time for turning-around a ship in a schedule.

– Maximum Turn-Around Time: the sum of service and waiting time for the ship having the largest tunr-around time in the scenario

5 Results

The simulation experiments lead to the following preliminary results summarized in Table 1 (stack by Destination) and Table 2 (stack by Line). For each performance indicator four different ship schedule scenarios are listed under the Distribution / Load Vol. heading, which compare the sequence policies; FIFO, HEF, and SJB for both positioning policies (BCTS and OTS).

Table 1. Summarized Results for the Stacking by Destination policy.

Container Stacking by Destination						
Distribution / Load Vol.	BCTS			OTS		
	FIFO	HEF	SJB	FIFO	HEF	SJB
Total Distance Traveled by SCs (m)						
Even / Low	1438346	1439634	1439634	1589574	1465436	1575574
Peak / Low	1438738	1438738	1443134	1484434	1504510	1450344
Even / High	2041725	2038344	2043510	2331357	2131857	2199624

Peak / High	2049180	2049978	2048466	2155839	2123205	2048466
Average Ship Turn-Around Time *(hh:mm)*						
Even / Low	08:54	09:08	08:40	06:57	08:30	07:04
Peak / Low	11:37	11:55	11:51	08:36	09:40	08:33
Even / High	10:12	11:26	09:39	08:03	08:10	07:20
Peak / High	15:12	15:24	13:41	12:02	13:41	12:34
Max Turn-Around Time *(hh:mm)*						
Even / Low	15:30	15:30	15:30	12:38	12:38	12:32
Peak / Low	23:02	23:02	23:02	17:50	17:19	21:30
Even / High	23:04	23:05	23:04	15:11	18:02	19:17
Peak / High	23:06	23:14	21:30	23:08	22:59	23:05

Table 2. Summarized Results for the Stacking by Ship Line policy.

Container Stacking by Ship Line						
Distribution / Load Vol.	BCTS			OTS		
	FIFO	HEF	SJB	FIFO	HEF	SJB
Total Distance Traveled by SCs *(m)*						
Even / Low	1445934	1445262	1440894	1 600 704	1475698	1586606
Peak / Low	1446928	1445934	1450358	1 494 822	1515052	1460494
Even / High	2051721	2048634	2053821	2 347 674	2146767	2215017
Peak / High	2059428	2063229	2058714	2 170 938	2138073	2060772
Average Ship Turn-Around Time *(hh:mm)*						
Even / Low	08:55	09:10	08:41	06:59	08:33	07:07
Peak / Low	11:39	11:57	11:53	08:38	09:43	08:36
Even / High	10:15	11:28	09:40	08:06	08:12	07:22
Peak / High	15:14	15:26	13:43	12:06	13:45	12:38
Max Turn-Around Time *(hh:mm)*						
Even / Low	15:30	15:30	15:30	12:38	12:38	12:32
Peak / Low	23:02	23:02	23:02	17:50	17:19	21:30
Even / High	23:04	23:05	23:04	15:11	18:02	19:17
Peak / High	23:06	23:14	21:30	23:08	22:59	23:05

Total Distance Traveled by SC — the difference in meters traveled by the 15 SCs indicates, as expected, that the shortest distance is when

BCTS positioning policy is used. When analysing the sequence policies in relation to the positioning policies, little effect is viewed when using BCTS. There are difference in distances recorded between the sequence polices for OTS with HEF and SJB having less distance travelled when load is high. The choice of stacking policy indicated minor differences between stack by Ship Line and stack by Destination. An analysis revealed an average improvement of 0,05 percent in choosing a stacking policy in which the containers are assigned according to Destination when using the OTS positioning policy. The shortest distance travelled by the SCs were found on average when using a stack by Destination. Stack by Line indicated minor changes between sequence polices within a positioning policy. The significant increases in distances travelled are between the two positioning policies.

Average Ship Turn-Around Time — as expected the average ship turn-around times for the OTS policy are lower than for the BCTS policy. Thus, there seems to be a trade-off between the distance travelled by the SC and the ship turn-around time. Regarding the sequence policies it seems as SJB often is the best choice. In analysing the difference between stacking policies, the stack by Destination indicated on average a faster turn-around than the stack by Line.

Max Turn-Around Time for a Ship — indicates that the longest times for turning-around a single ship are when applying the BCTS and using the HEF sequence policy. The OTS using the FIFO or the SJB show similar results. The choice of stacking policy indicted no influence on the maximum turn-around time for a ship under the scenarios.

Assuming that a fast turn-around time is the objective, the best positioning policy seemed to be the OTS policy. If the objective is to minimize the total distance in meters travelled by SCs then the BCTS policy appears to be the best choice. The sequence policies of arriving ships such as FIFO, HEF, or SJB can affect the performance as well. The most common sequence policy and the most 'fair' is the FIFO policy. The SJB policy when used with both BCTS policy and OTS policy resulted in turn around times that were on average faster than the FIFO or HEF policies. The use of the HEF policy yielded longer turn-around around times. The stacking policies indicated that choice of stacking assignment on the configured stacks could lead to shorter distances travelled by the SCs. In certain situations when the QCs are not the bottleneck, the stacking policy can affect the performance of the SCs.

6 Validation

Validation determines to which extent a simulation model is an accurate representation of the real system. In validating the SimPort model, we followed Law and Kelton [18] and performed a sensitivity analysis of the programmed model. Several sensitivity analysis experiments were conducted in which one ship with nine bays was simulated with combinations of one container or two containers positioned in different bays of the ship. We tested different input data, such as crane moves per hour, position of target stacks and containers in a ship, for its effects on the crane allocation to a bay on a ship, distances travelled by the SCs and the ship turn-around time by increasing or decreasing the values for the input data. We conducted further experiments on the container positions in the bays of the ship. These simulation results were consistent with our calculations and perceptions of the CT system. Thus, according to Law and Kelton [18], we can infer a *face validity* of the SimPort model. In further seeking to validate SimPort, a series of interviews and questionnaires were conducted. The collected initial results suggested that the Operations Directors and managers of several CTs found the SimPort model to be credible. Further details about the validation of SimPort can be found in Henesey [19].

7 Conclusion and Future Work

The objective of using MABS such as SimPort was to analyze which CT management policies could be best considered in relation to: ship arrival patterns, number of containers to be handled during a time period, changes in layout in the yard and berth. SimPort is able to reflect many of these types of changes into the model for simulation.

The agent-based manager system has indicated that some policies have faster ship turn-around times and lower distances travelled by SCs over other polices for certain scenarios.

Future work would be to evaluate other performances measures and developing more polices for testing; distribution of arriving ships, number of containers to be handled, characteristics of the containers and yard stacking policies. A proposal by a CT operated by the largest container terminal operator in the world is interested in evaluating one of its CTs using SimPort. The case study offers many tantalizing opportunities to further improve SimPort.

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Paper VII

Henesey, L. (2006)
Stakeholder Validation and Verification of SimPort

Paper to be submitted for publication.

Abstract

The simulator, called SimPort, utilizing agent technology for analysing operational policies for transhipping containers in a port container terminal is validated through interviews and questionnaires with groups of container terminal experts. The objective of the interviews was to ascertain that SimPort was appropriately detailed, credible and valid. The results from the interviews and questionnaires that are published in this paper indicate that the level of model detail in SimPort is acceptable. Simulation experiment results from SimPort were validated and verified with responses given by seven groups of container terminal experts. The validation and verification processes have assisted in determining the accuracy of SimPort in representing the real system.

1 Introduction

This work concerns the process of verification and validation that was conducted in developing and experiments conducted with SimPort simulator [1]. We attempt in this paper to determine the credibility of SimPort simulation model and whether the results can be considered trustworthy. In designing the simulation model, we have made a number of assumptions and have modelled entities which we believe give a fair approximation of a real container terminal (CT) system. The SimPort model, which is presented partly in Figure 1, is modelled in two parts; the physical CT and the management system.

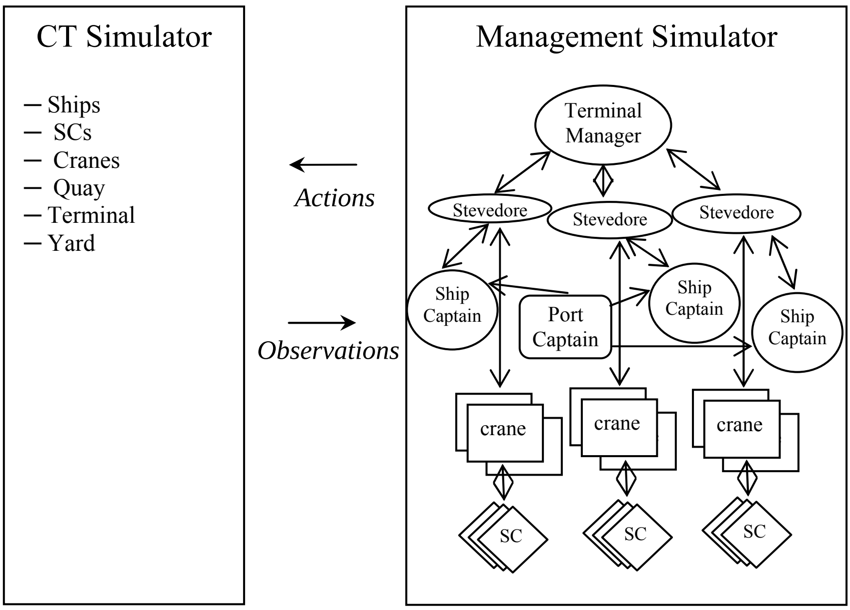

Figure 1. General view of the SimPort architecture

The CT system includes entities that were modelled and later implemented as code into SimPort; ships, straddle carriers (SCs), cranes, quay, terminal and the yard. These physical objects that make up the CT system are coordinated by a management system, which is modelled as a management simulator.

The management simulator is a hierarchical structured system in which a terminal manager allocates resources to stevedores. The stevedores are managers in a CT that try to fulfil the requests being made by arriving ships, which in the model is viewed as ship captains. Once the CT resources (cranes and SCs) are released for a stevedore to use, the stevedore then communicates directly with those resources.

The model of the management simulator reflects a typical CT that is public owned and managed similar to a land-lord arrangement. In this management type, the infrastructure and the resources are owned by a port authority. The resources are allocated to ships and stevedores, which serve the ships. Cullinane and Song [3], provide more details of port and CT management structures.

This paper is organised as follows. An overview of CT operations is described in the next section. This is followed by a discussion on validation and verification in section 3. Section 4 presents the technique used. Section 5 lists the results from the validation and verification process. A conclusion is drawn and pointers for further research are suggested.

2 CT Operations Overview

Initially, we considered in our model that a CT should be handling a large number of containers, which would require an Information System to help in the management. In building the SimPort model, a set of operations is identified, which can be considered sub-systems in the CT system. The four sub-systems defined are: ship-to-shore system; transfer system; container storage system; and delivery and receipt system [4]. A more detailed description of modelled CT operations is provided in a licentiate thesis by Henesey [5]. An overview of the sub-systems/operations is described:

- *Ship-to-shore system* – arriving ships require a berth spot or a place along a quay to be docked. A number of decisions must be made regarding to the ship turn-around time and the allocation of cranes and SCs. Ships are arriving at different times with different number and types of containers. The ships themselves are varying in size and length, which adds more complexity in locating a suitable berth spot. A number of policies are used in the sequencing and position of ships in the ship-to-shore system

- *Transfer system* – the movement of containers within a CT is conducted by SCs. The SCs will dispatch containers to a stack or deliver containers to a crane, which will load to a ship. The allocation and routing of SCs are most important decisions made in this operation.
- *Container storage system* – operation for storing containers using principally stacks. The stacks are allocated containers and organized according to various rules or policies.
- *Delivery and receipt system* – also known as the gate is where the containers are arriving into the CT on other modes of transport than by sea, i.e., road or rail. This operation acts as an interface of the CT to the land side. Usually, SCs or other types of transporters are employed in this task in fetching containers from stacks to be placed on truck or rail wagon using yard cranes. The container flow is bi-directional; container can enter or leave the gate.

3 Validation and Verification Process

In order to check whether SimPort is a credible model, we use a method described by Law and Kelton as verification [6]. The verification process is described by Brooks and Robinson [7] and Law and Kelton [6] as a method for ensuring that the model of the real system has been transferred to a computer model with sufficient accuracy. Some general questions that are asked in verification are; is the model implemented correctly, are the input parameters correctly defined and is the logic represented correctly.

Verification can be stated as building the *model right*, for example comparing the conceptual model with a computer representation, which is the implementation of the model. Law and Kelton list eight techniques for verification of simulation computer programs [6]. From the list, we have chosen three techniques that we deemed suitable for verifying SimPort and they are described in the context of how they were applied to SimPort.

- *Structured walk-through of the program* – this technique suggests that more than one person review the code used in building the simulator. In this technique, SimPort was developed by a group of four persons using methods from the area of software requirements engineering. Documentation was made in SimPort development as part of a university group project.

- *Trace* – Considered to be a robust technique in order to check communication or evaluating calculations made through visually checking, e.g. variable values or tracing a file during a simulation in order to ensure that the system is doing what it is programmed to do. In SimPort, the manager communication is traced via a debugger window. The debugger is useful in stopping a simulation run in SimPort and then trace to how the changes for certain variables were taken.
- *Run under simplifying assumptions* – This technique suggests testing a simulation model in which the assumptions are simplified. A 'generic model' was tested with SimPort and the results indicated that the entities were performing as what was to be expected.

Law and Kelton suggest that a validation process should be compared with the output when estimating a simulation model's true measures of performance [6]. The process can be seen as a method of determining whether the conceptual model is an accurate representation of the system. Validation is often stated as building the *right model.* According to Sommerville [8] validation should demonstrate that a program is suitable for its intended purpose rather than conforming to a specification. In validating simulation models such as SimPort, Law and Kelton [6] suggest validation to be a process of determining whether a model is an accurate representation of the system, *for the particular objectives of the study.* The techniques used for the validation process can be classified as either *discussion with domain experts or results validation.*

Results validation is suggested by Law and Kelton to be the most compelling method for validation in that the output of a real system is compared statistically to the output from a simulation [6].

We used a technique that can be classified as *discussion with domain experts* in validating the results for credibility and trustworthiness. The validation by groups or panels of CT experts is viewed as a method that can benefit the validation of the model and ascertained the credibility of the results. In the next section, a discussion of the methods for validating with CT experts is presented.

4 Method

Two methods were used in gathering data from experts in CT for post validation and verification of SimPort, classified as qualitative interviews and quantitative questionnaires. Interviews and questionnaires were conducted with 7 groups of CT experts that responded positively to having meetings. Three of the CT expert groups can be identified as representing international *terminal operators* that combined handled nearly 27% of the global container traffic for 2004. Four of the CT expert groups are identified as *port authorities* in the United States that have terminals for handling containers, representing nearly 3% of the containers handled globally in 2004. The industry representation from the seven responses accounts for about nearly 100 million containers handled from a total global throughput, estimated by Containerisation International, to be 315 million containers handled for 2004 [9].

4.1 Interviews

For understanding the problems of the operational policies in the transhipping of containers we started with interviewing directors at ports and CTs in North America and Europe. The interviews were conducted with open questions. The data collection from the interviews was useful in validating the configuration files and input for the simulation. In addition, the interviews assisted in refining SimPort by commnting on any irregularities or false assumptions. The main aspects taken into consideration when dealing with such interviews is the, level of standardisation and structure. The level of standardisation indicates how predetermined the questions are and in what order they come. The concept “structure” involves in what way the questions can be answered [10]. Therefore, the questions were designed before hand and asked in the same order for each interview

4.2 Questionnaire

After the interviews were conducted, during the meetings, a structured questionnaire was conducted. Yin [11], suggests that in order to measure the attitudes, e.g. towards the results of SimPort experiments, the Likert scale can be used. The Likert scale is a scale ranging usually from one to five so that an individual can give a response that either agrees or disagrees with a statement. This was the method used in the questionnaire. Before the questionnaire was sent out it was checked with a two port experts as a test, then later revised accordingly.

The ports and terminals that were chosen are listed in the Containerisation International's list of top ports of the world [9]. Due to distance, time and costs, we found it best to only meet with groups of CT experts in Europe and in the US. The goal with the results from the questionnaire was to get an understanding and a picture of the attitudes on questions related to the validation of the SimPort results.

5 Results

The results of the interviews and questionnaire are presented below. Responses are categorized according to type of question: input to SimPort, output from SimPort, and general questions related to the user requirements for a such a system. After each question and result, a short analysis is given.

5.1 Input to SimPort

The input to the simulation experiments, such as configuration files and parameter values used in simulations are reviewed for inconsistencies and unrealistic values, (the configuration possibilities are reviewed to find if they are applicable for their port) by the CT experts. If the parameter values are acceptable, this implies that the same parameter values could be applied in several other terminals.

Question 1. *The information that is used for developing the configuration files, does it consider enough parameters in conducting the experiments in SimPort?*

Yes = 5	No = 2

The respondents thought that SimPort considered the most important factors to consider in developing a simulator for a CT. All believed that including into the model bay configurations of the ships was additional information that would be an interesting factor to use in making decisions for berth assignment. The two respondents that replied with a no argued that also the gate and rail operations should be considered in the simulation, which is an interesting extension of SimPort. However, we are currently focusing on transhipment operations. Additionally, all agreed that dwell time of the containers would be interesting to view during the transhipment process. The simulation experiments conducted did consider dwell time.

Question 2. *Are the berthing policies, such as BCTS or OTS, considered in the operational planning at your terminal?*

Yes = 6	No = 1

The majority of the responses stated that the most common berthing policy was the BCTS. One response that was made by a port authority, which stated that they did not really have a policy, they simply assigned a ship to a berth that was available for a terminal that had 4 berths.

Question 3. *Are the scheduling policies SJB, HEF, or FIFO considered in the operational planning at your terminal?*

Yes = 7	No = 0

All responses from the seven groups of CT experts stated that they considered at least one of the three polices, with FIFO being the most accepted policy. Some of the respondents mentioned that often there are times when a major ship line would come outside of its reserved time window and thus force the CT managers to invoke a HEF policy. None of the CT managers mentioned that they used the SJB policy even though they thought it could work in reality, but may difficult to implement due to commercial reasons. The common statements in using the FIFO policy were either that it is the “most fair” or it is the “easiest to execute”.

Question 4. *Are the input assumptions accurate if not, why?*
All seven respondents replied that the assumptions, configurations, that can be made in the simulator seem to be accurate description to what they would expect for a real CT. Further comments about the input assumptions revealed that the model detail was a good representation of the CT. A number of CT experts stated that contracts with the shipping lines often have to be renegotiated annually. The assumptions in the simulator are interesting for CT managers because they are constantly monitoring the performance of their operations, size of the ships, the amount of containers being handled, etc.

5.2 Results from SimPort

The results from the SimPort simulation experiments are analysed by the CT experts in order to check if the results and calculations can be trusted.

Question 5. *Do you agree with the results produced by SimPort?*

Yes = 6	No = 1

Most respondents agreed that the results from a simulated scenario were credible and in accordance with their experiences from their own terminals. One of the respondents felt that the land-side interface of the terminal should also be modelled so that it may influence more accurately the results of the simulation experiments.

Question 6. *Do you find the results from SimPort to be helpful if so, how helpful is it?*

No impact	
Somewhat helpful	
Helpful	2
More than helpful	3
Very helpful	2

SimPort results were viewed by many to be very interesting in analysing how decisions may effect other parts of the system. Some respondents stated that SimPort was very helpful for considering the operating cost of the ship with terminal operations costs and this offered opportunities in assessing current and future demand. The results offered a clear way of comparing the benefits or disadvantages of using certain policies in the various scenarios. A few respondents advised that visualization could further help with validating scenarios and verifying how objects in a CT operated.

Question 7. *Do you find the results on ship costs to be valid?*

Yes = 6	No = 1

The respondents all felt that the results for the operating costs of ships to be acceptable to their knowledge of ship line costs. One respondent believed that a suggestion for improving SimPort would be to consider the costs of the containers and cargo onboard the ship to gain a better value for ship costs. In general, we can state that all respondents agreed that the ship costs are valid.

Question 8. *Do you find the results on travel distance of SCs to be relevant?*

Yes = 7	No = 0

All respondents stated that the travel distance to be an interesting performance measure that should be considered before deciding on position, sequence and stacking policies. One of the respondents provided the actual costs for fuel, labour, and the value of the machine itself and found when calculating these costs with meters travelled to provide further insight to his ship operations.

Question 9. *Do you find the results on % of Service Time to Total Turn-Around Time to be valid?*

Yes = 7	No = 0

The seven groups all responded that the results were inline with their own calculations and thought the results could be trusted.

5.3 General Questions

The general questions were discussed with the CT experts in order to check if the requirements of SimPort and to some degree, the users, are adequately considered in building SimPort and in simulation experiments.

Question 10. *Percentage of Transhipments at your terminal?*

0-19%	2
20-39%	1
40-59%	2
60-79%	1
80-100%	1

This question was addressed to gauge if the CT experts interviewed had experiences with transhipment handling. The two respondents that indicated less than 20% were port authorities in the US. The terminal handling operators were found to be handling the majority of transhipment in 40% to 100%. One of the operators stated that their terminal handled over 90% pure transhipment.

Question 11. *Berth Utilization at your terminal?*

0-19%	
20-39%	
40-59%	2
60-79%	3
80-100%	2

This question was designed to gain a better understanding of berth utilization, one of several measures for determining port or terminal productivity. In addition, some of the respondents indicated that they are fast reaching capacity limit and are keen on finding solutions before congestion and loss of service takes place. The five respondents reporting berth utilization of 60% or more agreed that they wanted to find means of running their operations more efficiently before any further capital expenses.

Question 12. *Does your port have an IT system for berth allocation for arriving ships that considers both the impact of stack arrangement and allocation of CT resources?*

Yes	No
0	7

Many stated that they passed this decision to middle managers who would make judgements based on either past experience or other things. A few respondents mentioned that they have heard of such systems being commercially offered, but did not think they would have much impact on improving the operations. The main obstacle seemed to be cost either the initial cost of such a software system and in training dockworkers or clerks to use it.

Question 13. *Does your port utilize straddle carrier operations?*

Yes	No
4	3

Though four of the seven respondents are using straddle carriers or SCs in the operations, all possess similar problems in berth assignment, sequence of ships and relationships of stack policies. In addition, the four respondents that answered yes to having SCs, added suggestions for the rules to be considered in SC assignment to cranes. The three respondents not using SCs reported that they use yard tractors or trucks to haul the containers in the terminal.

Question 14. *Average cargo "dwell times" in your port or terminal?*

1-5 days	2
6-10 days	4
11-15 days	1
16-20 days	
>20 days	

Dwell time for containers is an important issue when storing containers in the yard for CT managers in managing capacity. The dwell times for the transhipped containers were not easy for the respondents to estimate. Nonetheless, the majority of responses stated that no more than two weeks for a modern terminal or port is acceptable. Therefore, all agreed that a simulation run of at least two weeks should be considered in running the simulation experiments.

Question 15. *To what extent does berth assignment have an effect in the Total Terminal operations at your terminal?*

No Impact	
Slight Impact	
Has an Impact	2

Major Impact	3
Extreme Impact	2

All CT expert respondents indicated that berth allocation is an important issue in terms of start of operations and how the yard stacks should be tailored. Though it is important, the fact remains in that the decision making process is made by little or no analysis but on 'rules of thumb' and past experience.

Question 16. *To which extent does berthing influence the ship operations only at your terminal?*

No Impact	
Slight Impact	
Has an Impact	1
Major Impact	1
Extreme Impact	5

This question was designed to see if the CT experts viewed the ship operations separately from the terminal yard operations. Secondary, the question elicited information as to how berthing and other polices are considered in the start of vessel operations. Most of the CT experts agreed that berthing influences the start of the vessel and the way the ship will be serviced with number of terminal resources, such as cranes and SCs.

Question 17. *Do you find the choice of stacking policy to be important in the terminal management decision making?*

Yes	No
7	0

The responses from the CT experts validated that stacking is an important issue that should be considered in any simulation of CT operations. In the post validation process,further insight in how CT yards are managed was gained and reinforced from the CT experts, e.g. that the CT experts do use such stacking policies as assigning containers to stacks according to ship line or by destination, in combination with traditional policies. Some traditional polices are organizing container stacks by size or type of container.

Question 18. *What are the problems that your organization experiences related specifically to transhipment of containers?*
Majority of the respondents stated the main problems stem in not having the information at hand from the ship lines. Almost all respondents indicated that much work was needed to coordinate ships and ship agents with the stevedores. The responses motivated methods to coordinate the various actors in the CT system.

Question 19. *If there exist disruptions or bottlenecks, what are they and do they specifically occur in the transfer of containers from/to ship and stack? Why?*
In the transfer of containers, the general problems are 'managing the traffic' and allocating containers to transporters. This was viewed by the CT experts to be critical in order to keep the crane from being idle during operations.

Question 20. *What are some of the potential causes of disruptions and bottlenecks in ship operations that are located in these areas: technical, organizational, legal, and commercial?*
Most of the respondents stated that most disruptions stem from the organizational area, in that often a change in the vessel planning would be changed due to a decision by a vessel planner calling for a 'hot box' to be loaded. This change could effect crane operations and perhaps the total ship operations. Other such disruptions are, for example, in not finding the containers in their locations or having to search for them would lead to the crane being idle.

Question 21. *Are there any bottlenecks related to information flow and its characteristics?*
Many of the respondents claim that often data or information from Bill of Ladings is lacking and thus not sure as to how to handle a container thus slowing down vessel operations and effecting overall terminal operations. The inclusion of some elements of the bill of lading into SimPort model was well received by all respondents, such as destination and ship line owner. All CT experts agreed that they were looking into further IT investments in reducing the information bottlenecks and help them manage better.

Question 22. *Does ETA (Estimated Time of Arrival); in particular, of arriving cargo have any affect on the daily business and the planning?*
All respondents replied with yes. Having the knowledge for exact time was paramount for planning the operations. In using ship schedules for SimPort, CT experts agreed that the use of ETA and ETD (Estimated Time of Departure) were important data used for the planning of daily or weekly ship operations.

Question 23. *If yes, is it accurate enough?*
Most respondents indicated it could be better with more information such as number of hatches and size of the ship before it arrives. One respondent said it was good enough due to that he is running a dedicated terminal for one major ship line and he has direct information as to the physical characteristics of the ships.

Question 24. *If no, why is that so?*
All CT experts claim that one major barrier in obtaining ETA on arriving containers or cargo was problems with communication interchange and issues with labour

Question 25. *Does the port have any time or service restrictions during the week in working with line operators?*
All CTs indicated that they operated 7/24. 3 CTs stated that the additional cost in operating on weekends was mostly billed to ships. Whereas 5 stated that they would use a 'master contract' that would not apply these costs

6 Discussion and Conclusion

Feedback from the seven groups of CT managers was generally positive regarding to SimPort with several suggestions for improvement in respect to minor details that could be incorporated for an improved version. They indicated that they understood and agreed with the assumptions made in SimPort model. CT managers stated their confidence in the configuration of the operational policies and physical layouts to be what they would expect and in line with their own calculations, thus stating that the model was built right. The verification process can not be achieved completely by interviews and questionnaires. Nonetheless, some general questions regarding verification were partly achieved in the study, such as model correctness and credibility of input parameters obtained by meeting with domain experts in CTs. The verification techniques used, such as checking the code, debugging, tracing files and running under simplified assumptions, was conducted in the development of SimPort.

In order to check that the simulation results were credible, the CT managers were asked to give their opinion if they accepted them. The CT managers validated the processes for generating the tested scenarios and stated that the results were comparable to their own operations in four of the seven CTs operators; this is due to that three CTs do not use SCs in their operations but other systems.

Overall, the validation technique of discussion with CT experts has provided valuable feedback. A drawback of this method is that it is time consuming and expensive to do. Verification of SimPort was partly achieved by questioning the CT experts on the model and the whether the input parameters were defined correctly. For the researchers, the feedback helps to reinforce knowledge about the domain and whether the system being simulated is accurate enough.

However, some issues have been mentioned during the meetings and are suggested for further work, e.g., calculation of ship costs, visualization, modelling of more systems in the CT and flexibility of the model was mentioned as some areas for further work. The CT experts expressed that ship costs could be more detailed and provide further insight to the ship demands.

Visualization was recommended by many CT experts not as an alternative but an additional means for them to view the terminal layout and the allocation of cranes to ships at specific periods of time. This suggestion by the CT experts is considered in further development of SimPort. Other improvements are to model the container storage system with yard cranes and the delivery and receipt system. The CT experts stated that this would help much in developing a full CT simulator and in understanding how decisions made in these two operations may affect performance of the CT. For container storage, the suggestion to record dwell time (number of days that a container on average waits in a stack in a yard to be loaded to a ship, truck or train) would also make SimPort more credible in analysing capacity in the yard.

Finally, the flexibility in modelling other type of equipment would be useful for CT experts since many do not use SCs in their transfer operations. A proposal to use AGV instead of other types of transport equipment would be interesting for the CT experts to compare and evaluate.

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Paper VIII

Comparison and Evaluation of Two Automated Guided Vehicle Systems in the Transhipment of Containers at a Container Terminal

Lawrence Henesey, Paul Davidsson, Jan A. Persson

To be submitted for publication. Partially based on a paper published in Proceedings of the 5th International Conference on Computer Applications and Information Technology in the Maritime Industries, Oud Poelgeest, Leiden, Netherlands, 2006

Abstract

Due to globalization and the growth of international trade, many container terminals are trying to improve performance in order to keep up with demand. One technology that has been proposed is the use of Automated Guided Vehicles (AGVs) in the handling of containers within terminals. Recently, a new generation of AGVs, called IPSI® AGVs, has been developed which makes use of cassettes that can be detached from the AGV. We have developed an agent-based simulator for evaluating the cassette-based system and comparing it to a traditional AGV system. In addition, a number of different configurations of container terminal equipment, e.g., number of AGVs and cassettes, have been studied in order to find the most efficient configuration. The simulation results suggest that there are configurations which the cassette-based system is more cost efficient than a traditional AGV system.

1. Introduction

The transport of containers is continuously growing and many container terminals (CTs) are coping with congestion and capacity problems. For instance, the number of Twenty-foot Equivalent Unit containers (TEUs) shipped world-wide has increased from 39 million in 1980 to 356 million in 2004 and growth is projected to continue at an annual rate of 10 per cent till 2020 [1]. In order to handle such volumes, larger container ships are being designed and built with capacities of 12,000+ TEUs. Often due to both physical and economic constraints, big container ships are calling on smaller number of ports. Many shipping companies are trying to serve a geographic region, such as Europe, by establishing two or three main hubs from which smaller container ships will “feed” containers between ports in the region. With the large flow of containers being transhipped, a segment of the shipping business, called feedering is increasing, thus the number of containers being transhipped is also increasing. Furthermore, in a recent study by Ocean Shipping Consulting (*OSC*), the total transhipment throughput for Europe and the Mediterranean has increased more than 58 per cent between the years 2000 and 2004 to 22.5 million TEU [2]. In considering future demand, the study suggests that during the 2004-2010 time period North European transhipment demand will increase between 56-68 per cent and in South Europe/Mediterranean region by 80-97 per cent [2].

Enormous pressure is on the management of ports and CTs to find more efficient ways of handling containers and increase CT capacity. Traditional methods for increasing capacity, such as expanding the physical port or CT, are often not feasible. For example, in many ports in Europe, the amount of available land is restricted. Land expansion is not realistic because many ports and CTs are located inside major cities, such as; Hamburg, London, Marseille, and Rotterdam. Thus, management in ports and CTs are searching for other solutions to increase the efficiency and capacity, including the use of automation, e.g., Automatic Stacking Cranes (ASCs) and Automated Guided Vehicles (AGVs). Automation of the terminal equipment is argued by Ioannou et al. [3] to be a suitable solution for increasing efficiency and reducing operational costs for CTs. CTs use different types of transport equipment for moving containers between the marine side of the terminal (the quay) to the stacks which are located in the yard of the CT. The most common types of equipment used for the internal transport within a CT are shown in Figure 1.

Truck with Chassis **Reach Stacker**

Straddle Carrier AGV

Figure 1. Pictures of various transport equipment for CTs

Most common in North America is the use of a *truck with chassis* in which containers are directly placed onto a trailer hitched to a truck. *Reach stackers* are used mostly in smaller CTs because they have the advantage of being able to stack containers, but have a lower speed when compared to trucks and straddle carriers. Straddle carriers are widely used in Europe for their ability to transport and stack containers rather high (some versions can stack 5 containers high).

The use of AGVs is not a recent development. The first AGV system was introduced in 1955 for horizontal transport of materials and AGVs were first used for transporting containers in 1993 at the Delta/Sea-Land terminal located in Rotterdam. There has been much research conducted in various areas incorporating AGVs and CTs (c.f. Vis [4], for a comprehensive literature review on AGVs). Following two European Union sponsored projects; IPSI (Improved Port Ship Interface) and INTEGRATION (Integration of Sea Land Technologies), a system for handling containers using cassettes and AGVs has been developed but to date has not been used in a CT [5]. The cassettes are steel platforms detachable from the AGV and on which containers can be set. A possible advantage or merit of using cassettes is their ability to act as buffer, since containers can be placed on it without an AGV being present. A picture of an IPSI AGV is shown in Figure 2, transporting a cassette loaded with two containers.

Figure 2. An IPSI AGV transporting a cassette

To evaluate this new development in container handling, we will compare the IPSI AGV system to a "traditional" AGV system, which will be referred to as T-AGV. We perform a comparative analysis of the transport of containers between ship-side operations to the operations in the stacks located in the yard of the CT.

Because of complexity and capital and construction costs, *simulation models* are used intensively for understanding behaviour and testing strategies in CTs, e.g., see [6], [7] and [3]. Also, the simulation approach provides a method of evaluating a concept that has not been used in the real world [8]. We have developed a multi-agent based simulator (MABS) for comparing the performance of the two AGV systems according to a number of criteria, e.g., service time for a ship, utilization rate for the CT equipment, and operating cost.

The remainder of the paper is organized as follows; in section 2 a description of the problem is provided. In section 3, the methodology and model is presented. Section 4 provides a description of the simulation experiments. The results are presented and discussed in section 5. Conclusions are presented in section 6 with pointers for future work.

2. Problem Description and Model Assumptions

A CT is a place where ships will be berthed so that they can be unloaded and/or loaded with containers by Quay Cranes (QCs). The CT are often viewed as an intermodal interface for transport of containers between modes of transport linking the landside with the marine-side, e.g., containers are arriving or departing by, ships, trains or trucks and while in the CT they are temporarily stored in stacks [9]. In addition, we view CTs as an interface within modes of transport, e.g. the transhipping of containers from one ship to another ship in which the container may be temporarily stored at the CT. Ship owners often demand a fast turn-around time for their ships. By minimising the time a ship is berthed at a CT, the ship may have more time for sailing and thus opportunity for extra voyages, which implies that more revenue is generated by the ship. With the advent of "Just-In-Time" philosophy and the importance of speed in global supply chains, customers demand that their containerized cargo is transported fast and on time. Therefore, from a logistics perspective, improving the transport within the CT may help in decreasing the total transport time and cost of transporting cargo in containers.

CT managers often seek to optimise the use of their terminal resources. The most expensive piece of terminal equipment is often the quay crane (QC), for which the capital costs can be € 7 million or more [10]. Other CT resources are the transporters and in the case of IPSI AGVs, the cassettes. Many CT managers view the interface between the QCs and the yard as the most critical planning problem [11]. An objective that many CT managers share is to keep the assigned QCs from being idle so as to quickly serve (minimize the turn-around time) a ship.

In the scenario studied, a ship arrives at a CT with a number of containers to be unloaded and another set of containers are loaded onto the ship before it departs. The unloaded containers are to be transported from the QC area to stacks in the yard and the containers to be loaded are picked-up from stacks and transported to the QC area. This transportation is carried out by AGVs (either T-AGVs or IPSI AGVs with their accompanying cassettes) and we call the time it takes to perform it (including the return without container(s) as well as the load and unloading operations) the AGV cycle time. This definition is similar to the one used in a study comparing a Straddle Carrier system with an Automated Stacking Crane system by Vis [12]. The stacks are located in different areas of the yard and therefore have varying distances to the QC, implying different transport times. We model this by letting the AGV cycle time have random component for each transport. We also consider the time for the unloading and loading of containers from and to a ship by a QC, called the container handling time. Figure 3 illustrates a QC unloading containers onto a cassette for transport by an IPSI AGV to a stack.

Figure 3. Model of Container Terminal using IPSI AGV

The technical specifications of the two AGV systems considered are presented in Table 1. There are some differences between IPSI AGV and T-AGV, such as the speed and capacity, and this technical information is provided courtesy of TTS AB in Gothenburg, Sweden. The IPSI AGV is slightly faster then a T-AGV and has a higher loading capacity then the T-AGV. No containers are stacked on the T-AGV. The IPSI AGV utilizes a special locking pin for keeping containers stacked two containers high. Additionally, the IPSI-AGV is physically bigger than the T-AGV and can carry two 20′ containers on the same cassette side-by-side (i.e. up to four 20′ containers), whereas the T-AGV can carry at most one container unit (20′ or 40′). The lifting time for an IPSI AGV (the time for it to move under a cassette and lift it off the ground for transporting) is approximately 15 seconds. The T-AGVs do not have a corresponding lifting time since containers are directly loaded on top of them. The initial purchasing cost is provided by industrial partners and serves as an estimate. We describe the methodology and the simulation model used in the next section.

Table 1. Specifications of AGV systems

	IPSI AGV	T-AGV
Speed (both when empty and loaded)	20 km/h	15 km/h
Capacity	82,000 kg	55,000 kg
Maximum container capacity that can be transported	4 TEU (either 4 x 20′ containers or 2 x 40 containers)	1 TEU (one 20′ container) Or 2 TEU (one 40′ container)
Lifting time in picking up cassette	15 seconds	Not applicable
Initial purchasing cost	4,5 million kr	2,7 million kr
Additional costs (one cassette)	8,000 Skr	Not applicable

3. Methodology and Simulation Model

As Isoda [13], points out, mapping real world entities into programming languages has been one of the greatest desires of software developers. When building simulation models the ability to perform such mapping is of particular importance. Object-oriented modelling supports the mapping the behaviour of objects and agent-oriented modelling extends this by supporting also the modelling of pro-active entities as well as the interaction between such entities.

3.1 Simulation Model

In our model we targeted a scenario where there are entities which have a number of attributes and operations associated to them and can communicate with each other. The entities of the real world that we model are; QCs, AGVs (IPSI AGV and T-AGV), cassettes and containers. These entities have to coordinate with each other to complete the main task, which is the unloading/loading a ship. Therefore we model the real world entities as agents and in the simulation software we implemented them as objects with their own execution thread. During the simulation these objects work like processes in the operating system and perform their task in parallel. This behaviour is close to replication of the real world scenario where the entities of the system continuously perform their task (although they sometimes have to coordinate with each other to finish the main task).

The simulation model was implemented using DESMO-J, an open source library for the JAVA computer programming language that is available for download from the University of Hamburg, Germany, U.H. [14]. DESMO-J provides a runtime process based simulation engine that can be used to map port entities to software entities and to simulate the coordination of these process.

In the computer simulation, the entities use the Contract Net protocol to coordinate tasks. This protocol is used because of its ability to distribute tasks and self-organise a group of agents [15]. The protocol is suitable since our model describes tasks that can be characterised as hierarchical in nature and are well-defined. The Contract Net protocol implies that one agent will take the role of a "manager", which initiates a job to be performed by one or more other agents. The job may require that a number of participating agents respond with a proposal and the manager will accept a proposal and confirm it to a selected agent and reject the other proposals. This protocol seems to closely reflect the operational decisions that are made by the actual workers in the CT, especially when a foreman will communicate via radio with drivers and QC operators.

The system that we have modelled for an automated CT using IPSI AGVs is illustrated in Figure 4 and for a CT employing only T-AGVs is presented in Figure 5. They show a single ship that is docked along a quay with container stacks but with two different types of AGV systems. We have followed a general simulation process as described by Law and Kelton [8] and therefore we are testing a prototype with real data (see appendix for a description of the simulation process). We have focused on modelling the operations that involves the QCs and the AGVs that transfer containers between the quay and stacks. Presented in CT diagrams (Figures 4 and 5) are text boxes listing major decision factors that CT managers would consider when allocating QCs, AGVs and possibly cassettes (when using the IPSI AGVs). In deciding the resource allocation for a CT, regardless of type of AGV system employed, the following decision factor is given:

1. How many containers are to be handled for the ship?

Based on this the following decisions should be made:

2. How many cranes should be assigned to work the ship?
3. How many AGVs should be allocated to each crane?

In the IPSI AGV system presented in Figure 4, it also should be decided:

4. How many cassettes should be used?

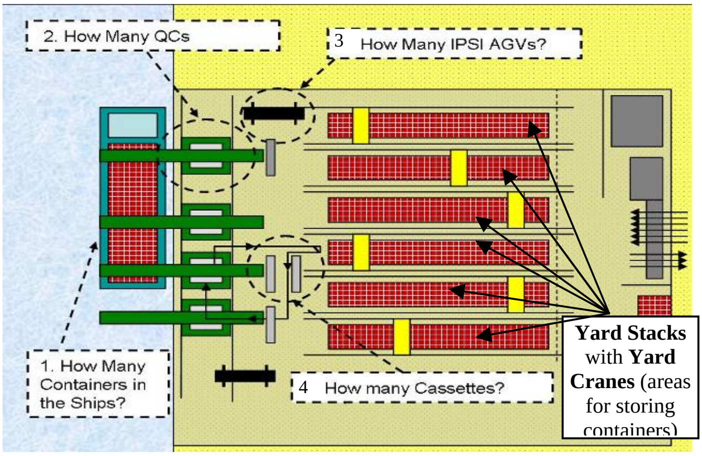

Figure 4. Model of a container terminal using IPSI AGVs

Figure 5 illustrates a CT in which T-AGVs would be employed, such as those used at CTA in Hamburg, Germany.

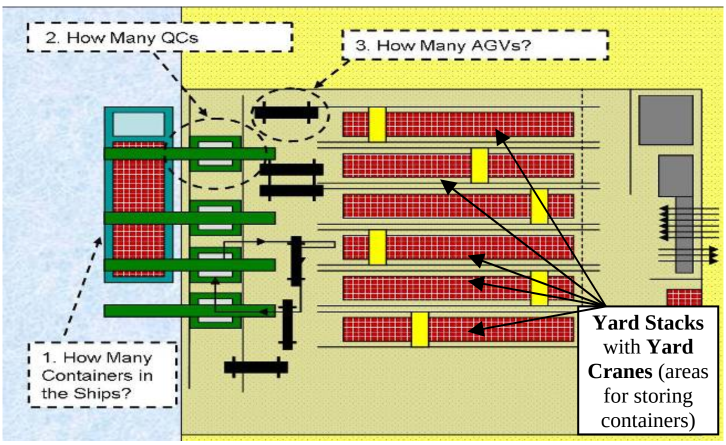

Figure 5. Model of a container terminal using T-AGVs

The biggest difference between the IPSI AGV system in Figure 4 and the T-AGV system in Figure 5 is the absence of cassettes. The containers are placed directly on the AGV in the T-AGV system as shown in Figure 5. A QC will wait for an available T-AGV to place a container on it rather than placing the container on the ground and then having to later pick it up and place it on a T-AGV, in order to reduce extra moves by the QC. This extra move can reduce the QC handling rate and can occur in the IPSI AGV system if there are no available cassettes.

3.2 Entities in the Model

The entities that are modelled are the following:

- **Ship:** contains the containers.
- **Quay cranes:** used to unload and load the containers.
- **AGVs** (IPSI AGVs or T-AGVs): used to transport container, from/to QC from/to a container stack.
- **Buffer:** Pick-up and drop-off area behind the QC that temporarily stores containers on cassettes or AGVs.
- **Cassettes:** A set of cassettes bound to a QC.
- **Containers**

The CT equipment in the simulation are partly modelled as agents, e.g., QCs, Buffer and the AGVs (IPSI AGVs, and T-AGVs). Ships and cassettes are modelled as objects in the simulator

The agents, which are considered to be reactive, make their decisions based the state of the entity it corresponds to and on the information in the messages they receive from other agents. The agents' goals are only implicitly represented by the rules describing their behaviour. The major advantage in using reactive agents, according to Wooldridge [16]; "is that overall behaviour emerges from the interactions of the component behaviours when the agent is placed in its environment". Further, Wooldridge notes that the intelligent, rational behaviour is linked to the environment that an agent occupies, thus intelligent behaviour is not disembodied, but is a product of the interaction that the agent has with its environment [16]. In the next section we define the agents in the system in more detail.

3.3 Agents in the model

This section defines the agents of the system along with their attributes, functions and messages.

3.3.1 Quay Crane (QC) Agent

The QC is responsible for the unloading and loading the containers from and to the ship. The number of QCs serving a ship is specified by the user.

Attributes

Each QC has:

- a unique name
- a set of AGVs (IPSI AGVs or T-AGVs) assigned to it
- a set of cassettes (for the IPSI AGVs)
- a buffer area where its cassettes or T-AGVs can be placed for loading/unloading containers
- a container handling time for unloading a container, this may be different for each container.

Moreover, the following are recorded for each QC:

- the number of containers unloaded from the ship and loaded to the ship
- the time it has been working (not including the idle time).

Functions

- In a real CT the QC will have varying container handling times, which we simulate by a computer generated random number using a linear congruence method chosen in a range specified by the user.
- When unloading, the QC will unload a container from the ship if there is a cassette (or T-AGV) with free space in the buffer area. If not, it waits until there is one available.

- When there are containers to be loaded available in the buffer area, the QC will load one container at a time to the ship.
- The QC finishes working when there are no containers to be unloaded or loaded for the ship.

3.3.2 Buffer Agent

A buffer agent is assigned to a QC

Attributes

- Unique name.
- Assigned to a QC and communicates with that QC's AGVs and cassettes in order to maintain their status conditions.

Functions

A buffer is assigned to a specific QC and the buffer is responsible for allocating free AGVs to either pick-up a container and move it or move empty (to pick-up container(s) at another location). The buffer is also responsible for the QC to stop unloading if there is no cassette available or the cassette is full and to stop loading if there is no containers available on cassettes or on AGVs. The Buffer agent will communicate with the AGVs and assign an AGV that is free to pick up a cassette (for the IPSI-AGV). Once a cassette is available the buffer agent will ask the QC to start working. When using T-AGVs, the buffer agent tries to find a free T-AGV and assign a container to that T-AGV. If no T-AGV is free then it waits until a T-AGV is free at the buffer. Pseudo-code describing the unloading and dispatching strategy of the buffer agent for the cassette-based system is given below:

```
WHILE still containers to unload DO
  IF cassette available that has room for more containers  THEN
    Ask QC to unload a container and place it on cassette
    Ask all AGVs for their status
    Wait for status reports
    IF AGV idle THEN
      Ask that AGV to fetch the loaded cassette
  ELSEIF cassette is full THEN
   Ask QC to stop unloading
   REPEAT
     Ask all AGVs for their status
     Wait for status reports
```

```
    UNTIL at least one AGV is idle
    Ask the idle AGV to fetch the loaded cassette
ENDWHILE
```

3.3.3 AGV Agent (IPSI AGV and T-AGV)

Each QC has a number of AGVs assigned to it. This value is specified by the user before the start of the experiment. An AGV is responsible to transport containers between a QC Buffer and container stacks.

Attributes

Each AGV has:

- a unique name
- a state (“free” or “busy”)
- a cycle time for transporting a cassette/container from the buffer to the stack and return back to the buffer. Or vice versa during the loading phase. The cycle time can be different for each move.

Moreover, the following are recorded for each AGV:

- the number of containers transported to/from the stack
- the time it has been working (not including the idle time).

Functions

- An AGV is responsible for transporting a container/cassette that is assigned to it by the QC.
- In a real CT the AGV will have varying transport times, which we simulate by a computer generated random number using a uniform method chosen in a range specified by the user.

4. Experiment Description

The input parameters are stored in a text file from which the simulator reads the parameters. The output of the simulation is a set of files implemented from the DESMO-J library, which contains information of all events taken place during the simulation. A trace file contains the overall performance of each QC, AGV and cassette involved in the simulation. The performance criteria that are used for evaluating and comparing the CT transport systems are:

- *Service Time*: is the time it takes to complete the unload/load operations for a ship, also known in the maritime industry as "turn-around time".
- *Utilization Rate*: *Active time / Service Time (Active time + Idle time). Active time* is the time a piece of CT equipment is busy, such as moving a container from the QC to a stack and *Idle time* is the time that it is not working. The utilization rate for the following CT equipment is recorded: *QC, AGV and Cassette.*
- *Throughput*: Avg. number of containers handled per hour during Service time for: *QC, AGV and Cassette*
- *Total Cost*: Equipment cost for serving a ship is calculated in the following ways (OPEX = operating cost per hour for a unit of CT equipment):
  - *QC:* number of QCs x OPEX for QC x Service Time.
  - *AGV:* number of AGVs x OPEX for AGV x Service Time.
  - *Cassette:* number of cassettes x OPEX for Cassette x Service Time.
  - *Total Cost: QC costs +AGV costs + Cassette costs*

4.1 Scenario Settings

The scenario settings were based upon data provided by industrial partners. The results from the simulations are based on average values, which necessitates that a number of simulation trials are made in order to get a valid estimation. The cycle times used in the simulation have been determined from prior analysis in which the stack distances and maximum speeds of the AGVs were tested. We used an approximation method to calculate the minimum number of simulation runs required in order to obtain results from a simulator with small enough statistical errors. The approximation method is presented in Law and Kelton [17] and applied by Vis et al. [18] in vehicle allocation at a container terminal. In this method, data from a limited number of replications (trial sample) is used to approximate the required minimum number of replications in the actual experiment (denoted as i) such that the relative error is smaller than γ ($0 < \gamma < 1$) with a probability of 1 –α. The i value can be calculated from the following equation:

$$i \geq S^2(i)\left[z_{1-\alpha/2} / \gamma' \overline{\mathrm{X}}(i)\right]^2 \tag{1}$$

where $S^2(i)$ is the variance of the trial sample, $z_{1-\alpha/2}$ is the $1-\alpha/2$ percentile of the normal distribution, $\overline{\mathrm{X}}(i)$ is the trial sample mean value, and $\gamma' = \gamma/(1+\gamma)$. Based on our trial sample we found that to obtain the error smaller than 2% (γ <0.05) with a probability of 95% that the number of generated replications would be sufficient at 100 for all experiments conducted in this paper.

In the simulation experiments, we use the settings listed in Table 2 for serving a single ship.

Table 2. Settings experimented in the simulator for a single ship

	AGV Type	
Input Settings for Scenario	**IPSI AGV**	**T-AGV**
Number of Containers	493	493
Number of QCs	3	3
Number of Cassettes assigned to an QC for each IPSI AGV	1- 4	n.a.
Number of AGVs per QC	1-5	1-5
Container handling time for QC	1-2 min	1-2 min
Travel cycle time for AGV	3-6 min	3-5 min

An "average ship" is used in which 493 containers are to be either unloaded or loaded. From information that was provided by industrial experts, the number of QCs to serve the ship is determined to be three. Each QC is assigned a buffer with a number of AGVs and posses a container handling time that is randomly generated for each container ranging between one-two minutes. The numbers of AGVs evaluated are from one to five and the numbers of cassettes are from one to four per IPSI AGV. Each IPSI AGV has a travel cycle time that is randomly generated for each cassette transported ranging between three to six minutes. The T-AGVs posses a random travel cycle time ranging between three to five minutes. Cycle time for the IPSI AGV includes the lifting of a cassette, transport it from a QC to a stack, detach the cassette and then return to the QC with an empty cassette; or the cycle time for the opposite direction, i.e., transporting from the stack to the QC. Cycle time for T-AGVs is similar to IPSI AGVs but does not have a lifting time or transport a cassette.

5 Simulation Results

Simulation experiments were conducted to evaluate various combinations of allocated terminal resources three QCs. Ship service time results are presented in Figure 7, for different number of AGVs and cassettes used (the exact values are given in the Table 3). They suggest that ship service time is generally faster for IPSI AGVs than for T-AGVs. When three or more IPSI AGVs with two or more cassettes each, the service time is close to its smallest value and instead the capacity of the QCs becomes the bottleneck. Ship service time results for the T-AGV system are similar to the IPSI AGVs when assigned with one cassette. The ship service time appears to be faster after two IPSI AGVs are assigned with two or more cassettes, average ship service time is 5,13 hours. The fastest ship service time is 4,10 hours when using five cassettes and either four or five IPSI AGVs. The use of an additional IPSI AGV when using five cassettes appears not to influence the ship service time. The standard deviation in Table 3 indicates that when using one AGV regardless of system type and number of cassettes will yield a deviation ranging 0,118% to 0,144% for 100 simulation runs. The standard deviation for the simulations evaluating two or more AGVs employed (ran 100 trials for each simulation) are averaging between 0.0535% and 0,0696%.

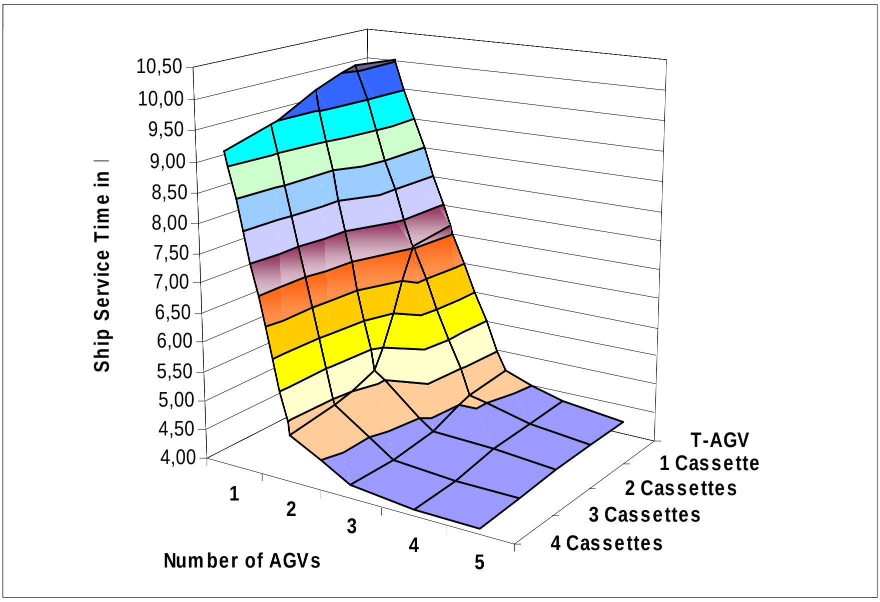

Figure 6. Simulation results for ship service time.

Table 3. Average ship service times and standard deviation:

No. AGVs	T-AGV	1 Cassette	2 Cassettes	3 Cassettes	4 Cassettes
1	**10,03** *0,1374*	**10,08** *0,1186*	**9,85** *0,1265*	**9,45** *0,1438*	**9,23** *0,1326*
2	**7,15** *0,0535*	**7,03** *0,0604*	**5,13** *0,0606*	**4,90** *0,0696*	4,78 *0,0640*
3	**4,65** *0,0647*	**4,58** *0,0671*	**4,32** *0,0530*	**4,23** *0,0600*	**4,23** *0,0630*
4	**4,33** *0,0629*	**4,30** *0,0593*	**4,27** *0,0668*	**4,15** *0,0643*	**4,10** *0,0608*
5	**4,20** *0,0563*	**4,20** *0,0564*	**4,18** *0,0619*	**4,13** *0,0665*	**4,10** *0,0611*

Bold – average ship service time
Italic – standard deviation

From the simulation experiments, we can compare the QC utilization rates in Table 4. Generally, we see that the more transport equipment is available, the higher is the QCs' rate of utilization. The rate of QC utilization becomes close to one when using three or more IPSI AGVs with at least two cassettes per AGV.

Table 4. Comparison of QC Utilization Rates

No. AGVs	T-AGV	1 Cassette	2 Cassettes	3 Cassettes	4 Cassettes
1	0,41	0,41	0,42	0,43	0,44
2	0,57	0,58	0,80	0,84	0,86
3	0,88	0,89	0,95	0,97	0,97
4	0,95	0,95	0,96	0,99	1,00
5	0,98	0,98	0,98	0,99	1,00

AGV utilization rates are presented in Table 5. We see that the utilization rate is close to 1 when only one AGV is used, that is, the QC is able to keep the AGV busy. When more AGVs are added, the utilization rate decrease and the AGVs spend more time being idle. In comparing T-AGVs with the IPSI AGVs, there is a recorded higher level of utilization when IPSI AGVs each have two or more cassettes. Utilization rates for the IPSI AGVs decrease in smaller increments as the number of cassettes increase.

Table 5. Comparison of AGV Utilization Rate (IPSI AGV and T-AGV)

No. AGVs	T-AGV	1 Cassette	2 Cassettes	3 Cassettes	4 Cassettes
1	0,957	0,962	0,995	0,997	0,991
2	0,687	0,673	0,939	0,971	0,983
3	0,659	0,680	0,730	0,755	0,744
4	0,543	0,559	0,570	0,575	0,578
5	0,477	0,484	0,476	0,469	0,468

A performance metric closely related to the utilization rate is the numbers of containers handled per hour during service time. The results for the different types of equipment are listed in Table 6-8.

Table 6. Average number of containers handled per hour per QC.

No. of AGVs	T-AGV	1 Cassette	2 Cassettes	3 Cassettes	4 Cassettes
1	16,43	16,30	16,73	17,35	17,76
2	22,94	23,32	31,95	33,47	34,29

3	35,27	35,78	37,99	38,74	38,74
4	37,85	38,14	38,44	39,52	40,00
5	39,05	39,05	39,20	39,68	40,00

Table 7. Average number of containers handled per hour per AGV.

No. of AGVs	T-AGV	1 Cassette	2 Cassettes	3 Cassettes	4 Cassettes
1		16,30	16,68	17,39	17,80
2	11,49	11,68	16,01	16,77	17,18
3	11,78	11,95	12,69	12,94	12,94
4	9,48	9,55	9,63	9,90	10,02
5	7,83	7,83	7,86	7,95	8,02

Table 8. Average number of containers handled per hour per cassette

No. of AGVs	T-AGV	1 Cassette	2 Cassettes	3 Cassettes	4 Cassettes
1	n.a.	16,30	8,34	5,80	4,45
2	n.a.	11,68	8,00	5,59	4,29
3	n.a.	11,95	6,34	4,31	3,23
4	n.a.	9,55	4,81	3,30	2,51
5	n.a.	7,83	3,93	2,65	2,00

An increase in the number of cassettes and AGVs adds extra capacity for transporting containers. The extra capacity provided by cassettes may be viewed as a 'floating buffer', which allows the IPSI AGVs to decouple the load of containers on a cassette and fetch another cassette. This activity assists in lessening the idle time of the QCs so that they can be more productive. Thus, from the above results one can conclude that it is useful to introduce a certain amount of IPSI AGV and cassettes in the simulation to make the crane busy throughout the simulation. As crane operating cost is higher than the AGV operating cost, these results can be helpful for CT management in deciding, e.g., how many cranes, IPSI AGVs and cassettes to be allocated to a ship. We shall now compare operating costs for the different configurations.

In Table 9 the total operating costs for employing the three types of CT equipment is presented. In determining the total operating costs for each CT equipment type, the hourly operating cost is multiplied by the number of CT equipment type employed, which is then multiplied by ship service time. The assumed hourly operating costs (including depreciation, maintenance, labour and fuel) used in the calculations are:

- QC: 905, kr/hr
- T-AGV: 43, kr/hr
- IPSI-AGV: 60 kr/hr
- Cassette: 0,50 kr/hr

In comparison between AGV and IPSI AGVs, IPSI AGVs are more expensive to operate than the T-AGVs.

Table 9. Total terminal equipment operating costs (in Swedish kronor)

Total QC operating costs					
No. of AGVs	T-AGV	1 Cassette	2 Cassettes	3 Cassettes	4 Cassettes
1	27 241 kr	27 376 kr	26 743 kr	25 657 kr	25 069 kr
2	19 412 kr	19 096 kr	13 937 kr	13 304 kr	12 987 kr
3	12 625 kr	12 444 kr	11 720 kr	11 494 kr	11 494 kr
4	11 765 kr	11 675 kr	11 584 kr	11 267 kr	11 132 kr
5	11 403 kr	11 403 kr	11 358 kr	11 222 kr	11 132 kr
Total AGV operating costs					
No. of AGVs	T-AGV	1 Cassette	2 Cassettes	3 Cassettes	4 Cassettes
1	1 294 kr	1 815 kr	1 773 kr	1 701 kr	1 662 kr
2	1 845 kr	2 532 kr	1 848 kr	1 764 kr	1 722 kr
3	1 800 kr	2 475 kr	2 331 kr	2 286 kr	2 286 kr
4	2 236 kr	3 096 kr	3 072 kr	2 988 kr	2 952 kr
5	2 709 kr	3 780 kr	3 765 kr	3 720 kr	3 690 kr
Total cassette operating costs					
No. of AGVs	T-AGV	1 Cassette	2 Cassettes	3 Cassettes	4 Cassettes
1	n.a.	15 kr	30 kr	43 kr	55 kr
2	n.a.	21 kr	31 kr	44 kr	57 kr
3	n.a.	21 kr	39 kr	57 kr	76 kr
4	n.a.	26 kr	51 kr	75 kr	98 kr
5	n.a.	32 kr	63 kr	93 kr	123 kr

The operating costs for both AGV systems increase as more AGVs are employed, however for IPSI-AGVs, the operating costs decrease as more cassettes are deployed to work with each IPSI-AGV. Naturally, there is a trade-off in that additional cassettes increase the operating costs associated for cassettes, hence we also need to study the total costs.

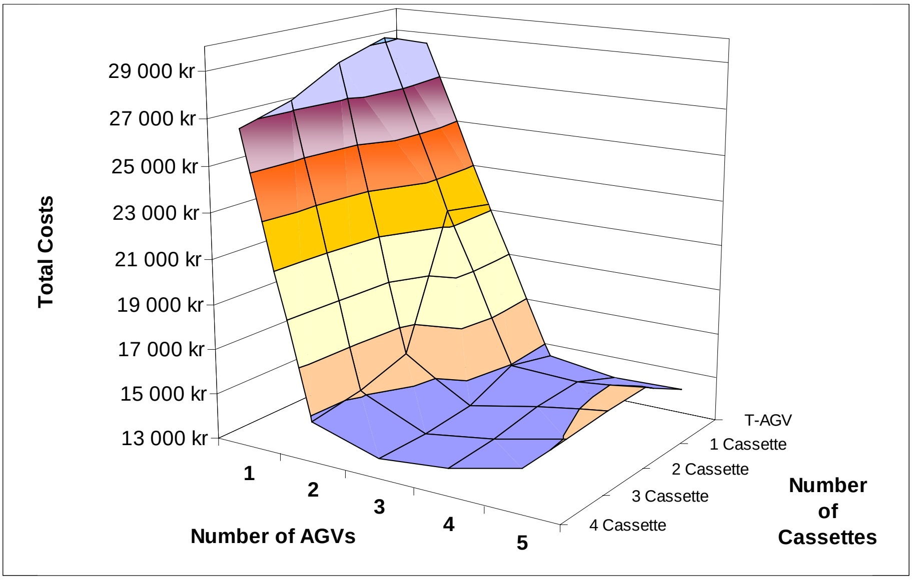

Figure 7. Total operating costs for serving a ship.

Table 10. Total operating costs for serving a ship.

No. of AGVs	T-AGV	1 Cassette	2 Cassettes	3 Cassettes	4 Cassettes
1	28 535 kr	29 206 kr	28 545 kr	27 400 kr	26 786 kr
2	21 257 kr	21 649 kr	15 816 kr	15 112 kr	14 766 kr
3	14 424 kr	14 939 kr	14 090 kr	13 837 kr	13 856 kr
4	14 001 kr	14 796 kr	14 707 kr	14 330 kr	14 182 kr
5	14 112 kr	15 215 kr	15 186 kr	15 035 kr	14 945 kr

In comparing the total operating costs in Table 10 and Figure 7, the addition of more AGVs and cassettes leads to lower costs up until three IPSI AGVs and three cassettes are employed. The total costs when adding further equipment increase, i.e., the time gained do not compensate for the extra cost. A possible choice for assigning CT equipment in the scenario studied would be the use of three IPSI AGVs with three cassettes each.

6 Discussion, Conclusion and Future Work

The cassette-based system posses some advantages in that it can act as a 'floating' buffer, meaning that it can allow the QCs to keep unloading/loading and not having to wait for an AGV to be available. Waiting time is lower for the QCs and thus they are obtaining better utilization rates. The initial results from the prototype AGV simulator provide some interesting observations useful for determining the number of machinery units to allocate for serving a ship. The simulation experiments that we have conducted are also creating further questions that require more investigation. Naturally there is a trade-off to be expected between service time and the costs for purchasing and operating equipment.

Compared to traditional simulation approaches, the agent-based modelling approach can provide better granularity in modelling the entities and having them communicate and coordinate amongst other entities. In Elder [19], he mentions the advantages of simulation methods over queuing techniques and we also find it difficult with traditional queuing models to model problems such as the AGV dispatching strategies (in this study carried out by the Buffer agent) that are used when applying cassette-based systems. The simulator has provided us much insight in the relationships among various terminal equipment types that can be used in container terminal operations.

For future work we would study other models for container handling time by the QC and the cycle time for AGVs (e.g., including stoppages caused by malfunctioning equipment, etc. which affects the productivity at a real CT). Another topic worth studying is different dispatching strategies for allocating containers to AGVs and cassettes. We plan to extend the model in several directions, e.g., including the unloading/loading taking place at the stacks, more detailed modelling of the AGV movements, etc.

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Paper IX

Application of Transaction Costs in Analyzing Transport Corridor Organisation structures by Using Multi Agent-Based Simulation

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Abstract

In analyzing freight transportation systems, such as the intermodal transport of containers, often direct monetary costs associated with transportation are used to evaluate or determine choice of transport corridor. In forming decisions on transport corridor cooperation, this paper proposes that transaction cost simulation modelling can be considered as an additional determinant in conducting transport corridor analysis. The application of transaction costs theory in analyzing the organisational structures and the transactions that occur, assists in indicating as to which governance structure results in higher efficiencies. The use of multi-agent based simulation for modelling the organisational structure and mechanisms provides a novel approach in understanding the organisational relationships in a regional transport corridor.

Keywords: Transaction Cost Economics, Transport Corridors, Multi-Agents Systems, Simulation, Terminals

IX

1. Introduction

The purpose of this paper is to apply elements from transaction costs economic theory in the design of a conceptual computer simulation model for analysing cooperation choice of transport corridor. The simulation model adopts a multi-agent approach in coordinating the intelligent behaviour among a collection of autonomous agents representing actors involved in the transportation of goods. This technological approach implies that the agents would be modelled to represent both users and providers in a transport corridor for simulation and analysis. The agents would be seeking to satisfy their own goals rather than searching an optimal organisational solution. Contracts and negotiations could be simulated and organisational structures analyzed, i.e., market, vertical and contract. The application of transaction costs theory would assist in explaining or predicting the behaviour of actors in a transport corridor. Additionally, multi-agent based simulation (MABS) could assist in analysing the decisions that are influenced by the different levels of transaction costs, such as whether shipping lines should purchase or build their own terminals as opposed to using terminals of others (make or buy). The research question that is studied is: "how can agent-based technology be used in analyzing the transaction costs and organisational structures in a transport corridor?"

A market has to exist first before governance structures can be formed [1]. Therefore the objective of the research presented in this paper is to analyze how the real organisations represented as agents and their transactions, which are incorporated in a model, influence the choice of a suitable structure for organisation in a transport corridor. In order to achieve this objective, we study goods transferred through the entire transport chain, from origin to final destination, in the most efficient manner, i.e., cost- and time-effective. Some examples of cooperation in transport chains are:

- the use of a common standard, e.g. an ISO container, may create strong interconnectivity with other actors in the organisation of shipping.

- improve the operations and utilization of resources. For instance, it is important that time tables meet customer requirements.
- use of new technologies which may help to bind firms closer, settle claims and develop trust.

The paper is structured as follows: In Section 2 a description of transaction cost theory is presented. The components that are to be represented by agents, in a generic transport corridor are described in Section 3. A simulation architecture based on a MABS approach is presented in Section 4. The model and design of the simulator is outlined in Section 5. Finally, in Section 6, we discuss our conclusions and provide an outlook onto future work.

2. Description of Transaction Cost Theory

In the book "*The Nature of the Firm*" [2], Ronald Coase observed that market prices often govern the relationships between firms, known as transactions. Ronald Coase noted that if transactions are not governed by the price system then an organisational structure must exist. The transaction cost approach was developed by Ronald Coase to identify what are the costs of providing for some transaction through the market rather than having it provided from within the firm [1]. Some transaction costs types are: searching costs, negotiation costs, and monitoring or policing costs.

In further developing transaction cost economics, Williamson [3] [4] has studied the organization of transactions and "governance structures" that occur whenever or wherever a good or service is transferred from a provider to a user. As one transaction occurs when a good or service is transferred, a stage of activity is terminating and another is beginning [3]. Transaction costs economics focuses on the transactions between the stages of activity where the firm is one type of organisational structure. Transaction cost economics can be seen as the mapping of forms of organisations into transactions. The existence of low transaction costs in global trade has been a leading element in globalization.

Transaction can be either internal or external to organizations. The transactions that occur within the organization are internal and may include such costs as managing and monitoring staff, products, or services. The external transactions costs when buying from an external provider may consider the source selection, performance measurement, and managing the contract. Transaction cost economics tries to answer such questions as: shall we make or buy? Is the market structure the best method to organize purchasing? When is cooperation beneficial? Kalevi et al. [5], provides some examples of transactions costs that can be considered to be related to trading partners located in a transport corridor:

- *Searching costs* – Caused by the search for transaction partners or alternative actions (examples are: the amount of time needed for the search at special organisations or institutions, costs which are caused by the use of telecommunication, online services or special publications or management consultants).
- *Information costs* – Due to lack of information in the process of interaction. This covers costs that are caused by the use of different languages (e.g. translation costs) or by technical problems that disturb the exchange of information (costs of technical equipment to overcome this disturbance).
- *Decision costs* – Arises from the participation of a group in the decision process. Due to different aims and motives of participants of decision groups, coming to an (shared) agreement is a very time-consuming process. Moreover, decision costs are caused by contracts that were not fulfilled in the way they were negotiated or by contracts that were not closed in the intended meaning.
- *Bargaining costs* – Caused by the process of negotiation (examples: costs of lawyers and consultants, costs of the required resources like costs of travelling and travelling time).
- *Control costs* – Emerge from the adaptation and supervision of transaction results (examples: costs controlling payments or arranged technical standards or quality).
- *Handling costs* – Emerge from the management of converging action cooperation (examples: costs involving human re-

sources, costs which are caused by the definition of business processes).

- *Adjustment costs* – Caused by the change of transaction conditions can be defined as costs of adjustment (examples: costs which are caused by the implementation of new laws or new IT-standards).
- *Disincentive costs* – Emerge by an opportunistic behaviour of the transaction partners or employees, i.e. every partner tries to interpret the contract to his own advantage (examples: unannounced high increase of prices by a supplier of products which have a very high level of specificity).
- *Execution costs* – Arise from the collection of overdue performances or payments. A possible example is the collection of proceedings.

Williamson [6] lists six key elements of which two are assumptions, fixed factors and four are variables, used to characterise a transaction. According to the theory, the variables can determine whether the transaction costs will be lowest in a market or in a hierarchy that can affect transaction costs *assumptions:*

- *Opportunism* – A situation in which one partner in a relationships exploits the dependence of another partner, i.e. increasing prices or reducing quality.
- *Bounded rationality* – Not possessing perfect information due to limited time or span of control. It is difficult to locate the best solution or know what alternatives may exist.

Transaction cost *variables*:

- *Asset specificity* – These investments are made by the trading partners who are specific, such as the tools, routines, knowledge or machines to serve a certain trade partner.
- *Uncertainty* – The plethora of new technologies and the increasing complexity that characterizes many systems impacts the decisions that are made.

- *Information Asymmetry* – Information or quality is not disseminated among all partners evenly. Typically characterized in many transportation networks are the number of "islands of information" which generate, release or retrieve information that is useful for a specific trading partner.
- *Frequency* – The number or volume of orders.

A major concentration of transaction costs theory has been on *governance structures* that seek to maximize the value net of production and transaction costs. Most transactions are carried out through a market governance structure. There are three main types of governance structures: *market, contracts, and vertical integration*. Markets are seen the most preferred solution to organize activities, when uncertainty and knowledge is imperfect. Contracts provide protection for transaction specific assets by binding both the provider and the user together for a certain time period. Vertical integration is employed in order to internalize the values of transaction specific assets. In Table 1 we compare the advantages and disadvantages listed by [7] on the three main governance structures resulting from transaction costs.

Table 1. Three Types of Governance Structures

Governance Structure	Advantages	Disadvantages
Market	Incentive on maximizing net value	Can't protect transaction-specific investments
Contracts	Some protection on investments	Not all possible contingencies can be contracted
Vertical Integration	Internalize values of transaction-specific investments	Can't control costs as well as markets

3. Components of a Transport Corridor

A main objective of the European Union's (E.U.) *Motorways of the Sea* initiative and especially in the *BalticGateway* and *EastWest* projects is to increase the use of intermodal freight, seaports and terminals in order to take more freight traffic off the road and rail systems [8, 9]. The enlargement of the European Union, especially in the East Baltic region offers many tantalizing opportunities and uncertainties for policy makers regarding to the choice of freight transportation systems and transport corridors. The investments and business decisions on seaports, rail networks, and roads in moving cargo between the new members states in the Baltic incites many questions that require further analysis. In particular, the terminals (seaports) require much attention and need to be studied since they are the "nodal point" between the land-based transport networks and marine transport networks. The terminals are often not explicitly taken into account when cargo transportation flows are analyzed at a regional level [10].

Shipping can be viewed as a network coupled with land-based transport networks (by trucks or railway), marine transport networks (ships) and seaports or terminals. As network organisations, *shipping* can be considered to be virtual organizations linked by supplier-customer relationships. Such relationships are often modelled as markets where goods are bought and sold between actors in the network. Transportation costs include physical movement costs and the non-monetary transaction costs between the organizations in the transport corridor. The use of market mechanisms in coordination or control has assisted in eliminating much of the administrative overhead, meaning that the fall in transaction costs significantly decreases the whole transportation costs.

In introducing a generic transport corridor, we have concentrated on a few actors that are involved in the transport of goods, e.g. the transport activity between Karlshamn, Sweden with Klaipeda, Lithuania [9]. Actors that we consider in modelling and simulating are the following: *terminal, freight forwarder, inland transportation providers, governmental legal authorities, shipper* and *ship line*. Some decisions made by the actors that could be modelled and simulated are for example, shippers decision of whether to use rail, ship or road, or the shippers decisions of whether to use a hierarchy (freight forwarder) or just contact the market (inland transportation providers and shipping lines) directly. By evaluating the agent's decisions we aim to identify the most cost-effective governance structure for moving goods between two ports, given for example current asset specificity and switching costs. We describe in more detail the following modelled types of actors in alphabetical order:

1. Freight Forwarder: The business of transporting goods involves many various activities. The use of sales contracts between the exporter and importer are the starting phase, where intermediaries may intervene such as freight forwarders. If the exporter or importer does not have their own shipping department, they will contact a freight forwarder. The freight forwarder will have contacts and contracts with various road haulers and steamship lines. The freight forwarder makes the necessary arrangements in taking responsibility of transporting a good from place of origin to the destination. In practice, this means that the freight forwarder will check with the government-legal authorities (e.g. customs), insurance companies, and the banks to insure the transport activity is cleared.

2. Governmental-legal authorities: Customs and governmental agencies from regional, national, and international make policies that effect shipping across borders, either by taxation or subsidizing. The inspections and clearance of goods and the way this activity is carried out can influence the transportation of goods and choice of transport corridor. The importance of fast clearance and transparency of the process is paramount as can be see on from the example of many shippers choosing Finnish ports over Russian ports in moving cargo to Russia [11]. The choice of transport corridor is influenced by such policies.

3. Inland Transportation Provider (Road and Rail): As road transport and rail cargo transport are becoming more and more effective competitors of sea transport, it is no longer possible to look at maritime transport, including port economics, separately from the total transport system. This explains why traditional modal split issues are reconsidered in a so-called system split model: "the choice will not primarily be a modal choice; it will really be a choice between different transport systems, some of which will contain a combination of several modes and some of which will depend on only one mode" [12]. Consequently, shippers do not necessarily choose a seaport, but they select a transport chain in which a seaport is merely a node.

With road and rail networks connecting many terminals to their shippers and with vessels calling at multiple terminals, the seaport or terminal is sensitive to freight variations and to competition. The seaport must develop a strategic plan and coordinate with its stakeholders on a path that will support the seaport and develop more mutual business in order to compete. The notion that a terminal will be competing with other terminals is now being redefined.

4. Shipper: Often a shipper is the person or organisation that initially decides to transport a good. Shippers are either seen as the exporter or importer, which depends on the contract, and in general are responsible for influencing the transport activity. The shipper can be a manufacturer in which it may ship parts to its factories- in this case it is taking an importer role. When the manufacturer ships the finished autos to its markets- it is taking an exporter role. In both examples the manufacturer was taking the shipping role. In other situations, a shipper may represent a large group of small firms, e.g. the Swedish log industry. By having such an organisation represent the thousands of small log companies, it can assist in negotiating better rates and contracts with shipping lines and terminals.

5. Shipping lines: Often shipping lines are only associated with transporting goods between ports on ships. The emergence of logistics has propelled many shipping lines, such as Maersk or DFDS lines, to develop integrated logistics systems where the ships are one component to a total transport system. In many cases shipping lines can take competing or cooperating roles. The “foot-loose” characteristics of the shipping lines influences the decisions on which transport corridors should be taken. The example of TEAM lines (a shipping line) moving its container operations from Karlshamn, Sweden to Åhus, Sweden has severely impacted the flow of containers in Karlshamn.

6. Terminal: The terminal is has an important position in transport corridors as the intermediaries in helping to reduce the number of transactions, which then leads to lower transport costs. A part of the transaction costs in a transport corridor can be seen as handling

> costs at railroad stations, seaport and terminals. Seaports and terminals are used by customers to reach the hinterlands or markets that they serve customers by accessing through transport corridors, which try to achieve overall transportation system performance by having lower costs and wider access to markets [13].
>
> Modern seaport and terminals are no longer passive points of interface between sea and land transport, used by ships and cargo as the natural point of intermodal interchange [14]. They have become logistic centres acting as 'nodal points' in a global transport system. The emergence of integrated freight transport system leads to new challenges in the field of efficiency, equity and sustainability. In order to meet the new requirements, active forms of intergovernmental co-operation, on the sub-regional and even global level, are indispensable.

The importance of operational integration among the actors in a transport corridor is generated by the need for greater efficiency. Operational intermodal integration in transport corridors is influenced by such forces as, trends in out-sourcing, more focus on supply-chain management concepts and liberalisation of new markets, i.e. Lithuania, Latvia, Estonia, Poland, etc. Governance structure of the market facilitates the exchange for goods to be transported and is considered as an input for decisions that influence the cooperation in the transport corridor.

By understanding the most efficient system for organising this integration (such as between actors) may be achieved by applying the transaction cost economics approach [3]. The choice of governance systems in the transaction costs approach seeks to understand how economic efficiencies can be created in a transport corridor. This choice of governance structure is dependent upon cost difference between a market, contract, or vertical (hierarchy).[1] In the case that asset specificity is high, such as a terminal buying a new crane or building a ramp to serve RoRo ships, a vertical form of governance structure is preferred by a terminal actor. If the asset specificity is low, such as locating a truck to move cargo to a terminal, then a market organization would be preferred. Often, market structure is characterized as being

[1] There exist additional types of hybrid governance structures that lie between market and hierarchy.

preferred in terms of incentives and ability to aggregate demand for exploiting economies of scale. Hierarchy is preferred for adaptive sequential decision making.

In Figure 1, we present the six actors and illustrate their relationships within a port or terminal community. This community can be seen as a subset of a larger transport corridor community. In transporting cargo from one port to another port, such as Karlshamn to Klaipeda in Figure 1, both ports have terminal communities with similar groupings of entities. In Henesey et al. [13], the relationships in a port community are identified to be either physical, implying that the relationships between the entities are more optional in nature, or incorporeal suggesting that these type of relationships are not material. Incorporeal relationships include for example, behaviour that may have impacts on the efficiency objective [13]. The solid lines in Figure 1 indicate where a physical relationship exists the incorporeal relationships are identified as a broken line that suggest incomplete information transmitting between the actors. The transport corridor between the two ports is represented as a red line that flows through both ports. The information flow is seen as being communicated between two port communities represented in the transport corridor.

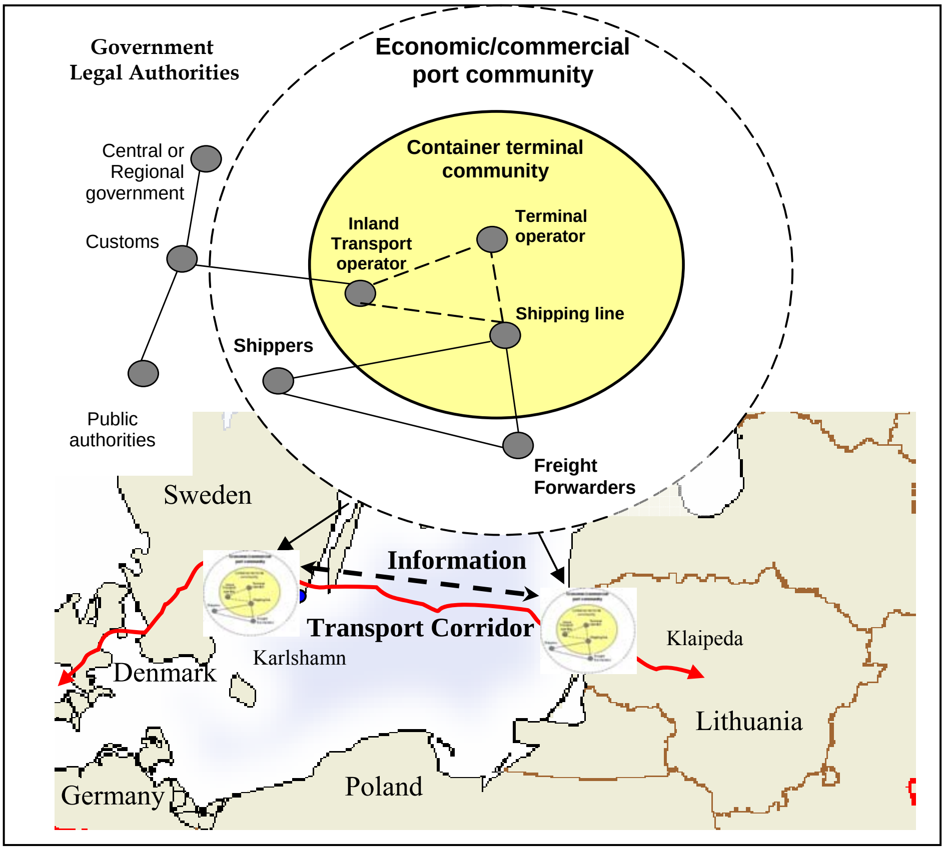

Figure 1. Illustration of the Transport Corridor Simulation

4. Architecture for Simulating Transport Corridor Choices

A computer based simulator model is suggested to model the actors that are involved in a transport corridor as agents. The following actors are modelled: *Freight forwarder agents, Governmental legal authority's agents Inland transportation provider agents, Shipper agents, Ship line agents, Terminal agents.*

In order to simplify the model the transaction cost types that are considered in the model are the handling costs, information costs and switching costs. For the transaction cost assumption we use bounded rationality. Both asset specificity and frequency are transaction cost variables that we analyse. The agents are considered to be bounded rationally and through their interactions with other agents organisational patterns will emerge. The output, such as types of governance structures, could be useful in future decision making for evaluating the total transport costs that include both the cost for transporting and the transaction costs.

Economic models incorporating MABS have been developed in investigating the theory of transactions cost economics. Klos [1] has developed an agent-based model for simulating and analyzing transaction costs economics. In our proposed model, agents can act autonomously on deciding preferences of which particular agent(s) to work with. The agents develop different preferences for other agents representing trading partners. The agents and three types of transaction costs are considered in the model, where the agents adaptively search suitable structural forms for organizing in order to satisfy transport demands.

Different polices and strategies for integrating terminal, shipping and logistics operations in transport corridor could be analyzed and compared through extending the work on simulation proposed by Klos [1]. The simulator is expected to generate results that would offer decision makers the ability to view the structure of a transport corridor system and the functions that the stakeholders have under various "what if" analyses. Different type of transaction costs questions that could be evaluated are for example:

- How can seaports, transport operators (land and sea based) and terminals improve performance by selecting a suitable governance structure?
- Which actors are working together and how they are cooperating in the transport corridor?

5. Simulation Design and Model

The proposed simulator model extends the work by Klos [1]. The extensions that we consider into the proposed model are;

- Employing the Beliefs Desires and Intentions (BDI) model for developing the individual agents and their behaviours.

- Introducing real transportation costs by considering the transport costs.
- Finally, we consider the agent's abilities to satisfy other agent's demands by considering the actual tasks required for satisfying transport demands.

5.1 BDI Model

The BDI architecture model is suggested to capture some of the characteristics of real stakeholders in the transport corridor. The agents will be representing the stakeholders in the system and would have incomplete beliefs – bounded rationality. The desires of the agents could be considered the individual goals that could be achieved by each of the agents, whether executing a task alone or with other agents. Intentions are similar to plans, which may be tightly integrated with other agent plans, to satisfy a transport demand.

One motivation for using the MABS approach is that it has been useful when applied to other areas of policymaking [15]. In particular to the transport corridor choices and transaction costs that influence those decisions, different forms of organisation could be investigated. Scenarios representing different levels of transactions costs and various forms of organisation could also be generated and analyzed. These analyses would help to assess what are the factors influencing performance in a systems perspective and give indication on what are proper governance structures. In order to achieve an objective such as intermodality, intensive cooperation and coordination amongst trading partners in the transport corridor are essential.

Further motivation in suggesting the BDI model is that given when bounded rationality exists and opportunism exists, transaction cost economics includes a rational analysis component that searches for the best organisational structure for various types of transactions. The proposed agent methodology would deal with the complexity in modelling the behaviour of the individual actors in the system.

5.2 Model Design

To satisfy a demand for transport, a specified set of tasks must be conducted. For instance, a task, m, could be the moving of a product or the handling of a container in a terminal. In executing the tasks, agents will represent different actors able to execute a particular task. We suggest that the model includes both a MABS, that would update input parameters to the simulation, and a matching algorithm formulated by Klos [1]. See the diagram illustrating the proposed simulator in Figure 2. The matching algorithm formulated in Klos [1] is based on Tesfatsion's [16] deferred choice and refusal (DCR) algorithm, which extends Gale and Shapley's deferred acceptance algorithm [17]. The matching algorithm will compute weights of working with other agents on a task based on dynamically updated input parameters from the MABS, and use the weights for deciding which agent should work with which agent for a particular task.

Our suggested approach is similar to an approach described by Robert Axtell's set-up for a variable effort model of firm formation [18], in that each agent should posses preferences for profit and past-experience with more of either preferred to less, *ceteris paribus*. Agent *i*'s profit is monotonically increasing with additional tasks, which implies that adding more tasks to satisfy a transport demand never decreases the profit. The assignment of preference weights is extended from Klos [1] by extending the Cobb-Douglas functional form. We suggest the following general formula for computing weights:

$$s_{ij}{}^{m} = f^{\cos t}\left(t_{ij}^{m}\right) + f^{transaction\cos ts}\left(o_{ij}^{m}\right) + \left(p_{ij}^{\alpha_i} \cdot r_{ij}{}^{1-\alpha_i}\right) \quad , \qquad (1)$$

where we adopt from Klos [1]*:*

$s_{ij}{}^{m}$ = weight assigned for agents *i* to cooperate with agents *j* in order to perform task, *m*,

p_{ij} = *estimated* profit that agents *i* calculates from coordinating with agents *j*,

r_{ij} = preference based upon past experience of agents *i* coordinating with agents *j* (we substitute trust in Klos [1], with preference),

$a_{\mathrm{i}} \in [0,1]$ = weight agents i assigns to p_i^j relative r_i^j,

our extension to the model:

$t_{ij}{}^{m}$ = transport cost parameter for agent i to perform task m for agent *j*,

o_{ij}^{m} = transaction cost parameter in which a task m is associated with a demand for a specific transaction cost,

$f^{cost}(t_{ij}^{m})$ and $f^{transactioncosts}(o_{ij}^{m})$ are functions (to be detailed in future work) for influencing the weights to a suitable degree due to transport cost and transaction costs, respectively.

The parameters (p_{ij}, r_{ij} *and*, t_{ij}^{m} and o_{ij}^{m}) are used as input to the simulation and will dynamically change during the simulation as the agents in the MAS update their preferences.

Each agent attaches a profitability weight, p_{ij} based on agents *i* general estimate of profit for agent *i* working with agent *j*. The estimate is partly based on asset specificity. We assume that a specialized provider of transport, e.g., a terminal offering cranes to lift cargo on or off a ship, can enjoy efficiency advantages. This interpretation of efficiency is applicable for the providers of transport. See Klos [1] for details on handling the general asset specificity.

Provided that asset specificity is proportional to differences in transport demand, it is possible that the assets required to satisfy a transport demand may not be easily switched to another provider. Since the asset specificity is connected to the actual tasks of the transport demand, we use o_{ij}^{m} to consider this. The more differentiated an agent's transport task is, the more specialized to that agent's are the assets which an agent that provides transport service, agents *j*, will be. We suggest to use parameter o_{ij}^{m} for primarily modelling transaction costs connected to handling cost, switching cost and information cost.

Initially, some of the agents in the transport corridor would possess predefined preferences, r_{ij}, of agent *i* working with agent *j* based on historical experience of past profit made and transaction costs incurred. The ability of an agent *i* to perform a task *m* with agent *j* is modelled through cost parameter, t_{ij}^{m}.

The calculated weights s_{ij}^{m} are used in the DCR for identifying which agents should be cooperating. The DCR algorithm will conduct one transport demand (and all its associated tasks) per time step and one task at a time. The result of the calculations performed by the DCR algorithm will lead to governance structures being formed, i.e. a matching of agents. Note that the DCR algorithm is capable to identify the situation where an agent should carry out the work himself, i.e. make instead of buying. The operation in transport corridor can be viewed in (at least) three hierarchical levels. The first level is occupied by the shipper agents, which receive transport demands. The transport demands may be sent to the freight forwarder agents, which are defined in the second level. Alternatively, the shipper agent or freight forwarder agents may contact agents directly in the third level for determining cooperation for satisfying transport demands. In order to identify the structure in the result of the DCR algorithm, the identification starts at the highest level, with continuation at the nearest level below which has an agent allocated for the task. Hence, it can be identified whether a shipper agent employs a forwarder (second level) or employs an agent at the third level directly. The use of the input from the MAS coupled with the selection process conducted by the DCR algorithm implies that organisational forms may emerge such as; alliances, coalitions, groups, networks and unions.

In the MAS diagram presented in Figure 2 we illustrate how the proposed simulator can realise the transportation costs by considering both the transport costs and transaction costs. For example, in the diagram we view the shipper agents processing transport demands and coordinating with other agents by calculating profitability and assigning a weight for a transaction costs. The government legal authority agent(s) may influence the environment of the system by levying taxes or offering incentives or subsides.

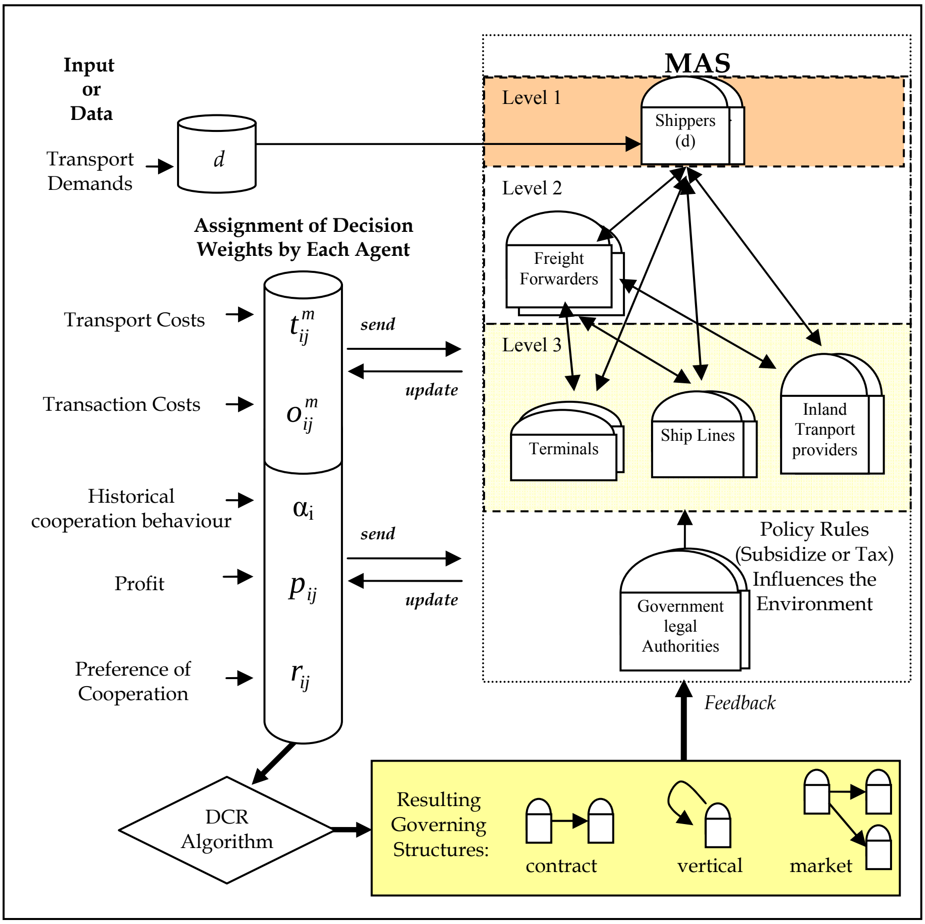

Figure 2. Input to the Simulation and MAS parts; agents' interactions leading to input to the DCR Algorithm, which results in the formation of organisation structures.

5.3 Conceptual Simulation Experiment

To illustrate the concepts from the above description, we will use a case example in which real actors are coordinating or contracting with each other along a set or well established transport corridor between Karlshamn, Sweden with Klaipeda, Lithuania [9]. All agents in the beginning of the time step will choose a set of preferences based on transaction costs, calculate transport costs for transporting, assign weights and identify (if possible) a preferred partner(s).

The agents will be dynamically matching based on updated parameters from the MAS. As an example of matching inland transport providers with shippers, we illustrate the input parameters in Table 2. In preference rankings in which a negative value is scored indicates that the coordination between the agents is 'unacceptable'. From the example in Table 2, AAK choose to cooperate with it's self to conduct the transport, which is considered a form of vertical integration. IKEA cooperates with DHL and this implies a contract form of organization. Volvo considers several partners in which Karlsham Xpress is the preferred choice. Since Volvo considers several partners it is an indicator of that a market form of organisation is suitable. Furthermore, if the simulation result happens to show, that Volvo buys from different providers of transport from time to time, the result is another indicator of the suitability of a market structure. The choice of operators and cooperation with them has an influence on governance structure.

Table 2. Example of operator selection of transport users and providers using weights. AAK (user 1) ranks itself as the best choice. IKEA (user 2) ranks DHL (provider 6) as the best choice. Volvo (user 3) ranks provider Karlshamn Xpress (provider 2) as first choice.

	Provider of Transport					
User of Transport	1 (AAK)	2 (Karlshamn Xpress)	3 (Schenker)	4 (DFDS)	5 (Food Tankers)	6 (DHL)
1 (AAK)	2,3	-0,5	-0,4	-0,5	-0,3	-0,2
2 (IKEA)	-0,3	-0,5	-0,2	-0,4	-0,3	4,3
3 (Volvo)	-0,2	5,1	2,4	1,1	3,1	3,3
4 (DHL)	1,4	-0,2	-0,1	-0,2	-0,5	1
5 (Electrolux)	3,1	-0,4	4,2	2,4	1,3	2,3
6 (SAAB)	-0,5	-0,3	-0,3	-0,5	-0,4	1

Software that is considered for the simulation tool are: JACK Intelligent Agents™, MAGNET and TNG. The first software, JACK Intelligent Agents is a multi-agent based system environment for building, running and integrating agents using a component-based approach (cf., [19]). The JACK software extends Java programming language by employing the following agent-oriented concepts: agents, capabilities, events, plans and resource management. The Multi-Agent Negotiation Test bed system (MAGNET) [20] is a framework for self-interested agents, which are either suppliers, customers, or may posses both traits in conducting commerce among themselves via negotiation of contracts for tasks. The agents may exhibit behaviour that is cooperative, competitive, and may possibly display tendencies that are both but not at the same time. The formation of a virtual organisation can be viewed for understanding the market infrastructure. Trade Network Game (TNG) [21] which combines evolutionary game play with preferential partner selection is suggested for evaluating alternative specifications for market structure, trade partner matching, trading, expectation formation, and trade strategy evolution. The evolutionary implications of these specifications can later be studied at three different levels: individual trader attributes; trade network formation; and social welfare, c.f. Agent-based Computational Economics website (ACE) [21].

6 Conclusion and Future Work

In this paper a conceptual model is proposed for simulating three transaction costs (switching, handling and searching), which are associated in determining the organisational structure in a transport corridor. The model introduces and describes an approach using MABS, which seems to provide additional means in understanding decisions on choice of cooperation in the transport corridor as well as other decisions effecting freight movements. By providing a framework model that integrates transaction costs and transport costs, MABS seems to be a suitable approach. The organisation forms can be analysed in the context of transaction costs and cooperation between actors in the transport corridor. A simulation model could be developed by further extending the work on TCE in Klos [22] by including additional variables, such as utility, income, number of firms such as in Axtell [18] with a study of negotiation protocols that is discussed by Resnschein and Zlotkin in Wooldridge [23]

Economic theory has provided many contributions to resource sharing and decision making, such as, compute optimum allocation introduced through economic models. The use of computer simulation utilizing MABS introduces a novel approach to analyzing transport corridors and transportation systems where transaction costs are considered. This paper has conceptually demonstrated how transaction cost theory could provide a useful base for models and tools to be further developed in assisting choice of transport corridors.

Further work with software such as JACK Intelligent Agents, MAGNET and TNG is required. Additional information and data collection from companies, i.e. questionnaire or interviews, would benefit the development of the agents in the transport corridor. Modelling the actual contractual transactions, i.e., the "buying" and "selling" of transport services for satisfying transport demands could be considered in the simulation.

A couple of situations that could be experimented are: opportunism with the agents in the system and more evaluation on the organisation structure that is best fitted for the actors in the transport corridor, i.e. vertical integration, market, or contract. The switching costs of one agent to another, e.g. the use of a road hauler to a rail road can be better identified or possibly measured in sums of money. The coordination practices of the agents in the system could be further analyzed and tested on how coalitions are formed. Some examples of agent coordination, which are considered deliberative are; cooperative planning, behaviour based decision making and negotiation based on either worth-oriented domains or task-oriented domains. The development of the suggested simulator in studying transport corridors in European Union financed project, such as in the *BalticGateway* [8] or *EASTWEST* [9] could be attractive, however such a simulator is vision to be applicable to other geographical areas.

Acknowledgements

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SIMPORT 2.0 MANUAL

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SimPort
Manual

Table of contents

1. Introduction

SIMPORT is a Windows® based computer simulator package that allows you to test and analyze management policies in a container terminal. The latest version of SIMPORT is 2.0, which is currently in public beta testing.

Hardware requirements for running SIMPORT 2.0 are:

Software	SIMPORT 2.0
Operating System:	Windows 2000, XP
Download Size:	~1 MB
Installed Program Size:	~3 MB
Minimum Hardware Requirements:	Intel® Pentium® 3 processor (1.7 GHz)

2. Description

SIMPORT 2.0 is a software application that simulates container handling in a container terminal. The application has a graphical user interface (GUI) where you can enter simulation data. In the application you will be able to create the following:

- *Terminal*, which symbolizes a real terminal with cranes, straddle carriers, a yard with container stacks, berth, apron etc
- *Quay,* symbolizes the space dedicated for berthing ships.
- *Crane*, symbolizes a real crane that unloads/loads ships with containers
- *Straddle carrier*, symbolizes a real straddle carrier that moves the containers from the quay to the stacks on the terminal yard and vice versa.
- *Yard Stacks,* symbolizes the area in the terminal in which containers are temporarily stored.
- *Ship***,** symbolizes a real ship that arrives to the terminal and unloads/loads containers.
- *Container*, symbolizes a real container. There are four (4) types of containers, TEU (Twenty feet Equivalent Unit), FEU (Forty feet Equivalent Unit), Hazardous and Refrigerated.

To give a realistic handling of the containers the simulation is based on several agents that are able to communicate and make decisions based on policies. A policy is a set of algorithms with specified rules saying how the same terminal activities, such as ship handling could be done. The agents handle the communication between each other as in the real world, e.g. the ship reports to the stevedore, the stevedore asks the terminal manager.

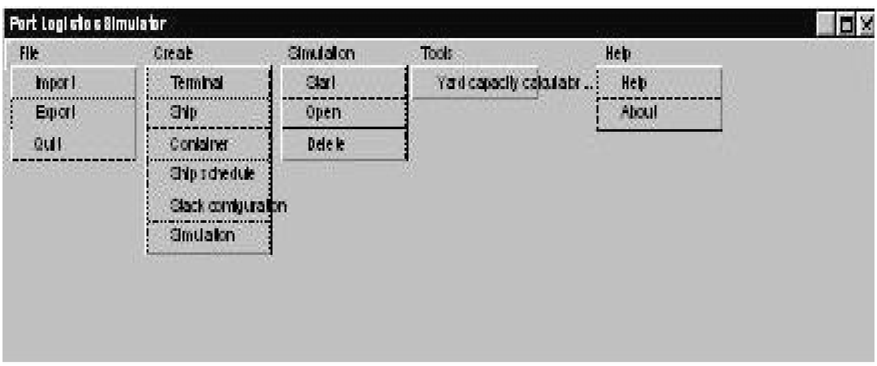
The application is assigned to work on the Microsoft Windows 2000 and XP operating system. To compare and run same simulation with different policies the configuration and result data is stored in a Microsoft Access database. Port specific words are described in the separate dictionary.

3. Download and Installation of SIMPORT 2.0

SIMPORT 2.0 is available on CD and can be installed by manually saving and unzipping the SIMPORT 2.0 package onto your hard disk. ODBC in Windows2000 must be installed in order for SIMPORT 2.0 in order for the simulator to access data from the database, Access®.

4. Main Window menu bar in SIMPORT 2.0

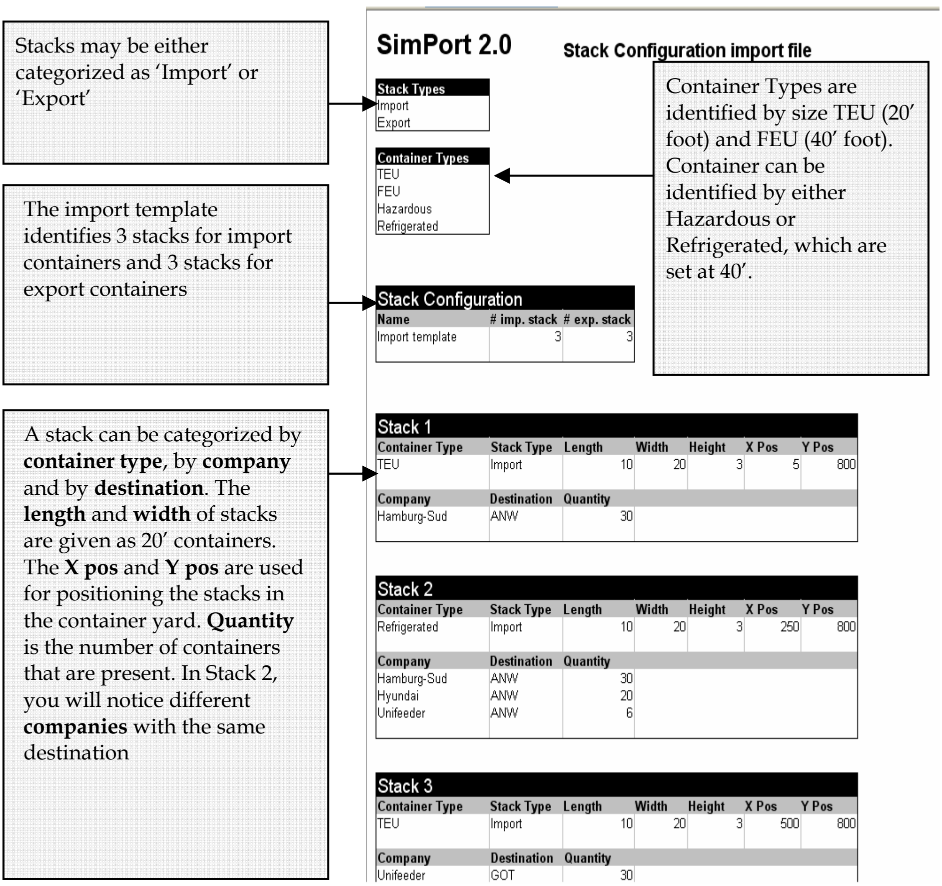
In the SIMPORT 2.0 toolbox, there are 5 buttons on the menu bar: FILE, CREATE, SIMULATION, TOOLS and HELP.



4.1 FILE

This function allows you to either [Import], [Export] data into the SIMPORT 2.0 Database or [Quit], terminate the run. Data that can be *Imported* into SIMPORT are the following:

4.1.1 Stack Configuration Import File:



Stack Types
Import
Export

Container Types
TEU
FEU
Hazardous
Refrigerated

Stack Configuration

Name	# imp. stack	# exp. stack
Import template	3	3

Stack 1

Container Type	Stack Type	Length	Width	Height	X Pos	Y Pos
TEU	Import	10	20	3	5	800

Company	Destination	Quantity
Hamburg-Sud	ANW	30

Stack 2

Container Type	Stack Type	Length	Width	Height	X Pos	Y Pos
Refrigerated	Import	10	20	3	250	800

Company	Destination	Quantity
Hamburg-Sud	ANW	30
Hyundai	ANW	20
Unifeeder	ANW	6

Stack 3

Container Type	Stack Type	Length	Width	Height	X Pos	Y Pos
TEU	Import	10	20	3	500	800

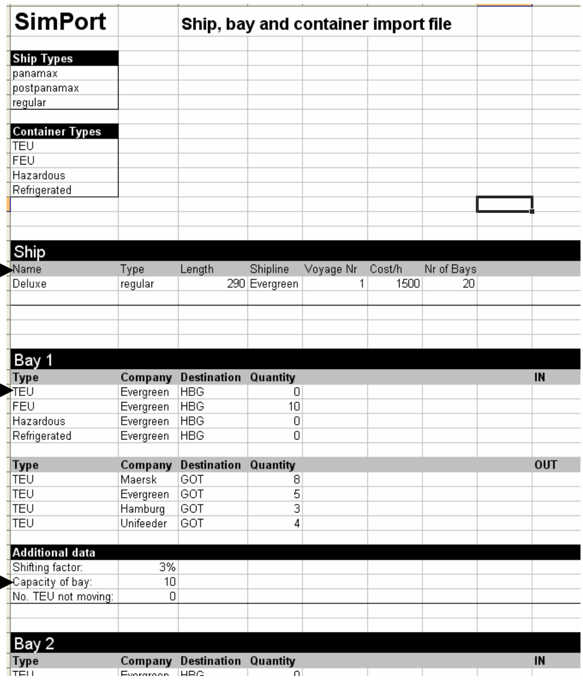
Company	Destination	Quantity
Unifeeder	GOT	30

4.1.2 Ship Configuration Import File:

Name of ship can be input in the file as well as the **Type,** from list of ship types. The **Length** of the ship and the **Shipline** that owns the ship. **Cost** of operating hour is inputted and **Number of Bays.**

Individual **Bays** are assigned containers, by the following properties: **Type, Company, Destination** and **Quantity.**

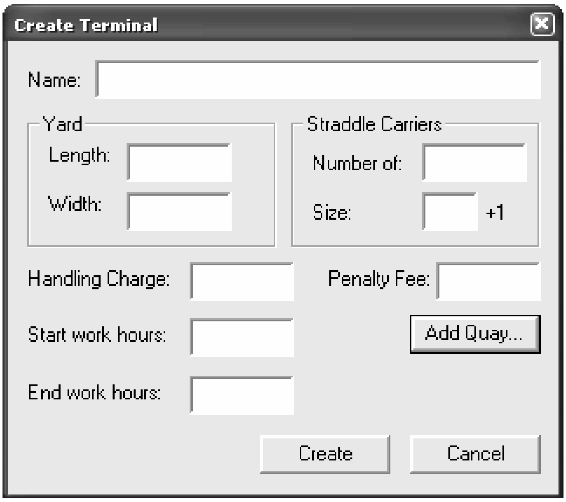
Additional Information is: **Shifting factor**, percentage of containers 'shifted', **Capacity of Bay** and **Number of TEU** not moving.



4.2 Create <TERMINAL>

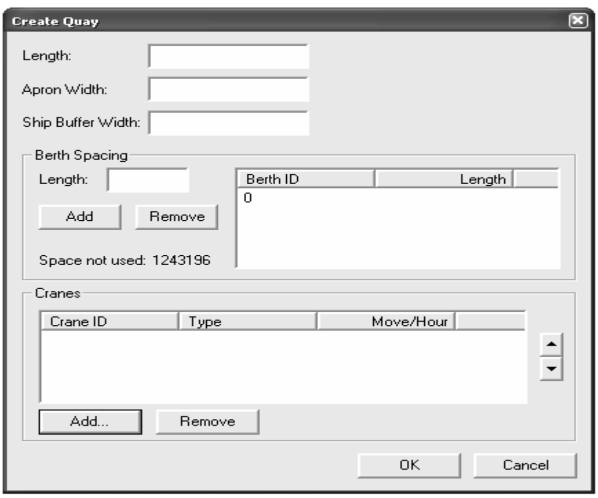
You will create your container terminal configurations in the **CREATE TERMINAL** window, includes a series of windows for in-putting your terminal data. The following input fields are used:

- Name (of the container terminal)
- Number of Straddle carriers / Size of Straddle carriers
- Yard length / Yard width
- Customer fee (Handling charge) / Penalty fee
- Start of working hours /End of working hours

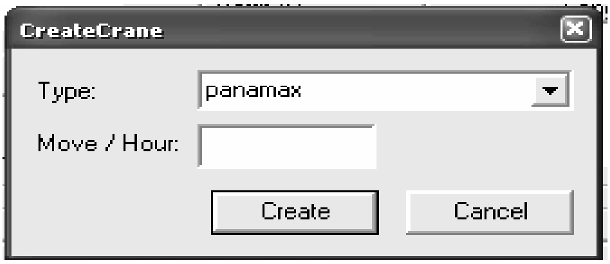


In the next window, **CREATE QUAY** by *clicking* the [Add Quay], the following information will be used as input:

1. Length of the Quay
2. Apron Width
3. Buffer Width
4. Berth Size by *clicking the* [Add], which assigns berth identification
5. Berth Spacing, can be added [Add] or removed [Remove]



6. Cranes and their properties can be established by *clicking* the [Add…] button to open the **CREATE CRANE** Window to add the following; cranes, handling rates (container moves per hour) and type of crane. You can delete crane information by *clicking* the [Remove] button.



The following information is stored in the SIMPORT 2.0 Database from the **CREATE TERMINAL** window:

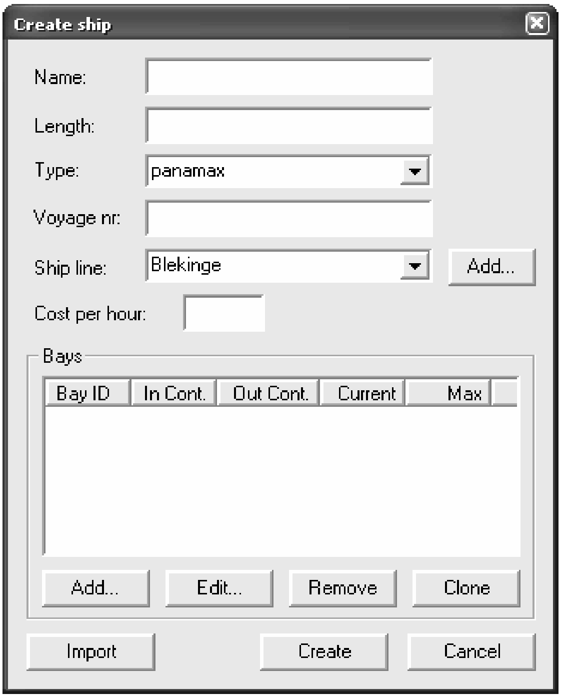
- Length
- Berth spacing
- Apron width
- Number of cranes
- Number of Straddle carriers / Size
- Type of cranes (choice from regular, panamax and superpanamax) + container handling rate
- Crane order

4.3 Create <SHIP>

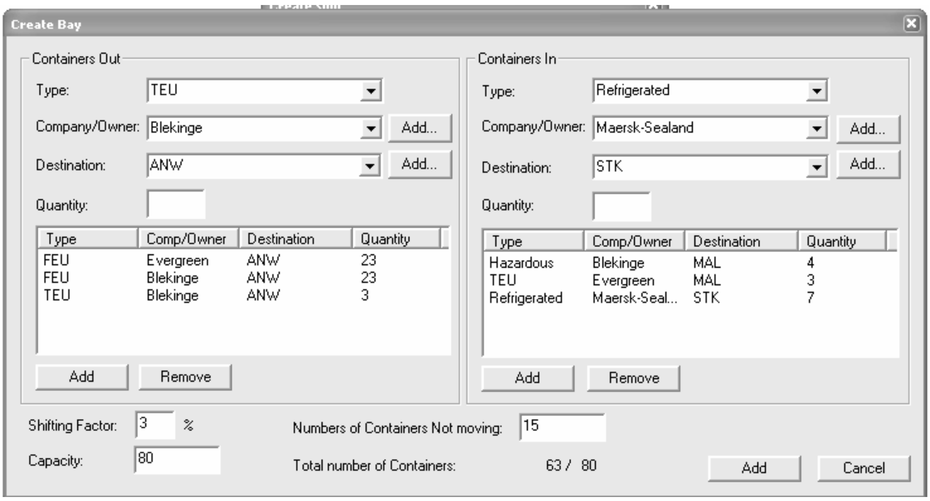
Ship configurations can be either imported using the Ship Configuration Import File (*refer to 6.1.2*) or can be keyed in through the **SHIP** window. You as a user can create a specific ship(s) for simulation by keying in the following information in the input fields:

- Name of ship

- Type of ship (choice from regular, panamax and superpanamax)
- Length
- Add bay
- Edit bay
- Ship line (you can [Add] a new ship line)
- Voyage number
- Cost per hour



From the **CREATE SHIP** window, you can configure the bays of the ship, which allow you to assign the number of containers that will be loading or unloading in a particular bay by *clicking* the [Add] button to get to the **CREATE BAY** window.



In the **CREATE BAY,** you can key in the following information into the input fields:

- Number of containers out [type, company, destination]
- Number of containers in [type, company, destination]
- Shifting factor (percentage of containers that may be shifted during the ship operations)
- Number of containers already there
- Maximum number of containers
- Capacity of the Bay
- Position on ship

The [Add] button allows you to add information to the Bay Field. You can remove the information on a Bay by *clicking* the [Remove] button. In order to save the information to be stored in the database, *click* the [Add] button next to the [Cancel] button, which terminates the process.

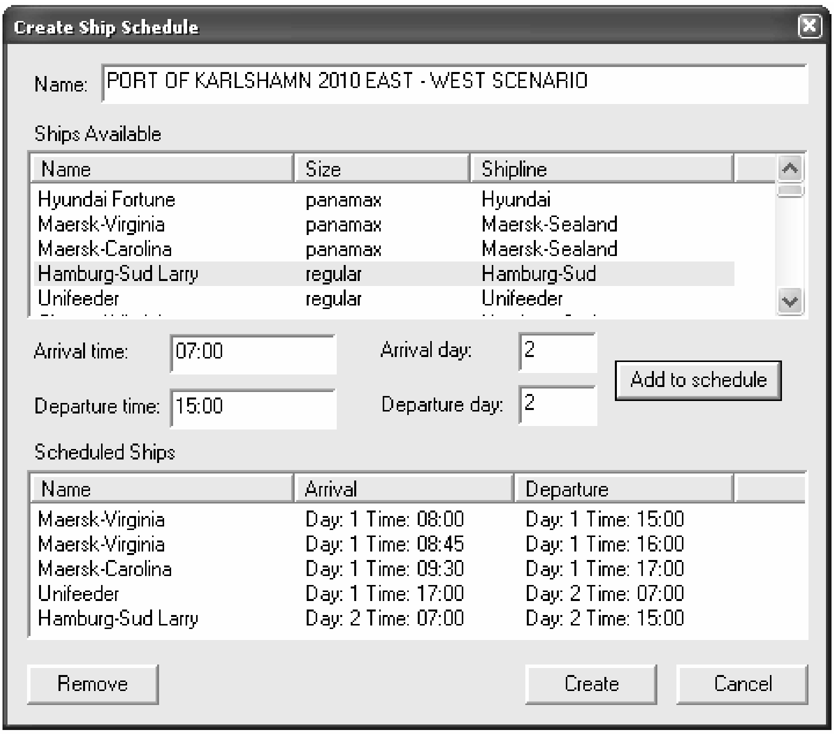
In the **CREATE BAY** window the [Edit] button allows you to edit a particular bay that has been created. The [Remove] button allows you to delete details on a bay. The [Clone] button makes copies of bay information.

To save the ship input to the database, *click* the [Create] button or you can cancel the process of configuring the ship by *clicking* the [Cancel] button.

4.4 Create <SHIP SCHEDULE>

A schedule of ships can be created by using the **SHIP SCHEDULE** window. You can input the following information in the fields:

- Name of schedule
- Ships Available – choice of ship to use for simulation
- Arrival Time – Arrival Day / Departure Time –Departure Day



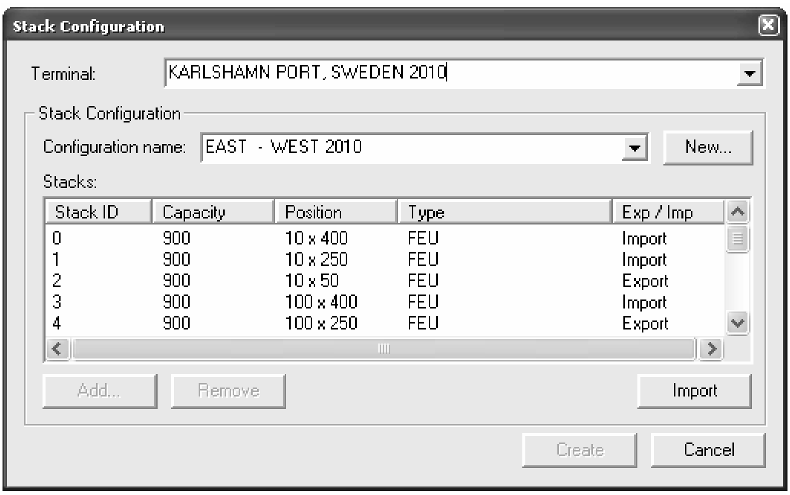
The [Add to schedule] button places a ship to a ship schedule. To delete a ship from the schedule, *click* the [Remove] button.

In order to save the ship schedule created by you, *click* the [Create] button. To terminate the process *click* the [Cancel] button.

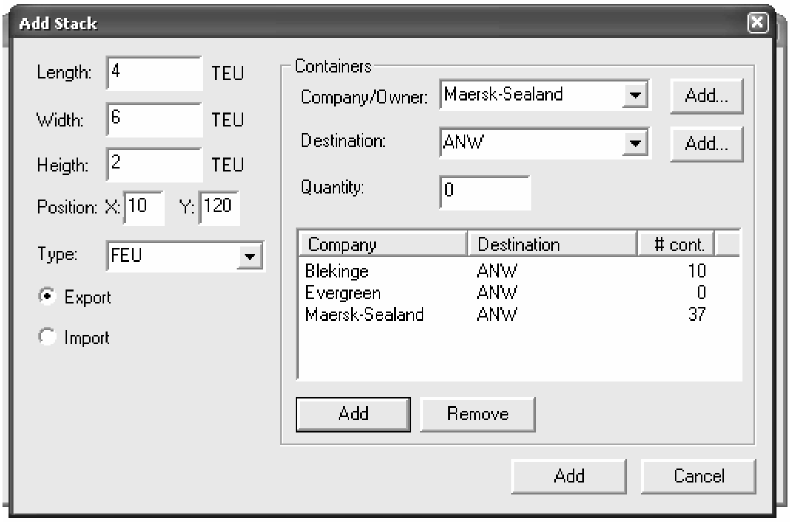
4.5 Create <STACK CONFIGURATION>

A number of stack configurations can be made in the **STACK CONFIGURATION** window. Either you can import the stack configurations for the container terminal yard by using the Stack Configuration Import File (*refer to 6.1.1)* or you can *click* the [Add] button to get the **ADD STACK** window so you can key-in the following information in the fields:

- Length (measured in TEU)
- Width (measured in TEU)
- Height (measured in TEU)
- Type (Container Type that can be stored in the stack)
- Ship line / Owner
- Destination
- Import/Export
- Position (Using X position and Y position coordinates)



The **ADD STACK** window allows you to add containers and set properties of containers to be stored in the stacks. In the company/owner field you can select or add a ship line. In the destination field you can select or add a port. In the quantity field you can key in the number of containers possessing the properties of the first two fields.



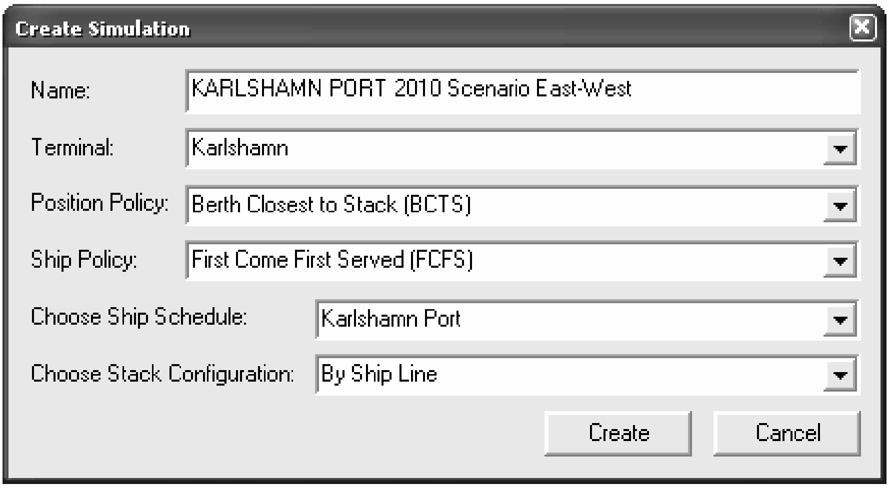
To save information on a stack, *click* the [Add] button to store the data on the SIMPORT 2.0 Database.

4.6 Create <SIMULATION>

To create a simulation for experiments, the following input has to be keyed-in in the fields:

- Name of simulation
- Terminal
- Position Policy being tested - select either Berth Closest to the Stack (BCTS) or Overall Time Shortening (OTS)
- Ship Policy for sequencing arrival of ship – select either First Come First Serve (FCFS), Highest Earnings First (HEF) or Shortest Job First (SJF)

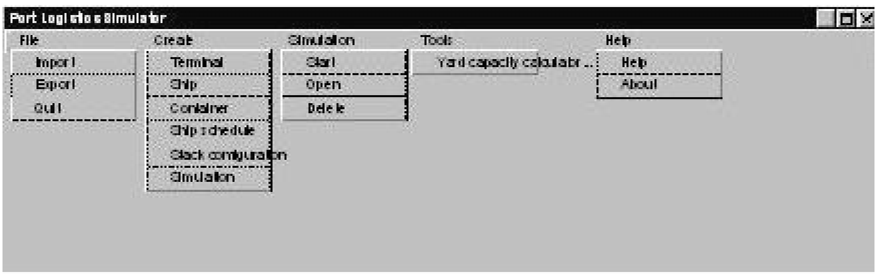
- Ship Schedule to be selected
- Stack configuration to be selected



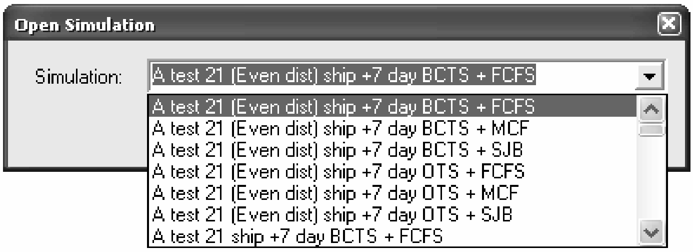
To save the information on the simulation experiment to the SINMPORT 2.0 Database, *click* the [Create] button or to terminate the process, *click* the [Cancel] button.

5. Simulation

The Simulation can be run by *clicking* on the [Simulation] Button on the **MAIN WINDOW** menu bar.

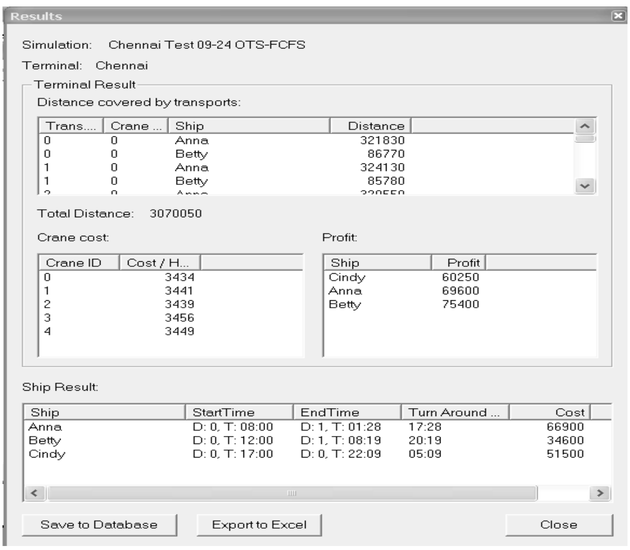


First, *click* the [Open] button under Simulation Field, in order to get the **OPEN SIMULATION** window, which contains the stored simulations for testing. Select the simulation and *click* the [Start] button to run.



Alternatively, you can delete a simulation by cli*cking* the [Delete] button on the **MAIN WINDOW** menu bar

The **RESULTS WINDOW** of the Simulation Experiment can be either saved to the SIMPORT 2.0 Database or exported to an Excel file.



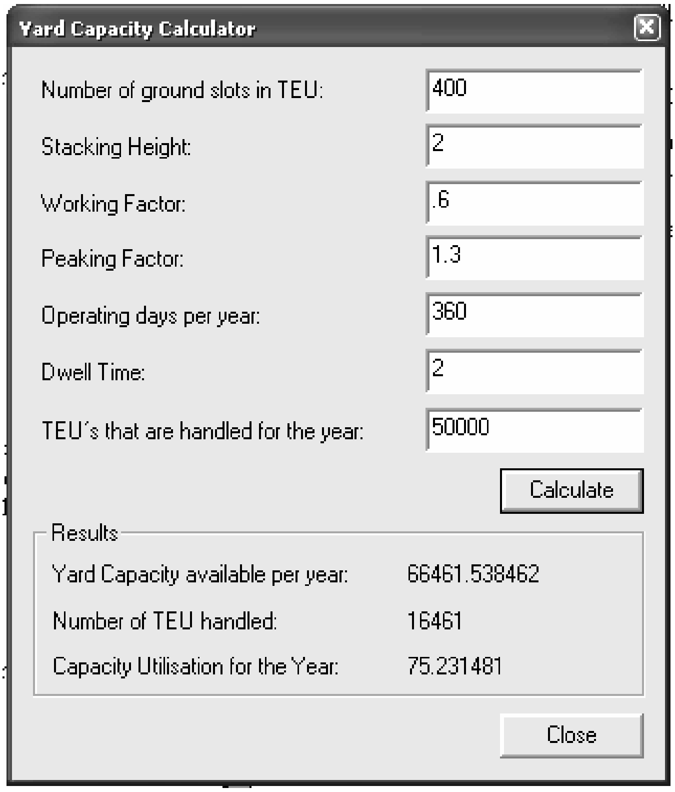
6. Tools

In the Tools field, *click* the [yard capacity calculator] button for calculating a container terminal yard capacity by in putting the following fields:

- Number of ground slots in TEU
- Stacking Height – height in containers that can be stacked
- Working Factor
    - Trucks operations are assigned a value of 0,6
    - Straddle carrier operations are assigned a value of 0 ,7
    - RTG are assigned a value of 0,9
- Peaking Factor the quotient of the peak month over the average month utilization. So if you have August being the "peak" month you will divide by the average, e.g., 15000/10000, which would yield a peaking factor of 1.5.
- Operating day per year – number of days that the terminal works.
- Dwell Time – number of days that the containers stay in the terminal
- TEU that are forecasted to be handled by the terminal for the year

The output from the calculation:

- Yard Capacity available per year
- Number of TEU that can be handled that is either <u>less</u> or <u>more</u> than the Yard Capacity available per year
- Capacity Utilization for the Year



7. Help

The **HELP WINDOW** found in the **MAIN WINDOW** menu bar provides an .html version of the SIMPORT 2.0 manual by *clicking* the [Help] button. For general information about SIMPORT 2.0, *click* the [About Simport] button.

8. Notes

Glossary of Container Terminal Terms Used in this Thesis[1]

Apron	- part of the Berth close to ships where Temp stacking is done.
(AGV) Automated Guided Vehicle	- is a mobile robot used highly in industrial applications, such as container terminal to move containers from point to point
ASC or Automated Stacking Cranes	- is an automated crane moored on a frame in yard for hoisting containers so that they can be for stacked.
Bay	- a section on a ship where Cargo Units such as ISO containers are stacked.
Bay Plan	- a list of containers to be loaded/discharged (according to cell location-optional), yard location, Container Characteristics, description of Bays on the ship and Ship Data.
Beam	- the width of a ship
Berth	- location in which ship are docked alongside a Quay to be loaded or unloaded at a Container Terminal. Functions as an interface between the Container Terminal and the ships. Some of the characteristics of a Berth are length, depth or draft.
Berth Assignment or Berth Assignment Plan	- a document describing which Berth and machines are to be assigned to a specific Ship. This decision is based on Ship line schedule (Ship Data), Bay plan (no. of Containers to be loaded/unloaded), Contracts, Berth Availability and Resource Availability.
Berth Availability	- availability of a Berth.
Berth Location	- location on a specific numbered or labeled berth. i.e., Berth 237
Berth Request	- a document with Ship Data that it requires a Berth to be assigned to it.
Berth Occupancy	- number of days that a berth is occupied divided by the number of working days in the year multiplied by 100 to give a percentage.
Bill of Lading	- a document that establishes the terms of contract between a shipper and a transportation company. It serves as a title, a contract of carriage and a receipt for goods. Usually contains the following information: port of discharge (POD), port of loading (POL), cargo contents (a physical description), shipper, ship and voyage number, seal number.
Booking Number	-before a shipment is received by the carrier, a request or order is made for equipment and space on a ship. Very similar to Bills of Lading but is used for export cargo
Carrier	- any firm, individual who, in a contract of carriage, undertakes to perform or to procure the transport of cargo, e.g., a trucking firm.

[1] Compiled from various sources: UNCTAD, Interviews, Webster's Dictionary, Chapman's Seaman's Dictionary, various trade and industry brochures and http://en.wikipedia.org.

Cell or Cell Location	- location in a container ship. Most ships today are cellularized.
Container	- a truck trailer body that can be detached from the chassis for loading into a ship, a rail car or stacked in a container depot. Containers may be ventilated, insulated, refrigerated, flat rack, vehicle rack, open top, bulk liquid or equipped with interior devices. A container may be 20 feet, 40 feet, 45 feet, 48 feet or 53 feet in length, 8'0" or 8'6" in width, and 8'6" or 9'6" in height.
Container Terminal	- a designated place or area for handling containers. This area is usually accessible by truck, railroad and marine transportation, where containers are picked up, dropped off, maintained and housed
Container Yard	- an area in a container terminal for handling/storing containers, which are either loads or empties.
Contract	- a contract between the port and a Ship Line that says among other things how many containers or other such cargo units the Ship Line brings.
CT	- abbreviation for Container Terminal
Discharge	- unloading; usually associated in unloading a ship or perhaps a rail wagon.
Dock	- a cargo handling area for ships that is parallel to the shoreline
Draft	- the depth of a loaded ship in the water, taken from the waterline, to the lowest point of the hull of the vessel; depth of water or distance between the bottom of the ship to water line.
Dry Port	- a facility located in the hinterland or away from a body of water and operates many of the activities associated with a traditional port or terminal, such as: stripping and stuffing containers; receiving and dispatching goods and containers, temporary storage for an arriving ship, etc.
Dwell Time	- time that a container waits in a terminal to be loaded or unloaded unto another mode of transport. Often attributed to either one or a combination of both of the following: Customer Delay or Operational Dwell time.
Feeder service	- transport service whereby loaded or empty containers in a regional area are transferred to a larger ship (often called a mother ship) for a long-haul ocean voyage
Feeder ship	- are ships of various sizes, but mostly understood to be sea going vessels with an average capacity of carrying 300-500 TEU. Feeders collect containers from different ports and transport them to central container terminals where they are loaded to bigger vessels. In that way the smaller vessels feed the big liners, which carry thousands of containers. Through the years feeder lines have also been established, organizations transporting containers over a predefined route on a regular base.
Forty-foot equivalent units (FEUs)	- unit of measurement equivalent to one forty-foot container. Two twenty-foot containers (TEUs) equal to one FEU. Often used to measure the container ship capacity and port throughput capacity.
Fork Lift	– container terminal machinery that lifts and moves containers

Freight forwarder	- individual or company who arranges for the transport of goods and handles the associated formalities on behalf of a shipper. Some duties are for example; booking space on a container ship, providing information to the tax authorities and filling required documents for export or import, etc.
Full Containerships	- Ships equipped with permanent container cells, with little or no space for other types of cargo.
Gantry Crane/GC	- a crane used for hoisting containers in or out of a ship and is usually moored on a frame or structure spanning across the beam of ship. Often referred to as Quay Crane.
Intermodal	- refers to the movement of containers or unitized cargo interchangeably between modes of transport where the equipment is compatible within the multiple systems.
Load List	- a list of containers to be loaded.
Lorry	- mode of transport than can carry cargo on the road. In US, often referred to as Truck.
LoLo	- acronym for Load-On Load-Off, a ship type in which cargo or containers can be loaded or unloaded by using ship cranes or shore cranes, e.g., Quay cranes.
Lorry Parking Spot	- place where lorries (trucks: US English) are loaded and unloaded
Malacca-Max	- maximum size that a ship capable of fitting through the Straits of Malacca. This reference is often believed to be the absolute maximum possible size for a container ship. Originally coined by Prof. Wijnolst and estimated to be an 18,000 TEU container ship with 18,000 TEUs, of 300,000 DWT, 470m long, 60m wide, and 20m of draft. The restriction is caused by the shallow point on the Strait, where minimum depth is 25 metres.
Manifest	- document for ship that lists in detail all the bills of lading issued by a Carrier (Ship Line) for a specific voyage. A detailed summary of the total cargo (containers) of a ship.
Operating Cost	- Cost per time period for operating a piece of equipment, such as a Quay Crane, a ship, Straddle Carrier, etc.
Panamamax	- maximum size that a ship can travel through the Panama Canal, which is determined by canal's lock chambers (33,5 meters wide and 320 meters long). The maximum dimensions for a ship to pass through the Panama Canal are: Length 294,1 meters; Beam 32,3 meters and draft 12,0 meters.
Partial Containerships	- Multipurpose containerships where one or more but not all compartments are fitted with permanent container cells. Remaining compartments are used for other types of cargo.
PC	- Port Captain. An entity (an object/agent) of a manager system.
Pier	- a structure perpendicular to the shoreline to which a ship is secured for the purpose of loading and unloading cargo
Port	- a port is a place or facility in which good may be shipped to or from. Ports have long been associated with maritime trade and the use of ships to carry cargo.

<table>
<tr><td>Port Calls</td><td>- ship arrival at a port.</td></tr>
<tr><td>Port Productivity Measures</td><td>- most general sense productivity measures output per unit of input. Port or Container terminal productivity deals with the efficient use of labour, equipment and land. A means of quantifying the efficiency of the use of these resources. Limits on the productivity of a container terminal may be imposed by either physical or institutional factors or a combination of both. Some examples productivity measures are given:
<table>
<tr><td rowspan="2">Crane</td><td>Net Crane Productivity</td><td>Moves
/
(gross gang hours-downtime)</td></tr>
<tr><td>Gross Crane Productivity</td><td>Moves
/
(gross gang hours)</td></tr>
<tr><td>Berth</td><td>Net Berth Utilization</td><td>(Container vessel shifts worked / year)
/
Container berths</td></tr>
<tr><td rowspan="2">Gate</td><td>Net Gate Throughput</td><td>(Containers / hour)
/
Lane</td></tr>
<tr><td>Truck Turnaround Time</td><td>Total truck time in terminal
/
Number of trucks</td></tr>
<tr><td>Gang</td><td>Gross Labor Productivity</td><td>Number of moves
/
Man hours</td></tr>
<tr><td rowspan="2">Yard</td><td>Yard Throughput</td><td>TEUs/year
/
(gross area in acres, hectare, etc.)</td></tr>
<tr><td>Yard Storage Productivity</td><td>TEUs capacity
/
(net storage area in acres, hectare, etc.)</td></tr>
</table></td></tr>
<tr><td>Container Capacity</td><td>- is used to determine the number of containers that can be handled with the current resources for the year (for a Port or Terminal). Unfortunately in the Port and Container Terminal Industry there are three main types of capacity; design capacity – based on rules of thumb; operational capacity – estimated by considering achieved results at similar ports; and physical capacity – which require 100% berth occupancy, which is not sustainable in the real world and takes no account of long-term commercial realities</td></tr>
<tr><td>Reefer</td><td>- refrigerated container</td></tr>
<tr><td>Reefer Stack</td><td>- is a Stack of Containers that are plugged to refrigeration unit.</td></tr>
<tr><td>Resource</td><td>- availability of specific resources (equipment, land, labour)</td></tr>
</table>

Availability	
Roll-on/Roll-off ships or RoRo	- ships specially designed to carry wheeled containers or trailers using interior ramps.
RMG	- Rubber Mounted Gantry, a mobile crane that is used for hoisting containers in a yard that is mounted on rail.
RTG	- Rubber Tired Gantry, a mobile crane that is used for hoisting containers in a yard that is mounted on rubber tires.
Service Time	– time that ship is served may include down (time that is non productive stop time for lunch, maintenance, etc.
Shifting Factor	- number of non-productive moves divided by total number of containers being unloaded and loaded for that specific ship and voyage measured in percentage.
Ship Broker	- representative of the ship line, also known as a ship's agent. Provides information to of Ship Line Schedule, to Stevedore: Load List, Bay plans, and Manifest.
Ship	- a vessel for water transportation of goods, such as containers.
Shipping Line	- an owner of ships and containers, it has an agreement with CT on services and associated costs.
Ship Line Schedule	- a time table of fixed dates, fixed Port Calls and ship's names and voyage number.
Ship Operations Time	- often called Ship Service Time is the time period for unloading and loading a ship.
Ship Types	- types of ships used for shipping containers. Cellular, RoRo, Geared, etc.
Shunting Yard	- area in which railroad cars are separated or hitched together.
Spreader	- a piece of equipment designed to lift containers by their corner castings, usually employed on Gantry Cranes or Quay Cranes, and Yard Cranes
Stack	- physical arrangement of containers assigned according to yard layout.
Stevedore	- individual or firm that employs longshoremen and who contracts to load or unload the ship. In our simulator Stevedore works for the benefit of a customer.
Stevedore Request	- a preliminary document that describes how many and exactly which berth, QC, and other machines are asked to serve a certain ship.
Straddle Carrier/SC	– Mobile container machinery that is used to move containers in the CT and can stack the containers
String Piece	- a part of the Apron where QCs rails are put..
Terminal	- an assigned area in which containers are prepared for loading into modes of transport such as: ship, pipeline, truck, or airplane, or are stacked immediately after discharge from other modes of transport such as: ship, pipeline, train, truck, or airplane
Terminal Handling Charge (THC)	- a charge made for service performed in a terminal..
Temp Stacking	- stacking of Containers in advance on the String Piece or on the Apron.
Temp Stacking	- it is a plan how Temp Stacking will be done based on expectation of

Plan	ship arrivals (Ship line schedule sent by Ship Broker), Bay plan, Cargo Unit Characteristics, and , Resource Availability.
TIR	- Transport International par la Route (road transport agreement allowing sealed containers to cross national frontiers), name of the Carrier (shipping line), container number, seal number, weight and type of Cargo Units.
Train	- mode of transport than can carry Containers
Transporter	- Mode of transport that is able to carry a Cargo Units, in the terminal, i.e. train, lorry, ship.
Transshipment	- a distribution method whereby containers are moved between large 'mother ships' and small 'feeder ship', or between equally large ships travelling north-south and east-west routes.
Transshipment Port	- a port where cargo is transferred from one carrier to another or from one ship of a carrier to another ship of the same carrier without the cargo or container leaving the port or terminal area.
Turn-around time	- time period that a ship will be worked while berthed at the quay.
Twenty-foot equivalent units (TEUs)	- container size standard of twenty feet. Two twenty-foot containers (TEUs) equals one FEU. Container capacity is often measured based on TEU as well as container port or terminal throughput capacity.
Utilization	- usually recorded as a percentage of the time that a resources is used or utilized. Some example are Quay, Berth, Crane, Cassette, etc.
Unitization	-the consolidation of a quantity of individual items into on large shipping unit for easier transporting and handling.
Yard Location	- a cell in a container stack according to Container Characteristics. There are several types of Stacks, for example a hazardous stack or reefer stack, etc.
Yard Location Assignment	- assignment of container to a location of a Stack in the Container Yard.
Yard Plan	- a list of discharged Containers possessing a location to be placed on yard (which Stack) based on a set policy.
Yard Truck	– Machinery used to transport container on a chassis in the Yard. Similar to a lorry.
Yard Planner/YP	- Yard Planner. An entity (an object/agent) of a manager system.
Wharf	- a structure built alongside the shoreline or perpendicular to the water where ships berth for loading or discharging containers or goods.

NOTES.

ABSTRACT

This thesis describes research concerning the application of multi-agent based simulation for evaluating container terminal management operations. The growth of containerization, i.e., transporting goods in a container, has created problems for ports and container terminals. For instance, many container terminals are reaching their capacity limits and increasingly leading to traffic and port congestion. Container terminal managers have several, often conflicting goals, such as serve a container ship as fast as possible while minimizing terminal equipment costs

The focus of the research involves the performance from the container terminal manager's perspective and how to improve the understanding of the factors of productivity and how they are related to each other. The need to manage complex systems such as container terminals requires new ways for finding solutions, e.g., by applying novel methods and technologies. The approach taken in this thesis is to model the decision makers involved in the container terminal operations and various types of terminal equipment, e.g., cranes, transporters, etc., as software agents. The general question addressed in this work is: can the performance of a container terminal be improved by using agent-based technologies?

In order to evaluate the multi-agent based systems approach, a simulation tool, called SimPort, was developed for evaluating container terminal management policies. The methods for modelling the entities in a container terminal are presented along with the simulation experiments conducted. The results indicate that certain policies can yield faster ship turn-around times and that certain stacking policies can lead to improved productivity. Moreover, a multi-agent based simulation approach is used to evaluate a new type of Automated Guided Vehicles (AGVs) using a cassette system, and compare it to a traditional AGV system. The results suggest that the cassette-based system is more cost efficient than a traditional AGV system in certain configurations. Finally, an agent-based approach is investigated for evaluating the governance structure of the stakeholders involved in a transport corridor.

The results of the research indicate that the performance of a container terminal can be improved by using agent-based technologies. This conclusion is based upon several studies, both conceptual and concrete simulation experiments. In particular, multi-agent based simulation seems to offer container terminal management a suitable tool to control, coordinate, design, evaluate and improve productivity.

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