Results from the development and use of an optimisation and simulation tool, NeuComb/Port

Jonas Waidringer
Department of Transportation and Logistics
Chalmers University of Technology, Sweden

Abstract:

This paper describes possible changes of a port terminal from an optimisation of the Port terminal, and the impacts derived from these changes. The optimisation is made with a specially developed theoretical tool, based on practical findings, the NeuComb/Port tool. The basis for this tool is neural networks and combinatorial graph theory. Since the tool works with advanced mathematics methods it is developed as a strategic model on an aggregated level.

In the paper some results from a set of runs on a real case, the Oslo port, are given. A short discussion about the implications of possible changes of a port terminal out of the results from an optimisation of the Port terminal is also given. The results are derived from a set of simulations and optimisations done in co-operation with a number of European ports, within the EU project, EUROBORDER. The results are roughly divided into three main categories, derived from three cases run in the tool. The results show that in a terminal with a fairly low throughput, there is little or no difference between pooling the resources and/or cargo compared to the reference case. A terminal with a fairly high throughput reaches the highest efficiency by pooling the resources.

Contact author:

Department of Transportation and Logistics
Chalmers University of Technology
412 96 Göteborg
SWEDEN

Telephone: +46 31 772 51 52   Fax: +46 31 772 13 37
Email: jowa@mot.chalmers.se

Introduction

The ports are an important but weak link in the transport chain, which gives great value to new ideas as to how it is possible to change the port operations (Frankel, 1987) Currently there exist few, if any models describing the Port terminal from a pure network perspective (Ojala 1992, and references therein). This paper derives from the need for a model of a Port terminal, described from a network concept The model is used in an EU research project, EUROBORDER In this project an optimisation tool will be built that works with two foliated networks; an information flow network, a cargo flow network and a set of resources constituting these networks. This relates closely to a conceptual framework developed for resources (Manheim, 1979)

The core of the model is the cargo flow and the corresponding network, since this is seen as the Port terminal's main function, and the essence of its activities. This generic model of a Port terminal is also of an academic interest since it is a different and structured way of describing the interrelations within the Port terminal system There are a number of different ways of describing a port, e.g. any terminal, but only a few from the network perspective This paper addresses the issue of evaluating and choosing different parameters to describe the port from a network perspective, and as a result proposes a model, NeuComb/Port The need for this kind of description and model derives from the demand to create a simulation and optimisation tool at a micro level. Since the network is a set of nodes and links, the parameters have to be consistent. The model, which is the result of this paper, is built upon network theory in general and neural[1] networks and combinatorial graph theory in particular. Another restriction is that the parameters have to be quantitative, since the network model is based upon mathematical operations.

The model as such is a tactical/strategic tool that can be used for long-term reorganisation issues in a Port terminal, since the model is a PC-based optimisation and simulation tool. This means either simulation of physical reconstruction, with corresponding changes in the terminal flow or reorganisation of the work in the Port terminal e.g. changes in the resource distribution. There are two ways of using the tool. The first is to utilise it as an optimisation tool for an already existing Port terminal. The second is to use it as a simulation tool, where it is possible to simulate any given set of parameters in a Port terminal The simulation is also used as a way of validating the model.

The cargo throughput and the resource utilisation are the main issues for optimisation, considering however the constraints implied by information, administration and legal factors. The networks are just a way of explaining abstract interactions and interrelations in the model.

The optimisations are done according to the boundary conditions determined by the information, organisation and legal conditions in the Port terminal. The model works with a superposition of three networks, which is though only a way of describing it graphically and in words. In the model/tool, boundary conditions are used to be able

---

[1] The part of neural nets that is used in this paper concerns the possibility to store information in both nodes and links

to take information, organisation and legal constraints into consideration when optimising, as well as simulating, the Port terminal

The NeuComb/Port tool makes it possible to build a model of any Port terminal with its specific characteristics. The result from the model is either an optimal use of the resources according to a given flow or an optimal flow according to a given set of resources. The utilisation of the resources is also shown. The result is displayed graphically as well as numerically. The tool is made with a generic[2] Port terminal model as a demonstration and with default values on all the parameters involved.

Frame of reference - the port

First the port environment is described in order to define the port as a part of an overall transport and logistical chain.
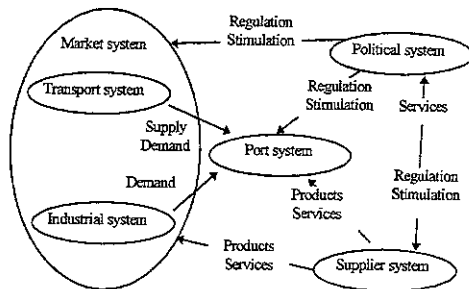

Figure 1 The environment of the port (Hulthén and IAHP, 1996)

The environmental influence on the port system can be described with activity relations (Figure 1). No detailed description about the port system and how the environment and the port system interact will be done. Instead Figure 1 should be seen as a way of defining the reference system for this paper.

Port models used as a base for planning and analysis may be classified in the following way (Ojala, 1992):

- Models with an econometric approach
- Models with an analytical approach
- Models using simulation technique

Econometric models normally deal with the macro-level aspects, and are widely used in research problems related to demand and supply. A system is described as a casual network of relationships between a set of variables.

Analytic models are created within the framework of Operations Research (OR). The basic idea is to develop a mathematical function, which can be solved by an algorithm under certain constraints.

---

[2] Generic is used in the sense of an aggregated non-specific, model

Simulation models use a numerical technique for specific mathematical models to analyse time-bound flows of events within a system, consisting of a large number of variables and constraints.

To provide our model with a background, some examples of how to describe a Port terminal are given, beginning with the terminal as a "black box", as shown in Figure 2.
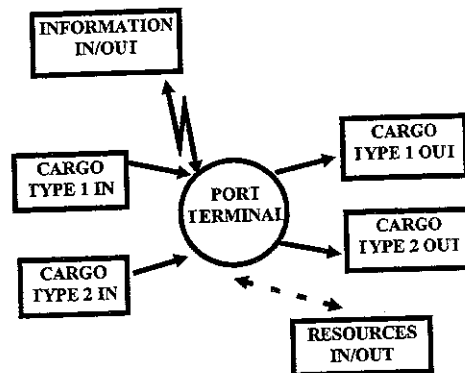

Figure 2 Different flows through the Port terminal

The description above is the simplest possible way of describing a Port terminal, in terms of logistical flows. The terminal is seen as a "black box" with cargo, information and resources going in and out of the box. The different flows and their future fate is not taken into account, instead the focus is on the results, i.e. what is actually going in and out of the model. This is in line with the systems approach (Churchman, 1981):

"The way to describe an automobile is first by thinking about what it is for, about its function, and not the list of items that make up its structure"

Within this frame the Port terminal is described with three main functions, receive/deliver, load/unload and transfer as shown in Figure 3 below
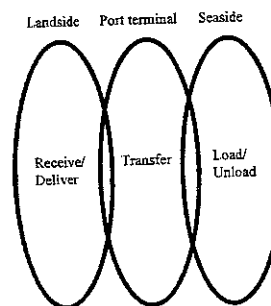

Figure 3 The Port terminal described by its functions

The analytical approach described above is used as a frame of reference for this paper, since the model developed is created as a base and as a tool for simulation and optimisation.

The port terminal from a network perspective

As mentioned before, the model describes the Port terminal as two foliated networks, the information flow network and the cargo flow network, and a set of resources constituting these networks. Figure 4 below shows a few selected nodes and possible links within and between these networks.
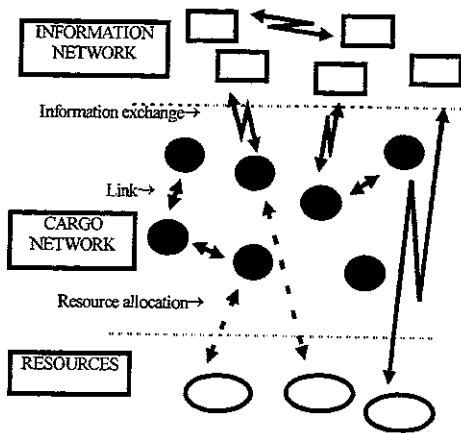

Figure 4 The Port terminal's two foliated networks, and set of resources.

The links between the different nodes are not a fixed set of links constantly connecting all the different nodes continuously. Instead the links between two nodes appear when there is a need for a link. In this sense it is possible to talk about links as spontaneous. The links are induced by a need, detected by the information network, which is transferred to the resource network. According to that a resource, i.e. a machine, personnel etc., is assigned to solve that need, creating the desired link.

The information, status, from the cargo network is transferred to the information network. It can for example be a need for transportation of the cargo from one node to another. In the information network data is also sent to the next node corresponding to the cargo node receiving the cargo. The resources are limited to use the links available in the cargo network, and when free, placed at a parking area.
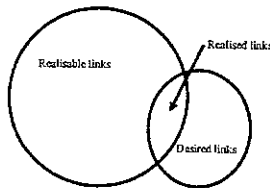

Figure 5 Different sets of links

Figure 5 above explains the way different types of links used in this modelling process are defined. The realisable links are all the links between all nodes in the network that are realisable defined by some kinds of criteria such as cost etc. Desired links are links one would like to use if there were no constraints on the network. Realised (physical) links are the links finally realised, by the set of resources, when all constraints have been imposed on the network. The total set of links in the network, called abstract (AL) or theoretical links, is the union of the realisable (RL) and desired (DL) links. $AL = RL \cup DL$

Results

The results given here are from a series of runs in the NeuComb tool (Waidringer & Lumsden, 1998) with the terminal of Ormsund in Norway as the actual case. All figures are authentic and the simulations are verified against real data for the current, figures are authentic and the simulations are verified against real data for the current, unchanged, scenario. Two cases have been run for the current and future scenarios. The figures used, the actual screen shots from the tool and the cases are described below.

The model and inputs used

The Ormsund terminal is shown in Figure 6 below, with the nodes and links constructing the port terminal network. Node number one is for example the check-in, node number three is the entrance etc. Since the tool is designed for an aggregated level, the model of the terminal has been properly adjusted. There are, for example, more storage areas and more links in the real case, but the users have done the estimates themselves. The reason for this is that the tool is supposed to be used on an aggregated level for tactic and strategic decisions in the port terminal. Therefore the models should not be too detailed, instead the main flows and categories should be modelled as accurate as possible.

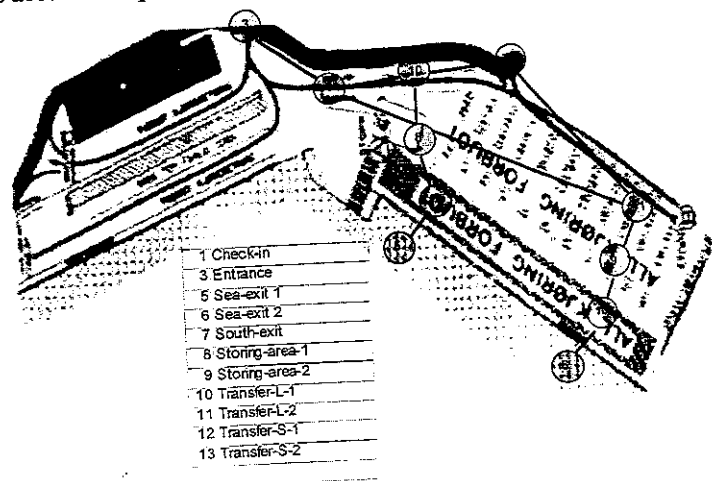| 1 | Check-in |
3	Entrance
5	Sea-exit 1
6	Sea-exit 2
7	South-exit
8	Storing-area-1
9	Storing-area-2
10	Transfer-L-1
11	Transfer-L-2
12	Transfer-S-1
13	Transfer-S-2

Figure 6 The Ormsund terminal

The basic model, called "current", is the Ormsund model and the model looks like Figure 7, when it is implemented in the NeuComb tool. The actual tool and its specifications are not described here. (Waidringer & Lumsden, 1998)
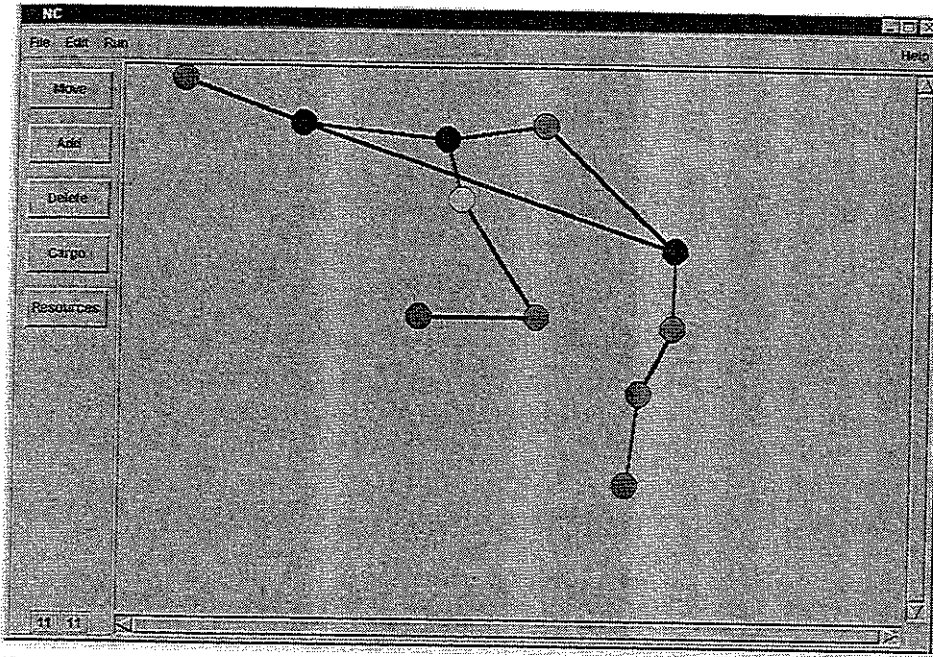

Figure 7 The NeuComb tool with the Ormsund terminal lay-out, current situation

Figure 7 shows the layout of the terminal, with the check-in at the upper left-hand side corner, corresponding to the layout in Figure 6 above.

To give the reader a possibility to follow the construction of the model and cases, the actual inputs are shown in tables below. It also gives an understanding of the size of the model and cases. The landside distribution for different cargo types in the current and future situations are shown in Table 1 below. Landside distribution means truckloads coming in and out of the terminal over a specified day. Import is going out of the terminal and export is coming in to the terminal from the landside. The tool works with different cargo types, for example imp.-1, imp.-2 etc. to distinguish between cargo destined to different ships, and as a way of determining directions of the flows.

Table 1 The landside distributions of container-trucks for both scenarios

Current					Future				
Time	imp.-1	imp.-2	exp.-1	exp.-2	Time	imp.-1	imp.-2	exp.-1	exp.-2
07-08	5	10	1	2	07-08	8	17	6	7
08-09	5	9	3	7	08-09	8	16	6	12
09-10	3	7	4	6	09-10	5	14	7	11
10-11	6	12	4	11	10-11	10	21	11	20
11-12	8	16	4	9	11-12	14	28	7	15
12-13	5	10	3	5	12-13	8	17	6	8
13-14	7	14	3	4	13-14	13	24	14	26
14-15	7	14	8	15	14-15	12	24	6	10
15-16	3	5	3	6	15-16	6	9	4	7
16-17	1	1	2	4	16-17	1	3	1	2

To make the cases as realistic as possible the runs were started with cargo that were already in the terminal. Storage area 1 has a capacity of 300 containers and storage area 2 has a capacity of 600 containers. Imp.-1 is import cargo at storage area 1 and so on. The capacities of the storage areas and the starting amounts were the same for both scenarios.

imp.-1	imp.-2	exp.-1	exp.-2
100	180	85	90

The Seaside distribution for both scenarios is given in Table 2 below. The first column shows the ship's arrival number, the next two columns shows the arrival and departure time of the ship, the columns for Exp. and Imp. shows the amount of cargo of each type that is supposed to be unloaded and loaded onto the ship, and the Quay column shows the appropriate quay.

Table 2 The seaside distributions of containers and ships for both scenarios

Current						Future					
Ship	Arr.	Dep.	Exp.	Imp.	Quay	Ship	Arr.	Dep.	Exp.	Imp.	Quay
1	07.00	10.00	30	50	Kai 1	1	07.00	14.00	53	88	Kai 1
2	07.00	13.30	40	110	Kai 2	2	07.00	17.00	70	190	Kai 2
3	10.30	14.00	15	60	Kai 1	3	14.00	19.00	27	105	Kai 1
4	14.00	16.00	00	25	Kai 2						

The future scenario model is simply called "future", and it looks like Figure 8 when implemented in the NeuComb tool.
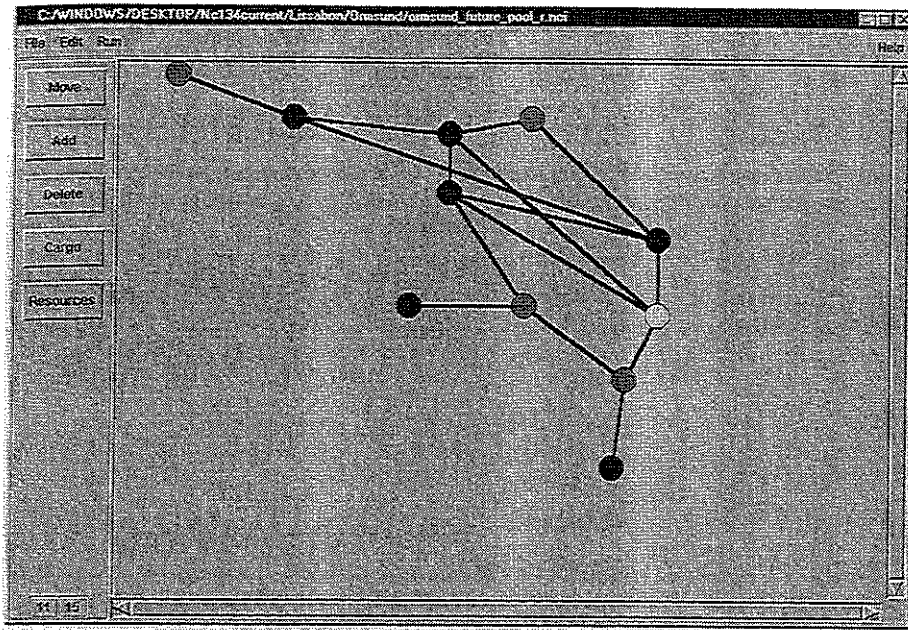
Figure 8 The NeuComb tool with the Ormsund terminal lay-out, future scenario

There are two main differences between the current situation and the future scenario. The first is that the amount of cargo of all types is more than double in the future scenario. The second is that there are 4 ships calling at the terminal in the current case and 3 ships in the future scenario. The extra blue lines (links) in figure 3 compared to figure 1 and 2 are links that allow the pooling of resources and cargo.

The cases run in the model

The two models, the current and the future scenario, have been run in the tool with 3 cases in each model:

- Case 1, Reference scenario: No changes = two operators and no advanced yard management system
- Case 2: Pooled resources = a single operator
- Case 3: Pooled resources and cargo = a single operator and an advanced yard management

A short clarification

The reference scenario is the current situation with no changes to the resources or the cargo. This means that there are external resources (trucks) coming in with the cargo, the cargo is then transferred to internal resources (straddle carriers). Since there are two different companies working in the terminal today the internal resources are divided into two separate areas. The cargo is divided by shipper, Maersk, Greenship etc. Case 2 is a test of the possibility of using a single operator for the internal

405

resources (straddle carrier) in the terminal. The idea is that it should be more efficient and less expensive to pool the resources in the terminal. In practice this means that the internal resources are allowed in the whole terminal. Case 3 is a development of case 2. The idea is that the cargo can be placed anywhere in the terminal. In that way it should be possible to cut down the number of internal resources. To be able to do this an advanced yard management system is required. This kind of system keeps track, in detail, of each container/trailer in the terminal.

The pooling of resources only involves the internal resources (straddle carriers) and not the trucks or cranes. These two cases, number 2 and 3, were seen by the users/operators as the most interesting cases to investigate in more detail. For the Ormsund terminal this is especially true, since they are situated in the middle of Oslo and therefore have a space problem, simply not enough storage capacity in the terminal. They have no opportunities to expand, instead other alternatives have to be considered that enhance the terminals efficiency. The results based on an evaluation of the efficiency figures and queues for the internal resources (straddle carriers) are displayed in a couple of diagrams shown below.

In the EUROBORDER project the resource utilisation was chosen as the main measure, calculated as occupied time/total time, where occupied time means all time the resource (Straddle carrier) is carrying cargo, including the queue time. This measure was agreed on at an early stage of the project and has been kept. The efficiency given in Figure 9 below is a slightly different measure that gives the efficient utilisation of resources at a given throughput and a given set of resources. To be more specific, if we have an identical system regarding throughput volume, available resources and elapsed time, this means that the most efficient solution will carry out the assignments in the shortest time. This gives, bearing in mind the measure above (occupied time/total time), that if the occupied time decreases the utilisation figure as defined above will decline. The most efficient system will therefore have the lowest utilisation figure. This is the basis for the calculations of the efficiency figures given in this document.

To give an example: The resource utilisation figure for case 1 (Unchanged) is 0,25 and the same figure for case 3 (Pooled resources and cargo) is 0,29. This gives a less efficient use of the resource in case 3. As stated above, this discussion is valid for all the figures about efficiency that are given in this paper.

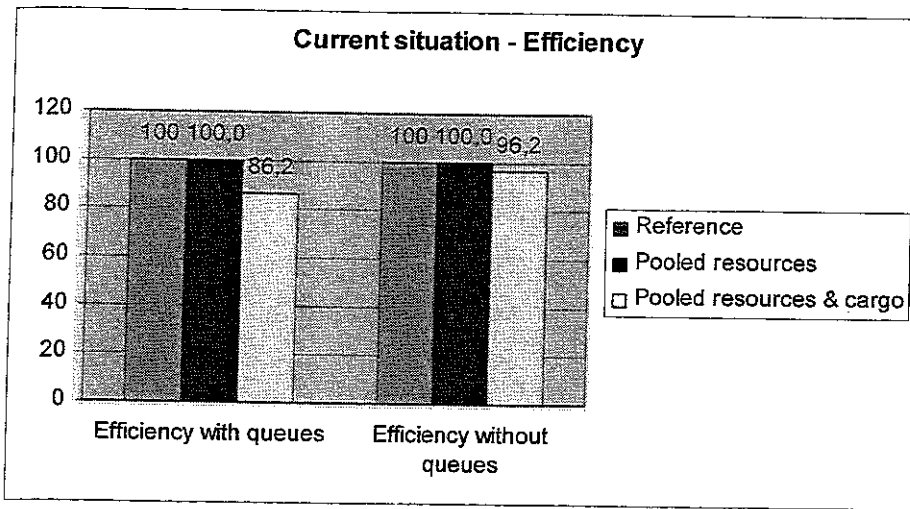**Current situation - Efficiency**

Figure 9 Efficiency figures for the current scenario

The figures are indexed and related to the reference (business as usual) terminal efficiency, which has been given the index of 100

The reason for this marginal cost reasoning is that if the basic figures for the cases, throughput volume, available resources etc. are the same, the system deviation will be marginal if only the changes are compared. This is a way of compensating for the eventual systematic deviations caused by errors in the figures used for building the models.
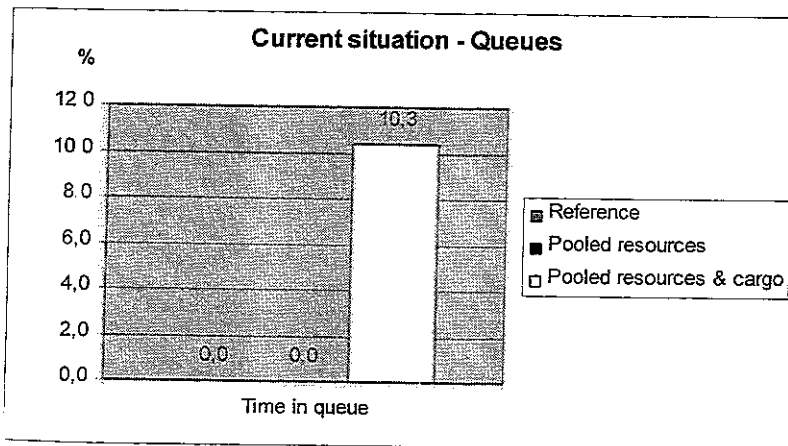
Current situation - Queues

Figure 10 Queues for the different cases in the current scenario

The percentage in figure 5 shows the percentage of the total time that the resources are standing in queue related to the total occupied time of that resource. As can be seen in the figure, only case 3 causes queues in the system.

Some general comments to the current situation:

- It is a sparse system with little overall activity, which gives less room for improvements
- Case 2, the pooled resources case and case 1, the reference case give the same efficiency of resources
- Case 3, the pooled resources and cargo case gives less efficient utilisation of resources and also creates queues
- The efficiency figures without queues are almost identical
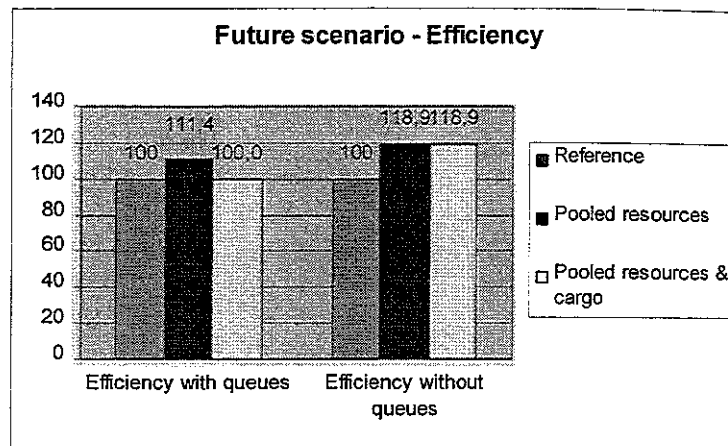- There are two main bottlenecks in the system, the check-in function and the container cranes

Figure 11 Efficiency figures for the future scenario

This figure corresponds to Figure 9 for the current situation, which means that it has the same basis for its construction. The reference case is set to 100 and the other cases are compared to this case. The future scenario's throughput volume is about double the current situation for all the cargo types.
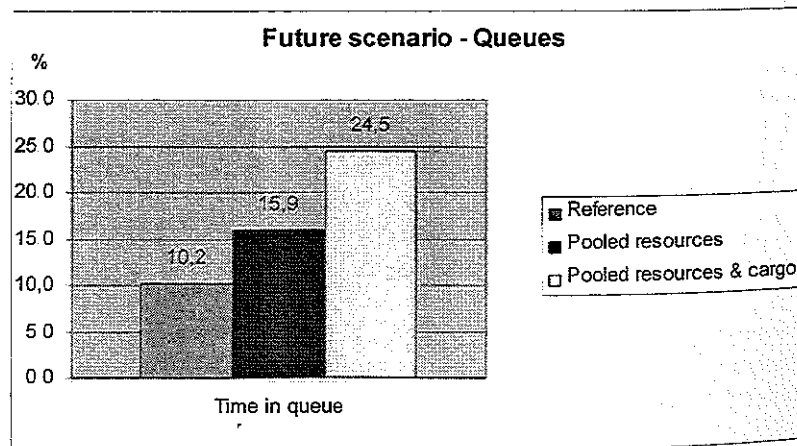

Figure 12 Queues for the different cases in the future scenario

This figure corresponds to Figure 10 for the current situation, which means that it has the same basis for its construction.

Some general comments to the future scenario:

- This is a much more dense system with more overall activity, which gives more room for improvements (and mistakes)
- Case 2, the pooled resource case gives better efficiency than unpooled.
- Case 3, the pooled resource and cargo case gives the same efficiency as the reference case, but create more queues than the other two
- The efficiency figures without queue show that the two, pooled cases are about 20% more efficient than the reference case for the actual transfers in the system
- The two bottlenecks remain, check-in and container cranes and there are overall more queues in the system
- None of the cases can handle all the goods, so the ships can not leave in time. This is mostly an affect caused by the capacity of the cranes.

To conclude, some comments about the results have to be made. In the current situation where the throughput is fairly low, there is almost no difference between the cases except that there are substantially more queues in case 3, the pooled resources and cargo case. This is not intuitively clear. The reason is that when the cargo is pooled the tool will use the basic strategy that is a first come first serve basis. This means that the cargo chose the shortest path and therefor queues will be created. The small difference in efficiency without queues is due to more transhipments of the cargo.

For the future scenario, with a much larger throughput, there are queues in all the cases. Here the highest efficiency is reached in the pooled resources case, which is expected since the queues and resource utilisation, is more evenly spread in a basically overloaded system. The pooled resources case gives less efficiency and considerable more queues. The reason is the same that was explained above. The interesting thing is that the efficiency without queues is almost the same. The explanation is that the cargo is more evenly spread in this case, and therefore the internal resources can be utilised better when pooled.

Conclusions - further research

In this paper the frame of reference, the Port terminal and network theory has been described and finally these two were combined into a network model of a Port terminal. This way of describing a terminal is seen as very useful, and actually any terminal or enterprise functioning in a similar way can be described. It has been presented within the EUROBORDER project, and received positively by users in Port terminals, since they are Port terminal planners and management that work with planning and organisation of ports.

By using the network approach, which is a very common metaphor in the society (Casti, 1995), our Port terminal model is easy to understand and useful as basis for discussions. The network approach allows us to break down the model from the aggregated level all the way down to the parameter level. This makes it very transparent and it is easy to choose the level of abstraction or detail needed. The model is flow-oriented which brings it close to reality. Yet, it is very useful from a pure modelling view, as in e.g. programming, where it has been used in the EUROBORDER project.

References

Casti, J. (1995). The Theory of Networks In: *Networks in Action*, (Batten D. Casti J and Thord R. Ed.) Springer-Verlag, Berlin

Churchman W.C. (1981). *The Systems Approach*. Dell Publishing Co. Inc., New York

Frankel E.G. (1987). *Port Planning and Development*. John Wiley & Sons, New York

IAHP (1996). *Future Role of Ports in Combined Transport* (Hulthén. L Ed.) IAHP Head Office, Japan

Manheim M.L. (1984). *Fundamentals of Transportation Systems Analysis, Volume 1: Basic Concepts*, The MIT Press, Cambridge

Ojala L. (1992). *Modelling approaches in port planning and analysis*, Publications of the Turkuu school of economics and business administration, Series A-4:1992, Turkuu

Waidringer, J. & Lumsden, K. (1998), *Simulation and optimisation of Port terminals, using a network concept*, presented, WCTR8, Antwerp