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ROBOTISED INTER TERMINAL TRANSPORT OF CONTAINERS
A SIMULATION STUDY AT THE ROTTERDAM PORT AREA

Jaap A. Ottjes, Mark B. Duinkerken, Joseph J.M. Evers
Delft University of Technology, Faculty of Mechanical Engineering
and Marine Technology, P.O. Box 5034,
2600 GA Delft, the Netherlands
E-mail: J.A.Ottjes@wbmt.tudelft.nl
Rommert Dekker
Erasmus University Rotterdam, Faculty of Economics
Burg. Oudlaan 50 3062 PA Rotterdam, the Netherlands
E-mail: dekker@opres.few.eur.nl

ABSTRACT

In this contribution we present a generic object oriented simulation model for overland transport of containers. The main entities in the model are containers, container terminals and vehicles for transportation of containers. A terminal or service center may have several handling centres which are the nodal points for inter terminal transport (ITT). Handling centres possess equipment for loading and unloading ITT vehicles. Three types of transportation vehicles are modelled: Automated Guided Vehicles, Automated Lifting Vehicles and the Multi Trailer System with manned traction units. The model is equipped with a rule-based planning and control system. The main performance indicator is the percentage of containers which arrives at the ITT destination late: this is expressed as the non-performance percentage. The model provides possibilities for studies of large scale ITT, in both relatively compact areas as the Rotterdam Port area and container transport over larger distances. The model is applied to the Maasvlakte, which is a part of the Port of Rotterdam, for the ITT container streams predicted for 2005, in which some 1.4×10^6 containers per year are to be moved.

INTRODUCTION

Container handling operations at the Maasvlakte are expected to expand considerably in the next ten years. Consequently there will be an increased need for container transport between the various modalities (rail, road, inland waterways, sea). Also, the transport between these modalities and other service centres such as depots for empty containers (empty depots) and distribution areas for value-adding activities will increase. This transport is called Inter Terminal Transport (ITT). At present ITT is executed by means of the Multi Trailer System (MTS). This system uses manned traction units (FTF), pulling a train of trailers on which containers with a maximum of 10 Twenty-foot Equivalent Units (TEU) can be carried. At the "Delta Sealand" container terminal of "Europe Combined Terminals bv" (ECT) the container streams between ships and stack are already fully automated using some 50 automated guided vehicles and 25 automated stacking cranes (van der Ham, 1990). The problem under consideration is whether the MTS system is efficient enough to handle the large container streams predicted for the year 2005 or whether other systems using automated guided vehicles would be more cost effective. In order to investigate this the Inter Terminal Transport simulation study was initiated. The project was carried out by the Logistic Technology Section of the Faculty of Mechanical Engineering and Marine Technology of Delft University of Technology, and the Section Econometrics and Operations Research of the Faculty of Economic Sciences of the Erasmus University Rotterdam, under the guidance of the Research School "TRAIL" (Evers 1995). The project was part of the "INCOMAAS" project, the aim of which was to define a masterplan for the infrastructure and container handling at the Maasvlakte up to 2020.

The objectives of this study are to develop a generic simulation model of the Inter Terminal Transport, including container handling at terminals, container transport between terminals, planning and control algorithms, and to apply this model to investigate the possible transport modalities for ITT at the Maasvlakte. The tasks of the ITT can be summarised as follows:

– The punctual (neither early nor late) collection of containers from their point of origin

–the punctual delivery of containers at the desired point of destination
–the possible bridging of discrepancies in both these tasks by 'buffering on wheels' or in a transport-stack 'on ground')

An important criterion is the arrival time of ITT transported containers at their destination, including the handling at the destination terminal. If this completion time is later than the permitted latest arrival time for the container this is considered as 'non-performance'. Non-performance is defined as the percentage of late containers and it is used as the most important criterion for the assessment of the ITT-options. Another important performance criterion for ITT is the punctuality of departure of means of container transport such as trains and barges. Further performance indicators, which often take the form of averages and distributions, include vehicle occupation rates, number of empty trips, vehicle loading rate (percentage loaded, only MTS), queuing of vehicles waiting to be loaded or unloaded and the equipment occupation at the Handling Centres.

MODELLING

Two models are developed. The container flow data are generated by the generator-model. This model provides input for the second model, the ITT simulation model. This model simulates the entire ITT process: the handling of ITT vehicles at the terminals, the trip and waiting times of ITT vehicles, the control of the entire process and a planning mechanism. The control and planning processes in the model are 'rule-based'. A separate planning module has been developed for the MTS-option to optimise the use of FTFs, (Kurstjens 1996).

The generator model

The output of the generator model provides the input for the simulation model. In addition to the configuration data the input data of the generator model include the data relating to the container flows, aggregated in the origin-destination matrix, in which the flows are shown on an annual basis. To determine the dynamic effects of ITT, it is important to know these flows over a shorter time basis. For this the flow dynamics are generated with the aid of statistical distribution functions. For the rail terminals the incoming and outgoing flows are generated with the aid of service timetables of the trains and shuttles., barge terminals, empty depots and distribution centres. In order to derive the arrival times, the size, origin, destination and available transport time windows of containers on marine terminals use is made of statistics.

The ITT simulation model

The design of the simulation model is object-oriented and is based on the process description method (Zeigler 1976). The simulation tool Must is used for the implementation (Must 1992).
The various objects contain the data structure of the components and, in the case of an active component, also the process description of the component.
The main component classes applied in the model are: (see figure 1)

Containers
The Inter Terminal Transport is simulated at container level. The object container serves as a model for the containers that are transported by the ITT. This means that during simulation a component is created for each container present in the system. Containers are grouped in packets. A packet is a group of containers with common ITT-origin and destination. For containers going from or to trains and barges, packets are grouped in batches and assigned to a batch carrier. At the start of its departure time window the container is available for transport. Each container-object keeps and updates the data that control the transport. When a container arrives at its destination the container data indicate whether it is on time. After recording of the performance the 'container' is removed from the model.

Terminals and handling centres
All the terminals except rail and barge service centres are equipped with a container stack which is called the 'uncoupling stack'. ITT flows to and from marine terminals are uncoupled from the sea side at this stack.

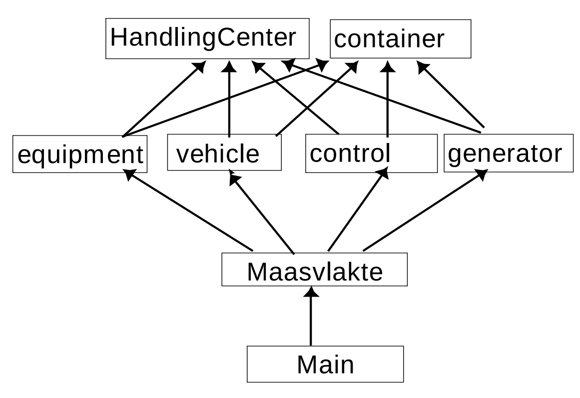

Figure 1: Relations between objects in the simulation model

Terminals are split into exchange points for ITT, the so called Handling Centres (HCs). Each HC has transhipment equipment to transfer containers to and from the ITT vehicles. Several terminal types and related equipment are modelled. The marine terminal, the distribution centre and the empty depot make use of the standard HC that has 'standard equipment'. The rail and barge service centre each have their own type of HC, because at these handling centres the containers are related to batch carriers, which require special equipment and handling procedures. Each rail HC comprises a number of rail tracks and vehicle tracks (termed "bundle"), served by one rail crane. A barge HC consists of one quay, with a quay crane. For both rail and barge HCs the processes are modelled more detailed than the standard HCs. Every HC possesses all the data on vehicles that are present or on route to it.

Equipment for container handling
The object equipment is used to model loading/unloading equipment at HCs such as straddle carriers, fork lift trucks and automatic stacking cranes. For a standard HC the move-time is drawn from a distribution. For the equipment at rail and barge HCs more detailed processes are modelled. Each cycle of the equipment process begins with 'select action'. This selection is made on the basis of a decision tree which can be summarised as follows: if there is only something to load or to unload, then do that; if both loading and unloading are possible, decide to unload a vehicle, unless the time needed for this exceeds the planned execution time (plan time) of the succeeding load container.

Vehicles: equipment for container transportation
In the model a vehicle is a component that can transport containers from its loading point to its destination. Three vehicle types are modelled: the Automated Guided Vehicle (AGV), the Automated Lifting Vehicle (ALV) and the Multi Trailer (MTS).

An AGV is a vehicle that is loaded and unloaded by equipment at the Handling Centre, but that can travel from the loading point to its destination under its own power. In the model, the control assigns an idle AGV to the loading equipment of the handling centre (crane) which loads the AGV. After that the crane activates the AGV, that travels to the destination with a user determined speed. At the destination, the AGV activates the crane at the destination and waits until unloading is completed. The AGV then is idle again.

An ALV is a vehicle that can both load and unload containers and travel from the loading point to its destination under its own power. In the model, the control activates an idle ALV. The ALV loads a container at its origin. Then it travels to the destination of the container, unloads the container and is idle again. The ALV type vehicle is in the design stage.

An MTS is a train of coupled trailers that can be loaded or unloaded with one or more containers by Handling Centre equipment. An MTS is pulled by a manned traction unit (FTF) from its point of origin to its destination. An MTS object cannot carry out any process itself. An FTF couples and uncouples itself to and from an MTS and rides from point of origin to destination. In the model, the control assigns an idle MTS to the equipment (crane) which loads the trailers with one or more containers. Then the MTS is put in a waiting queue at the handling centre. When an FTF arrives, the control can assign the FTF to the MTS. The FTF couples the MTS and travels to the destination of the containers on the trailers. At the destination, the FTF uncouples the MTS, puts it in a waiting queue and activates the crane at the destination. The MTS waits until it is unloaded, and then is idle again.

If necessary empty trips for AGVs, ALVs, MTSs and FTFs are generated. For an empty trip of an MTS, it is put in the waiting queue without a container load, and waits for an FTF. An empty trip for an FTF means that it does not pull an MTS. Both planning and control may generate empty trips.

Planning and control
The planning restores the balance between the number of ITT vehicles at the various handling centres and the known transport demand, calculates plan times for all known containers and generates the necessary empty trips for a number of future plan periods. The planning module is called up periodically every plan interval time.

The control process is activated after each job completion. It assigns 'idle' vehicles to HCs with urgent transport jobs. If no job is urgent, the control will assign vehicles to HCs that have transport jobs on the basis of planning times generated by the planning module. The non-urgent requirement for vehicles is determined by the number of containers that must be transported from a handling centre. This number is limited to a specific maximum, depending on the type of Handling Centre, its capacity and the length of the queue of loaded vehicles. In the MTS-option the control also allocates the FTFs to MTSs. For each vehicle type some additional control features are implemented.

CASE : THE MAASVLAKTE

The model that has been developed is used for an extensive experimental programme, the objective of which was to determine the characteristics of the various ITT-equipment options to be implemented at the future Maasvlakte terminals in the Port of Rotterdam. (Duinkerken 1996).

Figure 2 shows the area investigated. It consists of the ECT-Peninsula, with its marine terminals, and the peripheral service centres.

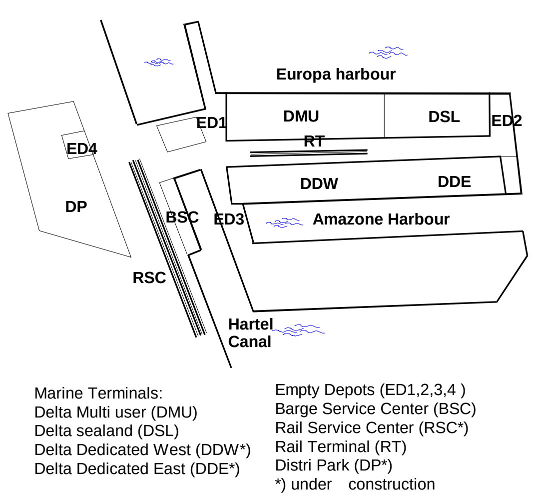

Figure 2: Layout of the Maasvlakte with terminals and service centers (2005)

The simulated system comprises the following terminals: the two existing marine terminals DMU and DSL and the two terminals under construction DDE, DDW, several empty depots (ED), the Barge Service Centre (BSC), the existing Rail Terminal (RT), the Rail Service Centre (RSC) which is in the design stage and a planned large scale distribution area called DistriPark (DP).

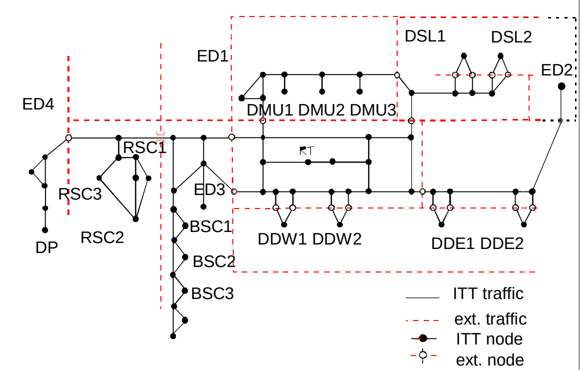

Figure 3: Transport network of the ITT area. The subdivision in Handling Centers is shown

In figure 3 the subdivision in handling centers (HCs) and the ITT traffic network as used in the simulations is indicated. Figure 4 shows a typical 'non performance graph', in which the non performance is shown as a function of the number of ITT equipment used and of the terminal load/unload capacities. The later is varied using a multiplication factor (capfactor) to adjust the HC handling capacities. The barge and rail capacities are not influenced by the capfactor. The results of the simulation experiments indicate that the non-performance percentage reached by robotised container transport is low (around 0.1%) and involves a relatively simple control system.

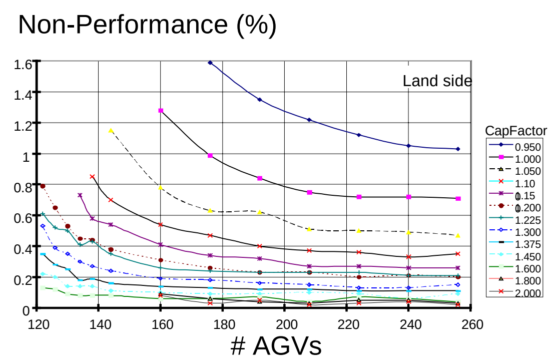

Figure 4: Non-Performance as function of the number of AGVs

Even with an advance planning and control system, however, the non-performance of the MTS remains relatively high (around 0.5%). This difference is attributable to the batch character of the MTS system, the large number of exchange points for ITT and the complexity of handling especially on the rail terminals.

The effective simulation run length was ten weeks preceeded by one week as a stabilisation period.

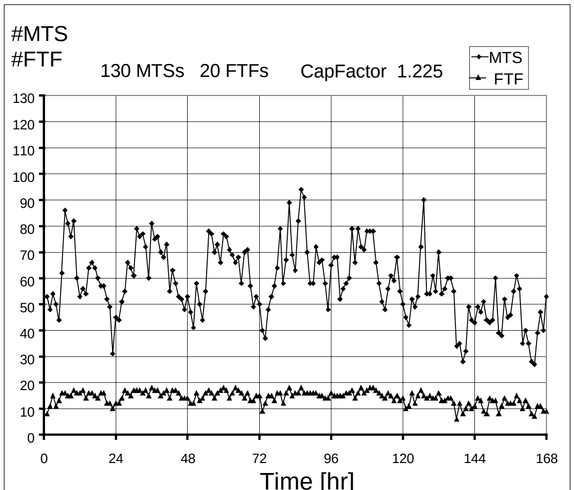

Figure 5: Number of active MTSs en FTFs (avg. per hour) in one week

Besides non performance measurements, several ITT vehicle characteristics and terminal equipment characteristics were recorded.

Figure 5 shows the number of active ITT vehicles as a function of time in a typical week for the MTS option. In order to investigate the possibilities of sharing terminal load/unload equipment, plots of aggregated equipment usage were made. Figure 6 shows that sharing equipment might level out the need for load/unload capacity at the handling centers of the terminal.

Finally for each simulated run the total system costs are calculated and plotted against the non performance in a 'non performance' versus 'cost' plot. In this plot the minimum cost line is drawn giving figure 7, showing the service rate as a function of the minimum system costs.

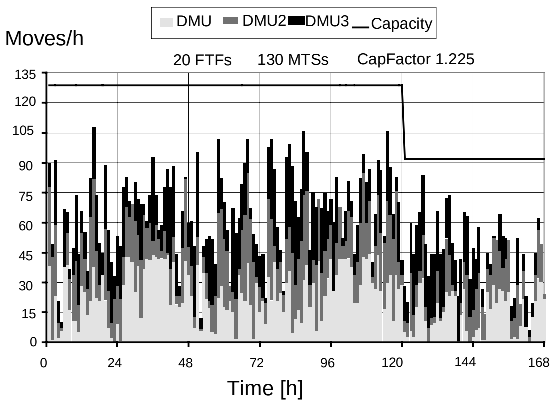

Figure 6: Aggregate number of moves per hour at DMU Handling Centers 1, 2 and 3 in one week

The service rate is expressed as (100% - non performance). The MTS system appears to be the most costly one because of the fact that the traction units are manned.

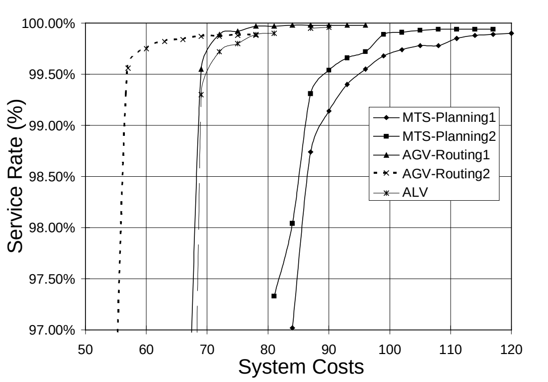

Figure 7:
Service rate (=100%-non performance) versus relative costs for a number of ITT vehicle types and planning and routing alternatives

The AGV option with routing 2 gives the lowest costs. The ALV system appears to be the best logistic option because it operates independently from the terminal equipment. It is anticipated that the control and planning algorithms developed will provide a suitable basis for their implementation in a practical application.

CONCLUSIONS

The problem of large scale Inter Terminal Transport was raised when making prognoses for the next century. A model with which the mutual transport between various container terminals and container service centers can be simulated has been created. The model is generic with regard to the lay-out and the terminals concerned. Three different vehicle options can be used: Automated Guided Vehicles, Automated Lifting Vehicles and the Multi-Trailer System. A number of models are available for the handling of containers at the transhipment points (handling centres). These simulate simple handling at marine terminals and advanced methods at rail and barge terminals. The model is applied to the Maasvlakte in order to determine the type and number of ITT equipment necessary to handle the situation predicted for 2005. It is concluded that robotised ITT with single container carriers has advantages compared with manned ITT using the multi trailer system. This difference is attributable to the batch effects introduced by the MTS system and to the complexity of handling on the rail terminals. The automated guided vehicle system appears to give the lowest total system costs. The model will be used for further investigations.

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