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SIMULATION OF SHIPPING TRAFFIC FLOW IN THE MAASVLAKTE PORT AREA OF ROTTERDAM

G.J. van de Ruit, M. van Schuylenburg and J.A. Ottjes
Faculty of Mechanical Engineering and Marine Technology
Delft University of Technology, P.O. 5034, 2600 GA, Delft, The Netherlands
Rotterdam Municipal Port Management
P.O. 6622, 3002 AP, Rotterdam, The Netherlands

ABSTRACT

Developments in the port of Rotterdam will cause a great increase in shipping traffic in the Maasvlakte, which in its turn raises doubts about the perpetuation of a smooth flow of traffic in this port area. The Rotterdam Municipal Port Management and the Delft University of Technology have therefore set up a joint research project to investigate the potential flow of shipping traffic in the Maasvlakte in the year 2010. This research has led to the development of a simulation model that can describe the interaction between vessels. Preliminary experiments with the model have indicated how many of the ships using the harbour basins will be delayed, how long the delays will be and at which points a bottleneck will occur. It was deduced that the traffic flow in the future Maasvlakte would be satisfactory, but that one part of the port area would come under relatively heavy pressure. More experimentation will be necessary before a conclusion can be drawn.

INTRODUCTION

Rotterdam is the world's largest port. Every year some three hundred million tons of goods, carried by thirty-two thousand oceangoing vessels and a great number of inland craft, pass through this major port. These goods movements take place in an area of 10,000 hectares, extending for 40 kilometres, between Rotterdam and the North Sea. In addition to Rotterdam, the ports of Schiedam, Vlaardingen, Dordrecht and - slightly further south - Moerdijk are also located in this region, while 50 kilometres to the north is another Main Port; Schiphol Airport. The combined transhipment potential forms the main artery of the north European goods flow.

With the aid of Port Plan 2010 (Gemeentelijk Havenbedrijf Rotterdam 1993) Rotterdam is preparing to retain its position as Europe's main port into the 21st century. It will create excellent opportunities for companies intending to establish themselves in the busiest port and industrial area in Europe. Port plan 2010 is based on the prognosis that the transhipment volume will have grown from 300 to 400 million tonnes by 2010.

During recent decades port activities have been moving westwards and deep sea container transhipment in particular is concentrating at the Maasvlakte. This will lead to a huge increase in the number of seagoing and inland vessels using the Maasvlakte, from 18,000 inland vessels and 3,000 seagoing vessels in 1990 to 22,000 inland vessels and 13,000 seagoing vessels in 2010.

It is important to determine whether this increased number of vessels will lead to congestion in the water area. To this end the Municipal Port Authority of Rotterdam and Delft University of Technology have set up a simulation programme. The objective of the research is to determine the traffic flow in the Maasvlakte in the year 2010.

SYSTEM DESCRIPTION

The system is 'the Maasvlakte in the year 2010'. This system consists of ships that enter the port area, sail to one or more terminals to load or unload and then leave the port area. By sailing along a route within the port, a ship lays dynamic claim to part of this area. Problems will arise whenever is impossible for ships to overtake or pass each other head on in a particular part of the port.

It is obvious that ships cannot pass each other when the space required is greater than the width of the fairway. However, owing to the hydrodynamic forces generated by the ships and their rotation in relation to their direction of movement, the space required by a combination of ships is much greater than the sum of their actual beams. Factors which play a part in this include: the size, shape and speed of the vessels involved, the wind and currents and the presence of sandbanks and bends.

MODEL DESIGN

For the model the port area has been simplified to a number of nodal points, or subsections of the route, which lie on a network of lines that gives access to all the terminals and the harbour entrances. Figure 1 shows the port area of the Maasvlakte and the location of the network of nodal points.

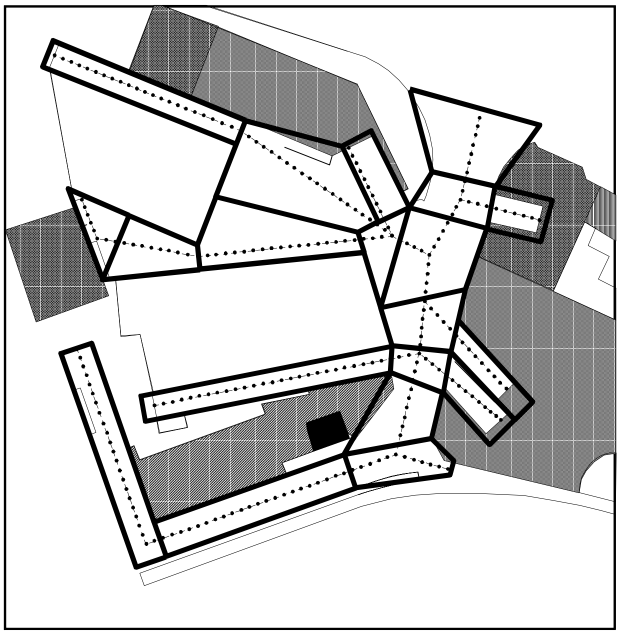

Figure 1 : The Maasvlakte port area showing sectors and nodal points

Depending on its length a ship occupies a number of nodal points and its route is defined by a sequence of nodal points. The route sailed is modelled by adding the next successive nodal point to the set of reserved nodal points and removing the rearmost nodal point from the set.

In modelling of the behaviour of shipping traffic a distinction is drawn between the assessment of traffic conditions and the timely prevention of situations which, according to the assessment, are unacceptable. To assess the traffic capacity, a specific capacity is attached to each nodal point, while a capacity demand is assigned to each ship. The capacity of a nodal point depends mainly on the width of the fairway; the capacity demand of a ship depends on its length, beam, shape and speed. The assessment criterion is that ships can pass each other in a nodal point, when the sum of their demands is equal to or smaller than the capacity of the nodal point. The actual capacity demands of a ship varies according to whether it is sailing, turning or moored.

A methodology has been developed to ensure the timely prevention of unacceptable traffic situations. This methodology is based on the assumption that before a ship can actually move there must be a specified free space in front of it. This can be implemented by allowing the ship to move to the next nodal point only after it has laid claim to a specific number of nodal points in advance of it. The claiming of a nodal point is the reservation of part of the capacity equal to the capacity demand of the ship. A condition for the claiming of a nodal point is that there is sufficient unclaimed capacity available ahead. If one of the nodal points to be claimed cannot meet this condition the ship will have to wait.

The free distance that a ship requires ahead of it and within which it therefore must claim nodal points consists of two parts:

- A minimum distance in relation to other ships, which will be called the 'claim length'
- A distance, depending on the place in the port area within which the fairway width and thus the capacity of the nodal point remains about equal. This distance is needed to prevent an impending bottleneck in time, so that a stoppage will not be created in an adjacent nodal point under the same conditions.

To model this, the port area is divided into a number of sectors within which all the nodal points have the same capacity (figure 1). Ships first try to claim the nodal points within their claim length on their sailing course. A nodal point can only be claimed when all nodal points on the course that are in the same sector as the nodal point can be claimed. Figure 2 gives a clear illustration which nodal points must be claimed.

To implement the methodology each sector is given the function traffic controller. When a ship wished to claim on or more nodal points, it reports to the sector controlling these points. By applying the criterion the sector assesses the future traffic situations and then indicates whether the ship may proceed.

IMPLEMENTATION

The simulation language 'Prosim' (Sierenberg & De Gans BV 1993) is used to implement the model. In the end the researcher has three programs available for research into the traffic flow in the Maasvlakte: a simulation program, an initiation program and an animation program. With the aid of the SADT-methodology (Marca and McGowan 1988), the place of these programs within the total range of activities that the researcher carries out in investigating the traffic flow in can be made clear. Figure 3 shows the Activity Factor

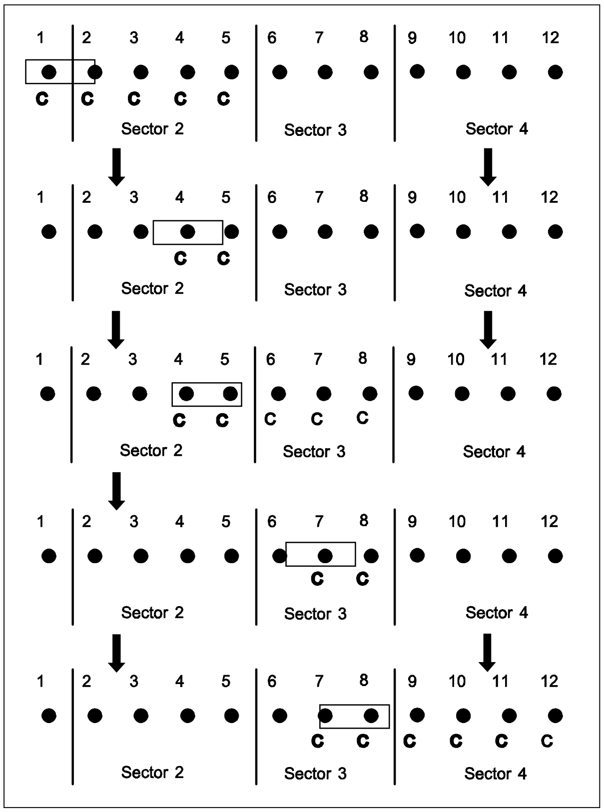

Figure 2 The claiming of nodal points (C = claimed by ship)

diagram. The initiation program carries out the activities shown in block A1; it transforms the data of port configuration into terms suitable for the simulation model. Activity block A4 stands for the running of the animation program; this program uses the researcher to depict the situation in the port area and make it comprehensible. Activity block A2 presents the actual simulation. The method described is implemented in the simulation program. A process oriented approach was used to construct the model. The simulation program consists of components with specific properties in which the active components follow a process. The processes are described by using the 'Process-interaction method' (Zeigler 1976). Here a condensed version of the informal model description will be given.

SHIP (class component)

Attributes:

→ Destinations (Set of the destinations that the ship must still visit)
→ Occupation (Set of the nodes reserved by the ship)
→ Claimed points (Set of the nodal points claimed by the ship)
→ Origin (previous destination visited by the ship)
→ Route point (succession of nodal points that the ship must follow)
→ Ship's number
→ Ship type
→ Nodal points to be claimed (set of nodal points that the ship tries to claim in a sector)
→ Status type (whether the ship is sailing, turning of moored)
→ Sailing distance (distance that the bow or stern of the ship must move)
→ Purpose of movement (destination to which the ship is sailing)
→ Delay per ship (the time that a ship in the port area has waited in order prevent unacceptable traffic situations)
→ Turning point (the nodal point where a ship turns when it cannot turn at the terminal)

Process:

As long as the ship still has to visit destinations do
  Determine purpose of ship's movement
  If the destination is a terminal, wait until this terminal can be allocated to the ship
  Determine the route from nodal point of origin to destination
  If the origin is a terminal follow through the claim routine to take up already reserved nodal points with sailing capacity demand
  Find out whether a ship needs to turn, and if so determine the turning point
  Follow the claim routine to claim the first part of the route.
  If the origin is a harbour entrance add the first nodal point of the route to the set of reserved nodal points
  If the origin is a terminal wait for the casting off time
  As long as the ship still has nodal point on its route do
    Determine sailing distance
    If first nodal point of the route has to be added to the set of reserved nodal points, follow the claim routine to claim part of the route to be sailed
    Wait for sailing distance divided by sailing speed
    If first nodal point of the route has to be added to the set of reserved nodal points do
      Add first nodal point of the route to the set of reserved nodal points
      Remove this nodal point from the route
      If this nodal point is a turning point wait for the turning time
    If the last nodal point of the ship has to be removed from the set of reserved nodal points
      Remove the last nodal point of the ship from the set of reserved nodal points
      Remove the claim on this point
      Activate the sector in which this nodal point lies
  If the destination is a terminal do
    Wait for mooring time
    Correct claims on the already reserved nodal points in order to reserve these nodal points with the moored capacity demand
    Activate sectors in which these nodal points lie
    Origin is this terminal
    Wait for handling time
  If the destination is a harbour entrance
    Remove all nodal points from the set reserved nodal points
    Remove claims on these nodal points
    Activate the sectors in which these nodal points lie
    Depart

Sub-process (claim routine when sailing):

Determine the nodal point following the last nodal point claimed
Determine the distance between the bow of the ship and this point
If this distance is smaller or equal to the claim length do
  Determine all nodal points on the route in the same sector as this nodal point
  Activate this sector
  Wait

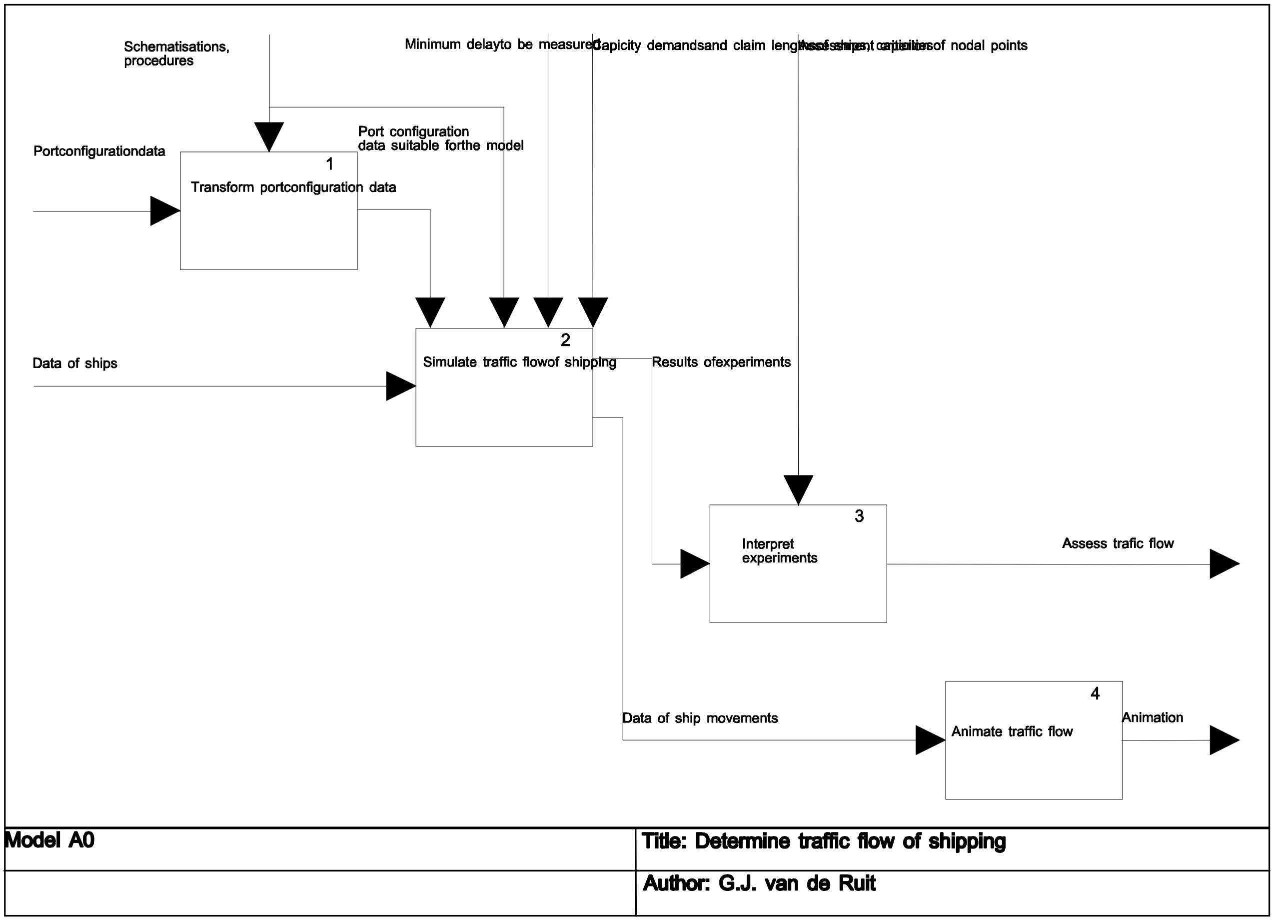

Figure 3 : Model A0 of the research project 'Traffic flow in the Maasvlakte'

Repeat sub- process
If this distance is greater than the claim length do
Record delay
end sub-process

SECTOR (class component)

Attributes:

→ Number of delays per sector (number of ships that has waited for this sector)
→ Capacity (Capacity of the nodal points in the sector)
→ Nodal points in the sector (nodal points belonging to the sector)
→ Sector number
→ To be claimed (set of ships that have been unable to claim one or more nodal points in the sector)
→ Delay time per sector (time the ships have waited for a sector because they could not claim nodal points in the sector)

Process:

Wait
For each ship that will claim the nodal point do
For each nodal point that the ship will claim do
Find the capacity demand that must be claimed for the nodal point
Find out if this capacity demand is smaller than the unreserved capacity of the nodal point
If each of these nodal points can be claimed then for each of them do
Reserve part of the capacity of the nodal point for the capacity demand that has been determined for it
Activate ship
Repeat process

NODAL POINT (class component)

Attributes:

→ Claimed (set of ships that have claimed the nodal point)
→ Nodal point number
→ Remaining capacity (the part of the capacity that has not yet been claimed by ships
→ Sector of nodal point (sector in which nodal point lies)

No process

DESTINATION (class component)

Attributes:

→ Destination number
→ Destination type (whether the ship's destination is a terminal or a harbour entrance)
→ Occupation limit (distance from the starting point of the terminal to the rear of the berth of the last moored ship)

→ Already planned (set of ships for which a berth is planned)
→ To be planned (set of ships for which a terminal has been allocated but which have not yet been allocated quay space)
→ Quay length
→ Nodal point at destination (set of nodal points that can be projected on the destination quay)
→ Remaining length (unallocated quay length)
→ Allocated (set of ships to which the terminal has been allocated)
→ To be allocated ships (set of ships that wish to use the quay but to which it has not yet been allocated)

Process:
Arrange berths for ships

EXPERIMENTS

The objective of experiments with the simulation model is to assess future traffic flow. For this, a number of performance indicators have been determined:

- the percentage of ships that will be delayed by traffic pressure
- the average delay for these vessels
- the delays in the various sectors
- the delays of the various classes of vessel

The criterion against which the traffic flow is assessed is a threshold value for the two most important performance indicators; the traffic flow is sufficiently smooth when less that 2% of the ships are delayed by an average of less than 15 minutes.

Figure 3 indicates what input is needed for experimental use of the model. The data of the ships and of the port area are based on forecasts for the Maasvlakte in 2010. With the aid of data on the vessels the generators are able to create and specify them. Traffic flow is determined by the nodal point capacity and the capacity demand and claim length of the ships. It is not at all easy to determine the values for these parameters with complete certainty. Experiments have been carried out using parameter values that, according to nautical experts, are the most feasible; an experiment with these values henceforth called the reference run. The ships are divided into a number of classes that behave in a similar way with regard to manoeuvrability. The capacity demand and claim length are related to a class of vessel.

For the reference run, the capacity demand for each class is three times the beam of the ship, for turning 1.25 times the length of the ship and when moored 1.5 times the beam of the ship. For all classes the claim length is defined as 100 metres. The nodal point capacities have a value of 95% of the average breadth of the fairway in the sector. The results of experiments with the reference run showed that 2% of the ships were delayed by an average of 14 minutes. According to the assessment criterion the future traffic flow in the Maasvlakte will be acceptable. Considering the occupancy of the various sectors, it emerged that 95% of all delay occurred in one sector. The last performance indicator shows that in the model larger vessels are relatively more often delayed that smaller ones, which agrees reasonably well with practical experience.

A number of experiments were carried out to investigate how seriously deviating parameter values would affect the simulated traffic flow. Figure 4 shows the sensitivity of the model to variation in the capacity demand. The capacity demand when sailing is successively 2, 2.5, 3 and 3.5 the beam of the ship; the capacity demand when moored is 1, 1.25, 1.5 and 1.75 time the beam of the ship; the capacity demand when turning is 1, 1.125, 1.25 and 1.375 times the length of the ship. From the figure it is clear that great care must be exercised in determining this parameter. The value of the claim length is a less strong determinant; Figure 5 shows that an increase in the claim length from 100 to 500 metre results only in a marginal change in the traffic flow.

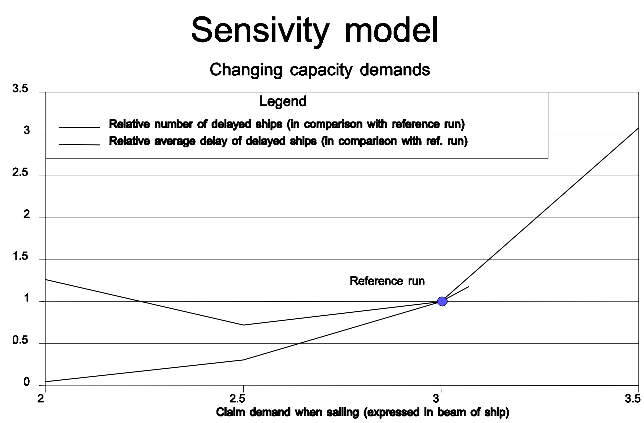

Figure 4 : Sensitivity model for changing claim demands

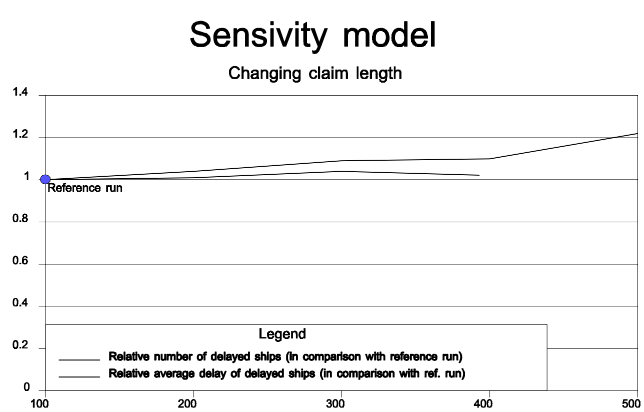

Figure 5 : Sensitivity model for changing claim length

CONCLUSIONS AND RECOMMENDATIONS

To investigate the traffic flow in the Maasvlakte in 2010 a simulation model that can describe the behaviour of shipping traffic has been developed. From the results of experiments with this simulation model it appears that in the future approximately 2% of the vessels will be delayed by traffic pressure; the average delay for these vessels will approximately 14 minutes. On the basis of the assessment criterion that has been defined, the future traffic flow in the Maasvlakte will be considered acceptable. A reservation is that some parameters used in the simulation model upon which the traffic flow is heavily dependent cannot yet be determined with complete certainty. A recommendation is to use a simulator and interviews with pilots to increase the reliability of these conclusions.

The following extensions of the simulation model are possible:

- In some cases ships following each other are at sailing at to great a distance apart. This can be prevented by adapting the model used to differentiate between ships overtaking each other and those passing each other head on.
- The effect of changing weather conditions and tides has not yet been considered. The effects of these factors could be modelled by the introduction of a component that expands or contracts the capacity of the nodal point according to the weather and tide.

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