FOR THE FORECASTS of the future need of infrastructure for rail and road traffic in the Netherlands the Integral Traffic and Transport Study was carried out, where passenger-transport as well as commodity-transport were taken into consideration.

With reference to the forecasts for commodity transport the modalsplit was determined parting from the modes rail, road and inland navigation.

In view of the important role played by inland navigation in the total national and international commodity transport of the Netherlands, the Ministry of Transport requested the Netherlands Institute of Transport to determine the future transport flows on the Dutch waterwaynet, parting from the transport forecasts of this mode.

The Dutch waterwaynet is relatively long (totally abt. 4000 kms, only channels and rivers), about 40% is accessible for ships of minimum 1350 ton, whilst on the most important international waterways such as the Rhine push-navigation is possible up to maximum 10,000 ton.

Though the smaller waterways, in view of the tendency to use bigger ships, do become less significant, they still form an amount of reserve-capacity for smaller ships, which can be used when congestions occur on the main waterways.

The potential bottlenecks in the waterwaynet are formed specially by locks and bridges, which in comparison to the waterways themselves have a reduced capacity.

Inland navigation has a number of specific traffic-technical characteristics which have been of considerable influence on the building of the model which was developed for the assignment of the traffic flows forecasted to the network.

In the first place the big variety in size of the vehicles, compared to that in road transport can be mentioned. The loading capacity of current shiptypes varies between abt. 100 and 10.000 ton. The waterways themselves show a great variety; there are channels, rivers, locks and bridges. Each one of the mentioned categories has its own resistance characteristics for shipping, whilst moreover most of the waterways do have a restricted accessibility, which excludes the navigation of ships above a certain loading capacity.

In order to arrive at an operational model the vessels were divided in 8 shipsclasses. To each class a representing standardship was chosen with given technical characteristics such as loading capacity, engine capacity etc. The network was divided in about 1100 links and 75 zones were distinguished in total.

The traffic flows to be assigned were differentiated according to the shipsclasses, so that in total 8 (75 x 75) origin-destination tables had to be made out.

This sub-division of the traffic flows was necessary because the choice of route per shipsclass may differ; 3 reasons can be mentioned to this effect:

a) the accessibility-restrictions in the network; the bigger the ship, the less the choice possibilities

b) the velocity that can be realized on a certain route differs per shipsclass; three differences are bigger on one waterway than on another

c) the relative appraisal of the factors time and distance differs per shipsclass; this is related to the cost-structure (it was supposed that the transport-costs which are a function of transport-time and distance are determinant for the choice of route).

Though the choice of route may differ per shipsclass, the shipsclasses cannot be assigned to the network independently of each other. This is related to the fact that the transport-time per link is a function of the volume-capacity ratio (for rivers and channels this is a velocity function; for locks and bridges a waiting-time function).

The model was made suitable for two assignment techniques:

a) all or nothing assignment

b) capacity restraint assignment

Since the all or nothing method can be considered a special case of the capacity restraint method (all capacities are infinite) this method is not dealt with specially.

Before the set-up of the model as a whole is explained (par. 4) in the first place will be explained how the volume-capacity ratio is calculated with a traffic volume made out by vessels of different shipsclasses (par. 2) as well as how the transport-time per link is calculated (par. 3).

A list of the symbols used is given at the end of this paper.

The Calculation of the Volume-Capacity Ratio

The maximum value which the traffic volume on a link can assume—given certain suppositions—is called the capacity of that link.

The volume-capacity ratio which indicates to which extent the capacity is used, is the explanatory variable in the model for the velocity on a waterway or the demurrage-time at a lock or bridge.

It goes without saying that the amount of 100-ton vessels that can pass a lock during a week is much bigger

A Traffic Assignment Model for Inland Navigation

by

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than the number of 1000-ton ships. Consequently one should bear in mind, when determining the capacity, a certain division of the ships over shipsclasses; moreover the volume-capacity ratio should have to be calculated only then in case the traffic volume is composed in accordance with this division.

Since these suppositions cannot be handled in practice, a method was developed which is flexible with reference to variances in the loading capacities of the ships.

As was mentioned before, each loading capacity is represented by a certain standard-ship with given technical characteristics. From these standard-ships one ship is chosen as normal-ship, as a unit of traffic volume and capacity; with the aid of equivalence figures the different standard-ships can be converted into normal-ships:

$$(1) \quad I_n = \sum_{s=1}^{S} \alpha_s I_s \qquad (s = 1, \ldots . S)$$

whereby:

I_n = traffic volume in normalships per unit of time

α_s = equivalence figures for standard-ships of class s

I_s = number of ships of class s per unit of time

S = maximum shipsclass

the equivalence figures are determined here in accordance with the concerning capacities:

$$(2) \quad \alpha_s = \frac{C_n}{C_s} \qquad (s = 1, \ldots . S)$$

whereby:

C_n = capacity in normalships per unit of time

C_s = capacity in standardships of class s per unit of time

The calculation of C_n and C_s must of course take place based upon empirical research. When applying a type-classification of links in so-called "equivalence-classes" a restricted number of sets of equivalence figures $\alpha_s (s = 1, \ldots . S)$ is sufficient. If of each link the capacity in normalships C_n is given, the volume-capacity ratio based on normalships I_n/C_n can be calculated out of any given traffic volume, given the equivalence figures:

$$(3) \quad \frac{I_n}{C_n} = \frac{\sum_{s=1}^{S} \alpha_s I_s}{C_n} \qquad (s = 1, \ldots . S)$$

By substituting (2) into (3) it can be shown that this method of calculation is similar to:

$$(4) \quad \frac{I_n}{C_n} = \sum_{s=1}^{S} \frac{I_s}{C_s} \qquad (s = 1, \ldots . S)$$

which implies that the choice of a normalship does not influence the calculation of the volume-capacity ratio.

The Calculation of the Travel-Time Per Link

In principle the following data per link are available:

a) first node-number "A"
b) second node-number "B"
c) distance: d
d) maximum velocity of the fastest ship (depending on sub i and sub j): V_{max}
e) current speed from A to B: V_{cur}
f) constant travel-time: t_c
g) capacity in normalships per week: C_n
h) equivalence class
i) linktype AB
j) linktype BA
k) accessibility class (maximum shipsclass)

Given the traffic volume in normalships per week, calculated according to equation (1), parting from the equivalence class (sub b), the travel-time per link can be calculated using the above mentioned data.

The basis-formula is as follows:

$$(5) \quad t_s^{AB} = (t_v^{AB})_s + t_c$$

whereby:

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t_s^{AB} = travel-time for shipsclass s from A to B

$(t_v^{AB})_s$ = variable travel-time (dependent on traffic) for shipsclass s from A to B

t_c = constant travel-time; equal for all shipsclasses in both directions

The linktype per direction indicates which resistance-functions should be applied in order to calculate:
$(t_v^{AB})_s$ and $(t_v^{BA})_s$ $(s = 1, \ldots\ldots S)$

Hereby there is an essential difference between waterways on the one hand and locks and bridges on the other hand.

As far as waterways are concerned the linktype is linked with the accessibility class, which implies that the linktype is equal in both directions.

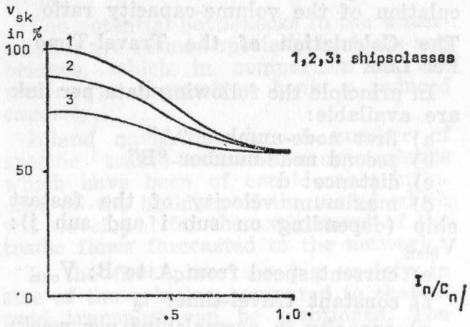
Per linktype there are as many resistance functions as there are possible shipsclasses according to the accessibility class; for each shipsclass there is a velocity function of the following type:

$$(6)\quad v_{sk} = \frac{f(I_n)}{C_n}$$

whereby:

v_{sk} = velocity shipsclass s, linktype k in per cents of V_{max}

In diagram 1 the 3 functions belonging to accessibility class 3 are drawn as an example:



The relative speed per shipsclass v_{sk} as a function of the volume-capacity ratio for accessibility class 3.

DIAGRAM 1

The velocity-functions only indicate the velocity in per cents which are all related to a parameter V_{max} differing per link, which is expressed in kms/hour. The maximum velocity of the fastest ship according to the velocity-functions is per definition 100%; V_{max} indicates the absolute value of this velocity. The calculation of the variable resistance (depending on traffic) for a link representing a waterway is as follows:

$$(7)\quad (t_v^{AB})_s = \frac{d}{\frac{v_{sk}}{100} V_{max} \pm V_{cur}}$$

If the linktype represents a lock or bridge, then the variable resistance (depending on traffic) can be considered equal to the average waiting-time per ship, which is a function of the volume-capacity ratio:

$$(8)\quad (t_v^{AB})_s = t_o = 6\left(\frac{I_n}{C_n}\right)$$

whereby:

t_o = average waiting-time per ship (equal for all shipsclasses)

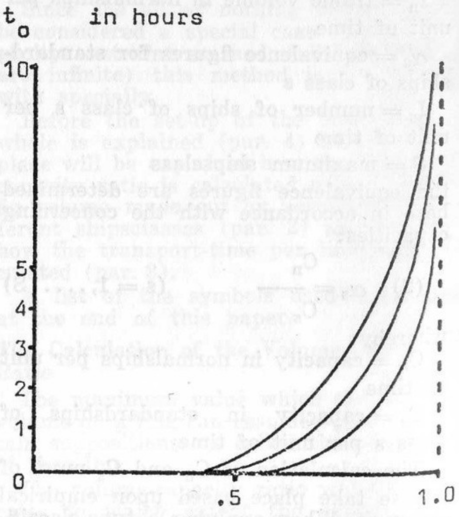
The waiting-time function to be used and consequently the linktype may differ per direction.

Parting from observed traffic-intensity patterns, a number of functions for the calculation of the waiting-time were determined by means of simulation (see diagram 2).

The Assignment Procedure

In the foregoing paragraphs an explanation is given of how the travel-times for the different links in the network can be calculated. A following step is the determination of the choice of route.

There was parted from the supposition that the transport-costs are determining



The average time on demurrage t_o as a function of the volume-capacity ratio I_n/C_n for three different categories of locks.

DIAGRAM 2

for the choice of route, in that sense that one endeavours to minimum costs; these costs depend on the travel-time and distance along the complete route:

(9) $K_s = \beta_s T + \partial_s D$

whereby:

K_s = total transportcosts for the complete route for shipsclass s

β_s = costs per unit of time for shipsclass s

T = total travel-time for shipsclass s

∂_s = costs per unit of distance for shipsclass s

D = total distance

The "shortest" route algorithm of Whiting/Hillier and Minty was applied for the determination of the routes with the lowest costs; such alteration had to be built in as to take the accessibility restrictions into consideration when choosing the route.

For the assignment of the traffic to the network the all or nothing as well as the capacity restraint method were applied. The flow-chart of the all or nothing assignment in diagram 3 illustrates how the various phases in the calculation procedure are linked together.

In the first place all volume-capacity ratios are taken equal to 0, then the travel-times are calculated based thereupon. The cheapest routes are calculated then per origin-destination pair and per shipsclass, whereafter 100% of the traffic out of the origin-destination tables (0D) is assigned to the network according to these routes.

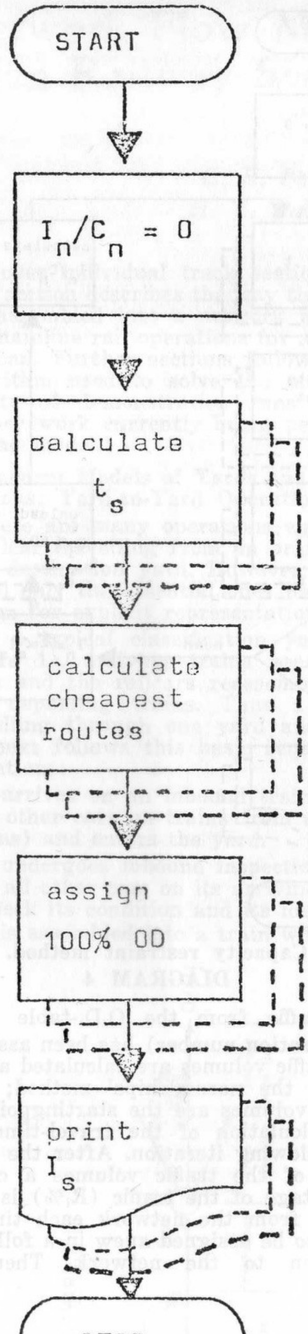
Operations which are made per shipsclass are indicated in the diagram as a "group" of operations (interrupted lines).

The simplifying supposition of the all or nothing method, whereby all volume-capacity ratios are taken equal to 0, is replaced in the capacity restraint method by a system whereby a feedback from the volume-capacity ratios, which result from the assignment, to route-choice is effected.

To this effect the traffic is assigned through a number of iterations respectively assigned anew so that finally an equilibrium is obtained, whereby the costs of the routes chosen (per origin-destination pair and per shipsclass) are approximately equal, whilst the routes not chosen are all more expensive (Wardrop's second principle).

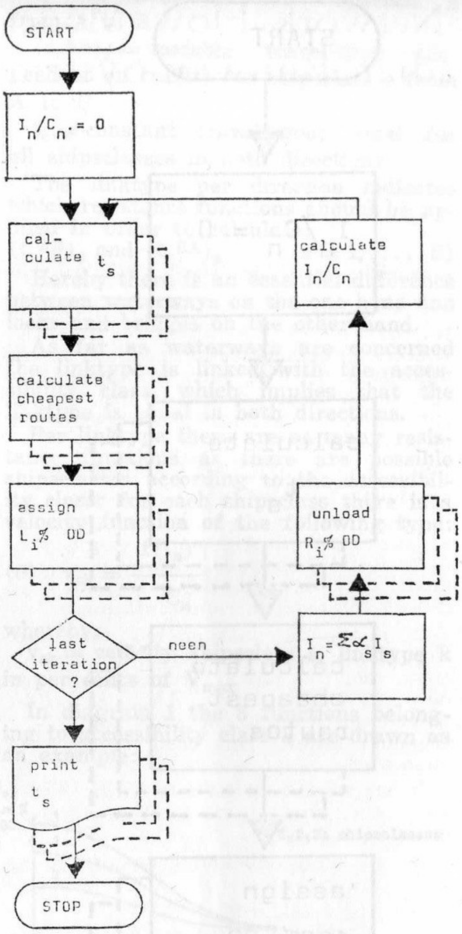
The assignment procedure by the capacity restraint method is shown schematically in the flow-chart in diagram 4.

At the starting-point all volume-capacity ratios are, just like with the all or nothing method, taken equal to 0, however after a certain percentage of



All or Nothing Assignment.

DIAGRAM 3



Capacity restraint method.
DIAGRAM 4

the traffic from the O.D.-table (L_i%; i = iteration number) has been assigned, the traffic volumes are calculated according to the normalships' method; these traffic volumes are the startingpoint for the calculation of the travel-times for the following iteration. After the calculation of the traffic volumes a certain percentage of the traffic (R_i%) is withdrawn from the network each time, in order to be assigned anew in a following iteration to the network. Then the volume-capacity ratio is calculated anew etc.

The percentages L_i and R_i have to be specified beforehand.

Though generally spoken satisfactory results can be obtained with this method, a good equilibrium in terms of equal costs cannot always be obtained, specially with high volume-capacity ratios (the average waiting-time is very sensitive to variations in traffic volume then).

In order to eliminate this objection, the Netherlands Institute of Transport is working now on the development of a system, whereby the percentages L_i and R_i are determined endogeneously.

List of Symbols

C_n—capacity in normalships per unit of time

C_s—capacity for shipsclass s per unit of time

d—distance of a link

D—distance of a route

I_n—traffic volume in normalships per unit of time

I_s—traffic volume shipsclass s per unit of time

S—maximum shipsclass

K_s—total transportcosts over an entire route for shipsclass s

t_c—constant travel-time

t_o—average waiting-time per ship

t_s^{AB}—travel-time from A to B for shipsclass s

$(t_v^{AB})_s$—variable (traffic-dependent) travel-time from A to B for shipsclass s

v_{sk}—velocity shipsclass s, linktype k as a percentage of v_{max}

V_{cur}—speed of current

V_{max}—maximum velocity of the fastest ship (dependent on linktype)

α_s—equivalence figure for ships of shipsclass s

β_s—costs per unit of time for shipsclass s

∂_s—costs per unit of distance for shipsclass s

t_s—travel-time shipsclass s in any direction