New Dutch Capacity Standards for Freeway Weaving Sections Based on Micro Simulation

Raymond Vermijs

Abstract

Traffic engineers in The Netherlands are not satisfied with the present guidelines on freeway capacity. For this reason the Dutch Ministry for Transportation, Housing and Water Management gave order to make a manual on freeway capacity. One of the chapters in this manual is on weaving sections. This paper describes the research on weaving capacity needed to make the first version of this chapter. The research consisted of a literature search on weaving capacity worldwide and a simulation study on the capacity of Type A weaving sections using the micro simulation model FOSIM. In the simulations weaving section length, weaving flow rate and truck percentage were varied. The results are presented in capacity diagrams for specific weaving section configurations. Capacity results are combined in diagrams for all configurations together. Estimated pcu values for trucks are not the same for all configurations considered.

1. INTRODUCTION

As in most countries in the world, capacity guidelines for freeways in The Netherlands are based on the Highway Capacity Manual (TRB 1994). Due to differences in traffic characteristics, freeway design and legislation between the United States and The Netherlands there is a need for specific capacity guidelines for the Dutch freeway network. Traffic engineers often complain that they have to evaluate designs for freeway sections with standards that are out of date or that do not apply to the specific traffic volumes. In view of this fact, the Dutch Ministry of Transport, Water Management and Public Works decided to make a Dutch Freeway Capacity Manual. In order to gather all the information needed to make this manual, the Ministry sponsored a series of studies on the capacity of different types of freeway sections and the factors that influence capacity (see e.g. Botma, v. Goeverden, Bovy 1998).

The study described in this paper deals with the capacity of weaving sections (Vermijs 1997). The goal of this study is to obtain sufficient data on weaving capacity to make a new set of guidelines. The study contains two important parts:

- a literature search on capacity values of weaving sections
- a simulation study on capacity values for a selected group of weaving sections

For weaving capacities from literature a study by Minderhoud and Papendrecht (1996) is used that describes 160 publications on freeway capacity in different parts of the world. By using a microscopic simulation model valid for capacity assessment of weaving sections in The Netherlands, a wide variety of capacity values are obtained. These values form the basis for diagrams and tables for freeway design and evaluation purposes. Special attention is payed to the possibility to use passenger car equivalents for trucks.

The following section gives a brief overview on traffic operations on freeway weaving sections. It describes the mechanism of traffic break-down on weaving sections and presents an account of the most important factors that influence capacity. Then the results of the literature search on weaving capacity are presented in Section 3. Section 4 describes the simulation study setup, followed by the simulation results in section 5.

2. TRAFFIC OPERATION ON WEAVING SECTIONS

2.1 General

Before we discuss weaving capacity and the factors that affect weaving operation we have to look at the processes that form the basis of traffic flow on weaving sections. The general lay-out of a weaving section and the traffic flows on it is shown in *Figure 1*.

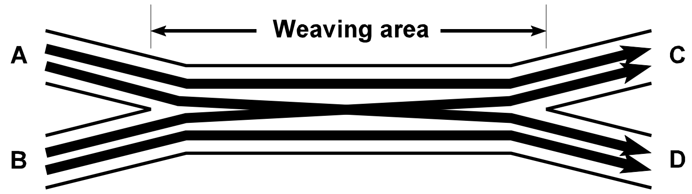

Fig. 1 - General lay-out of a weaving section

The Highway Capacity Manual describes weaving as: *"the crossing of two or more traffic streams traveling in the same general direction along a significant length of highway, without the aid of traffic control devices"*. These crossed traffic streams or weaving flows are flows AD and BC in *Figure 1*. While flows AC and BD have little or no interaction with other flows on the section, AD and BC have a direct influence on each other because they use the same physical part of the roadway. To see how this interaction takes place we first look at an individual driver in a weaving flow.

2.2 Individual manoeuvres on a weaving section

Figure 2 shows the steps taken by a driver who is part of a weaving flow.

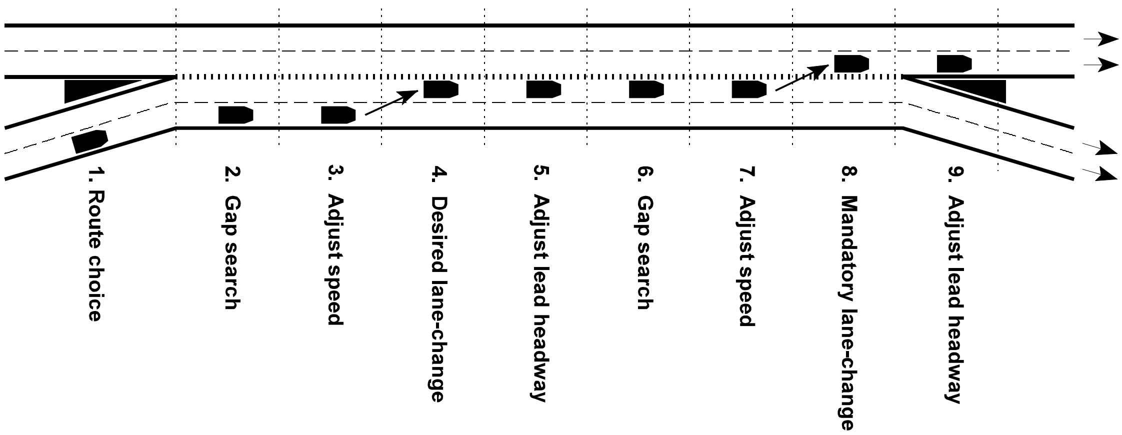

Fig. 2 - Possible steps by an individual driver in a weaving flow

In general a lane-change consists of four basic steps:

- gap search
- adjust speed
- execute lane-change
- adjust lead headway

Given the fact that an on-ramp can have more than one lane, the mandatory lane-change to reach the destination-lane is possibly preceded by a desired lane-change. This desired lane-change often takes place upstream of the actual weaving section. Whether all steps are necessary, depends on the actual traffic state. When traffic volumes on the weaving section are very small, speed and lead headway adjustment are usually not needed.

2.3 Combined manoeuvres on a weaving section

When individual driver manoeuvres on a weaving section are combined, we can distinguish three basic lane-change settings that are depicted in *Figure 3*. Situation A shows a car entering an adjacent stream of cars, situation B shows a car that leaves the stream it is currently in. Situations A and B can be compared with an on- and off-ramp lane-change respectively. On weaving sections they occur separately, as well as combined. Situation C is typical for a weaving section. It is a combination of situations A and B in which two (or more) cars change places within a short period of time. While doing so, the cars exchange gaps and the drivers accept an extreme small net distance headway **hn** as they change lane. When they have finished their lane-change the total distance headway from leader to follower **ht** is usually sufficient to maintain normal speed, perhaps after a small correction. Situation C represents a very efficient weaving operation within a compact area.

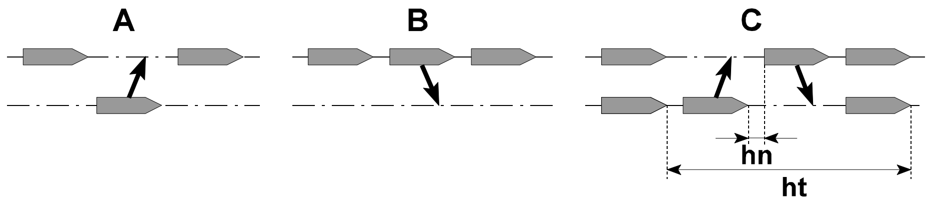

Fig. 3 - Three lane-change manoeuvres on a weaving section

Situations A and C only occur when traffic volumes allow gaps of sufficient size to accommodate the necessary lane-change manoeuvres. It is obvious that when volumes are substantial and speeds are low, **hn** can become negative and situation C is no longer possible. This leads to a traffic flow on the weaving section in which there is only room for operations like in situations A and B, at the cost of decreased traffic volumes.

2.4 Traffic break-down on a weaving section

Looking at a weaving section at capacity conditions a situation like in *Figure 4* can be seen. Because of high weaving and non-weaving flow rates speeds decrease and gap-searching and lane-changing becomes a problem for the drivers on the weaving section. Gap-searching in a dense traffic flow usually leads to braking manoeuvres that cause even lower speeds. As most lane-changes on a weaving section take place within the first 350m or so, first signs of traffic break-down will occur in that area (Schuurman and Vermijs 1993).

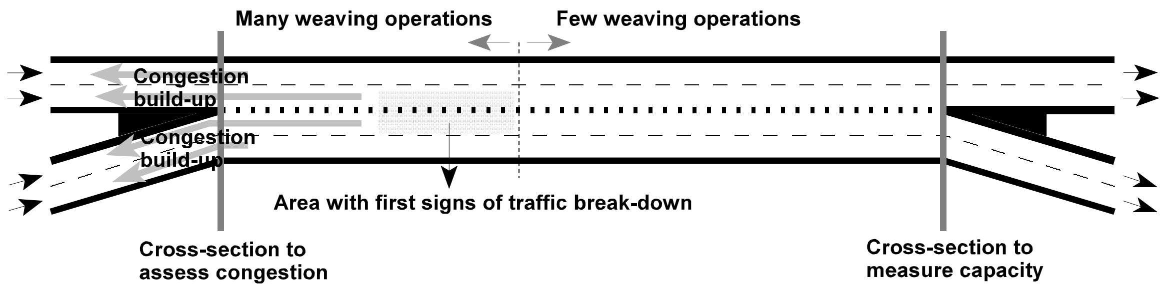

Fig. 4 - Traffic operations at traffic break-down and measuring cross-sections

2.5 Capacity of weaving sections

Macroscopic traffic flow law (e.g. May 1990) dictates traffic flow break-down when speeds become lower than a critical speed and densities are high. This is usually preceded by a period with traffic flow at capacity level. In view of the general definition for capacity by Boekholt et al (1996) capacity for a weaving section is defined as:

> *"The maximum number of vehicles (per hour) that can pass a weaving section during a period of time, under prevailing road, environment, traffic and traffic control conditions."*

If capacity of a weaving section is to be measured the best cross section to do so is downstream of the area traffic break-down occurs. In that way we can avoid the disturbing influence of congestion building up in the first part of the weaving section (see *Figure 4*). We do need an extra cross section at the beginning of the weaving section to establish the fact that congestion has occurred. This way we can be sure maximum throughput has been reached.

2.6 Factors influencing weaving section capacity

Capacity of weaving sections depends on a number of influencing factors. Beside factors that influence traffic flow on freeways in general, specific factors for weaving sections can be distinguished (for a specific configuration):

- *weaving section length*
  To execute a lane-changing manoeuvre a certain amount of space is required. It is obvious that the weaving section length influences the time drivers have to perform lane-changes. If weaving section length is reduced drivers compensate loss of space with lower speed. Lower speed can eventually lead to lower capacity.
- *origin-destination pattern*
  The proportions of the non-weaving and weaving volumes are of direct influence on the capacity of a weaving section. Without weaving flows a weaving section operates like a normal freeway section with the same number of lanes. With increasing weaving flow rates traffic operation is increasingly disturbed by lane-changes and capacity will drop. To describe the origin-destination pattern we use:
  - total flow rate V
  - weaving flow rate Vw
  - smallest of the two weaving flow rates Vwmin
  - volume ratio VR = Vw/V
  - weaving ratio R = Vwmin/Vw
- *Traffic flow composition*
  In a traffic flow trucks and buses usually take up more space than the average car. Because of their characteristics, these vehicles need more time and space to perform a lane change in dense traffic. A high proportion of these vehicles influences weaving section capacity in a negative way. Normally we only look at the proportion of trucks. They form the largest group of non-passenger vehicles.
- *Entering speed*

On on-ramps travel speeds may be low due to an upstream traffic light or curve. Vehicles entering a weaving section at a considerable lower speed than average, have a negative influence on speed on the weaving section. This may have a negative impact on capacity.

Of the influence factors mentioned above weaving section length and weaving flow rate are thought to have the greatest influence on capacity, especially when traffic flow rates are expressed in passenger car units. *Figure 5* shows these influences on capacity in a graphical way.

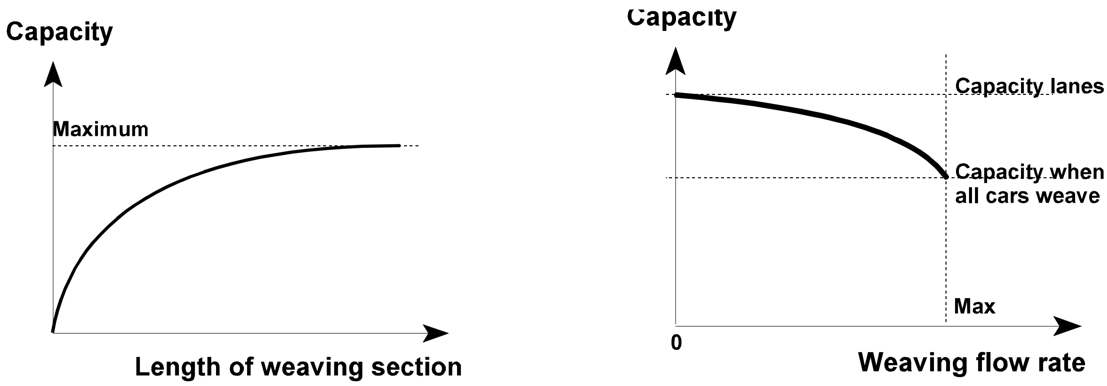

Fig. 5 - Hypothetical influence of weaving section length and weaving flow rate on weaving section capacity

When weaving section length is zero capacity is zero as well. Capacity is at its maximum when a weaving section has a certain length. More length does not help to increase capacity. When weaving flow rate is zero, capacity is at a level comparable to that of a carriageway with the same number of lanes. The marginal effect of weaving cars on capacity is considered to be larger than the marginal effect of non-weaving cars, so the effect of weaving flow rate on capacity is nonlinear.

3. OBSERVED CAPACITY OF WEAVING SECTIONS

One of the important parts of the study on capacity of weaving sections is a literature search on reported capacities in different parts of the world. On the total of 160 selected documents on capacity, only a few deal with the capacity of weaving sections. There were a few difficulties in comparing reported capacity values:

- lay-out of weaving sections differs from one country to another
- different values for passenger car units for trucks are used (and not always reported)
- a lot of effort is put into the assessment of weaving and non-weaving speed. In these cases capacity can be determined by assuming a certain critical speed.
- reported capacity values are based on various aggregation periods. Periods of 5, 15, 30 and 60 minutes are used
- length and traffic flow rates are different for every weaving section.

Because of differences in lay-out an international comparison of weaving capacities is based on the number of lanes on the weaving section. Nakamura et al (1991) and Kuwahara et al (1991) report capacities of two- and three-lane weaving sections on the Tokyo Expressway. Skabardonis et al (1989) estimated weaving capacity by using results of a specially calibrated version of INTRAS. Other American results were reported by Cassidy et al (1990) for a 5-lane weaving section and Alexiadis et al (1993) for thee-lane weaving sections. From the Netherlands weaving section capacities are reported by Klein (1987), Vermijs (1991), Transpute (1993), Schuurman and Vermijs (1993) and Grontmij (1996). It concerned five four-lane and one three-lane weaving sections. *Figure 6* shows all capacity values found.

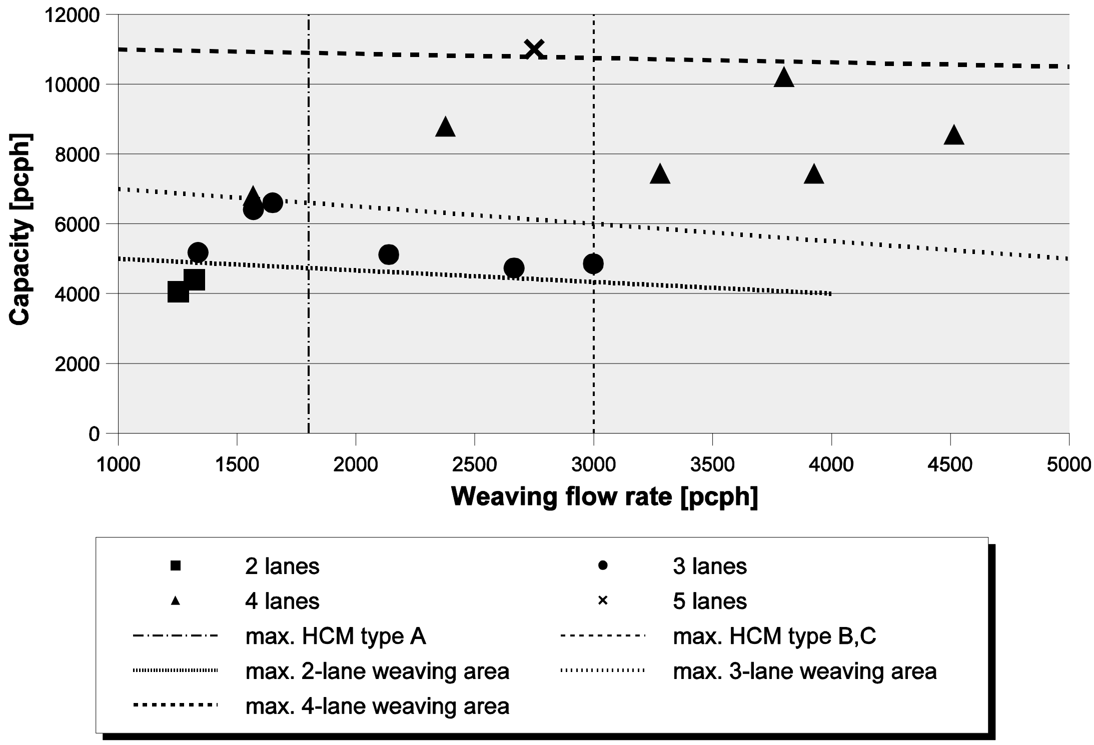

Fig. 6 - Observed weaving section capacities

Most capacity values are well within the range allowed for evaluation with the HCM method. Capacities found in The Netherlands in most cases relate to Type A weaving sections. Most of them have a 4-lane configuration (triagles in *Figure 6*). They have observed capacities at weaving volumes much higher than can be evaluated with the HCM (> 1800 pcuph), and the Dutch guidelines, which are a copy of the HCM on this point. The lines indicating maximum capacity values for weaving sections with a specific number of lanes are arbitrarily drawn in between the observed capacity values.

4. SIMULATION STUDY SETUP

4.1 The simulation tool

For useful guidelines the effects of the most important influencing factors on the capacity of weaving sections must be known. The HCM guidelines are largely based on empirical data gathered on the freeway network in the USA. The freeway network in The Netherlands is not extended enough to obtain a sufficient amount of empirical data to cover all aspects of weaving sections. The results of the literature search described in the previous section are too poor for a detailed description of weaving capacity. Therefore, a microscopic simulation model validated for Dutch freeways is used to provide sufficient data. This model FOSIM (Freeway Operations SIMulation,Vermijs 1992) has been tested and used for several research projects concerning capacity of freeway bottle-necks in The Netherlands since the early 90's (Vermijs 1991; Vermijs and Schuurman 1994). It was developed at the Transportation Research Laboratory of the Faculty of Civil Engineering at Delft University of Technology under sponsorship of the Dutch Ministry of Transport, Water Management and Public Works.

4.2 Weaving section configurations

In the simulation study for the first version of the Dutch Capacity Manual, the variety of configurations of weaving sections is limited to the symmetric ones, or Type A according to the HCM. This type of weaving section is most common in the Netherlands. *Figure 7* shows two examples of these symmetric weaving sections.

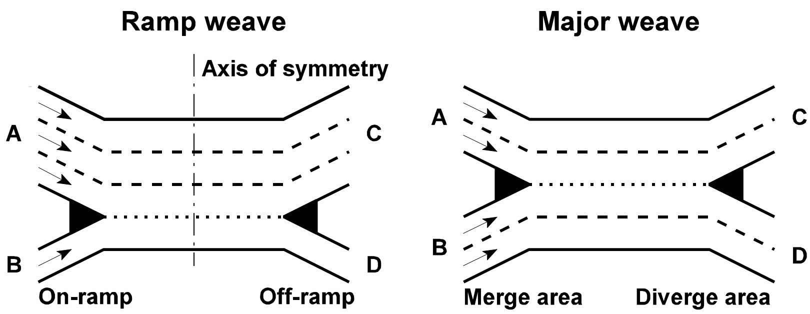

Fig. 7 - Two examples of type A weaving sections

In total 7 configurations were simulated: 4 ramp weave sections and 3 major weaving sections. They are shown in *Figure 8*.

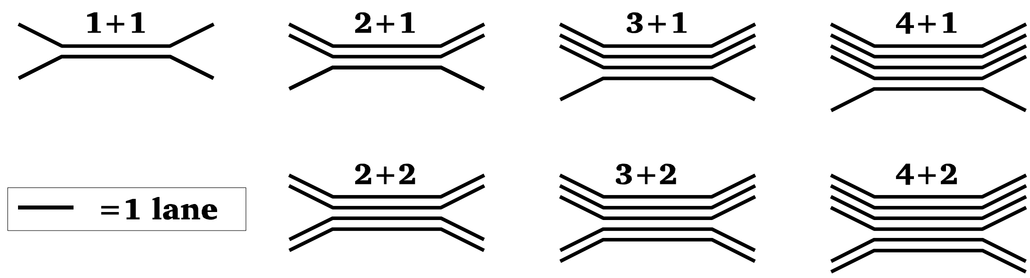

Fig. 8 - Weaving section configurations evaluated in the simulation study

4.3 Factors influencing weaving capacity

The influencing factors varied in the simulation study were weaving section length, origin-destination pattern (weaving flow rate) and truck percentage. *Table 1* contains all value ranges used. The values for weaving section length depend on the configuration and the lengths frequently used in the freeway network. In the Netherlands there are guidelines for minimum length of freeway sections. Within this length a driver driving at design speed must be able to resolve route information presented on information panels and have a good chance of reaching the destination lane. In *Table 1* the minimum length for every weaving section configuration is highlighted.

<table>
<tr><th>configuration</th><th>length [m]</th><th>% weaving cars in ramp flow</th><th>% trucks</th></tr>
<tr><td>1+1</td><td>100,200,300,400,500</td><td rowspan="4">50,75,100</td><td rowspan="7">5,10,15</td></tr>
<tr><td>2+1</td><td>200,300,400,500,600</td></tr>
<tr><td>3+1</td><td>200,300,400,500,600</td></tr>
<tr><td>4+1</td><td>200,300,400,500,600</td></tr>
<tr><td>2+2</td><td rowspan="3">400,500,600,800,1000</td><td rowspan="3">25,50,75</td></tr>
<tr><td>3+2</td></tr>
<tr><td>4+2</td></tr>
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= minimum length Lmin with regard to route information (at 120 km/h design speed)

Table 1 - Influencing factors for weaving capacity used in simulation

For the simulated traffic flows there are a few rules:

- The two weaving flows on the weaving section are kept equal at all times (R=0.5)
- The average flow rate per lane on all carriageways is the same
- Truck percentage is equal on all carriageways

Each weaving section configuration was simulated for three different weaving flow rates. To define these flow rates a percentage of the total ramp flow is designated for weaving. For a configuration with 4+1 lanes 100% weaving cars in the ramp flow means that the volume ratio VR = 200/500 = 0.40. For a configuration with 2+1 lanes 100% weaving cars in the ramp flow means VR = 200/300 = 0.67. The major weaving sections were simulated using smaller percentages of weaving cars than those of the ramp weaves because of the percentages found in practice. The combination of all influencing factors sums up to a total of 7*5*3*3=315 cases.

4.4 Simulated traffic composition and flow

Simulated cars and drivers are divided into five types of vehicle-driver-combinations. Three of them are passenger car types, two are trucks. The cars have attributes (length, desired speed, max. acceleration rate, etc.) that represent the average car population on Dutch freeways. On configurations with 1+1 lanes free speeds were suppressed to 60% of the normal level. These weaving sections are usually found in between clover leaves on which speeds are low.

During a simulation all ingoing flows on the weaving section are gradually increased. When congestion occurs on an upstream cross-section capacity has been reached. Volumes and speeds are aggregated for five minute periods.

FOSIM is a stochastic micro simulation model. Different seeds for the random generator lead to slightly different results. For every case 100 different seeds were used, leading to 100 capacity values.

5. SIMULATED CAPACITY OF WEAVING SECTIONS

5.1 General results

For every weaving section case described in the previous section a diagram is made with the cumulative frequencies of capacity values for three truck percentages (see *Figure 9*).

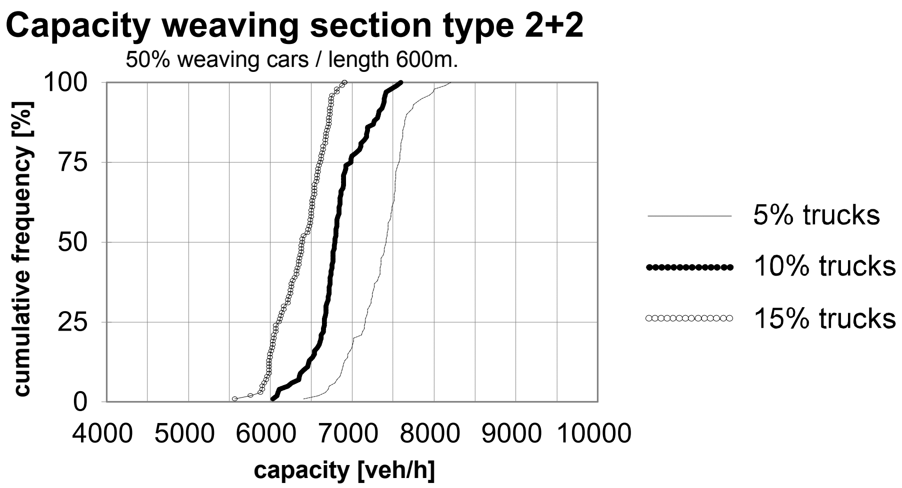

Fig. 9 - Cumulative frequency of capacity values for a simulated case

After having done several Kolmogorov-Smirnov tests on the simulated distributions, they all appear to be normal (for a 0.01 level of significance). Standard deviations were in the 200-400 vphpl range, except for weaving section types 1+1 (100-130 vphpl) and 4+1 (300-500 vphpl). The 315 median values of the distributions were used to make 21 diagrams for capacity as a function of weaving section length, as shown in *Figure 10*. These diagrams are comparable with the left diagram in figure 5.

Figure 10 clearly shows that the effect of weaving section length on capacity is small. This goes for all major weaving sections. It is caused by the fact that most weaving operation takes place in the first part of the weaving section. For the same reason the effect of length on capacity for ramp weaves is greater. The effect of the weaving flow rate on capacity is clear.

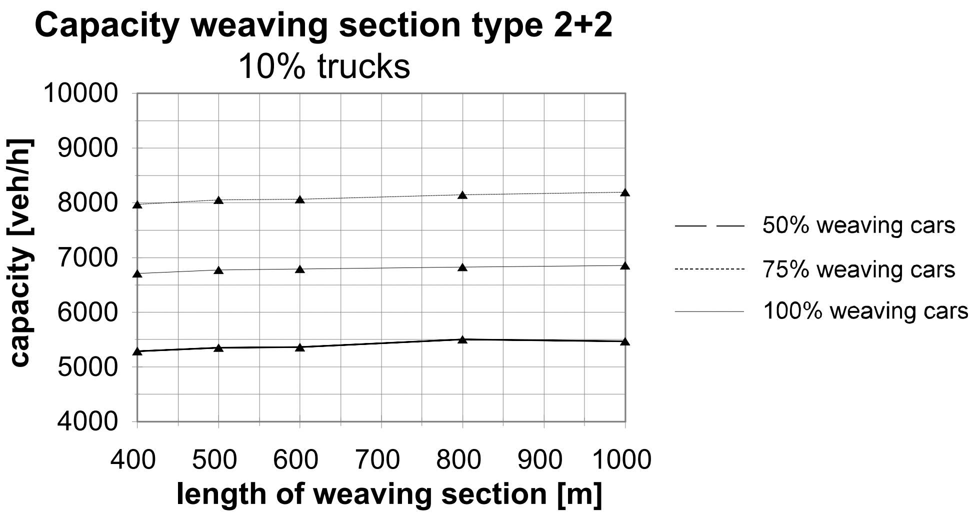

Fig. 10 - Capacity diagram for a 2+2 type weaving section

Percentages of weaving cars were transformed into weaving flow rates to be able to compare different weaving section types on the basis of a single diagram. For the length of each weaving section type, the minimal allowed length Lmin is used. The result is shown in *Figure 11*.

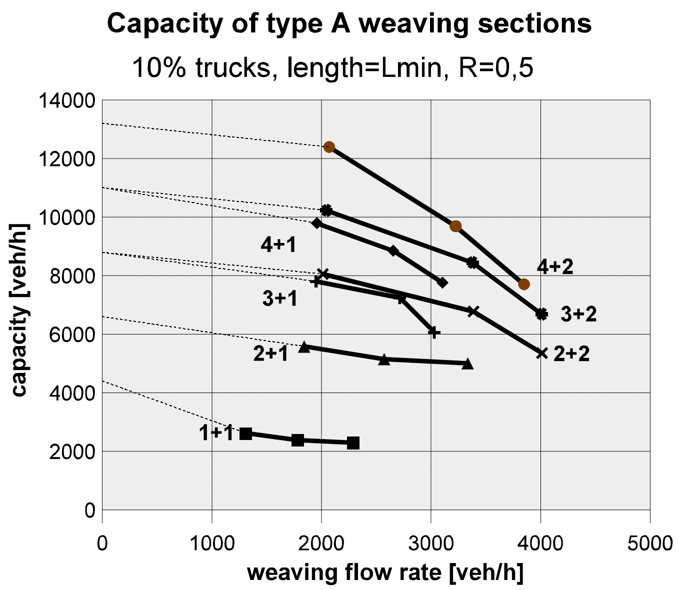

Fig. 11 - Capacity diagram for different weaving section types

The capacity values for zero weaving flow rates are based on an average lane capacity of 2200 vphpl for 10% trucks. Because of the suppressed free speeds the capacity values of the 1+1 type weaving section are relatively low. The marginal effect of weaving flow rate on capacity in case of 1+1 and 2+1 type weaving sections is not what we expected (see section 2 of this paper). The diagrams should have a form comparable with the right diagram in *Figure 5*. It might be caused by the fact that simulated flow rate is lower than anticipated due to cars that cannot make a necessary lane change in time to reach their destination lane. There will be some further research on this point. Where the diagram of *Figure 11* can be used to get a quick insight in the capacity of a specific weaving section, the capacity diagram of *Figure 10* gives a more accurate account of the capacity of the weaving section under consideration. Both types of diagrams are presented in the new guidelines.

5.2 Pcu values for trucks

If we use a fixed value for the number of passenger car units for trucks, the capacity diagrams for different truck percentages shown in *Figure 10* (and 11) should coincide. For every weaving section configuration a pcu value was estimated by trying to get the best match in diagrams for different truck percentages. *Figure 12* shows an example for a 2+2 type weaving section. The pcu values used in Dutch guidelines for 0% grade are 1.5 for light trucks and 2.0 for heavy trucks. With an equal share of both light and heavy trucks the resulting pcu of 1.75 leads to a diagram also shown in *Figure 12*. *Table 2* contains all estimated pcu-values.

configuration	1+1	2+1	3+1	4+1	2+2	3+2	4+2
pcu for trucks	2.5	3.1	3.2	3.6	2.7	2.8	2.9

Table 2 - Estimated pcu values for weaving sections

It is clear that the pcu estimations lead to different results and the values found are much higher than 1.75. Research by Dijker et al (1997) resulted in a pcu value for trucks under non-congested conditions of about 2.5. The trucks used in the simulation study have an average pcu value of 2.25 at capacity. Yet, the estimated pcu values are higher than 2.5. Apparently the influence of trucks on capacity in case of weaving sections is greater than under normal car-following conditions. This can be explained by the limited manoeuverability of trucks in comparison to passenger cars.

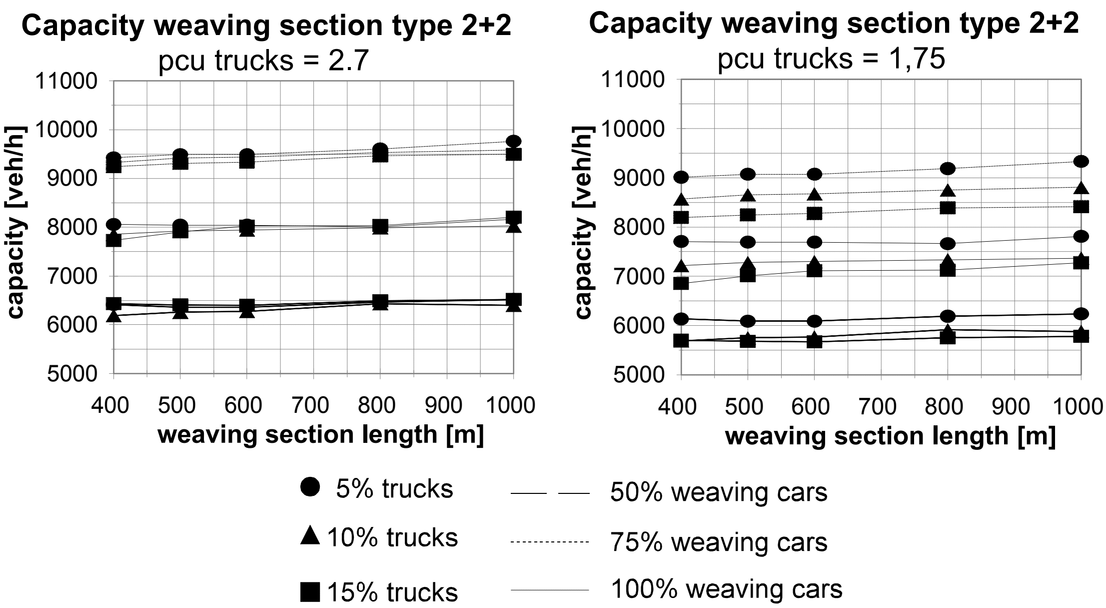

Fig. 12 - Capacity diagrams with estimated and standard pcu values for trucks for different truck percentages

6. CONCLUSIONS

On measured capacity of weaving sections

It is difficult to make an international comparison on weaving capacity. Reported capacities relate to different weaving section lay-out, various aggregation periods and pcu 's for trucks. Measured capacities for weaving sections in The Netherlands are often higher than the range allowed according to the present guidelines.

On simulated capacity of weaving sections

- Capacity obtained from FOSIM simulations has a normal distribution.
- Weaving capacity declines with increasing truck percentage and increasing weaving flow rate.
- Weaving section length has little influence on capacity when lengths used in practice are considered.
- Estimated pcu values for trucks are not the same for different weaving section types.
- The capacity diagrams for weaving sections suggested for the new Capacity Manual for The Netherlands enable a quick insight in the capacity of a specific configuration. They can be used for simple weaving sections only.

Recommendations

- Extra simulation research is needed to cover all aspects of weaving section capacity.
- Instead of using pcu's for trucks it is better to use vehicles and truck percentage when capacity of weaving sections is the issue.

Acknowledgment

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