

The capacity of asymmetrical weaving sections

TRB Paper #03-3066

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submission date
7/31/2002

word count
total number of words: 5999 (abstract: 132)
number of figures & tables: 6
total: 5999 + 6.250 = 7499

ABSTRACT

The Dutch capacity manual for freeways has been extended with, amongst others, capacity values for asymmetrical weaving sections. This paper presents these capacity values, which were estimated through simulation. Capacities were determined for 10 weaving section configurations, 5 weaving section lengths, 4 percentages of trucks, and 4 percentages of weaving traffic, using symmetrical OD patterns. It was found that weaving section length had limited influence on capacity, mainly because the minimum lengths are already considerable. The percentage of trucks and the weaving flow rate were of more importance: as expected, capacity decreased with truck percentage and weaving flow rate. Sensitivity analyses showed that for non-symmetrical OD patterns quite different capacity values resulted than for the symmetrical OD patterns. Consequently, in the future additional simulations with different OD patterns may be required.

KEYWORDS

Weaving, capacity, traffic operations

INTRODUCTION

Traditionally, Dutch traffic engineers to a large extent relied on foreign manuals for highway capacity. For instance, the Dutch design guidelines for freeways (1) contain the 1985 HCM (2) method to determine the Level of Service on weaving sections. There are, however, significant differences between both highway design and traffic characteristics in The Netherlands and other countries. Consequently, the Transport Research Center of the Dutch Ministry of Transport, Public Works and Water Management decided to develop a capacity manual specifically aimed at Dutch freeways, which was published in 1999 (3). Because not all relevant freeway segments were covered in this manual, an extended version was published in 2002 (4), that included the capacity of asymmetrical weaving sections. The study that was carried out to estimate the capacity for this type of weaving section is presented in this paper.

The first section of the paper describes asymmetrical weaving sections and the traffic operations that can be expected on these. This is followed by a discussion of the method that was used to estimate capacity. In this case, capacities were determined through simulation. The applied simulation model is described together with the simulation study setup. The estimated capacity values are then presented and analyzed in detail, and conclusions are drawn.

TRAFFIC OPERATIONS ON ASYMMETRICAL WEAVING SECTIONS

Classification of weaving sections

At weaving sections a merge area is closely followed by a diverge area, as a result of which traffic streams have to cross each other within a limited amount of space (5). Several types of weaving sections can be distinguished. For the Dutch capacity manual a distinction is made between *symmetrical* and *asymmetrical* weaving sections. In the case of symmetrical weaving sections there is symmetry around the center of the weaving section, in the case of asymmetrical weaving sections there is not (see Figure 1).

The subdivision in symmetrical and asymmetrical types is quite similar to the subdivision used by the HCM, which distinguishes weaving configurations of type A, B, and C according to the number of required lane changes. Symmetrical weaving sections always correspond to type A, while asymmetrical weaving sections belong to type B or C. This means that the HCM's subdivision is somewhat more detailed, but the reason for the subdivision is the same for both manuals: the traffic operations are different for the distinguished types.

Factors that influence traffic operations

Traffic operations are determined by road design and traffic characteristics. Elements of road design specific for asymmetrical weaving sections with important impacts on traffic flow are weaving section configuration and weaving section length. Of course, other, general, design elements, such as lane width, lateral clearance, curvature, grade, and the application of ITS measures, can also be relevant, but they were not included in this study. The most important traffic characteristics that influence traffic operations are traffic composition and the origin-destination pattern (OD pattern).

The configurations that are allowed in The Netherlands can be fully described by the number of lanes on the entry legs and exit legs and the presence of tapered lanes. To illustrate this, Figure 1 schematically shows all configurations that were considered in this study. For example, the first of the ten configurations in Figure 1 can be described as a $2+1 \rightarrow 1+2$ weaving section, with a two lane and single lane entry leg and a single lane and two lane exit leg. The fourth configuration includes a tapered lane on the right entry leg. The configuration is denoted as a $2+2(\text{taper}) \rightarrow 2+1$ weaving section.

Weaving section length is defined as the distance between the entry and exit gore. The minimum length of each configuration follows from the Dutch guidelines for guide signs (6). These guidelines lead to a minimum length of 600 m for a $2+1 \rightarrow 2+2(\text{taper})$ weaving section up to 1300 m for a $4+1 \rightarrow 3+2$ weaving section. For long weaving sections it is questionable if the section should be considered a single discontinuity or a succession of a separate merge and diverge area. For instance, the HCM procedures for weaving apply to weaving segments up to 750 m long (5).

With regard to traffic composition the most important distinction is between passenger cars and trucks because the differences between these two categories are most pronounced: trucks occupy more space than passenger cars, they have more difficulty maneuvering (changing lanes, accelerating), and the speed limit for trucks is only 80 km/h, compared to 120 or, on some parts of the Dutch freeway network, 100 km/h for passenger cars. Most trucks in The Netherlands are equipped with speed limiters to prevent them from exceeding the speed limit by too much, but, still, the observed range of truck speeds tends to be rather large.

The OD pattern specifies the volumes traveling between the origins A and B, and the destinations C and D (see Figure 1). For weaving sections the OD pattern is commonly described with (5):

- the total flow rate in the weaving segment v ,
- the weaving flow rate $vw = vw_1 + vw_2$, with vw_1 for the larger and vw_2 for the smaller of the weaving flows,
- the volume ratio $VR = vw/v$,
- the weaving ratio $R = vw_2/vw$.

Relations between factors of influence and traffic operations

Traffic operations on (asymmetrical) weaving sections are to a large extent determined by the way traffic distributes itself over the available lanes. The way this happens strongly depends on the weaving section's configuration in combination with the OD pattern. Problems occur when:

- the capacity of one of the legs is not sufficient,
- lane changes (locally) lead to densities high enough to cause breakdown,
- weaving is hampered because there are too many vehicles in the two lanes adjacent to the merge gore and speeds decrease. When speeds go down, weaving may become even more difficult because on average following distances then also decrease (see (7) for a more elaborate discussion).

Symmetrical weaving sections can only function as bottlenecks when there is weaving traffic. Further, with increasing weaving traffic, the capacity of symmetrical weaving sections decreases. In contrast, most asymmetrical weaving sections can reach capacity without weaving traffic. For instance, if there is no weaving traffic at a $2+1 \rightarrow 1+2$ weaving section, the capacity of the single lane exit leg can be insufficient while the traffic in the two lane exit leg experiences a high level of service. Probably, somewhere between an OD pattern without weaving traffic and an 'asymmetrical' OD pattern that exactly fits the weaving section's lane configuration, there exists an OD pattern with which the weaving section can reach its highest capacity.

The influence of weaving length is most significant when the available space and time to change lanes is smaller than drivers would use without a weaving length restriction. It can be expected that for short weaving sections length is an important factor and that with increasing length the influence becomes less important. For symmetrical weaving sections, for instance, it was found that most lane changes take place within the first 350 m (7).

Vermijs (7) showed that the influence of traffic composition on the capacity of symmetrical weaving sections cannot be taken into account by the application of a fixed passenger car unit (pcu) value for all situations: the pcu value varied between weaving section configurations. The pcu value is related to the limited maneuverability of trucks, the influence of which is even more prominent during congested conditions because their maneuverability deteriorates at low speeds.

ESTIMATION OF CAPACITY

Definition of capacity

The way capacity should be estimated is related to the definition of capacity that is used. The following definition was derived from the Dutch capacity manual (3): *'capacity is the median of the distribution of the maximum flow rate at which vehicles can traverse a road segment during a five minute period under given roadway, geometric, traffic, environmental, and control conditions.'* The applied estimation method for asymmetrical weaving sections, which is described in the next section, complies with this definition.

The median of the distribution is required by the Dutch design methodology that belongs to the long-term transportation policies in The Netherlands (8) that existed when the study was carried out. In short, this methodology assumes certain variations in capacity and daily traffic volume patterns, both estimated from practice, and uses a queuing model to forecast the average percentage of drivers that is expected to experience congestion on working days (9). This percentage should not exceed the maximum values specified by the Ministry (8). It is noted that the methodology does not make a distinction between capacity and queue discharge rate, and that new long-term policies are under development.

Estimation method

Capacity estimation through simulation

As was done for symmetrical weaving sections (7), a traffic simulation model was used to estimate the capacity of asymmetrical weaving sections. It might seem that this approach is fundamentally different from the other

available option, that is, measure capacities directly in the field, but, in fact, both approaches are eventually based on empirical data. While the field study approach uses empirical data to estimate capacity itself, the model approach may not involve field data to estimate capacity, but empirical data do play a crucial role in model development. Further, when the field study approach is used, this does not mean that the empirical data themselves can be included in a capacity manual. Instead, the data have to be analyzed to derive capacity values that can be generally recommended. It could be said that in case of the field study approach this analysis is performed after the measurement of the capacities, and that in case of the model approach the analysis has already been performed during the model development. In the end, of course, the essential prerequisite to apply the model approach is the availability of a suitable, valid, model. For Dutch freeways the model FOSIM (10, 11) is suited.

The microscopic simulation model FOSIM was specifically developed to analyze bottlenecks on Dutch freeways. The model is property of the Transport Research Center of the Dutch Ministry of Transport, Public Works and Water Management and is maintained and developed by the Transportation Research Laboratory of the Delft University of Technology. It has been validated for a wide variety of freeway segments (see, for instance, (12, 13)), and is frequently used by Dutch highway designers. The model was previously regarded sufficiently valid to be used to estimate capacities of symmetrical weaving sections for the Dutch capacity manual (3). Although FOSIM is also considered valid for other types of bottlenecks, it was decided to carry out a validation study specifically for asymmetrical weaving sections (14).

The traffic operations on a 2+2→3+1 weaving section at the A12 freeway near The Hague were simulated with FOSIM and compared with real observations, collected with double induction loops and video equipment. The weaving section (see Figure 2) was rather complex: an on-ramp was located just upstream of the weaving section on one of the entry legs, and downstream of the single lane exit leg there was a signalized intersection that was frequently oversaturated during short periods of time. The resulting queues sometimes reached the freeway and affected the traffic on the weaving section.

Several traffic flow characteristics were compared:

- capacity: the median of the capacity distribution calculated with FOSIM equaled 7200 veh/h, while observations from the A12 site indicated a value of 7225 veh/h,
- fundamental diagrams: the results from simulation and real observations were reasonably similar. Speed-flow diagrams indicated somewhat higher speeds in FOSIM than in reality, but these differences may, at least partly, be explained with systematic measurement errors and driver reactions on information from dynamic speed control panels, which are not represented in the model,
- breakdown location: both in the simulations and in reality breakdown started at two locations at approximately the same time: just downstream of the merge gore and somewhat further downstream in the lane leading to the single lane exit leg,
- distribution of the vehicles over the lanes: in FOSIM relatively more vehicles used the median lane on the weaving section than in reality, but the difference was limited,
- distribution of lane changes over the weaving section's length: because the available lane change data from the A12 were somewhat unsuited, only a crude comparison between simulation and reality could be made. The comparison indicated that in FOSIM more vehicles change lanes at the beginning of the weaving section. It is known from experience with the model that some refinement of the input can alleviate this difference with reality, but because this refinement has no influence on capacity, it is normally not used in practice and was also left out in the validation study.

Overall, the resemblance between simulation and reality was judged satisfactory. It might, nevertheless, be argued that only a single weaving section configuration was analyzed and that, consequently, FOSIM can only be used for this configuration. However, because the model performed well for a rather complex situation and because of the existing confidence in the model due to earlier validation efforts, the model was deemed generally valid for all configurations that were to be included in the update of the capacity manual.

Capacity estimation with the model FOSIM

To estimate capacity with FOSIM, the flow rate in the simulation is slowly increased until traffic flow breaks down. When this happens, capacity must have been reached and the maximum flow rate during a five minute aggregation interval, as required by the definition of capacity, in the simulation is used as an estimate for capacity. Series of simulations, each with a different seed for the model's random generator, are performed to obtain capacity distributions. The median of each distribution is used as the capacity of the simulated road section under the given traffic conditions (traffic composition and OD pattern) and under base conditions.

The method requires two cross sections where traffic is monitored: one just downstream of the bottleneck to measure the highest throughput and one just upstream to determine whether breakdown has

occurred. It is important to measure the highest throughput rather quickly after the onset of congestion: at asymmetrical weaving sections with limited numbers of weaving vehicles typically not the whole carriageway is immediately affected when breakdown occurs which means that the flow rate can still increase after capacity is reached, but then the OD pattern changes accordingly.

Simulation setup

Capacities were estimated for 10 weaving section configurations (see Figure 1). Their geometries were derived from the Dutch design guidelines for freeways (1) and the Dutch guidelines for guide signs (6). Only major weaving sections were studied, that is, none of the legs were on-ramps or off-ramps. For each configuration 5 weaving section lengths were considered (see Figure 1): the minimum length according to the guidelines (L2), one shorter length (L1), and three longer lengths (L3 up to L5). The weaving sections were often so long that they may rather function as separate merge and diverge areas than as single weaving sections. Because FOSIM requires that the areas where drivers have to change lanes to reach their destinations are explicitly specified, the consequences of weaving section length on lane changing behavior were considered when the input for the simulations was prepared. In essence, it was assumed that in every case as soon as drivers arrive at the weaving section they start looking for a suitable gap. On longer weaving sections, however, the risk these drivers are willing to take when they change lanes increases slower with the distance traveled on the weaving section than on shorter weaving sections. Further, it was assumed for shorter weaving sections that more drivers already make anticipatory lane changes before they reach the weaving section than for longer weaving sections.

The proportion of trucks in the simulations equaled 5, 10, 15, or 20%. The desired speeds of the vehicle types were set to represent traffic on a freeway with a speed limit of 120 km/h. During the simulations the flow rates increased in 90 minutes from half the approximately maximum flow rate the entry legs could provide to the maximum flow rate. The ratios of the flow rates on the two entry legs corresponded with the ratios of the number of lanes of each leg.

As was previously done for symmetrical weaving sections (7), symmetrical OD patterns were used, that is, the number of weaving vehicles from both entry legs was equal (weaving ratio $R=0.5$). The percentage of weaving vehicles in the minor stream, further to be called 'percentage of weaving traffic', was then used to define the number of weaving vehicles. Suppose, for example, that the percentage of weaving traffic equals 75% for a $2+1 \rightarrow 1+2$ weaving section. For this configuration the ratio of the flow rates in the entry legs equals 2:1. Because 75% of the flow rate from the single lane entry leg has to weave, this means that 37.5% of the vehicles from the two lane entry leg has to weave. Consequently, the volume ratio equals 37.5%. For each weaving section configuration simulations were run for 25, 50, 75 and 100% of weaving traffic.

To obtain capacity distributions, 100 simulations were carried out for each combination of weaving section configuration, weaving section length, traffic composition, and OD pattern (percentage of weaving traffic). This means that a total of 80,000 simulations was run. Further, simulations were performed to assess the sensitivity of the results to the inputs used. This was firstly done because a part of the input for the model was based on assumptions. Specifically, the lengths of the previously described lane change areas were varied to study the consequences for the simulated traffic operations. Secondly, the capacity manual has to define within which margins of the input values the capacity estimates can be used. It was examined whether the simulation results are also valid for freeways with a lower speed limit, namely, 100 km/h, and for OD patterns that differ to a certain extent from the symmetrical OD patterns used in the simulations.

ESTIMATED CAPACITY VALUES

All estimated capacity values are shown in Figures 3 - 6. Each figure presents the results for a different proportion of trucks. The capacity values are plotted as a function of weaving section configuration, weaving section length, and weaving flow rate. Capacity is shown on the vertical axis and weaving flow rate is shown on the horizontal axis. Weaving flow rate is used instead of percentage of weaving traffic to better enable comparison of different weaving section configurations. Texts in the graphs identify the weaving section configurations to which the capacity values belong. When capacity values for different weaving section configurations overlap, different line types are used to differentiate between these configurations. Markers identify the weaving section lengths. Because the lengths differ between the weaving section configurations, they are indicated by the cardinal variables L1-L5. Figure 1 presents the actual lengths that belong to these variables.

In some cases congestion did not occur in each (or any) of the 100 simulation runs (with different random seeds). In other words, the generated flow rates were not always sufficient to reach capacity. In those cases, a lower bound for capacity might sometimes still be given, but in the four figures such values are left out. Specifically, there are missing capacity values for the $2+1 \rightarrow 2+2$, $2+1 \rightarrow 2+2$ (taper), and $4+1 \rightarrow 3+2$ weaving

sections. For the first two configurations it is not surprising that capacity was not always reached: the number of lanes on the exit legs is larger than the number of lanes on the entry legs. When flow did break down in these weaving sections, this was due to local high densities which occurred because in order to change lanes drivers have to use certain specific lanes on the weaving section. In the third case, at first it does seem awkward that capacity was not always reached, but this can be understood when the applied OD pattern is considered. The entry legs consist of a single lane and a four lane carriageway, thus, according to the simulation setup, the ratio between the flow rates in the two legs equaled 4:1. Because for high percentages of trucks the maximum flow rate that can be generated is especially low for single lane carriageways, according to this ratio the maximum generated flow rate for the four lane entry leg is also rather small compared to the flow rates that four lane carriageways can accommodate. As a consequence, the total flow rate frequently proved too limited to cause breakdown for small amounts of weaving traffic. Of course, if the flow rate from the four lane entry leg were increased further, capacity would be reached, but then the OD pattern would not conform to the pattern specified in the study setup.

ANALYSIS OF THE CAPACITY VALUES

Only symmetrical OD patterns were considered. This means that the number of vehicles that was generated on entry leg A (see Figure 1) equaled the number of vehicles that was destined for exit leg C, and that the same was true for entry leg B and exit leg D. For most asymmetrical weaving sections, however, the number of lanes at the corresponding entry and exit legs are not equal. Irrespective of the size of the weaving flow rate, this means that in those cases one of the exit legs cannot cope with the amount of traffic that can be generated at the entry legs. It could be said that the applied OD patterns are rather adverse for the performance of asymmetrical weaving sections.

The graphs show that capacity decreases when the amount of weaving traffic increases. There are several, not entirely obvious, explanations for this relationship:

- before drivers reach the weaving section they may already make anticipatory lane changes. This has consequences for the distribution of vehicles over the lanes: the lanes from the two entry legs that lie next to each other on the weaving section are already used more intensely upstream of the weaving section. When the percentage of weaving traffic is high, the number of vehicles in these lanes can be large enough to reduce vehicles' speeds before they have reached the weaving section, or even to lead to breakdown. In the simulations that were carried out, though, the flow rates and OD patterns were such that breakdown always initiated on the weaving section itself. In any case, when speeds are already considerably reduced when the vehicles enter the weaving section, the capacity of the weaving section can suffer,
- on the weaving section the number of vehicles in the two lanes adjacent to the merge gore increases with the percentage of weaving traffic, as a consequence of the anticipatory lane changes described previously. When the number of vehicles in these lanes is too high, weaving becomes increasingly difficult and speeds decrease. With higher percentages of weaving traffic, this already happens at lower flow rates (measured over the whole carriageway). Breakdown does, however, at least in the cases that were simulated, not initiate at the beginning of the weaving section, but further downstream in the lanes that lead to the exit leg with insufficient capacity. The decrease of speed due to weaving, however, does influence capacity negatively,
- on single lane entry legs passenger cars may be held up by trucks. As a consequence, clusters of vehicles arrive at the weaving section. When many vehicles in these clusters have to weave, temporarily high densities may occur in the lane to which these drivers have to merge to reach their destination and speeds in this lane can decrease strongly. When enough traffic arrives at the weaving section, such a temporary breakdown may become permanent because, at least in the simulations, after traffic has become congested the maximum flow rate the weaving section can accommodate is somewhat lower than before. This capacity drop is, for instance, due to heavy vehicles that have difficulties accelerating at low speeds. It is noted that such a difference between capacity and queue discharge rate is not taken into account by the methodology for which the capacity values were estimated,
- when the rightmost exit leg consists of more than one lane, weaving traffic enters the lanes leading to this leg via the median lane. This means that this lane is temporarily occupied by heavy vehicles and other slower vehicles which normally drive in the shoulder lane. This has negative consequences for the capacity of this lane.

The relevance of these explanations may differ between weaving section configurations. Further, several explanations may be valid at the same time.

As expected, weaving sections that consisted of more lanes could facilitate more traffic. It was further found that different capacities result for weaving sections with the same total number of lanes but with different

configurations. This is related to the symmetrical OD patterns that were used. For instance, compare the $4+1 \rightarrow 3+2$ configuration with the $3+2 \rightarrow 4+1$ configuration. In the case of a $3+2 \rightarrow 4+1$ weaving section the number of vehicles generated on the two lane entry leg (origin B) is destined for the single lane exit leg (destination D). This means that when breakdown occurs, the flow rate from the two lane entry leg is still quite limited compared to the flow rate it can accommodate. In contrast, in the case of a $4+1 \rightarrow 3+2$ weaving section, when congestion starts, the flow rate from the four lane entry leg is relatively closer to the maximum this leg can cope with.

The results show that weaving length in most cases has only limited effect on capacity. This was expected because in general the minimum weaving length was already considerable. A more substantial effect sometimes did occur for high percentages of weaving traffic, in which cases capacity sometimes increased significantly with weaving length. This can be explained by the fact that with higher percentages of weaving traffic weaving becomes more difficult and, consequently, requires more weaving length. Further, in the simulations when the weaving length is longer, the risk drivers are willing to take when they change lanes increases somewhat slower with the distance traveled on the weaving section.

As was done by Vermijs (7), pcu values were estimated to assess the influence of the percentage of trucks on capacity. For each weaving section configuration a pcu value was chosen in such a way that for every truck percentage and percentage of weaving traffic the estimated capacities in pcu/h matched. Although the capacities did not always show satisfactory agreement, pcu values appeared to lie between 2.4 and 2.8. This variation of pcu values is smaller than the variation that was found for symmetrical weaving sections (7), but, still, it seems better to use capacity values that are specifically estimated for a certain percentage of trucks than capacities expressed with pcu values.

It is often assumed that capacity distributions are Gaussian. The Anderson-Darling test at a 5% significance level showed that the distributions that resulted from the simulations were indeed generally Gaussian, that is, in approximately 90% of the cases, except for the $2+2(\text{taper}) \rightarrow 2+1$, $2+1 \rightarrow 2+2(\text{taper})$, and $2+1 \rightarrow 2+2$ weaving sections, in which cases only about 50% of the capacity distributions were Gaussian. The coefficient of variation of the capacities lay between 3 and 6%, except for, again, the $2+2(\text{taper}) \rightarrow 2+1$, $2+1 \rightarrow 2+2(\text{taper})$, and $2+1 \rightarrow 2+2$ weaving sections, for which the coefficient of variation rather lay between 5 and 10%. It is noted that in reality larger variations can be expected, because simulation does not take into account all influences on capacity.

The capacity values in the Dutch capacity manual are based on five minute aggregation intervals. In contrast, the HCM uses 15-min capacity values. To assess the consequences of this difference, additional simulations were run for 1-, 10-, and 15-min aggregation intervals. As expected, 1-min capacities were considerably higher than 5-min values. This is mainly related to the effect of temporal fluctuations of flow due to chance when 1-min capacities are determined. Such fluctuations play a far less important role for the other three interval lengths. In fact, 5-min capacities and 10- and 15-min values were generally rather similar: between 5-min and 15-min values mostly differences between 1 and 6% were found. The differences that still existed can be explained by the fact that during the simulations the flow rate that was generated increased in time. Apparently, 5-min aggregation intervals are, at least in the simulations that were carried out, sufficient to obtain sustainable capacities. Keller (15), although for two-lane highways and following a different approach, found similar results with empirical data.

The first part of the sensitivity analysis concerned the sensitivity of the results to the assumptions that lay behind the input, specifically, the lengths of the lane change areas. It was found that the results were robust for reasonable variations of the lengths of these areas. The second part determined within which margins of the input the results can be used. The analysis showed that the results are valid for both freeways with 120 km/h and 100 km/h speed limits. The results do, however, appear rather sensitive to the applied OD matrix. Consequently, the new capacity manual will recommend the capacity tables to be used only if the OD pattern in reality conforms closely with the symmetrical OD patterns applied in the simulations.

Because traffic operations are determined by a complex combination of highway design, driver behavior, and vehicle characteristics, it is difficult to assess exactly to what extent the capacities from this study can be used outside The Netherlands. A comparison of the procedures for weaving sections in the HCM and the Dutch guidelines contained in (16), and a short overview of capacities observed in reality (7), may, however, clarify this issue to a certain extent.

CONCLUSIONS

Capacity values for asymmetrical weaving sections were estimated through simulation for an update of the Dutch capacity manual for freeways. Simulation was used because of the availability of a model that takes into account the most important influences on capacity and that is valid for asymmetrical weaving sections. Capacities are now available for 800 combinations of weaving section configuration, weaving section length,

percentage of trucks, and percentage of weaving traffic. From these, the influence of weaving section length was rather limited, mainly because the minimum lengths were already considerable. The percentage of trucks had a more important effect on capacity, which could not satisfactorily be described with a single pcu value. This study only considered symmetrical OD patterns, and it was found, as expected, although the underlying reasons are rather complex, that capacity decreased with increasing weaving flow rate. Sensitivity analyses indicated that when the OD pattern does not correspond rather closely to the symmetrical type used in the simulations, the results from this study cannot be used. This means that in the future probably additional research is required for non-symmetrical OD patterns.

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LIST OF TABLES AND FIGURES

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FIGURE 2 Schematic representation (each line represents one lane) of the weaving section at the A12 freeway

FIGURE 3 Capacity values for traffic streams with 5% of trucks; L1-L5 refer to Figure 1

FIGURE 4 Capacity values for traffic streams with 10% of trucks; L1-L5 refer to Figure 1

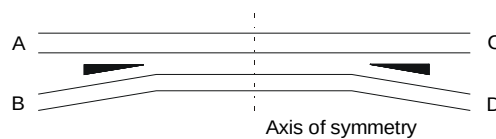
FIGURE 5 Capacity values for traffic streams with 15% of trucks; L1-L5 refer to Figure 1

FIGURE 6 Capacity values for traffic streams with 20% of trucks; L1-L5 refer to Figure 1

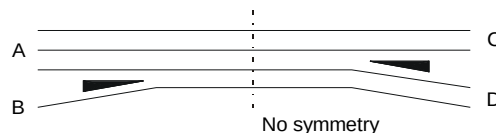
FIGURES

Classification of weaving sections:

Symmetrical weaving section:



Asymmetrical weaving section:



Weaving section configuration	Description	Length				
		L1	L2	L3	L4	L5
	2+1 → 1+2	800	<u>1000</u>	1100	1200	1300
	1+2 → 2+1	600	<u>700</u>	800	900	1000
	2+1 → 2+2	700	<u>800</u>	900	1000	1100
	2+1 → 2+2 (taper)	500	<u>600</u>	700	800	900
	2+2 (taper) → 2+1	650	<u>750</u>	850	950	1050
	3+1 → 2+2	800	<u>1000</u>	1100	1200	1300
	2+2 → 3+1	650	<u>750</u>	850	950	1050
	3+2 → 4+1	800	<u>1000</u>	1100	1200	1300
	4+1 → 3+2	1100	<u>1300</u>	1400	1500	1600
	2+3 → 3+2	800	<u>1000</u>	1100	1200	1300

FIGURE 1 Overview of asymmetrical weaving sections; each line represents one lane; traffic direction: from left to right

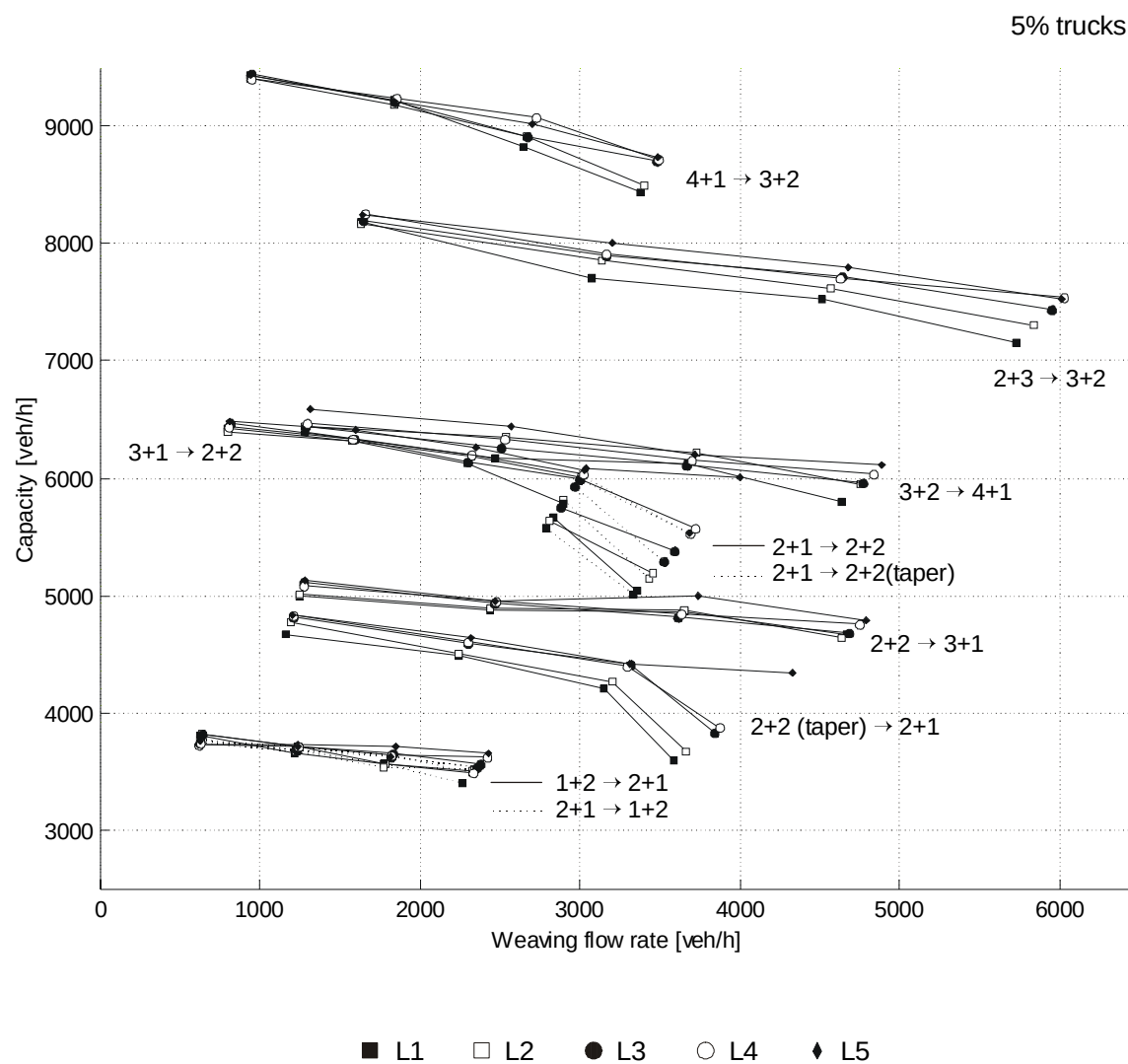


FIGURE 3 Capacity values for traffic streams with 5% of trucks; L1-L5 refer to Figure 1

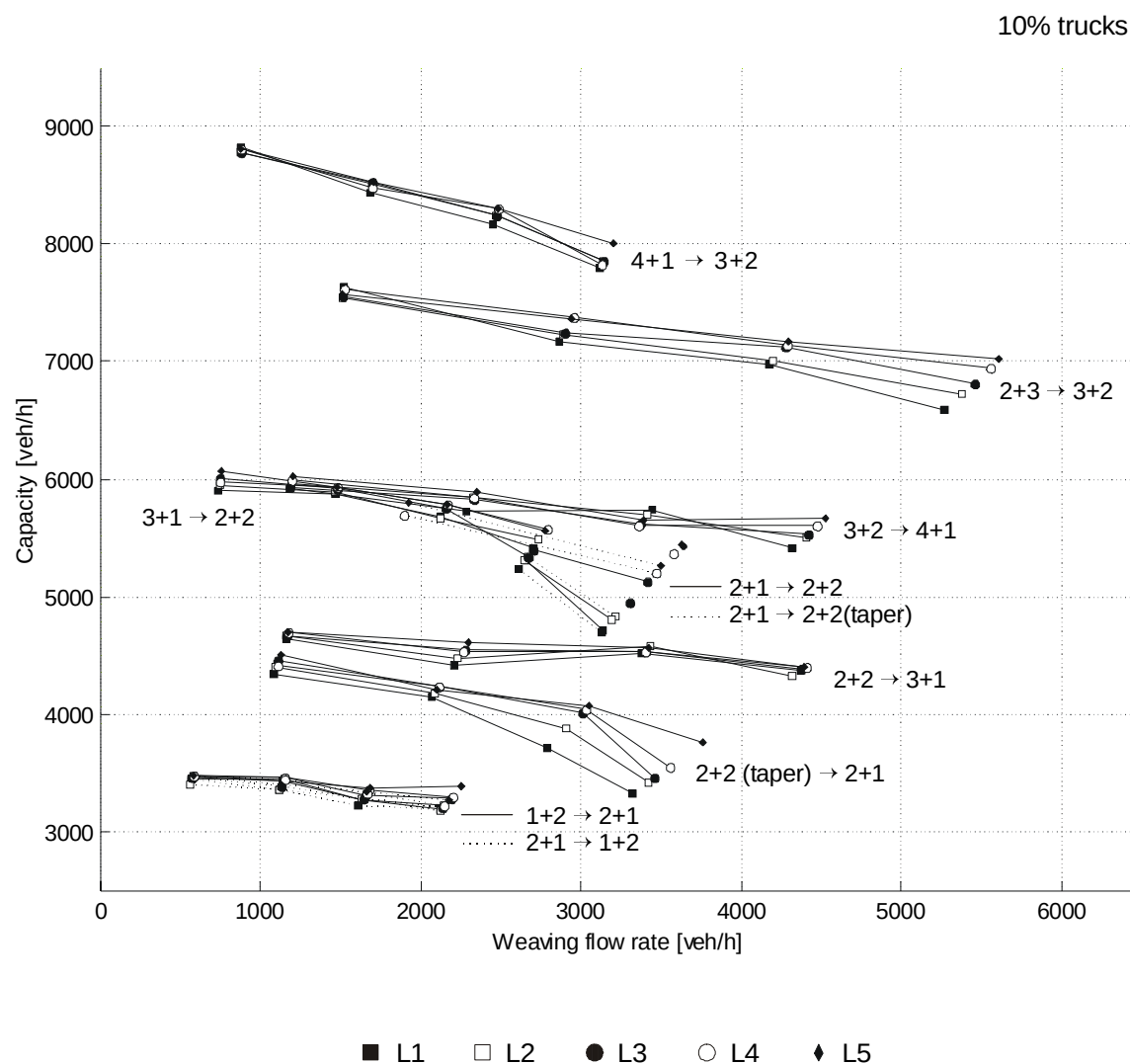


FIGURE 4 Capacity values for traffic streams with 10% of trucks; L1-L5 refer to Figure 1

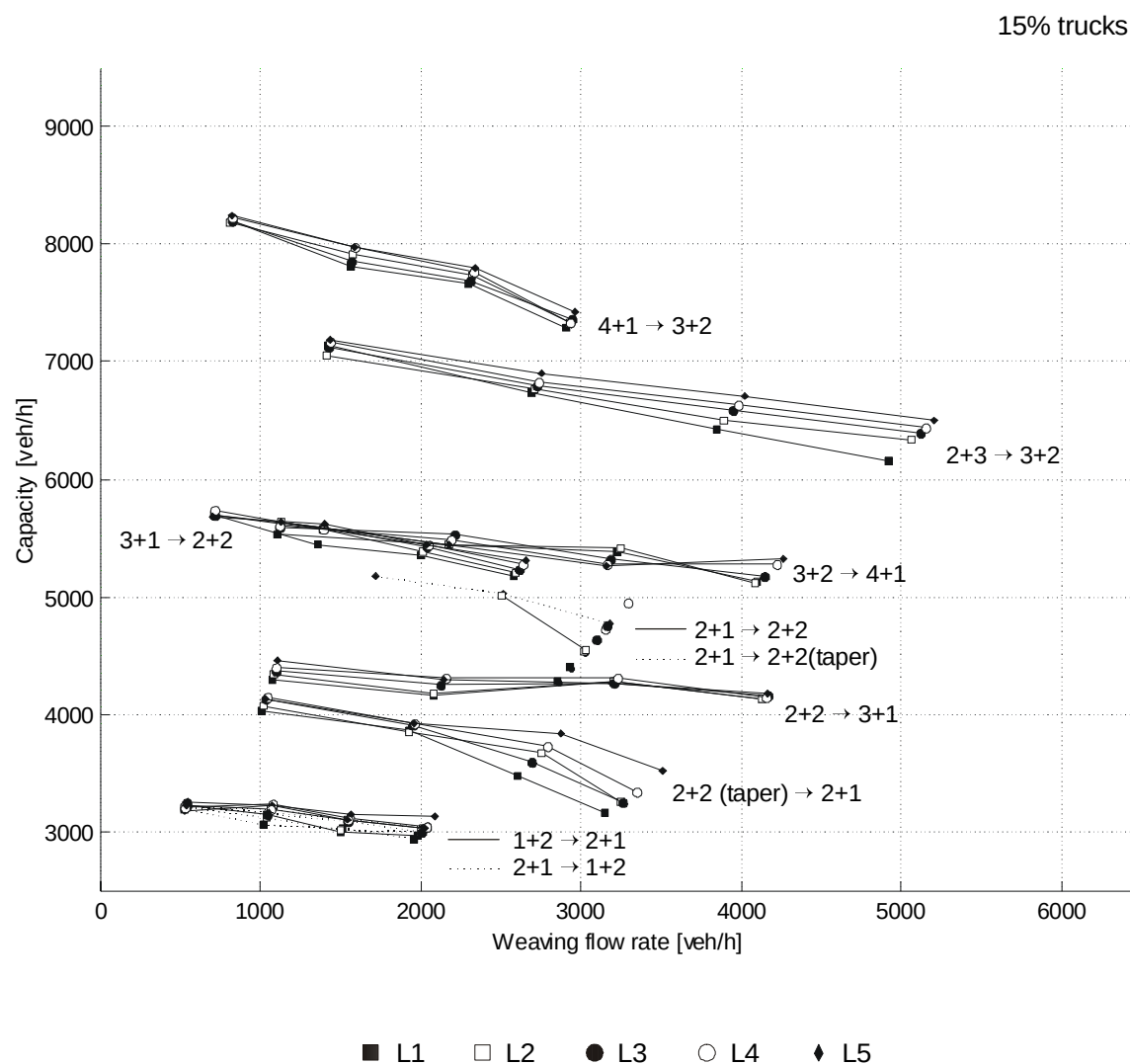


FIGURE 5 Capacity values for traffic streams with 15% of trucks; L1-L5 refer to Figure 1

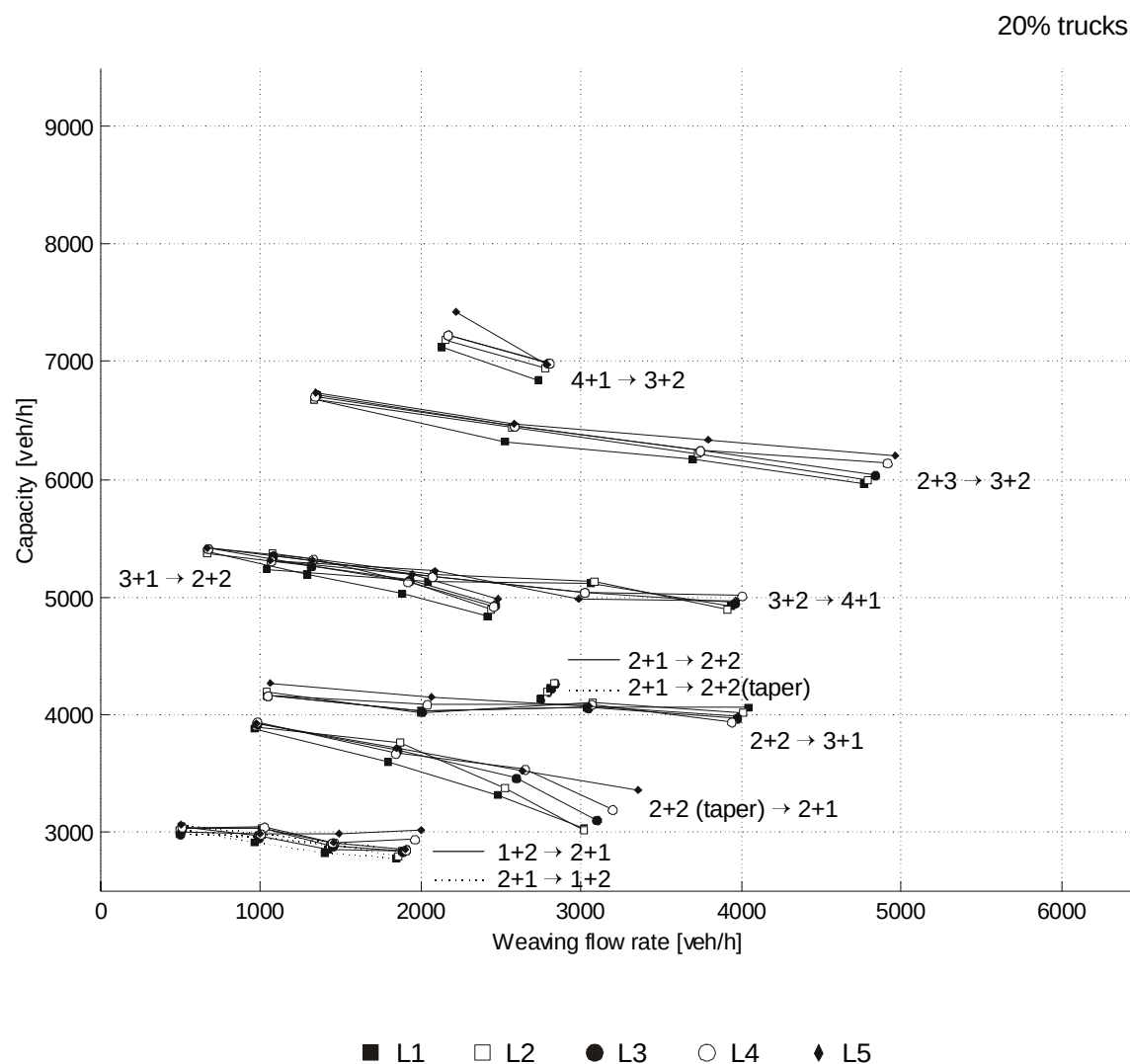


FIGURE 6 Capacity values for traffic streams with 20% of trucks; L1-L5 refer to Figure 1