The proposed new version of German Highway Capacity Manual

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1 Introduction

In Germany, the standards for the actual application of traffic engineering methods are specified in various guidelines. In 1994, the first draft of a highway capacity manual was presented on behalf of the Federal Minister of Transport to improve the practical applications of traffic engineering theories. Meanwhile, much of the content of the first version of the German Highway Capacity Manual (German HCM) are no longer up to date. On contract from the Federal Minister of Transportation, three main chapters are revised: Motorway (Autobahn) Sections, Two-lane Highways, and Unsignalized Intersections.

This paper describes the main new features in the revised chapters of the new German HCM. A lot of new research results have been incorporated into the manual. The LOS-classifications for all types of highway and street facilities are given.

1 Motorway sections

The German motorways are characterized by two features that is special among the motorways of the world: (1) No General Speed Limit; (2) Command of Drive on Right and Prohibition of Overtaking on Right. As a result more than 30% of the total motorway mileage is driven with a speed of over 130 km/h. Averaging over the whole west German motorway network, the passenger car speed on German motorways is about 120 km/h with a 85-percentile of 145 km/h. Local speed distribution under low traffic volumes could also indicates much higher speeds with average passenger car speeds of 150 km/h and 85-percentiles of 180 km/h. The speed limit on German motorways for trucks is 80 km/h.

In a highway capacity manual, motorway (Autobahn in German) capacity is very important. Here the basic figure is the maximum capacity of one lane. In Germany, the maximum capacity of one lane is estimated to be about 1800 veh/h. In the real world, the maximum capacity of one lane is actually over 2000 veh/h. This is underlined by measurements by counting equipment in Germany. Here also traffic flows of 2200 veh/h or more can be observed for one lane of motorways. On

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motorways with two lanes per direction a flow of 4000 veh/h or more are frequently observed.

On the American motorways (freeways) the rule of “Keep in Lane” affects an equal distribution of flow on the traffic lanes, so that the capacity of one lane can be used for estimating the capacity of the whole motorway that usually has two to four lanes per direction. In Germany (also in most of the other European countries), because of the rule of “Command of Drive on Right and Prohibition of Overtaking on Right”, the traffic flow is not equally distributed on the lanes of motorways. The distribution of the traffic flow on the lanes is a function of the total traffic flow of one direction of the motorway. On capacity of a motorway with two lanes per direction, the lane split of traffic flow is about 60% (on the left lane) to 40% (on the right lane) through 70% to 30%. That is, a traffic flow of 4000 veh/h on motorway with two lane per direction means a maximal traffic flow of 2400 veh/h (60%) or 2800 veh/h (70%) on the left lane. Also on German motorways with more than two lanes per direction, no homogeneous lane split is observed. Figure 1 shows an example for the lane split of traffic flow on German motorway with two lane per direction and the corresponding speed-flow relationship.

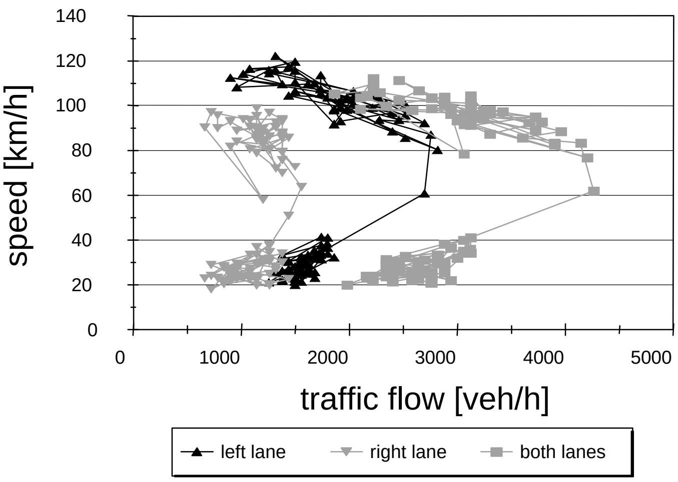


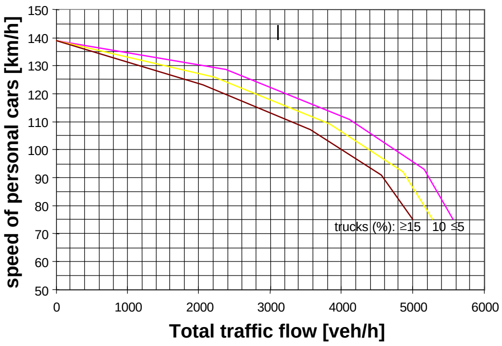
Figure 1 – Lane split and speed-flow relationship on a German motorway

In accounting for the lane split of traffic flow on motorways, speed-flow relationships of the whole direction carriageway are used. In the proposed new version of the German HCM the speed-flow relationships are distinguished according to (Ponzlet 1994; Brilon and Ponzlet 1996)

1. type of the motorways
   - number of lanes (4- or 6-lane motorways)
   - driver behavior (long distance or metropolitan motorways)
2. weather and light conditions (Light and Dry, Light and Wet, Dark and Dry, and Dark and Wet)

These speed-flow relationships are obtained by comprehensive measurements on German Motorways.

Figure 2 shows the speed-flow relationships for the 6-lane long distance motorways and the 4-lane metropolitan motorways under Light and Dry condition.



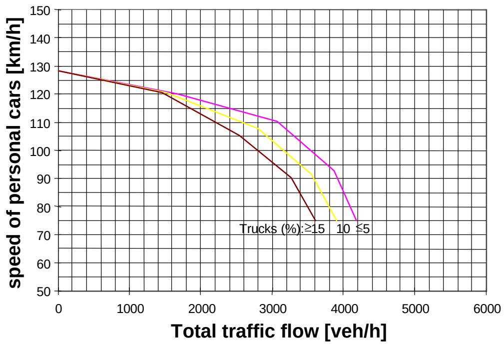


Figure 2 –Examples of Speed-flow relationships on German motorways
left: 6-lane long distance motorways under Light/Dry condition
right: 4-lane metropolitan motorways under Light/Dry condition

The theoretical capacity on German motorways under ideal conditions (Light and Dry) are presented in Table 1. The reductions of the theoretical capacity under other light and weather conditions are given in Table 2. In both tables the values are in vehicles per hour.

Truck percentage	6 - lane motorways	4 – lane motorways	
		metropolitan	long distance
0%	5470	4150	3630
5%	5340	4020	3580
10%	5200	3890	3530
15%	5070	3750	3480

Table 1 – Theoretical capacities on German motorways under ideal conditions

Weather and light conditions	6 - lane motorways	4 – lane motorways	
		metropolitan	long distance
Dark	-360	-380	-210
Wet	-540	-380	-350
Dark an Wet	-880	-730	-550

Table 2 – Reductions of capacity under other conditions

2 Unsignalised intersections

In the chapter of unsignalized intersection, some new research results are integrated that complete the calculation procedures in the previous version of the German HCM. The main changes are discussed below.

2.1 Potential capacity for a movement

The potential capacity is calculated according to the gap acceptance method. For the calculation the Siegloch's formula is used (1973). The necessary parameter critical gap t_g and follow-up time t_f are estimated under German conditions.

In contrast to the previous procedure in the German HCM, the t_g and t_f values are now considered as independent of the speed on major streets according to the new research results. The potential capacity C of the individual minor traffic streams is given in Figure 3. The potential capacity is expressed in passenger cars per hour (pcph). It is a function of the conflicting volume q_p that is expressed in vehicle per hour (veh/h). Figure 3 depicts the application of Siegloch's formula (1973) using t_g and t_f values estimated earlier in Germany. In the future, this diagram for estimating the potential capacity should be modified again if new measurements indicate new t_g and t_f values.

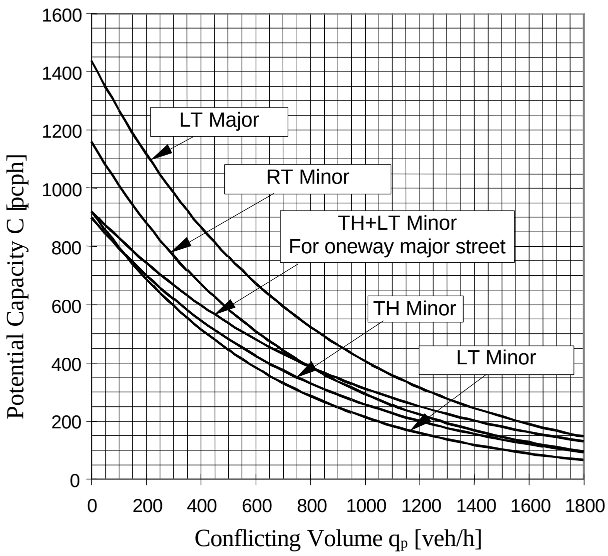


Figure 3 - Potential capacity for different movement types

2.2 Impedance factors for streams of rank 4

Normally the capacity of a minor stream can be calculated by multiplying the potential capacity with an impedance factor that indicates the probability of queue-free state in the higher-ranked streams. For instance, the capacity of minor-through stream (rank 3) is the potential capacity multiplying with the probability of queue-free state in the major left-turn streams (rank 2). For streams opposing more than one higher-ranked major streams that have the same rank the probabilities of queue-free state can be estimated by calculating the simple product of the queue-free probabilities.

Because of the independence between queue-free probabilities in major streams of different ranks the capacity of the minor left-turn stream (rank 4) cannot be estimated by using a simple impedance factor that results from the product of the queue-free probabilities in stream of rank 2 and 3.

In HCM (1994 and 1997) a correction function is used (HCM 1994, chapter 10, eq.10-6 or fig.10-6) for accounting for the statistical independence in the higher ranked streams. This correction function is based on an empirical work from Grossmann (1991). Unfortunately, this function somewhat overestimates the queue-free state under certain conditions.

In the proposed new version of German HCM the formula from Wu (1998) is used for estimating the impedance factor. This formula is derived from the queuing theory and is more accurate than the formula in HCM (1994 and 1997). The formula from Wu (1998) is

$$p' = \frac{1}{1 + \frac{1 - p_{0,j}}{p_{0,j}} + \frac{1 - p_{0,k}}{p_{0,k}}} \quad (1)$$

where p' = impedance factor for the minor street left turning stream (rank 4);
$p_{0,j}$ = probability of queue-free state for conflicting major street left-turning traffic (product of the p_0 for both directions, rank 2);
$p_{0,k}$ = probability of queue-free state for conflicting minor street through traffic from the opposite direction (rank 3).

Eq. 1 is a universal formula that can be extended to other constellations of streams of different ranks. The details may be found in Wu (1998).

2.3 Two-stage priority

At many unsignalized intersections there is a space in the center of the major street available where several minor street vehicles can be stored between the traffic flows of the two directions of the major street, especially in the case of multilane major traffic. This storage space within the intersection enables the minor street driver to pass each of the major streams at a time. This behavior can contribute to an increased capacity.

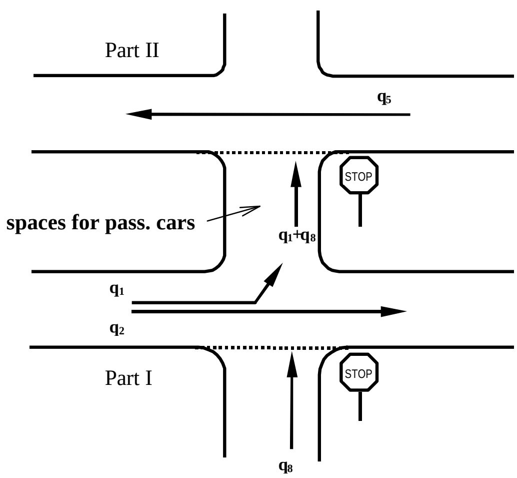


Figure 4 - Minor street through traffic (movement 8) crossing the major street in 2 phases.

Brilon et al (1996) developed a model considering this type of intersection based on a concept from Harders (1968). This model is used both in the new versions of the U.S. HCM and the German HCM. The details of the calculation procedure can be found in the new U.S. HCM (1997).

2.4 Shared/short lanes and flared minor street entries

The basic calculation procedures assume in a first step that each of the traffic streams, which have to give way, has its own traffic lane at the intersection. The capacity for the individual movements (left turn, straight ahead and right turn) are calculated separately. If the streams share a common traffic lane, the capacity of the shared lane is then calculated according to the shared lane procedure of Harders (1968) (cf. eq.10-9 in HCM 1994).

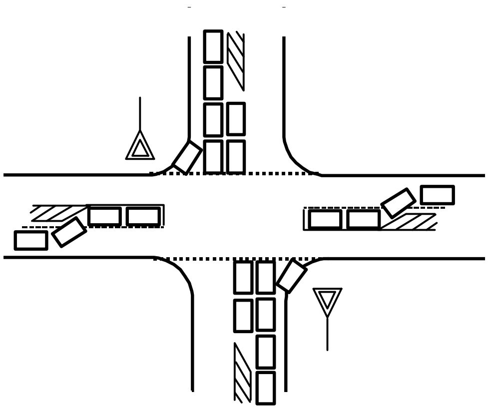


Figure 5 - Possible queues at the approaches to an unsignalised intersection

In the real world we find, however, constellations which are of intermediate nature. These are short additional lanes with a few (sometimes only one) places (cf. Figure 5). Their capacity can neither be estimated by the solution for infinitely long separate lanes nor by the shared lane formula.

To deal with this problem, Wu (1997a) derived a procedure, which can account for the length of the turning lanes exactly when calculating the capacity of the shared/short lanes and flared minor street entries. The details of this procedure can be found in Wu (1997a).

2.5 Capacity of roundabouts

Roundabouts have meanwhile become the most popular type of intersection in many areas. They provide advantages in costs, optical design, capacities, space consumption, and safety.

The from Wu (1998) proposed formula for the capacity of an entry to a roundabout is used in the new German HCM. This formula reads

$$c_e = \left(1 - \frac{\Delta \cdot q_c}{n_c}\right)^{n_c} \cdot \frac{n_e}{t_f} \cdot \exp\left(-q_c \cdot (t_0 - \Delta)\right) \qquad (2)$$

with c_e = maximal entry flow (capacity of the entry) in pcph

q_c = flow on circular lanes at the subject entry in pcph

n_c = number of circular lanes

n_e = number of lanes in the subject entry

$t_0 = t_c - \frac{t_f}{2}$

t_c = critical gap in sec

t_f = move-up time in sec

Δ = minimum headway between vehicles in the circular lanes in sec

The parameters t_c = 4.12s, t_f = 2.88s and Δ = 2.10s have been found to represent driver behavior at roundabouts in Germany (cf. Wu 1997b) if eq.2 is used as the capacity model.

Figure 6 shows the capacity according to eq.2.

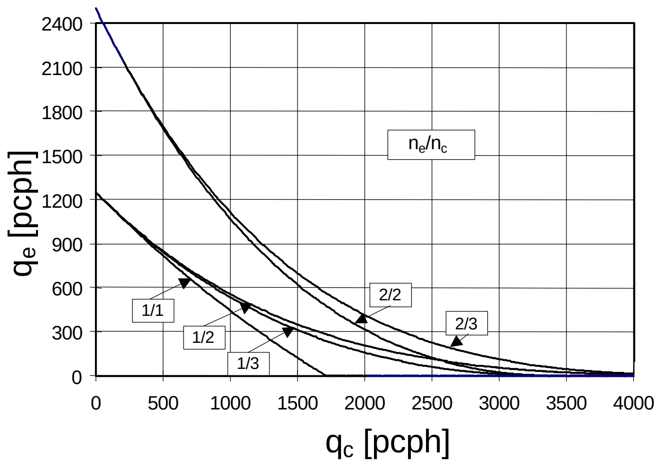


Figure 6 - Capacity at roundabouts (cf. eq. 2)

3 Two-lane rural highways

In each country, the road network in large extend is formed by two-lane rural highways. Also in Germany 90 % of the rural roads have just two lanes. Here the general speed limit is 100 km/h and the speed limit for trucks is 60 km/h.

Base on a simulation study, new speed-flow diagrams for two-lane rural highways are introduced. The diagrams range from the level-and-straight highway to the steep-and-winding mountain road. It can be stated that the capacity of a level-and-nearly-straight two-lane highway is in the range of 2500 veh/h. For rather-steep-and-curved roads the value for the capacity could be as low as 1000 to 1500 veh/h. These are unexpectedly low values since they are even lower than in the current guidelines.

Figure 7 shows two examples of these speed-flow diagrams for the level-and-straight highway (left) and the steep-and-winding mountain road (right) in the proposed new German HCM. Other speed-flow diagrams are referred to the work of Brilon and Weiser (1998).

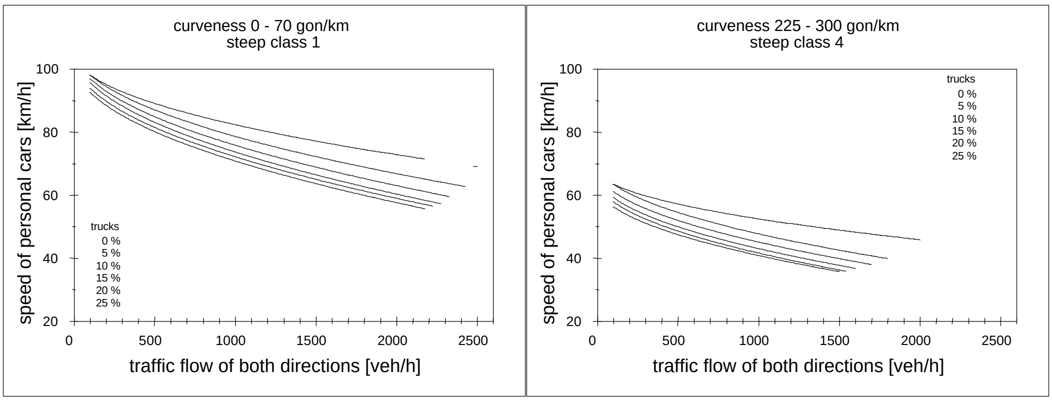


Figure 7 – Examples of the new speed-flow diagrams for two-lane highway

In contrast to the traditional speed flow diagrams, which are convex, the curves in the new diagrams show a concave shape. This function, however, represents clearly the same shape of data points obtained both from measurements and simulations.

The concave shape means that under very small flows the travel speeds have a strong tendency to decrease with additional flow. However, once a level of 300 - 400 veh/h is reached the speed-flow relation turns over into a more linear shape.

Another aspect of the concave shape is the fact that at capacity there is no continuous transition into congested conditions. Instead the transition to congestion there is a sudden drop to lower speeds and high densities, a fact which is often experienced by drivers on crowded roads. The congested arm of this diagram is, however, not necessarily shown in highway design guidelines. This arm would be an independent branch of the diagram at lower speeds.

4 Level of Service (LOS)

The classifications of Level of Service in the previous version of German HCM (Table 3) is retained except that for two-lane rural highways. For the two-lane rural highways the discussion on classification of LOS is not yet completed. Meanwhile, the old classifications are still used.

5 Summery

Special attention is drawn to recent research results which are included or to be included into the proposed new version of the Germany Highway Capacity Manual. This are

- new approach for capacities of motorways under different weather and light conditions obtained by comprehensive measurements. The capacities of motorways are given in four cases: (1) Light and Dry; (2) Light and Wet; (3) Dark and Dry; (4) Dark and Wet
- new approach for capacities at unsignalised intersection which includes improvements and additional procedures on
  - potential capacity

- capacity of traffic stream of higher ranks
- capacity of shared-short lane
- capacity of two-stage priority
- capacity of roundabouts

- new approach for capacities of two-lane rural highways obtained by microscopic simulations.

The proposed new version of German Highway Capacity Manual is scheduled to be released in the year 2000. Until that time, more research results may be incorporated into the manual.

	Motorways	Entrance ramps, weaving areas	2-lane rural highways	Unsignalised intersection	Signalised intersection
LOS	Average travel speed of passenger cars	Degree of saturation	Average travel speed of passenger cars	Average queue delay per vehicle (maximum of all movements at the intersection)	
A	≥130	≤0.30	≥ 80	≤ 10	≤ 25
B	≥115	≤0.55	≥ 70	≤ 15	≤ 40
C	≥100	≤0.75	≥ 60	≤ 25	≤ 60
D	≥ 85	≤0.90	≥ 50	≤ 45	≤ 80[1)]
E	≥ 75	≤1.00	< 50	> 45[2)]	≤100[2)]
F	< 75	>1.00	< 40	$x > 1$	$x > 1$
	km/h		km/h	s	s

[1)] and degree of saturation $x \le 0.85$ [2)] and degree of saturation $x \le 1.00$

Table 3 – Level of Service for different types of highway facilities

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