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A new Model for Level of Service of Freeway Merge, Diverge, and Weaving Segments

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Abstract

In most of the existing highway capacity manuals, level of service (LOS) of freeway weaving segments and ramp junctions is traditionally defined by the speed, volume or density in critical areas of merge, diverge and weaving manoeuvres. In that traditional concept several capacity values of different critical areas (merge, diverge, weaving) as well as upstream and downstream basic freeway segments within the influence areas are evaluated separately. In this paper, a new model which considers the total segment of freeway merge, diverge, and weaving as an entire object is introduced. A combined volume-to-capacity ratio is used for defining the LOS of the total segment. According to the probability and queuing theory, the volume-to-capacity ratio of the whole segment can be considered as a combination of volume-to-capacity ratios in the different critical areas under consideration. The parameters of the new model can be calibrated with field data. Those parameters are functions of the number of lanes on the freeways, the number of lanes in the on-ramps or off-ramps, the length of the acceleration, deceleration, or weaving sections. Varying the model parameters the function can be fitted to the existing capacity models for different types of weaving segments or ramp junctions. With this model, the traffic quality (LOS) can be obtained directly as a function of the volumes on the freeway and on the on-ramp or off-ramp respectively. The new model has the following advantages: a) a uniform function for all types of freeway weaving segments and ramp junctions, b) traffic quality assessment for all critical areas under investigation in one step, and c) easy calibration. The new model will be incorporated into the new edition of the German Highway Capacity Manual (HBS 201X).

Kewords: Capacity, Ramp Junctions, Weaving Areas, Concept of Level of Service

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1. Introduction

In most of the existing highway capacity manuals, e.g. the US Highway Capacity Manual (HCM 2000, TRB 2001) and the Germany Highway Capacity Manual (HBS 2001, FGSV 2001), Levels-of-Service (LOS) at junctions on freeways (weaving segments, on-ramp junctions, and off-ramp junctions) are traditionally defined to represent reasonable ranges in the three critical flow variables: speed, density, and volume in critical areas of merge, diverge and weaving manoeuvres. Threshold values of the speed in the critical areas under consideration are applied to determine different levels of flow conditions. The speed is then correlated with the predefined LOS. The volume or density can be then obtained according to the existing volume-speed-density relationship.

That traditional concept of LOS for freeway merge, diverge, and weaving segments evaluates the traffic quality and capacity values of different so-called critical areas (cf. the circles in Figure 1) separately. Normally, the traffic quality of the merge area for on-ramps, of the diverge area for off-ramps, and of the weaving area is most important. The volumes of those critical areas (cf. the area for v_M in Figure 1) are predominately used for assessing the traffic quality of the segments. The LOS of this critical area is normally a function of this critical volume (v_M) and thus a function of the approaching volumes on the freeway and on the on-ramp (for an on-ramp junction / entrance), and of the departing volumes on the freeway and on the off-ramp (for an off-ramp junction / exit). Depending on the geometric configuration, e.g. the number of lanes on the major freeway and in the ramps as well the length of the critical areas (merge / diverge / weaving), this functional relationship can vary. Nevertheless, those relationships are clearly defined if the geometric configurations are known.

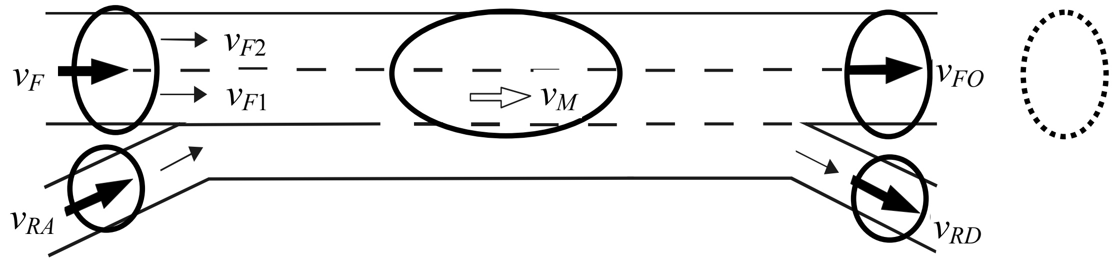


Figure 1 - Critical areas at freeway merge, diverge, and weaving segments

As mentioned previously, the traditional concept of LOS only considers the traffic situation in the basic freeway segment and in the in- and out-flow segments separately. An overall assessment of the merge, diverge, and weaving segment is not possible or very difficult.

2. The model in the existing HBS2001

In HBS 2001, chapter 4, the traffic quality of freeway merge, diverge, and weaving segments is determined by examining the volume-to-capacity ratio on the basic freeway segment, directly upstream (v_F) or downstream (v_{FO}) of the segment, on the approaching ramp (v_{RA}), and on departing ramp (v_{RD}) separately (indicated in as circles in Figure 1). Sometimes it is also needed to check the volume-to-capacity ratio of the freeway segment more distantly downstream of the segment (doted circles in Figure 1) because a basic freeway segment can have a lower capacity than at the merge, diverge, or weaving segment due to a different speed levels and lane utilisation.

In the HBS2001 a weaving segment is treated like a merge segment. The departing flow on off-ramps is always treated with default values and thus is taken into account implicitly.

The desired traffic quality of the total merge, diverge, or weaving segment can only be achieved if all of the mentioned areas are examined to be of sufficient quality. The traffic quality of the worst area is then decisive for the total merge, diverge, or weaving segment. For example, the quality of service of a merge segment (entrance) must be examined in two areas: a) the merge area, and b) the downstream freeway segment. In the HBS 2001, the volume-to-capacity ratio x is used for defining the LOS (cf. Table 1). If the capacity values of the different areas are known, the LOS of those sections can be obtained according to the corresponding volume-to-capacity ratio thresholds.

Table 1 - Thresholds for defining LOS in HBS 2001

LOS	volume to capacity ratio x_{LOS} [-]
A	≤ 0.30
B	≤ 0.55
C	≤ 0.75
D	≤ 0.90
E	≤ 1
F	—

Weaving and merge segments

Given the traffic demand, the critical volume v_M in the merge (or weaving) area can be easily computed. For a merge (or weaving) area the critical volume v_M is the sum of the approaching volume of the on-ramp v_{RA} and the volume of the far-right lane of the major freeway v_{F1}. That is (cf. Figure 1),

$$v_M = v_{F1} + v_{RA} \tag{1}$$

with v_M = critical volume in the merge (or weaving) area, pcu/h
v_{F1} = volume of the far-right lane of the major freeway, pcu/h
v_{RA} = volume approaching in the on-ramp, pcu/h

The volume of the far-right lane of the major freeway v_{F1} is normally a function of the total volume of the major freeway v_F. In the HBS 2001, it is assumed that off-ramp volume is included in the volume of the far-right lane of the major freeway and thus is taken into account implicitly.

The volume of the far-right lane on the major freeway v_{F1} can be considered as a linear function of the total volume of the major freeway upstream of the segment under consideration v_F (cf. Westphal, 1995). That is,

$$v_{F1} = a + b \cdot v_F \tag{2}$$

with v_F = total volume of the major freeway upstream of the segment, pcu/h
a, b = parameters to be calibrated

Then, the critical volume v_M in the merge (or weaving) area is

$$v_M = v_{F1} + v_{RA} = a + b \cdot v_F + v_{RA} \tag{3}$$

With predefined thresholds between two adjacent service volumes of the critical merge volume v_M (e.g. 2200 pcu/h for LOS E/F, Table 1), the allowed on-ramp service volume $v_{RA,LOS}$ is also a linear function of the total volume of the major freeway v_F. That is,

$$v_{RA,LOS} = (v_{M,LOS} - a) - b \cdot v_F = A - b \cdot v_F \tag{4}$$

with A = $v_{M,LOS} - a$ = const.

This linear function is presented as monographs in the HBS 2001 (cf. Figure 2). The calculation of the merge volume v_M can be omitted and v_M can be incorporated in the monographs implicitly. Because this function cannot be calibrated for the whole range of possible values of v_F, it is only depicted in the middle of the monographs. That is not satisfying for an application in practice. Furthermore, for very low total volumes v_F (Figure 2, shadowed area to the left), the capacity of the on-ramp can be decisive for the whole merge segment. Here, an extra check must be done regarding the on-ramp capacity. It is also the case for the major freeway with a very high total volumes v_F (Figure 2, shadowed area to the right). Here the capacity of the major freeway is decisive. It is desirable to find a function that can consider all of the three decisive areas (major freeway / on-ramp / merge) simultaneously.

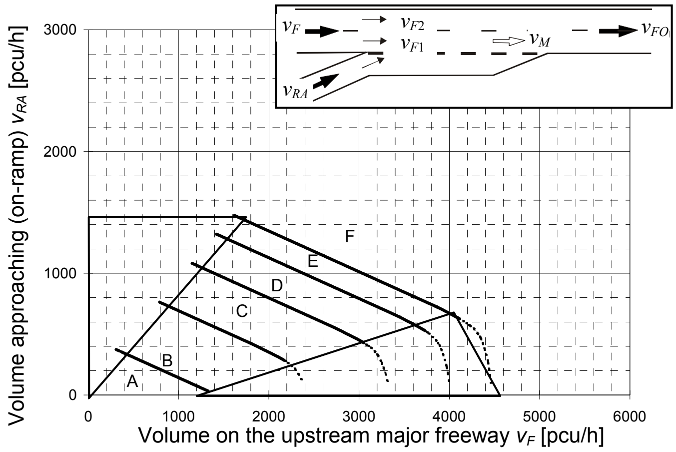


Figure 2 - Monograph for LOS of a typical merge segment in the HBS2001 (typical)

Diverge segments

In the HBS 2001 only the capacity of the off-ramps is accessed. The capacity estimation for the diverge area is omitted totally because of missing empirical data. It is also desirable to find a function that considers all of the decisive areas (major freeway / off-ramp / diverge) of the diverge segment simultaneously.

3. The new model for Level-of-Service

In this paper, a new model is introduced for determining the LOS of freeway merge, diverge, or weaving segments. The new model considers these segments as a whole object. According to the probability and queuing theory, the volume-to-capacity ratio of the whole segment can be considered as a combination of volume-to-capacity ratios in the different critical areas under consideration.

The theoretical consideration is presented as following.

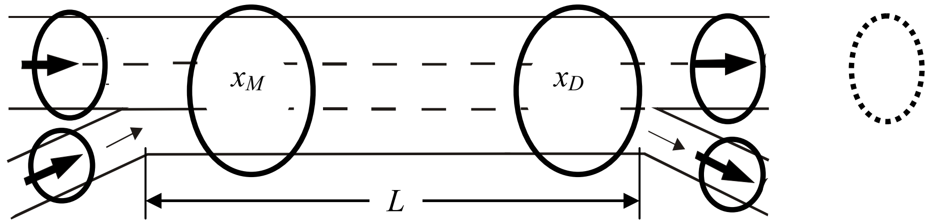


Figure 3 - Volume-to-capacity ratios in different areas of freeway weaving segments

In general, the probability, that a certain cross-section on a certain lane is occupied by a vehicle, is equal to the volume-to-capacity ratio of the lane. That is,

$$\Pr_{occ} = x \tag{5}$$

For a freeway segment with n traffic lanes, a combined total volume-to-capacity ratio of the total freeway segment can be defined as the probability that all available lanes are occupied simultaneously:

$$\Pr_{occ,total} = \prod_{i=1}^{n} \Pr_{occ,i} \iff x_{total} = \prod_{i=1}^{n} x_{lane,i} \tag{6}$$

In case of equal volumes on all lanes, this results in $x_{lane,i} = x_{lane}$ and

$$x_{total} = x_{lane}{}^{n} \tag{7}$$

At a merge or diverge point the volume-to-capacity ratio (here defined as the probability of occupation) has to be the same on both sides of the merge or diverge point (Wu, 1997). Thus, the following equations holds for the case that the traffic volumes are equally distributed on all freeway segments and ramps under consideration:

$$x_{RA}^{\ n_{RA}} + x_F^{\ n_F} = x_M^{\ n_M} \quad \text{and} \quad x_D^{\ n_D} = x_{RD}^{\ n_{RD}} + x_{FO}^{\ n_{FO}} \tag{8}$$

with v_M = critical volume in the merge (or weaving) area, pcu/h
v_F = volume of the major freeway upstream of the merge (or weaving) segment, pcu/h
v_{RA} = volume approaching in the on-ramp, pcu/h
v_D = critical volume in the diverge area, pcu/h
v_{FO} = volume of the major freeway downstream of the diverge segment, pcu/h
v_{RA} = volume departing in the off-ramp, pcu/h
n_{XX} = number of lanes for the corresponding section

In reality the traffic volume is seldom equally distributed on all lanes because of different traffic behaviours and boundary conditions. The power n_{XX} to the volume-to-capacity ratio x is normally not equal to the number of lanes. In general the following equations holds:

$$x_{RA}^{\ a1} + x_F^{\ b1} = x_M^{\ c1} \quad \text{and} \quad x_D^{\ c2} = x_{RD}^{\ a2} + x_{FO}^{\ b2} \tag{9}$$

The parameters $a1$, $b1$, $c1$, and $a2$, $b2$, c2 can be calibrated against field data.

If there are two critical areas in succession (cf. Figure 3, merge area M and diverge area D), the first one (downstream, D) can impact the following one (upstream, M) significantly. The impedance depends on the volume-to-capacity ratio at the first critical area and the distance between both critical areas. According to the queuing theory the second critical area is occupied by the queue caused by the first critical area if the queue length N behind the first critical area is larger than the number of storage places between both critical areas. For example, in case of an M/M/1 queuing system the probability that the second critical area is impacted by the first one is (cf. Figure 3)

$$\Pr_{imp,M} = \Pr(N > N_L) = x_D^{\ N_L+1} \tag{10}$$

where x_D is the volume-to-capacity ratio of the first critical area (diverge area), N_L is the number of available storage places between both critical areas. For equally distributed traffic volume is

$$N_L = L \cdot D_{L,opt} \cdot N_L = \frac{L}{S_{L,opt}} \cdot c_L \cdot N_L \tag{11}$$

where L is the length between both critical areas, $D_{L,opt}$, $S_{L,opt,}$ N_L, and c_L are the optimum density and speed at capacity, the number of lanes, and the capacity of the freeway segment between both critical areas.

As an approximation, the following equation for a general queuing system holds:

$$\Pr_{imp,M} = \Pr(N > N_L) = x_D^{\ f(N_L+1)} \tag{12}$$

The function $f(N_L+1)$ is monotonically increasing against the number of available storage places N_L and therefore against the length of the freeway segment L between both critical areas.

The actual combined total volume-to-capacity ratio of the second critical area - here, it corresponds to the volume-to-capacity ratio of a weaving area $x_{W,\mathrm{total}}$ - is then (cf. Figure 3)

$$x_{W,total} = x_W^{\ c3} = x_M^{\ c1} + \left(x_D^{\ c2}\right)^{f(L+1)} = \left(x_{RA}^{\ a1} + x_F^{\ b1}\right)^{c1} + \left(x_{RD}^{\ a2} + x_{FO}^{\ b2}\right)^{c2\cdot f(N_L+1)} \tag{13}$$

Using those derived equations, the combined volume-to-capacity ratio for different merge, diverge, and weaving segments, e.g. for a grid of freeway network, can be estimated. However, a huge amount of field data would be necessary for the calibration work.

Following the logic above, the relationships between the volume-to-capacity ratios in the merge, diverge, and weaving segments can be established:

- *In the merge and diverge segment*: The combined volume-to-capacity ratio of the critical areas (areas M and D in Figure 3) can be expressed as a superposition of the volume-to-capacity ratios in the merge or diverge flows. That is,

$$x_{RA}^{a1} + x_F^{b1} = x_M^{c1} \quad \text{and} \quad x_D^{c2} = x_{RD}^{a2} + x_{FO}^{b2} \tag{14}$$

  The superposition can be calibrated by the parameters $a1$, $b1$, $c1$, and $a2$, $b2$, $c2$ in order to take into account the geometrical configuration of the segment. Normally, those parameters correlate strongly to the number of lanes in the major freeway and in the ramp under consideration.

- *In the weaving segment*: The weaving area can be considered as a combination of the merge and the diverge area. Again, the combined volume-to-capacity ratio in the weaving area can be expressed as a superposition of the volume-to-capacity ratios in the merge and diverge areas. That is,

$$x_W^{c3} = x_M^{c1} + \left(x_D^{c2}\right)^{f(N_L+1)} = \left(x_{RA}^{a1} + x_F^{b1}\right)^{c1} + \left(x_{RD}^{a2} + x_{FO}^{b2}\right)^{c2 \cdot f(N_L+1)} \tag{15}$$

  This superposition can be calibrated by the parameters $c3$ and a function $f(N_L+1)$ which is monotonically increasing against the length of the weaving area L.

The model parameters $a1$, $a2$, $b1$, $b2$, $c1$, $c2$, $c3$, and the function $f(N_L+1)$ can be calibrated with field data. Those parameters are normally functions of the geometrical configurations, such as the number of lanes in the legs of a segment (major freeway / on-ramp / off-ramp), and the length of the acceleration (or deceleration, weaving) lanes etc.

4. Application in the HBS

In case of L = infinite, one obtains $(x_D^{c2})^{f(N_L+1)} \Rightarrow 0$ and $x_W^{c3} = x_M^{c1}$. The weaving segment is transferred into a merge segment. In the HBS 2001, the length of the weaving area is predefined as a constant for a standard design and thus is not taken into account in the calculation. The difference between a weaving segment and a merge segment is then considered by different model parameters.

Normally, the values of the model parameters a, b, c are different and they are dependent on geometrical configurations of the corresponding legs (major freeway, on-ramp, or off-ramp) of the segment under investigation. As an approximation and simplification, $a = b = c$ is assumed. This simplification is not critical for practical applications because the resulting deviations for the capacities of the merge and diverge area are quite small. Thus,

$$x_M^{a} = x_{RA}^{a} + x_F^{a} \quad \text{or} \quad x_{RA} = \sqrt[a]{x_M^{a} - x_F^{a}} = x_M \cdot \sqrt[a]{1 - \left(\frac{x_F}{x_M}\right)^a} \tag{16}$$

and

$$x_D^{a} = x_{RD}^{a} + x_{FO}^{a} \quad \text{or} \quad x_{RD} = \sqrt[a]{x_D^{a} - x_{FO}^{a}} = x_D \cdot \sqrt[a]{1 - \left(\frac{x_{FO}}{x_D}\right)^a} \tag{17}$$

At capacity with x_M and $x_D = 1$, this results in

$$x_M^{a} = x_{RA}^{a} + x_F^{a} = 1 \quad \text{or} \quad x_{RA} = \sqrt[a]{1 - x_F^{a}} \tag{18}$$

and

$$x_D^{a} = x_{RD}^{a} + x_{FO}^{a} = 1 \quad \text{or} \quad x_{RD} = \sqrt[a]{1 - x_{FO}^{a}} \tag{19}$$

With $x = v/c$ this corresponds to

$$v_{RA,\max} = c_{RA} \cdot \sqrt[a]{1 - \left(\frac{v_F}{c_F}\right)^a} \quad \text{and} \quad v_{RD,\max} = c_{RD} \cdot \sqrt[a]{1 - \left(\frac{v_{FO}}{c_{FO}}\right)^a} \tag{20}$$

The parameters c_{RD}, c_{RA}, c_F, and c_{FO} are the capacities of the off-ramp, the on-ramp, the upstream major freeway, and the downstream major freeway.

As an example, Figure 4 shows the typical shape of the proposed function for a merge segment. It can be seen, that the boundary conditions

$$v_{RA} = c_{RA} \text{ at } v_F = 0 \text{ and } v_{RA} = 0 \text{ at } v_F = c_F$$

are satisfied. Similarly, also the following conditions hold:

$$v_{RD} = c_{RD} \text{ at } v_{FO} = 0 \text{ and } v_{RD} = 0 \text{ at } v_{FO} = c_{FO}$$

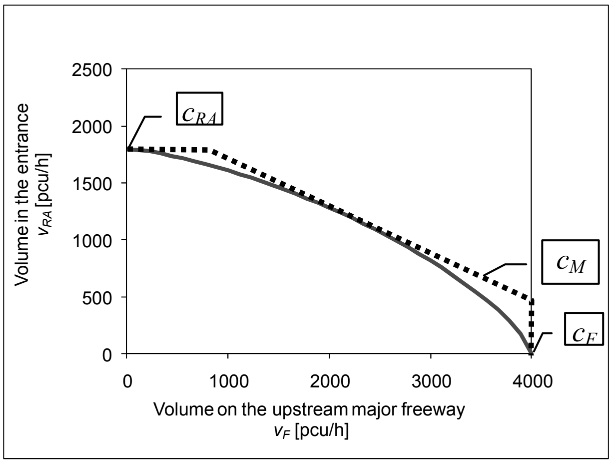


Figure 4 - Fitting the new function to the capacity limits of different areas under investigation

Varying the model parameter a, the function can be fitted to the existing capacity models for different types of segments (cf. c_M in Figure 4 for the example of a merge segment). Normally, the value of the model parameter a depends on the number of lanes on the major freeway and the number of lanes on the on-ramp / off-ramp. For a weaving segment, the value of the model parameter a depends also on the volume v_{RD} in the following off-ramp. In addition, the value of the model parameter a depends on the length L of the acceleration / deceleration / weaving segment. However, for freeway merge, diverge, and weaving segments with a standard design, the length L can be considered as a constant and it can be neglected. Furthermore, in the HBS 2001, only a default departing volume v_{RD} is considered. Thus, the model parameter a depends actually only on the geometrical configuration, that is, on the predefined type of diverge segment.

If the volume-to-capacity ratios on the major freeway (x_F) and on the ramps (x_{RD}, x_{RA}) are given, the combined volume-to-capacity ratio of the total merge or diverge segment (here x_M and x_D) can be directly calculated as follows:

$$x_M = \sqrt[a]{x_{RA}{}^a + x_F{}^a} \quad \text{and} \quad x_D = \sqrt[a]{x_{RD}{}^a + x_{FO}{}^a} \tag{21}$$

The total LOS of the merge or diverge segment can be then obtained according to the Table 1.

If the service volume-to-capacity ratio (cf. Table 1) for the merge or diverge segment is known ($x_{M,LOS}$ and $x_{D,LOS}$), the allowed volume-to-capacity ratios on the major freeway (x_F) and on the approaching and departing ramps (x_{RA} and x_{RD}) can be calculated according to the following equations:

$$x_{RA}{}^a + x_F{}^a = x_{M,LOS}{}^a \quad \text{and} \quad x_{RD}{}^a + x_{FO}{}^a = x_{D,LOS}{}^a \tag{22}$$

Those equations yield

$$x_{RA} = x_{M,LOS} \cdot \sqrt[a]{1 - \left(\frac{x_F}{x_{M,LOS}}\right)^a} \quad \text{and} \quad x_{RD} = x_{D,LOS} \cdot \sqrt[a]{1 - \left(\frac{x_{FO}}{x_{D,LOS}}\right)^a} \tag{23}$$

This corresponds to

$$v_{RA} = c_{RA} \cdot x_{M,LOS} \cdot \sqrt[a]{1-\left(\frac{v_F}{c_F \cdot x_{M,LOS}}\right)^a} = c_{RA,LOS} \cdot \sqrt[a]{1-\left(\frac{v_F}{c_{F,LOS}}\right)^a} \tag{24}$$

and

$$v_{RD} = c_{RD} \cdot x_{D,LOS} \cdot \sqrt[a]{1-\left(\frac{v_{FO}}{c_{FO} \cdot x_{D,LOS}}\right)^a} = c_{RD,LOS} \cdot \sqrt[a]{1-\left(\frac{v_{FO}}{c_{FO,LOS}}\right)^a} \tag{25}$$

With those two functions, the traffic quality (LOS) for different values of v_F and v_{RA} (or v_{RD} respectively) can be obtained directly. Figure 5 depicts a typical shape of the new function for a merge segment. It can be clearly seen, that at $v_F = 0$ (for the *y*-intercept) and at $v_{RA} = 0$ (for the *x*-intercept) the traffic quality of the merge segment and the traffic quality of the major freeway are decisive for the total segment.

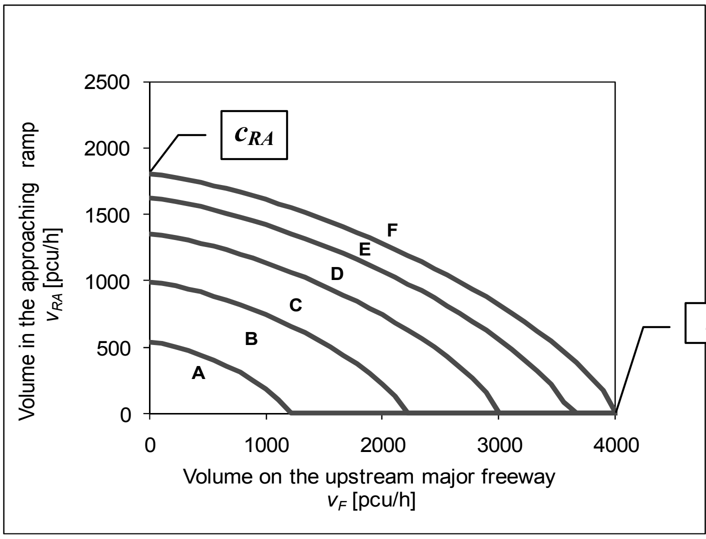


Figure 5 - Illustration of LOS for a merge segment according to the new model

The new model is incorporated into the current draft of the new German Highway Capacity Manual (HBS 201X). Compared to the model in the old edition (HBS 2001), the new model has the following advantages:

- A uniform function for all types of freeway merge, diverge, and weaving segments
- Traffic quality assessment for three critical areas in one step:
  - on-ramp / off-ramp
  - major freeway upstream / downstream
  - merge / diverge / weaving manoeuvre area
- All boundary conditions satisfied, and
- Easy calibration

Based on the data of HBS 2001 and some recent investigations (Weiser et al., 2006; Friedrich et al, 2006 and 2008), the new model was calibrated. Using the new model monographs for all types of merge, diverge, and weaving segments of the current design guidelines (RAA, 2008) are constructed in the new edition of the German Highway Capacity Manual (HBS 201X).

The service volumes for diverge segments are expressed by the following equation:

$$v_{RD,LOS} = c_{RD,LOS} \cdot \sqrt[a]{1-\left(\frac{v_{FO}}{c_{FO,LOS}}\right)^a} \tag{26}$$

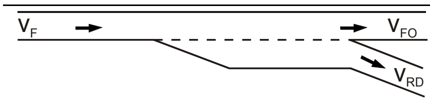
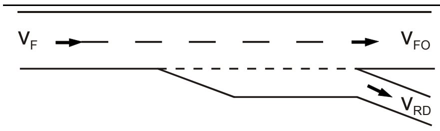
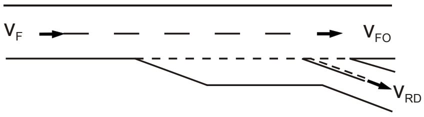
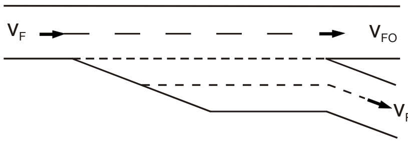
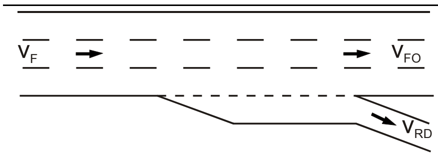
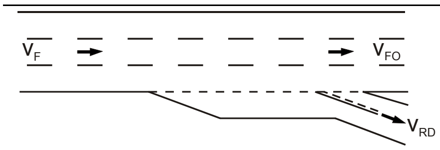
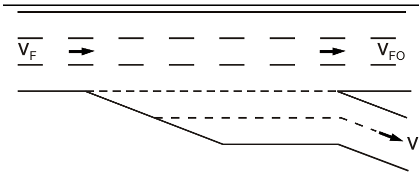
with $v_{RD,LOS}$ = service volume departing on the off-ramp (exit) for a given LOS

$c_{FO,LOS} = c_{FO} \cdot x_{LOS}$

$c_{RD,LOS} = c_{RD} \cdot x_{LOS}$

c_{FO} = capacity of the major freeway downstream of the diverge area (Table 2)
c_{RD} = capacity of the off-ramp (Table 2)
a = model parameter (Table 2)
x_{LOS} = service volume-to-capacity ratio for a given LOS (Table 1)

Table 2 - Parameters for diverge segments (equation (26))

Type of diverge segment	capacity of the major freeway downstream of the diverge area c_{FO}	capacity of the off-ramp c_{RD}	a
	2000	1800	1,05
	4000	1800	1,9
	4000	3060	1,9
	4000	3600	1,9
	5700	1800	1,9
	5700	3060	1,9
	5700	3600	1,9

The service volumes for merge (or weaving) segments are expressed by the equation

$$v_{RA,LOS} = c_{RA,LOS} \cdot \sqrt[a]{1-\left(\frac{v_F}{c_{F,LOS}}\right)^a} \tag{27}$$

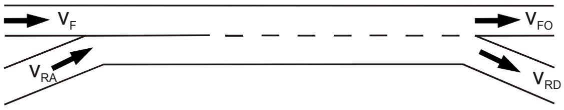
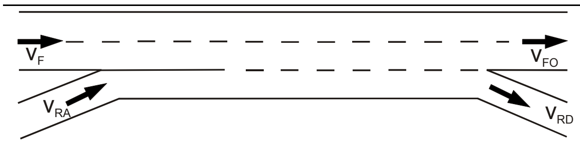
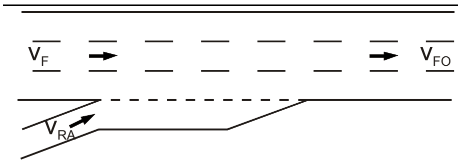
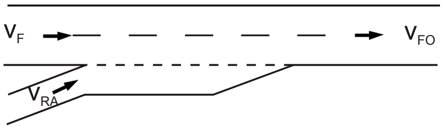
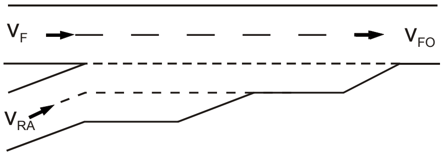
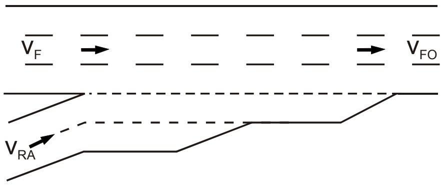
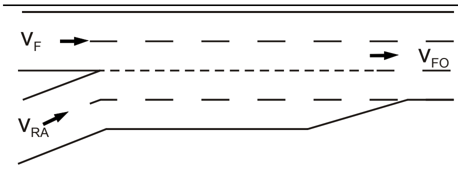
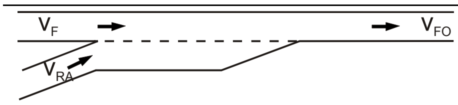
with $v_{RA,LOS}$ = service volume approaching on the on-ramp for a given LOS

$c_{F,LOS} = c_F \cdot x_{LOS}$

$c_{RA,LOS} = c_{RA} \cdot x_{LOS}$

c_F = capacity of the major freeway upstream of the merge (or weaving) area (Table 3)
c_E = capacity of the on-ramp (Table 3)
a = model parameter (Table 3)
x_{LOS} = volume-to-capacity ratio for a given LOS (Table 1)

Table 3 - Parameters of merge and weaving segments (equation (27))

Type of merge or weaving segment	capacity of the major freeway upstream of the merge (or weaving) area c_F	capacity of the on-ramp c_{RA}	a
	2000	1800	1,4
	4000	1800	1,3
	5700	1800	1,9
	4000	1800	1,5
	4000	2700	1,5
	5700	3800	1,5
	4000	3800	1,9
	2000	1800	1,2

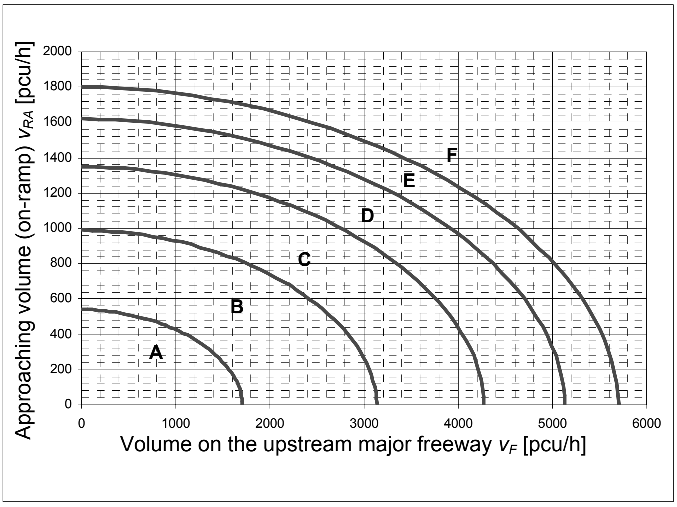


Figure 6 - An example for the definition of LOS (equation (29)) for merge segment with a 1-lane on-ramp to a 3-lane freeway

According to the equations (26) and (27), the LOS for the merge, diverge, or weaving segments can be defined depending on the traffic volume on the major freeway and the approaching or departing volumes on the ramps. As an example, Figure 6 shows a picture depicting the equation (27) for a merge segment with a 1-lane on-ramp to a 3-lane freeway. Similar pictures are constructed for all types of merge, diverge, and weaving segments in the proposed HBS 201X. The users can estimate the LOS directly by the use of those pictures.

5. Summary and conclusions

According to the probability and queuing theory, a new model considering the combined volume-to-capacity ratio for a whole freeway merge, diverge, or weaving segment is derived. The model has a uniform function for all types of freeway merge, diverge, or weaving segments. The LOS can be then assessed in one step for the three critical areas under consideration: a) on-ramp/off-ramp, b) major freeway upstream / downstream of the segment, and c) area of merge / diverge / weaving manoeuvres. According to the new model all boundary conditions can be satisfied. Furthermore, because of the simple model parameters, the new model can be easily calibrated. The new model delivers a very useful procedure for determining LOS at freeway merge, diverge, or weaving segments. This procedure will be incorporated in the new German Highway Capacity Manual (HBS 201X).

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