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Estimation of the Peak-hour Demand in the German Highway Capacity Manual

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Abstract

Traditionally, traffic count statistics in Germany contain the so-called relevant hourly volume, which is defined as the 30th-highest hour of the year when listing the hourly volumes in descending order. When the first edition of the German Highway Capacity Manual (HBS) was prepared in 2001, the Federal Government decided that this 30th hour should be used as the basis for the level of service determination for all Federal freeways and trunk roads. While German freeways are quite well equipped with inductive loop detectors, there are much fewer counts on rural roads and almost no long-term data on urban roads. With the current redraft of the German HBS detailed advice will be given on how to estimate peak-hour demand (all vehicles and heavy vehicle portion), based on the n-th highest hour concept depending on the available traffic counts. As the HBS will be divided into three major parts: freeways, rural roads, and urban roads, three separate chapters for the peak-hour demand estimation will be provided. Whereas for freeways the task consists in finding the comparable site equipped with inductive loop detectors, for urban roads it is a matter of establishing which time periods of the year and weekdays are appropriate for manual short-term counts as estimation of the 30th hour of the year. For all kind of traffic devices the requirements on traffic demand models for level of service calculations are described.

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Keywords: Demand; Peak-hour; Traffic counts; Road traffic census; Traffic demand models

1. Background

The former German design guidelines for cross-sections (RAS-Q, FGSV 1996) only defined that the user of the guidelines had to determine the relevant period (relevant hour group, commuter versus recreational traffic) of the traffic demand as the desired input to the cross-section determination. For practical applications it was further stated, as it had also been the case in former guidelines, that in regular cases the demand could be assumed to be 10 percent of the average annual daily traffic (AADT). Therefore, in the majority of the practical tasks engineers just used one tenth of the AADT to determine the traffic demand as a basis for the planning and design of road facilities.

When the first edition of the German Highway Capacity Manual (HBS 2001, FGSV 2002) was prepared in 2001, the concept of the n-th highest hour of the year listing the hourly volumes in descending order was introduced to determine the traffic demand. The Federal Government decided further that the 30th hour should be used as the basis for the level of service determination for all Federal Freeways and trunk roads. The reason for this decision

was that the 30th highest hourly volume coincides with the so-called relevant hourly volume (MSV) that traffic count statistics in Germany traditionally contained.

When the n -th highest hourly volume of the year is the basis to determine the level of service (LOS), it can be ensured that the facility under consideration does not exceed the desired LOS in up to $n-1$ hours of the year. It therefore allows for an improved reliability of the analysis.

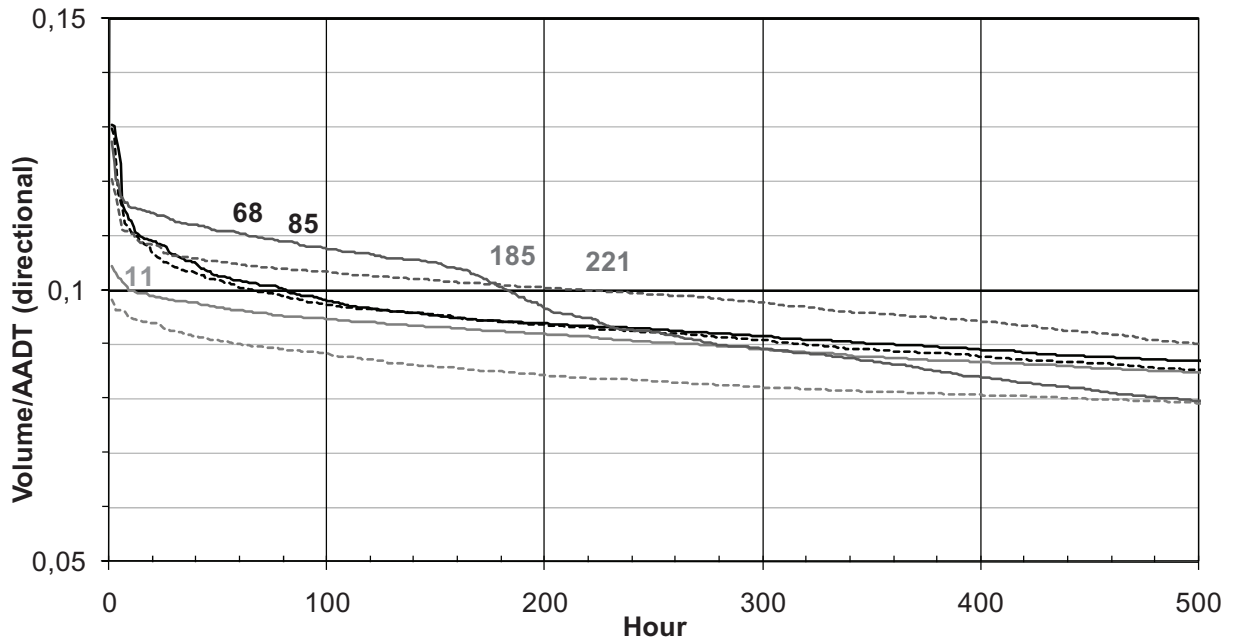


Figure 1: Set of examples of the 500 highest hourly volumes of a year (freeway sections with 2 lanes per direction and an AADT around 30000 veh/day)

Figure 1 shows the 500 highest hourly volumes of different freeway carriageways with 2 lanes per direction and around 30000 vehicles per day. The light gray continuous line represents a commuter freeway with inbound traffic where even the highest hour of the year does not reach the 10 percent of the AADT. In the opposite direction (light grey dotted) 10 percent of the AADT is reached in the 11th highest hour of the year. The black lines are from a freeway with very high volumes during recreational traffic in less than 20 hours of the year. Here 10 percent of the AADT is experienced in the 68th and 85th hours respectively. Finally, the dark grey lines represent a rural freeway with some recreational peaks where 10 percent of the AADT is counted in the 185th and 221st hours respectively. This small example illustrates that the simple use of 10 percent of the AADT to determine the traffic demand doesn't allow for any knowledge about the number of hours with a LOS worth than the one determined. On the contrary, the concept of the n-th highest hourly volumes leads to a clear limitation of the period of the years with a LOS worse than desired.

When the concept of the n-th highest hour was introduced in 2002, some concerns about how to determine the n-th or the 30th highest hourly volume of the year arose. Whereas for freeways the task consists in finding the comparable site equipped with inductive loop detectors, for urban roads there are almost no permanent counts available. In the following, the suggestions for the current redraft of the German HBS are presented. In the HBS detailed advice will be given on how to estimate peak-hour demand (all vehicles and heavy vehicle portion), based on the n-th highest hour concept depending on the available traffic counts. As the HBS will be divided into three major parts: freeways, rural roads, and urban roads, three separate chapters for the peak-hour demand estimation will be provided.

2. Demand for freeway facilities

The basis for the assessment of all kinds of freeway facilities (basic freeway segments, freeway merge, diverge, or weaving segments) in the German HBS (either the last edition from 2002 or the current draft) is the traffic demand in a 60-minute period. The measure of effectiveness is the volume-to-capacity ratio. As the capacity is highly influenced by heavy vehicles, the share of heavy vehicles must also be provided. Heavy vehicles are defined as trucks with more than 3.5 tons total permitted weight, trailers, and buses. All other vehicle types as passenger cars, light trucks up to 3.5 tons, passenger cars with trailers and motorcycles are counted as so-called light vehicles as to say similar to passenger cars.

The German freeway network is more than 12,500 km long and it is equipped with more than 600 permanent traffic counting sites for statistical reasons (FITSCHEN, NORDMANN, 2009). Furthermore, several other inductive loop detectors are integrated in active traffic management systems. The statistical counting sites are placed in such a way that at least each branch of the network is equipped with one set of inductive loop detectors. Therefore, it is possible to assign a representative counting site to each basic freeway segment. The AADT is estimated for all basic freeway segments based on the German road traffic census (manual counts) every 5 years (KATHMANN et al. 2007/2009). The directional demand of the n-th hour on a freeway segment expressed as hourly volume v_n can then be calculated on the basis of the AADT from the last road traffic census and the representative permanent count as follows:

$$v_{n,Y} = \frac{v_{n,C,Y}}{AADT_{C,Y}} \cdot AADT_Y = \frac{v_{n,C,Y}}{AADT_{C,Y}} \cdot \frac{AADT_{C,Y}}{AADT_{C,Y-i}} \cdot AADT_{Y-i} = v_{n,C,Y} \cdot \frac{AADT_{Y-i}}{AADT_{C,Y-i}} \quad (1)$$

With $v_{n,Y}$ = directional volume at n-th hour of the year as basis for LOS determination in year Y , veh/h
 $v_{n,C,Y}$ = directional volume at n-th hour of the year at a representative count site C in year Y , veh/h
 $AADT_{Y-i}$ = directional average annual daily traffic in year of last manual count $Y-i$, veh/d
 $AADT_{C,Y-i}$ = directional average annual daily traffic at a representative count site C
in year of last manual count $Y-i$, veh/d

This kind of analysis has been performed for the entire freeway network and traffic data from 2007 by the Federal Highway Research Institute (BASt) as shows figure 2. The results could form the basis for any LOS determination in the existing freeway network.

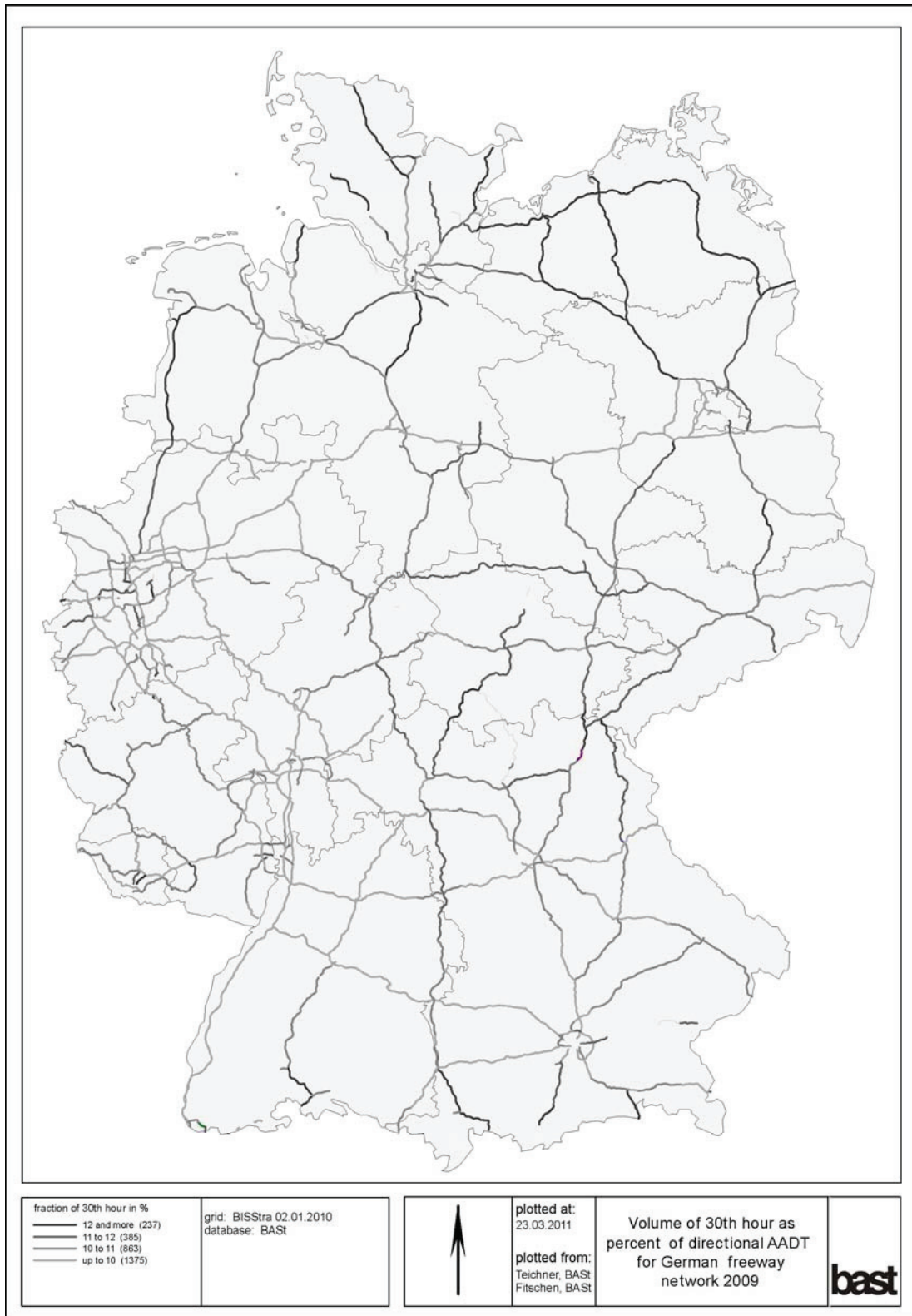


Figure 2: Volume of 30th hour as percent of directional AADT for German freeway network in 2007 (estimations by BASt)

Traffic demand models have to be applied when future freeway facilities are to be assessed or structural changes within the network or the demand are expected. Assignment models on a national level are usually performed based on average weekday daily traffic AWDT. In this case K-factors have to be derived from representative count sites.

In summary it can be stated that because of the huge number of permanent count sites in the German freeway network, it is fairly easy to estimate the demand defined as the n-th highest hourly volume of a year. This value then forms the basis for the LOS determination described in the German HBS.

3. Demand for facilities of rural roads

The basis for the assessment of all kinds of automotive facilities of rural roads (2-lane/2+1-lane highways as well as signalized and unsignalized intersections) in the German HBS (either the last edition from 2002 or the current draft) is the traffic demand in a 60-minute period. The measure of effectiveness is the density for segments and the delay for intersections. As the traffic flow is highly influenced by heavy vehicles, the share of heavy vehicles must also be provided. Heavy and light vehicles are defined as for the freeway facilities. For intersections a further distinction between longer and shorter heavy vehicles may be provided but this is not strictly required.

The German rural road network consists of around 40,000 kilometers of Federal trunk roads and more than 190,000 kilometers of rural roads under the responsibility of regional or local road authorities. The BAST analyses more than 700 permanent count sites within the Federal network for statistical reasons. In the rest of the network only very few inductive loop detectors are available. The manual counts within the road traffic census taking place every 5 years are performed only partially. When these data are available, the demand may be estimated similar to freeways. But in many cases special counts are necessary to assess the quality of service of existing or future rural road facilities.

The German road traffic census with manual counts every 5 years follows a systematic framework to determine a set of parameters for each segment (cf. KATHMANN et al. 2007/2009). For segments with an AADT of 7000 vehicles per day or higher volumes the traffic is counted during a total of 28 hours spread over normal weekdays, Fridays, holidays, and Sundays. For segments with lower volumes traffic counts are limited to a total of 18 hours (without Fridays). The idea behind the manual counts is to determine the AADT with less than 5 percent error rate for all segments. The estimation of the parameters follows the idea of a synchronized behavior between permanent count sites and the manual counts sites. In other words, some key parameters are estimated for both manual and automated count sites. Then, functions to estimate the AADT and other desired values are calibrated using data from permanent counts and are then applied to the manual count data. The volume of the 30th highest hour of the year, the so-called MSV, was not used in the past and was, therefore, only of minor interest for the road traffic census. Up to 2005 the volume of the 30th highest hour (MSV) was only reported for the dominant direction as a fixed share of the estimated value for the total cross section.

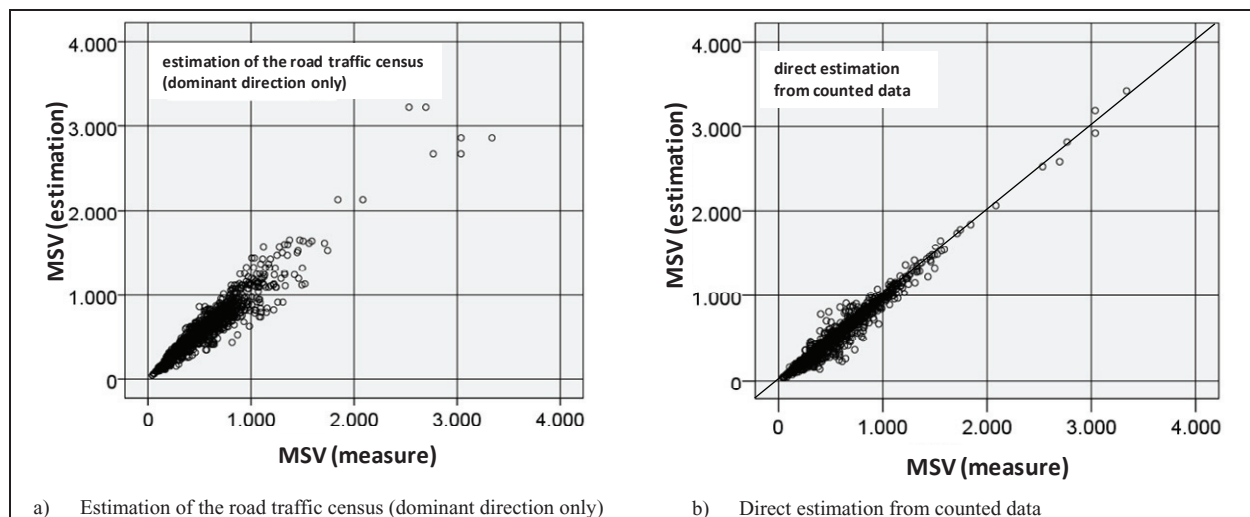


Figure 3: Accuracy of the MSV for the dominant direction (ARNOLD et al. 2010)

Figure 3 shows the traditional estimation of the MSV for the road traffic census (a) as well as a direct estimation from the counted data (b). It clearly demonstrates that the use of the maximum hourly value of the counted data as the estimation of the MSV is already quite good although it slightly underestimates the MSV for low volumes. The aim of the ongoing research by ARNOLD et al. (2011) is to improve the estimation of the MSV for the 2010 road traffic census. The final results of the manual counts 2010 are expected to be published by the end of 2011.

As in this case the concept of the redraft of the next HBS is to estimate the 30th highest hourly volume based on the maximum volume during a well selected counting period. ARNOLD et al. (2011) analyzed two different approaches: (a) an automated counting (e.g. by radar) for a week and (b) a manual counting over one or few days. They distinguish between (1) segments serving predominantly business travel and (2) segments with significant recreational traffic. In the first case a week between end of March and end of October (summer time) without holiday influence is appropriate for the counts. Short term counts should be conducted on Tuesday till Thursday (6 to 8 a.m. and 3 to 6 p.m.) or on Friday (noon to 7 p.m.) if predominant. On segments with dominant recreational traffic it is recommended to count in July or August on Saturdays and Sundays between 9 a.m. and 7 p.m. when typical conditions are expected. April to June or September and October are also possible although less recommended. ARNOLD et al. (2011) derived a set of correction factors which are to be applied to the maximum hourly volume within the counting period.

Table 1: Correction factors for maximum hourly volume of count period in summer time on segments serving predominantly business travel (ARNOLD et al. (2011))

Predominant weekday	Count interval					
	Week			day		
Hour	30th	50th	100th	30th	50th	100th
Monday to Thursday	1,01	0,98	0,94	1,10	1,07	1,02
Friday				1,06	1,00	0,95

Table 2: Correction factors for maximum hourly volume of count period on segments with significant recreational traffic (ARNOLD et al. (2011))

Predominant season	Month of count	Count interval					
		Week			Day		
	Hour	30	50	100	30	50	100
None	July –August	1,06	0,99	0,89	1,10	1,03	0,93
	Apr-Jun + Sep-Oct	1,08	1,01	0,91	1,16	1,08	0,98
Winter	July –August	1,36	1,24	1,08	1,41	1,29	1,12
	Apr-Jun + Sep-Oct	1,42	1,30	1,12	1,50	1,36	1,22
Spring	July –August	1,14	1,06	0,93	1,24	1,14	1,01
	Apr-Jun + Sep-Oct	1,09	1,00	0,88	1,21	1,12	0,99
Summer	July –August	0,97	0,91	0,82	1,05	0,98	0,88
	Apr-Jun + Sep-Oct	1,28	1,19	1,08	1,39	1,30	1,17
Autumn	July –August	1,18	1,10	1,01	1,25	1,17	1,07
	Apr-Jun + Sep-Oct	1,12	1,04	0,95	1,25	1,16	1,06

Traffic demand models have to be applied when future rural road facilities or with substantial changes in demand are to be assessed. Assignment models performed on the basis of volumes in a 60-minute or up to 4-hour period are recommended for all rural road facilities in order to take the direction of the volumes into account. Models based on the average annual daily traffic AADT may be used for segments only. If the period of the model is larger than 60 minutes, peak hour factors have to be derived from representative count sites. More detailed information and the requirements on traffic demand models for level of service calculations in general are described in chapter 5.

4. Demand for facilities of urban road facilities

The basis for the assessment of all kinds of automotive facilities of urban roads (urban arterials as well as signalized and unsignalized intersections) in the German HBS (either the last edition from 2002 or the current draft) is the traffic demand in a 60-minute period. At intersections the delay for pedestrians and cyclists is calculated for a 60-minute period, as. On the contrary, for separate bicycle facilities a 15-minute period and for separate pedestrian facilities a 2-minute period has to be determined. The measure of effectiveness is the density for segments and the delay for intersections. For bicycle facilities and for pedestrian facilities the density is the measure of effectiveness, too. As the traffic flow of automotive facilities is highly influenced by heavy vehicles, the share of heavy vehicles must also be provided. Heavy and light vehicles are defined as for the freeway facilities. Again for intersections a further distinction between longer and shorter heavy vehicles may be provided.

On urban roads in Germany permanently working inductive loop detectors are more the exception than the rule. When these data are available, the demand may be estimated similar to freeways. But in most cases special counts have to be conducted to assess the quality of service of existing or future urban road facilities. These counts ought to take place between end of March and end of October (summer time) on a Tuesday, Wednesday, or Thursday. Weeks with holiday influence ought to be excluded. For these counts two 4-hour counting periods that include peak traffic are recommended. ARNOLD et al. (2007) compared different counting periods. They calculated an average absolute value of the relative error for the estimation of the demand of 4 percent for 8-hour data compared to 17.2 percent for a 4-hour count. The periods are recommended as follows:

- 6:00 to 10:00 a.m. (alternatively 6:30 to 10:30 or 7:00 to 11:00) and
- 15:00 to 19:00 p.m.

The volumes are aggregated to 15-minute periods. Then, the four following intervals with the highest volume in sum are determined. This represents the estimation of the demand in the 30th highest hour of the year.

For future urban road facilities or structural changes in the network or the demand the application of demand models is necessary. Therefore, an analysis period of 60 minutes or up to 4 hours is recommended. The assignment of the AWDT is only acceptable if the LOS of segments are to be determined. If the analysis period is longer than 60 minutes peak hour factors have to be derived from existing facilities to estimate the demand for the further assessment (cf. no. 5).

5. Traffic demand models for level of service calculations

Traffic demand models usually consist of four different actions:

- trip generation
- trip distribution
- modal-split
- assignment (route choice)

Traffic demand models are necessary for existing facilities if changes in the transport system, in land use, and/or in traffic behavior are expected to substantially influence traffic demand. For new facilities traffic demand models are compulsory.

With respect to the assessment of the quality of service of planned road facilities based on the German highway capacity manual (HBS) the following requirements for traffic demand models are given:

- Light and heavy vehicles should be assessed in different model parts.
- Models always have to be calibrated using appropriate empirical data (e.g. travel time and length distributions, modal splits for different travel length and intersection movements) for each model stage. In a first step the existing situation must be modeled.

- The network model shall contain all the network elements and traffic origins and destinations within the influence area of the facility under consideration in sufficient detail.
- In order to estimate movements in junctions impedance functions for turning movements in nodes have to be included in the assignment model.
- In case of substantial changes in the structure of the network or the demand all four model stages must be calculated taking different trip purposes into consideration. Otherwise, the trip matrix may be adapted to new sums of origin and destination demand in a step-by-step process.
- In order to use as analysis period the peak hour or a few hours including the peak hour the assignment modeling should be performed for different trip purposes separately.

The quality of the model must be analyzed by the comparison of the empirical and the modeled volumes for the existing situation. As one possible indicator the so-called GEH-factor invented by Geoffrey E. Havers in the 1970s (cf. HIGHWAYS AGENCY, 2008) is presented:

$$GEH = \sqrt{\frac{2 \cdot (v_M - v_C)^2}{v_M + v_C}} \quad (2)$$

With v_M = volume from the traffic demand model, veh/h
 v_C = volume from the count, veh/h

Values of the GEH below 5 demonstrate a good correspondence. In case of values above 10 the model should be reanalyzed. The quality is acceptable if at least 85 percent of the counting sites show GEH-values below 5 and if the value of GEH remains below 4 for the sum of the volumes of all sites.

For existing facilities the demand is calculated on the basis of the changes between the model results for the future and the existing situation as follows:

$$v_{n,F} = v_{n,C} \cdot \frac{v_{T,M,F}}{v_{T,M,E}} \quad \text{OR} \quad v_{n,F} = v_{n,C} + (v_{T,M,F} - v_{T,M,E}) \quad (3)$$

With $v_{n,F}$ = future directional volume at n-th hour as basis for LOS determination, veh/h
 $v_{n,C}$ = counted directional volume at n-th hour, veh/h
 $v_{T,M,F}$ = future directional volume in time period T as model result, veh/time period
 $v_{T,M,E}$ = existing directional volume in time period T as model result, veh/time period

Both equations are used in practice and therefore, both are mentioned here. In case of new road facilities the result of the model serves as demand estimation. In case of greater analysis periods in the model than 60 minutes a peak hour factor is necessary to estimate the hourly demand volume:

$$v_{n,F} = K \cdot v_{T,M,F} \quad (4)$$

With $v_{n,F}$ = future directional volume at n-th hour as basis for LOS determination, veh/h
 K = volume of the n-th hour as portion of the volume in the analysis period T in the model, time period/h
 $v_{T,M,F}$ = future directional volume in time period T as model result, veh/time period

The K -factor has to be determined from empirical data for similar facilities with similar demand characteristics. Therefore, traffic counts according to the descriptions above are recommended.

6. Conclusions and further steps

The German Road and Transportation Research Association (FGSV) is currently working on a redraft of the German highway capacity manual (HBS). The final draft is expected to be completed by the end of 2011. Then the draft will be discussed between the federal states and the federal ministry in order to agree on a final version which then can be introduced by the federal ministry. For the implementation the question whether to apply the currently

used concept of the 30th highest hour of the year or change maybe to the 50th highest hour will be part of the debate. Investigations seem to show that difference between the 30th and the 50th highest hour are very small in most cases. But the few remaining cases require further analysis.

The chapters on demand are prepared in a sub-committee lead by the author of this paper. The draft for the demand on urban road facilities was approved by the corresponding FGSV-committee in October 2010. The other two chapters are not available yet as some additional research results of ongoing projects are to be incorporated into them.

Compared to the current edition of the HBS (FGSV 2002) the new chapters will provide more practical descriptions on how to estimate the needed traffic demand. For all kind of road facilities the existing data is taken into consideration when the procedures are described. This will lead to a higher quality of demand estimations as well as of quality of service assessments by reducing errors and uncertainties. Road planning and design will become more reliable.

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