HUMAN FACTORS FOR TRAFFIC OPERATION AT SIGNALISED JUNCTIONS

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ABSTRACT

Measuring Human Factors here means getting new input values for calculation of signal timing programs (for signal guidelines), capacities (for capacity manuals) or for simulation models. This presentation focuses on the changes in the saturation flow rates and time headway values. On straight-ahead lanes, saturation flow rates of between 2080 and 2236 vehicles/hour GREEN were counted, which were thus above the guiding value of 2000 vehicles/hour GREEN. The influences of the longitudinal inclination, the turn-off radii for drivers turning left or right and the influence of heavy-vehicle traffic on the saturation flow rates were investigated. When the time headway values were determined, a value of 1.8s/vehicle is an acceptable guiding value. An upgrade and various turn-off radii exerted varying influences. Those were transferred and used in the HBS 2001 (the German "Highway Capacity Manual") together with factors regarding the influence of the lane width and pedestrians. It is recommended to only use two factors out of the five at a time (in contrast to the HCM with up to nine factors). At the end of the decade, new measurements were made to up-date the factors in the new German guidelines, the HBS 2010. New diagrams show the new approaches.

1. MEASURING THE HUMAN FACTORS AT SIGNALISED INTERSECTIONS

Today in Europe, like twenty years ago, despite the ecological constraints there is still a clear trend towards increasingly powerful and bigger cars. New developments in automotive engineering are also resulting in many vehicles becoming lighter and faster. Reference should additionally be made to changes in traffic light engineering (e.g. shorter transition periods) and changes in the geometry of junctions. And there might be differences between drivers in towns and those in the suburbs and villages and even differences between regions. The way drivers deal with congestion, which is becoming increasingly common, can also have an influence on the traffic flow at traffic light installations. These factors may have led to a change in the behaviour of motorised road users, because in the end it is the human being, who interacts with the traffic signals, the car, the driver in front of him as well with the street design and reveals Human Factors. All those changes over the years can manifest itself in shorter rear-to-front distances in the waiting queue, in greater accelerations when pulling off, or in shorter reaction times and in shorter time headways when driving over the stop line.

For the purpose of describing those Human Factors, which characterise the traffic flow at signalised junctions in Germany, various measurements were made – in that large scale for the last time – in 1994 [1]. Those were made at 11 junctions and 69 lanes in the capital Berlin and surrounding smaller cities in order to provide information on possible changes in driving behaviour, and to answer the question as to whether the input values for calculation of signal programs (for signal guidelines), capacity of lanes (for capacity manuals) or for parameters for simulation models relating to traffic light control systems or traffic flow on streets should be updated. Many more junctions were passed with a specially equipped measuring vehicle.

The following were used for description of the traffic flow at signalised junctions:

- Distances in the waiting queue,
- Reaction times when pulling off,
- Displacement-time diagrams for pulling off and stopping,
- Speeds and accelerations when pulling off and stopping,
- Saturation flow rates and
- Time headway values with the time gap method.

Measurements were made with the aid of video cameras, induction loops and the equipped vehicle, so that up-to-date values might be obtained for these components. The distances and reaction times were determined off-line on the computer screen. The use of the measuring vehicle made it possible for the distance covered to be recorded at regular intervals. For determination of the efficiency of a lane in the approach area of a traffic light installation, use was made of both the point count and time gap methods.

Measurement of the distance from the front edge of the first stationary car to the stop line gave mean values between 0.63m and 1.54m. The weighted mean from these measurements (1.00m) can be regarded as a guiding value for practice.

A mean vehicle length of 4.50m per motor vehicle should be should be assumed. A value of 4.25m was found for the mean car length. If account is taken of the observed rear-to-front distance of 2.00m, the length of road occupied by one motor vehicle in the waiting queue (front-to front distance) can be assumed to be 6.50m. A value of 6.00m was specified in the RiLSA [2], the German signal guidelines 1992 edition, which was also translated into English.

The first vehicle in the queue generally pulls off before the start of the GREEN period. For a RED/AMBER period of 2s, mean values of between - 0.52s and 0.18s were established for this starting reaction time, which is referred to the start of the GREEN period. Drivers turning left or right who are not guided by signals start significantly later (0.05s to 0.49s). If there is a RED/AMBER transition signal, or if is of reduced duration, the starting reaction time increases. Thus, for a RED/AMBER period of 1s (which is now determined in the newest RiLSA edition 2010 [3]), a starting reaction time of 1.31s was established.

The mean values of the following reaction times (time between two successive vehicles pulling off) were between 0.78s and 1.10s. For the duration of 2s usual in Berlin for the RED/AMBER transition signal, a starting reaction time of 0s and a following reaction time of 1s for each following car can be assumed for the sake of simplicity.

In the course of drivers with a specially equipped measuring vehicle in the Berlin city area, displacement-time relationships were recorded for pulling off and stopping at several locations. The positions 1 to 10 were evaluated. Pulling off and stopping from the first position are significantly different from pulling off and stopping from positions further back, that is to say are more rapid, because driving is, in the main, uninfluenced by other vehicles. The displacement-time diagrams also differ from one another as far as the fifth position. There is also a clear tendency for vehicles at higher positions to require more time to cover the same distance.

For vehicles at the first position, the greatest acceleration when pulling off is, in the mean, $2.8 m/s^2$ (2.0s after starting), the mean deceleration when stopping is between $1.5 m/s^2$ and

2,1m/s^2. For pulling off from the second to the tenth position, a mean acceleration of 1.8m/s^2 was determined shortly after the start. For stopping at these positions in the queue, a mean breaking deceleration of 0.8m/s^2 should be reckoned with shortly before the vehicle comes to a standstill.

2. SATURATION FLOW RATES AND TIME HEADWAY VALUES

This presentation now only focuses on the changes in the saturation flow rates and time headway values and the difference between the two. Saturation flows rates can be gained through counting the vehicles crossing the stop line during the GREEN period. The time gap method leads to average time headway values at every position in the starting queue. With a given (average) time headway value the saturation flow can be determined as:

$q_S = 3600/t_H$

with q_S = Saturation flow [vehicles/hour GREEN] and
t_H = Time Headway (in a saturated lane) [s].

In the Berlin city area, on straight-ahead lanes, saturation flow rates of between 2080 and 2236 vehicles/hour GREEN were counted, which were thus above the guiding value of 2000 vehicles/hour GREEN given in the RiLSA [2]. The influences of the gradient (a reduction up to 11 % at an ascending gradient of 3%), the turn-off radii (a reduction up to 17% at a radius of 20 m for a left turn and a reduction up to 15 % at radius of 10 m for a right turn without the influence of pedestrians) for drivers turning and the influence of heavy-vehicle traffic on the saturation flow rates were also investigated. The reduction of the saturation flow as a function of the percental fraction of heavy-vehicle traffic in the total traffic has been represented by a regression curve (see figure 1) of the form $y = 0.83 \cdot e^{0.21\ HVT}$ with a high coefficient of determination (0.96).

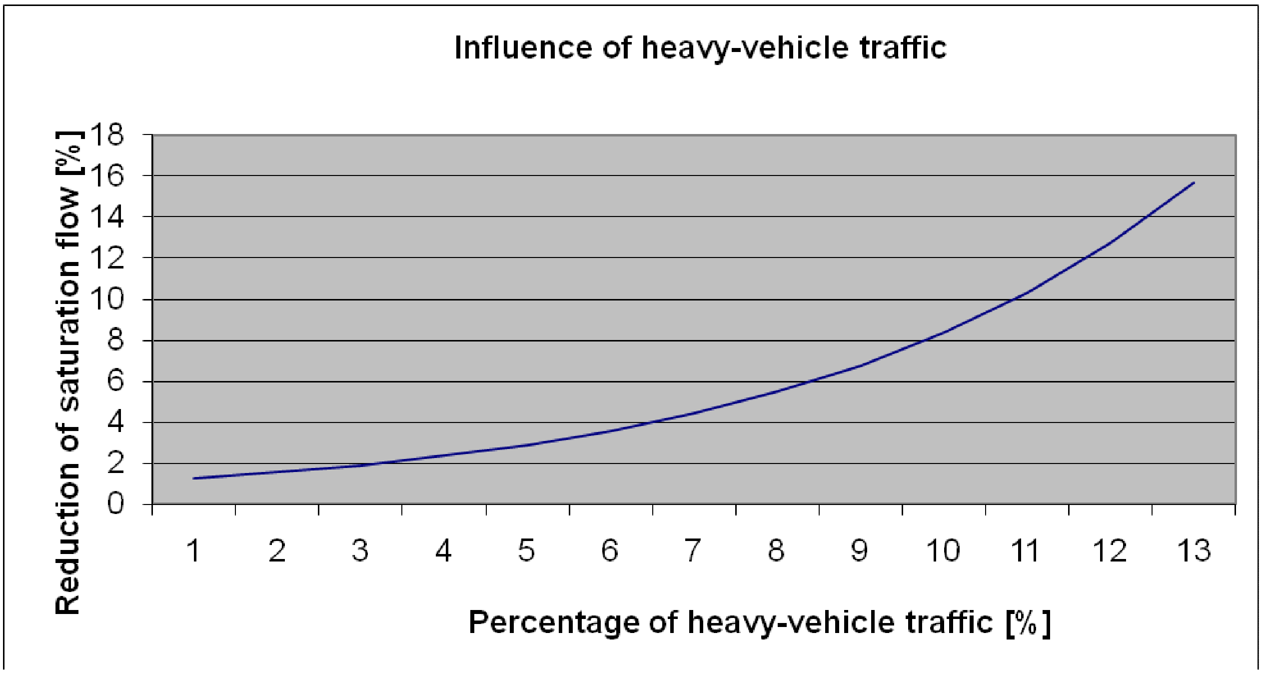

Figure 1 – Influence of heavy-traffic vehicles (after [1])

The measurement of time headway values – as the central input for the determination of the GREEN period at signalised junctions – with the time gap method goes back to the 1940s in the USA and is closely linked with the name Greenshields [4]. Before tubes and later on metal loops together with computers could be used in order to record the time headways, time recorders marked the headways with the help of hand held button contacts and ink pens on paper rolls.

If you look at the results of the average time headway values at every position in the line of cars starting after the GREEN signal, a very characteristic curve can be seen with the first car crossing the stop line quite early, but the next positions being slow at the beginning. With time passing, the following positions will cross the stop line faster and tend to go towards a constant time headway value (see figure 2 and table 1 for a special example):

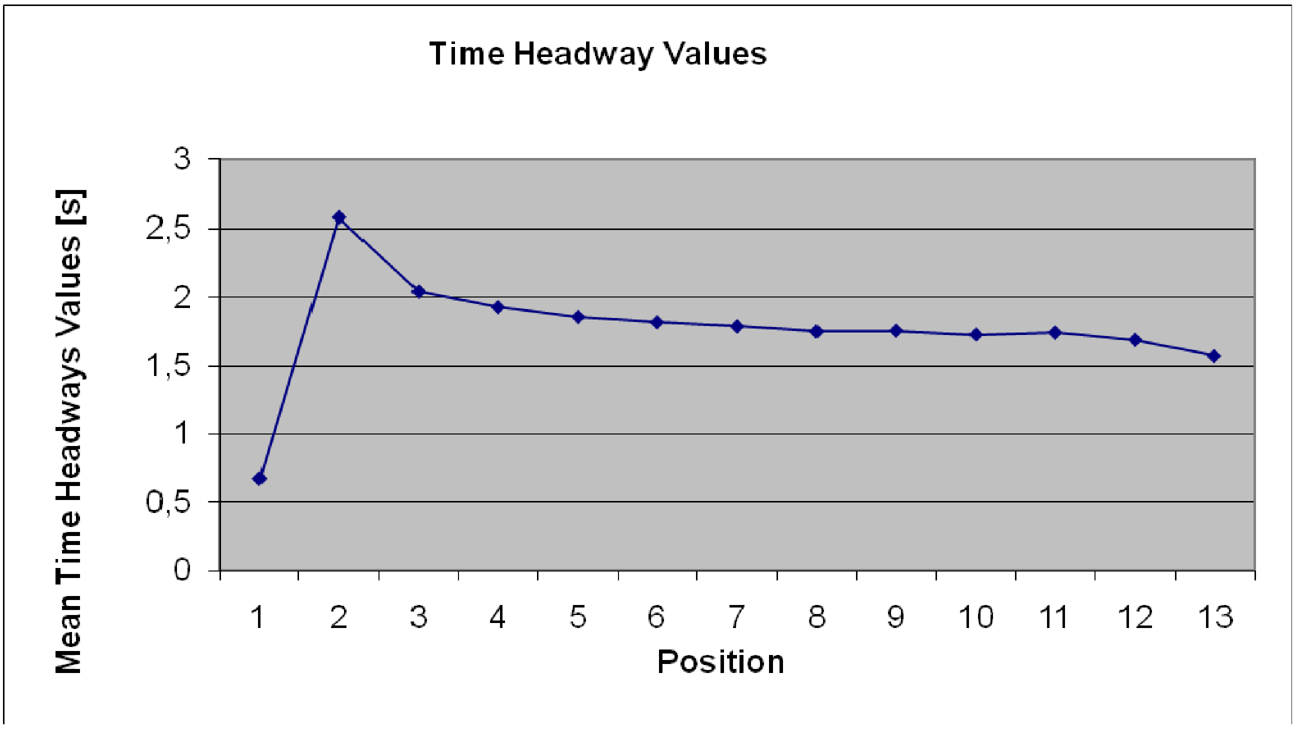

Figure 2 – The time headways at every position (after [1])

Position	Mean Time Headway [s]	Standard Deviation	Number N (sum = 10486)
1	0,677	0,905	1093
2	2,575	0,629	1049
3	2,042	0,551	1060
4	1,929	0,485	1022
5	1,857	0,517	969
6	1,818	0,517	915
7	1,788	0,523	874
8	1,751	0,517	826
9	1,757	0,511	751
10	1,729	0,514	684
11	1,743	0,496	574
12	1,691	0,490	432
13	1,572	0,452	237

Table 1 – The mean time headways at every position with standard deviation (after [1])

The following conclusions can be drawn from the measurements made with the time gap method with a mean value over all positions: At the Berlin measuring sites, a mean time headway value of 1.75 to 1.80s/vehicle should be assumed. So there were no significant changes, compared with older measurements, when the time requirement values were determined, a value of 1.8s/vehicle being an acceptable guiding value.

Various influences were analysed on the street: An ascending gradient (+ 0.1s at an incline of 3%) and various turn-off radii (up to + 0.3s for a radius of 20m for a left turn and a radius of 10m for a right turn) exerted varying influences.

Corresponding influences could not be established for a descending gradient or the turn into a roundabout. There were, however, differences between the different lanes of an approach road, and at different times of day. Different reasons for travelling (e.g. excursion traffic) and rain on the carriageway had only a very minor effect on the measured values.

It should, however, be observed that the time headway values calculated from the saturation flow rates are slightly lower: If the point count and time gap method are compared, it becomes clear that the time headway values (with the point count method) are approximately 0.1s smaller. Since, with both methods, account was taken of the drivers who drove through AMBER, this difference can be attributed to the dependence of the point count method on the duration of the GREEN period and an the fact that, with the point count method, only the GREEN period (without the AMBER period) is added, which led to higher saturation flow rates than 2000 vehicles/hour GREEN (see above). On the other hand the time gap method includes the slow cars at the first positions (i,e. number 2 until number 4, see figure 2).

If you observe saturation flows at very short GREEN periods (> 10s, see table 1), the share of the cars crossing the stop line at the AMBER period becomes enormously big.The result is a much bigger saturation flow rate and time headway value.

GREEN period [s]	Saturation flow rates [vehicles/hour GREEN]	Time Headway values [s/vehicle]
> 10	2000	1.8
10	2400	1.5
6	3000	1.2

Table 2 – Saturation flows and time headway values at a short GREEN period (after [5])

In measurements in the Land of Brandenburg, lower saturation flows were counted (between 1704 and 1998 vehicles/hour GREEN), which can possibly be attributed to a regional difference in drivers' reactions and driving styles The originally suspected influence of vehicle-specific characteristics of vehicles produced in the GDR (lower engine power output, lower acceleration) can be neglected, as only a very small fraction of such vehicles was observed at the selected measuring sites, four years after the German wall was torn down. In Potsdam, the value was between 2.02 and 2.07s/vehicle; in Oranienburg, it was 2.20s/vehicle.

If the Berlin measurement results are compared with older investigation results determined with the aid of the time gap method, no striking change in the mean values is seen. A change in behaviour can thus not be established.

3. THE GERMAN HBS 2001

The results for the factors regarding the heavy-vehicle traffic, the turning radii and the gradients were transferred and used in the HBS 2001 [5] (the German “Highway Capacity Manual”) as adaption factors together with factors regarding the influence of the lane width and the pedestrian traffic for the turning vehicles. It is recommended there to only use two adaption factors out of the five at a time (in contrast to the HCM [6] with up to nine factors). The idea of the saturation flow as a mean of comparing capacities and building a Level of Service (LoS) was thus introduced into a German guideline.

Influences		**Adaption factors**
Heavy-vehicle traffic	HVT < 2% HVT = 2…15% HVT > 15%	f_{HVT} = 1.00 f_{HVT} = $1\text{-}0.0083\ e^{0.21\ HVT}$ f_{HVT} = 1 / (1 + 0.015 · HVT)
Lane width	2.60m 2.75m ≥ 3,00m	f_W = 0.85 f_W = 0.90 f_W = 1.00
Radius	R ≤ 10m ≤ 15m > 15m	f_R = 0.85 f_R = 0.90 f_R = 1.00
Gradient	ascending + 5% + 3% plane 0% descending - 3% - 5%	f_G = 0.85 f_G = 0.90 f_G = 1.00 f_G = 1.10 f_G = 1.15
Pedestrians	strong medium weak	f_P = 0.80 f_P = 0.90 f_P = 1.00

Table 3 – Adaption factors for the saturation flow rates (after [5])

The saturation flow under the given circumstances equals

$$q_S = f_1 \cdot f_2 \cdot q_{S,\ st}$$

with

q_S = Saturation flow [vehicles/hour GREEN] under the given circumstances,
f_1, f_2 = Adaption factors and
$q_{S,\ st}$ = Saturation flow [vehicles/hour GREEN] at a standard situation (2000 vehicles/hour GREEN and no influences, no or a very small percentage of heavy-vehicle traffic).

In order to get own results for the saturation flows, it is recommended in the HBS to make own measurements at signalises junctions with saturated waiting queues. At least the cars during 20 intervals should be counted.

In 2005 extensive traffic measurements were carried out in the German city of Dresden (17 lanes at 11 junctions) to obtain saturation flow rates including influence factors [7]. The results correspond very well to the HBS 2001.

4. NEW MEASUREMENTS AND THE HBS 2010

But at the end of the first decade of the 21st century, new measurements of saturation flow rates [8] were made in the German city Darmstadt to up-date the guideline values and factors in the new German "Highway Capacity Manual", the HBS 2010 [9], like the draft version is called now despite the fact that it will be ready at the end of the year 2012. The saturation flow is determined with three factors including the adaption factor for heavy-vehicle traffic and new diagrams for the adaption factors (see figures 3-5) show the new approaches.

The saturation flow under the given circumstances equals

$q_S = 3600/t_H$

with $t_H = f_{HVT} \cdot f_1 \cdot f_2 \cdot 1.8s$,
$f_1 = \min(f_W, f_R, f_G)$ and
$f_2 = \max(1, f_G)$.

q_S = Saturation flow [vehicles/hour GREEN] under the given circumstances,
f_{HVT} = Adaption factor for heavy-vehicle traffic,
f_1, f_2 = Adaption factors,
f_W = Adaption factor for the lane width,
f_R = Adaption factor for the turning radius and
f_G = Adaption factor for the gradient.

f_1 is chosen among the smallest of the three adaption factors.

The new adaption factor for heavy-vehicle traffic equals

$$f_{HVT} = \frac{q_C + 1{,}75 q_{TB} + 2{,}5 q_{LT}}{q_{AV}}$$

with
q_C = number of cars [C/h]
q_{TB} = number of trucks and busses [TB/h],
q_{LT} = number of long trucks with trailers [LT/h] and
q_{AV} = sum of all vehicles [AV/h].

If only the number of all the heavy-traffic vehicles is known, but not the number of trucks, busses and long trucks in special, the adaption factor for heavy-vehicle traffic equals

$$f_{HVT} = \frac{q_C + 1{,}9 q_{HVT}}{q_{AV}}$$

with
q_{HVT} = number of heavy-vehicle traffic [HVT/h].

When it comes to calculate the GREEN period for every direction at the junction, the new HBS will take the cars crossing the stop line at the AMBER light into account: 1s has to be added to get the effective GREEN time ($t_{GP,eff} = t_{GP} + 1s$). The base capacity G [vehicles/hour] of a lane will then be $f \cdot q_S$

with $f = (t_{GP,eff}/t_C)$ and t_C as the signal circulation time.

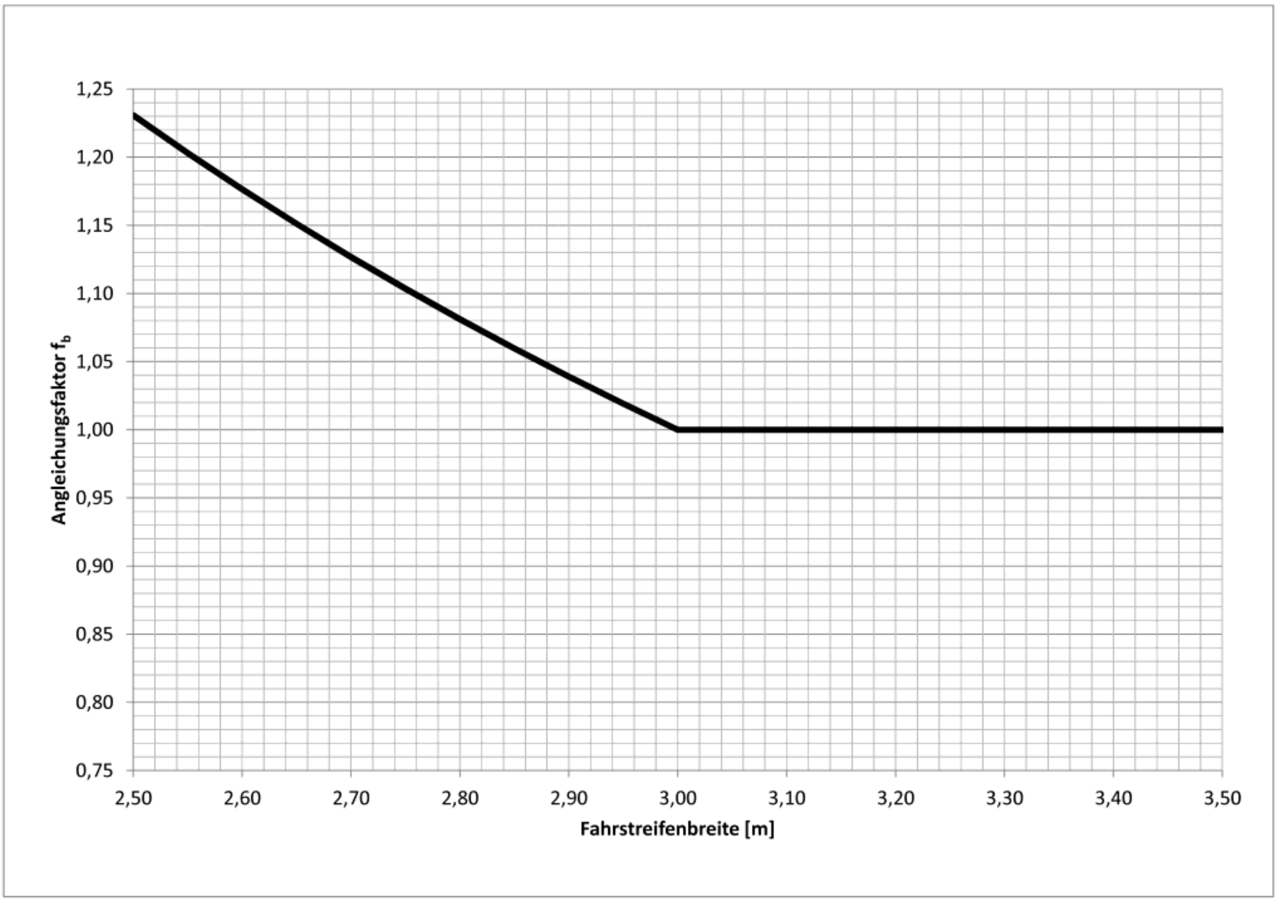

Figure 3 - Influence of the lane width (“Fahrstreifenbreite”, source: [5])

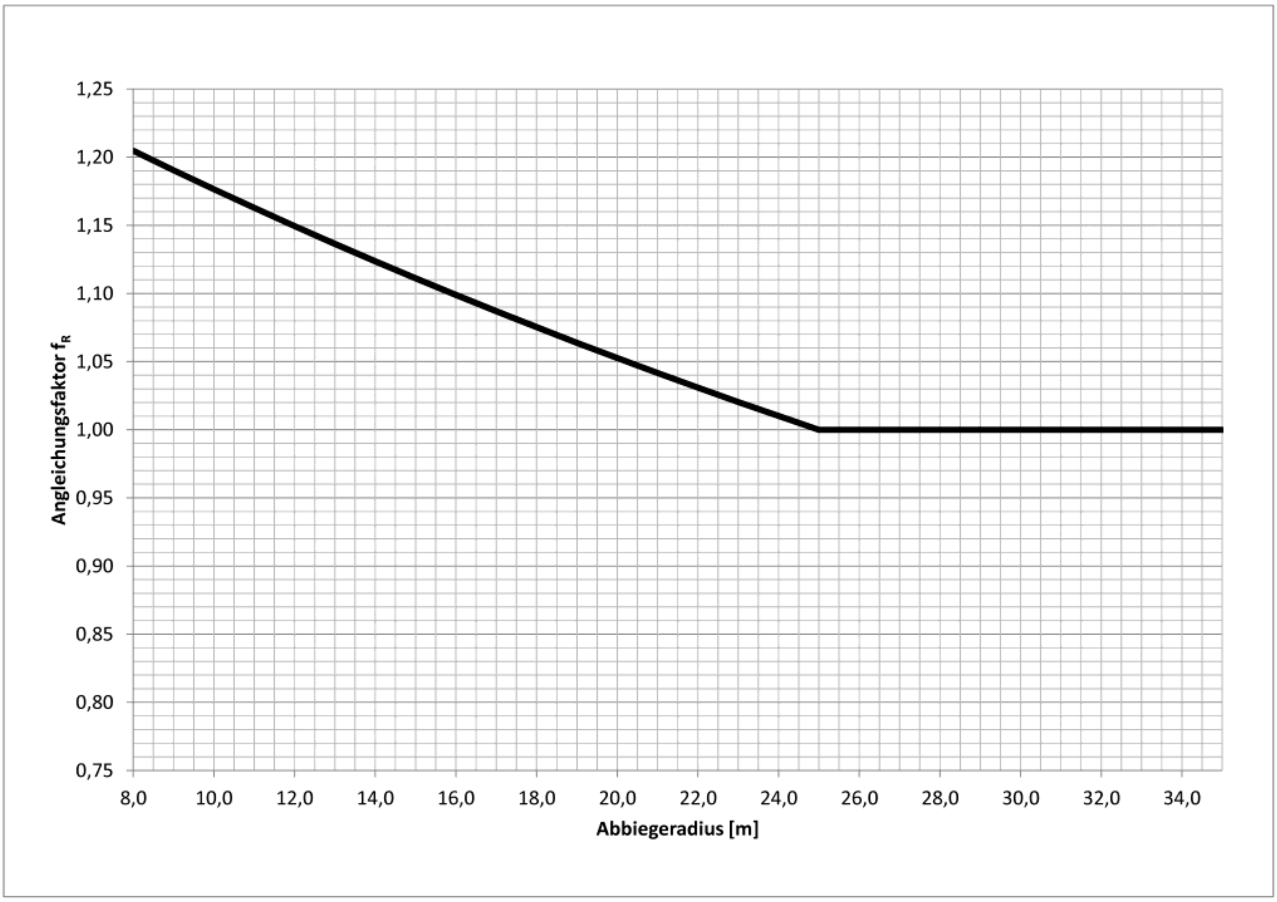

Figure 4 - Influence of the turning radius (“Abbiegeradius”, source: [5])

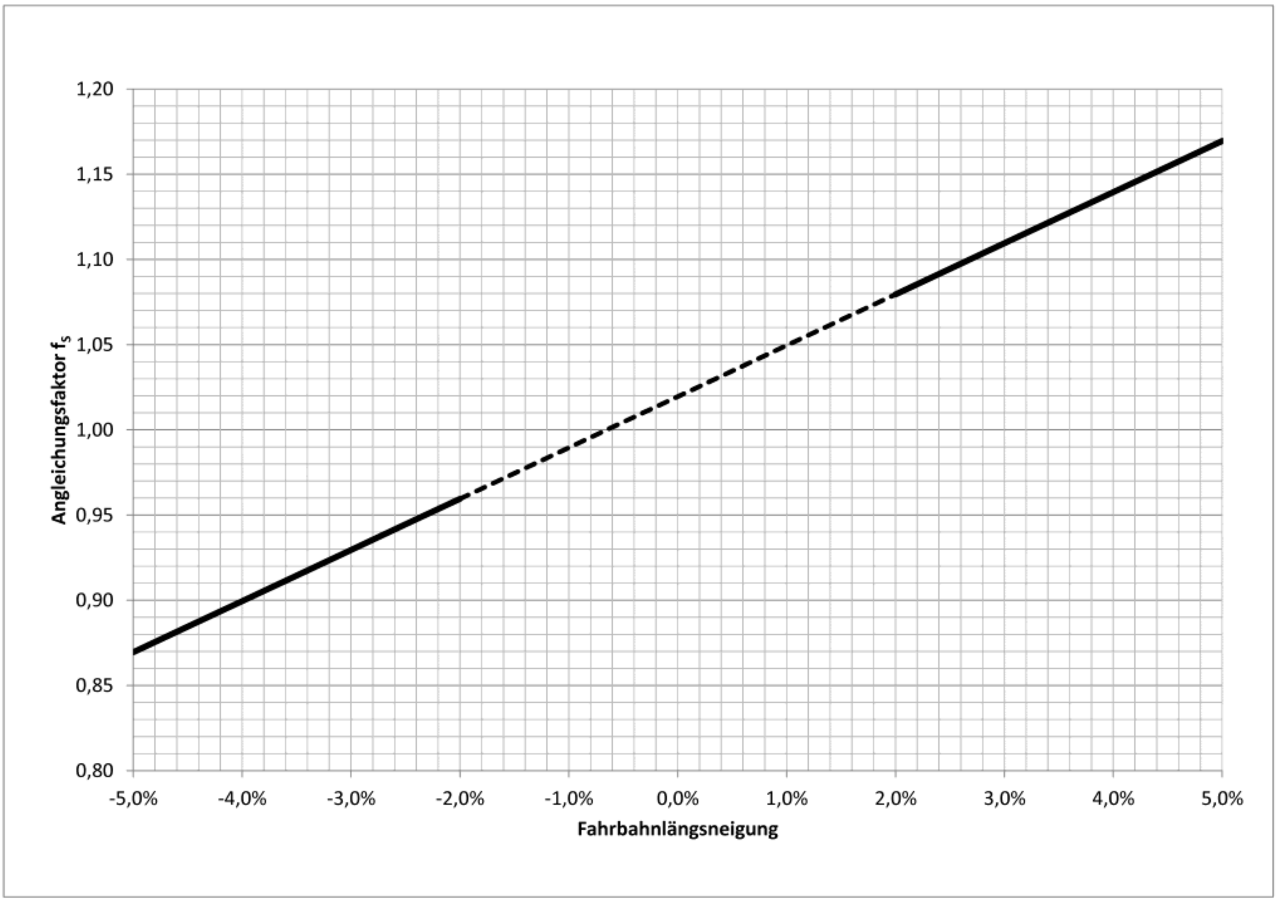

Figure 5 - Influence of the gradient (“Fahrbahnlängsneigung”, source: [5])

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