Determinant of the Existing Sight Distance and its Influence on the Speed on Highways

Borislav Hristov

Department of Engineering Sciences, University of Applied Sciences Berlin (HTW Berlin), Germany

E-mail: Borislav.Hristov@HTW-Berlin.de

Abstract. The main task of a high-quality road design is to provide the driver with a clear information about the course of the road at an early stage. The good visual guidance on highways is a prerequisite for adequate driving safety. Therefore, the sight distance has a significant impact on traffic safety, performance, speed behavior and driving comfort. At least the required stopping sight distance should always be guaranteed on highways, in order to ensure traffic safety and quality of traffic flow. The purpose of the stopping sight distance is to enable the driver to stop in time in front of an unexpected obstacle with a certain height on the road or in front of the end of a traffic jam. In addition, as a regulating element in road design, it is intended to ensure early driver information and orientation. The driver reacts to external influences by choosing the speed and changing it. Therefore, the speed parameter itself represents the best and most suitable evaluation criterion for driving behavior. In this paper, it has been succeeded to prove, that the existing sight distance exerts an influence on the speed on highways in Germany. A clear increase in the 85th percentile speed was determined with an increasing existing sight distance up to 400 m. At a sight distance above 400 m $V_{85}$ remained almost constant. An increase in the 15th percentile speed was only noticeable up to a sight distance of 300-350 m, after which $V_{15}$ remained at the same level.

1. Introduction

The main task of a high-quality road design is to provide the driver with a clear information about the course of the road at an early stage. The good visual guidance on highways is a prerequisite for adequate driving safety. According to the Road Traffic Act in Germany, drivers are obliged to adjust their speed according to the existing sight distance conditions. Therefore, the sight distance is an important design parameter, which has a significant impact on traffic safety, performance, speed behavior and driving comfort. It has a significant influence on traffic safety, performance, speed behavior and driving comfort. The existing sight distance varies depending on terrain, trees and objects beside the road etc. and differs from the required stopping sight distance, which should always be guaranteed on roads in Germany. The purpose of the stopping sight distance is to enable the driver to stop in time in front of an unexpected obstacle with a certain height on the road or in front of the end of a traffic jam. In addition, as a regulating element in road design, it is intended to ensure early driver information and orientation. The driver reacts to external influences by choosing the speed and changing it. Therefore, the speed parameter itself represents the best and most suitable evaluation criterion for driving behavior.
2. State of research and regulations

2.1. Road characteristics and driving behavior

Driving behavior can be understood as a uniform multi-layered control system (figure 1), which in road traffic is referred to as Driver - Vehicle - Road ([13], [14]). This system is to be understood as an ordered classification of influencing variables on the driving behavior. The driver reacts to external influences by choosing the speed and changing it through deceleration and acceleration. Therefore, the speed parameter itself represents the best and most suitable evaluation criterion for driving behavior.

Figure 1. Multi-layered control system Driver - Vehicle - Road.

2.2. Sight distance

With regard to the influence of the sight distance on the driving behavior, there are different opinions in the literature. In the investigations of [1] a clear dependence of speed on sight distance is determined on two lane roads. [2] observes that a low sight distance (< 300 m) is associated with a strongly inconsistent driving behavior of the faster traffic component. Larger sight distances result in a decrease of the road curvature and an increasing uniformity of the speed behavior can be observed. The effect of sight distance in its lower range is only critical if its impression contradicts the curvature. The influence of the sight distance itself is inconsistent and of varying relevance. According to [3], there is a clear drop in speeds below a sight distance of approximately 300 m. Furthermore, with decreasing sight distance, the difference between the speeds \( V_{85} \) and \( V_{15} \) is also reduced. [4] and [5] establish similar relationships between stopping sight distances and percentile speeds. [5] state that with decreasing average stopping sight distance the speeds and speed differences between \( V_{85} \) and \( V_{15} \) decrease, especially in the range between 300 m and 350 m. The variation between \( V_{85} \) and \( V_{15} \) is halved at a decrease of the average stopping sight distance from 300 m to 100 m (figure 2).

Figure 2. Relationship between average stopping sight distance and percentile speeds according to [5].
2.3. Analytical methods for determining the existing sight distance

The lateral sight distance along curves can be determined graphically (figure 3) as an envelope curve from beams between eye points and target points. Each line’s length is the calculated relevant stopping sight distance ([6]). The eye and target point heights are both 1.0 m on highways and lie in the axis of the own lane. The target point height is set for the recognisability of a vehicle at the end of a traffic jam.

![Figure 3. Graphical determination of the visual field according to [6]](image)

This procedure is based on the method developed by [7] to determine the existing sight distance, which [8] calls the visual field method. In this method, a line with a required minimum stopping sight distance length is stretched at regular intervals and thus enables the calculation of the required lateral visual field in the layout plan (figure 4). It becomes clear that the effort required to implement this method by hand is considerable.

![Figure 4. Sight rays in the layout plan according to the visual field method [7].](image)

In 1999, the sight beam method was further developed into the sight cone method by [9], which works completely spatially. Its accuracy depends mainly on the density of the cross section profiles and the level of detail of its processing with regard to the terrain modelling (figure 5). The sight rays from a point of view to all target points up to the decisive visible obstacle are combined as sight cones. In the mathematic sense, this spatial cone has no circular vertical intersection surfaces and does not have to be closed. With this method, not only individual sight rays are considered, but also the entirety of such spatial cones of sight generated from standpoints.

![Figure 5. Model sketch of the sight cone method in CARD/1 according to [10].](image)
The calculation of the existing sight distance is possible with CAD programs directly during the design. The prerequisite for this is a sufficiently accurate digital terrain model of the entire traffic facility as well as of the terrain with all possible obstacles reducing the sight distance.

2.4. Design model of the stopping sight distance according to the German design guidelines for highways RAA (2008)

The required stopping sight distance $S_h$ according to the German design guidelines for highways [11] is the distance required by a driver driving with the recommended speed to stop in front of an unexpected obstacle (e.g. the end of a traffic jam) on a wet road. The required stopping sight distance varies according to speed and longitudinal inclination (figure 7). It is a controlling dynamic design element in road design, which is integrated to ensure early driver information. It is therefore a design parameter, which is of decisive importance for traffic safety and quality of traffic flow and should always be guaranteed. Thus, it corresponds to the stopping distance of a freely moving vehicle and is composed of the distance during the reaction and impact duration $S_1$ and the braking distance $S_2$ (figure 6). The transmittable braking deceleration is assumed to be constant at 3.7 m/s$^2$ (braking without ABS). The average reaction and impact time in this model is 2.0 s.

In order to enable the drivers to orientate themselves in time about the course of the road ahead and thus to drive without increased attention requirements, 30% higher sight distance than the required stopping sight distance, the so called orientation sight distance, should be guaranteed for the respective design class. The values of the required stopping distance according to [11] are shown in figure 7 as a function of speed and longitudinal inclination. Positive values show an ascending inclination and negative values – a descending inclination.
3. Research methodology

3.1. Route selection and route characteristics

The A72 highway between the cities Hof and Chemnitz, which is one of the oldest highways in Germany, was chosen for this study. In the 1930s, the A72 was originally planned as a "corner connection" of the basic network routes Berlin - Nuremberg and Frankfurt - Dresden. The A72 was rebuilt between 1990 and 1995, with the axis and gradients closely following the original planning of the 1930s. Such upgrading of existing highways with a near-existing route, improved gradients (larger rounding radii, lower longitudinal inclinations) and improved cross-sections can lead to inconsistencies in the spatial alignment. In particular, insufficient sight distance, discontinuities and a danger of misinterpretation of the spatial elements can occur.

3.2. Determining the existing sight distance

The precise determination of the existing sight distance on the route was of primary importance for the present study. After basic preliminary considerations regarding the selection of a suitable design method, it was found that on motorways, the implementation of all possible in-situ methods was associated with many aggravating circumstances and in some cases was also practically impossible. For these reasons, the decision was made to determine the existing sight distance with the road design program CARD/1. An important prerequisite for the correct calculation of sight distance was the completeness of the survey data for the route parameters for the A72 federal highway, which were available as planning documents and, in some cases, in digital form. These data were imported into the CARD/1 program system. The first step was to create the axis in the layout plan from the state border to Chemnitz. As there were some missing points with their elevation data, these had to be recalculated by interpolations in order to create a complete closed digital terrain model (DTM). In a second step, the gradient with all tangent intersection points and rounding radii was generated from the axis. In the next step, the cross-sectional data for the entire section, which were provided by the Saxony Highway Authority, were entered into the program. Finally, the existing sight distance in both directions of travel was calculated. Eye and target point were located in the middle of the own (left) lane. The eye point height was set at 1.0 m and the target point height was 1.0 m as well.

Figure 8 shows an example of the sight distance in a left curve with R = 1000 m on a six-lane highway cross-section and a constant longitudinal inclination of 4.9% from two different eye points at a height of 1.0 m: in the right lane and in the left lane. Clearly visible is the better recognition of the curve from the right lane compared to the left lane.

Graphic sight distance bands were created for the whole route in both directions. The calculated existing sight distance was divided into classes of equal width (50 m). As the resolution of the human eye is limited and unmovable objects can be perceived at a distance of maximum 500 m, the calculated sight distances were limited at 500 m and the following 6 classes were defined:

- Class 1: existing \( S_h \leq 250 \) m
- Class 2: \( 250 \) m < existing \( S_h \leq 300 \) m

Figure 8. Left curve with R = 1000 m at constant longitudinal inclination \( s = 4.9\% \).
In order to investigate the influence of the existing sight distance on the speed behavior, it was necessary to measure the speeds of free moving vehicles.

### 3.3. Measurement methods for determining the speed behavior

The statistical value for a speed oriented to the driving behavior is the 85 percentile speed $V_{85}$. This is the speed which is not exceeded by 85% of the vehicles driving unhindered on a wet, clean road.

#### 3.3.1. Pursuit driving

In this method, a randomly selected vehicle was pursued along the entire route by a test person with the measuring vehicle. The random selection allows for a representative image of the total collective of vehicles. In order to exclude any influence on the speed choice, it is assumed that a time gap is maintained between the measuring and the tracked vehicle. A time gap of 3 to 4 seconds to the vehicle in front has proven to be favorable on highways. This distance should be kept as accurately as possible during the measurement run so that the speed of the vehicle being followed can be realistically represented. 12 measurements were carried out by 12 test persons on the entire route. In total, the speeds from the pursuit runs were recorded over a total length of 1344 km. The records from the pursuit runs were used to create speed profiles for each run over the course of the route. Subsequently the 15, 50 and 85 percentile speeds were calculated and plotted.

In order to check whether the speed distributions of the relatively small collective of pursuit drives fit into the distribution of speeds of a larger collective, cross-sectional measurements should be carried out at selected points on the highway for comparison.

#### 3.3.2. Cross section measurements

The speed behavior of free-moving vehicles was recorded with cross-sectional measurements at several fixed stations and could therefore be recorded on a much broader statistical basis and with less effort than with pursuit runs. The only possibility for the cross-sectional measurements were the bridge structures over the highway. In the present study, the speeds of approximately 150 vehicles per measuring point were recorded at three measurement cross sections, which was considered sufficient for the statistical verification of the speeds measured by the pursuit runs. The Wilcoxon test for paired samples was selected to compare the speed distributions from the two measurement methods. All local comparisons showed no significant differences between the speed distributions at the three measurement cross sections in both directions.

### 4. Presentation and interpretation of the results

#### 4.1. Results of the sight distance calculation

It is clear from the literature that the effective relevant existing range of vision on rural roads for the orientation of the driver is a maximum of 300 - 350 m. On highways, however, there are significantly larger existing sight distance ranges (figure 9) and because of the high speed level, larger required stopping sight distance ranges are calculated accordingly. Existing sight distances of up to 5000 m were often calculated. However, sight distance of this magnitude should not be considered relevant for perception and information reception in road traffic and does not influence driving behavior in any way. This limit, which corresponds to the greatest distance at which stationary objects can be perceived is 500 m as stated above.

Figure 9 shows an example of a sight distance band. It can be seen that even on highways there are many sections where the existing sight distance (blue line) is below the required stopping distance (turquoise line). Notice, that the required sight distance never reaches 200 m.
4.2. Results of the pursuit runs
The speed profiles for each individual trip in each direction were determined from the recordings made during the pursuit runs over the course of the route. Subsequently, the percentile speeds $V_{85}$, $V_{50}$ and $V_{15}$ were calculated. In addition, the speed differences between the speeds $V_{85}$ and $V_{15}$ were shown. The profiles were very detailed, as the speed values were available every 2 meters. Examples of different speed behavior on two sections with similar road characteristics, the one being with and the other without speed limit $V_{zul} = 130$ km/h, are presented here. From the example in figure 10 it is clear that due to the speed limit ($V_{zul} = 130$ km/h) in the section Pirk - Plauen-Süd the level of $V_{85}$ remains relatively constant. The $V_{85}$ speed profile shows that the permissible speed is exceeded by 4 km/h on average. The average, maximum and minimum speed differences over the entire section are 17.6 km/h, 28.7 km/h and 7.7 km/h respectively.

In contrast, the speed level in the section between the cities Treuen and Reichenbach, on which there is no speed limit, is significantly higher (figure 11). Although this section contains curves with relatively small radii, the $V_{85}$ speed even reaches 180 km/h. The differences between the slow and fast
driving vehicles are twice higher than on the section with speed limit. The average speed difference between the speeds $V_{85}$ and $V_{15}$ is 33.0 km/h over the entire section, the minimum value is 17.8 km/h and the maximum difference is 55.7 km/h.

![Figure 11. Speed profiles from the pursuit runs and speed difference ($V_{85} - V_{15}$) in the section Treuen – Reichenbach.](image)

4.3. Influence of sight distance on speed

As expected, the existing sight distance has an influence on the speed $V_{85}$. With increasing sight distance a clear increase in speed could be determined (figure 12). At a sight distance of less than 250 m, the average speed of $V_{85}$ is 144.4 km/h and up to a sight distance of 400 m it increases constantly. The speed $V_{85}$ is 10.4 km/h (7.2%) higher in the last class compared to the one at a limited sight distance under 250 m (class 1). At a sight distance over 450 m the $V_{85}$ speed remained almost unchanged compared to the sight distance of 400 m and no trend of increasing speed could be stated. For this reason, all sight distance ranges greater than 400 m were combined in the last class 5 and class 6 was removed (figure 12). An increase in the speed $V_{15}$ was only noticeable up to a sight distance of 350 m. Therefore, sight distances greater than 350 m have no influence on slow-moving vehicles.

![Figure 12. Influence of the existing sight distance on $V_{85}$ and $V_{15}$.](image)
5. Conclusions
A methodology for assessment of the speed and the existing sight distance on highways has been shown in this paper. It has been found, that the existing sight distance has a clear influence on the speed $V_{85}$ on highways. With increasing sight distance up to 400 m, a constant increase in speed could be determined. Furthermore, it has been stated, that an increase in the speed $V_{15}$ was only noticeable up to a sight distance of 350 m and sight distances greater than 350 m have no influence on slow-moving vehicles. It is therefore recommended, that city highways should be designed in a way to ensure a sight distance of at least 400 m in order to allow a constant traffic speed level and to increase traffic safety.

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