**4th International Symposium on Highway Geometric Design**
**Paper No. 31**

# Hard Shoulder Running as a Short-Term Measure to Reduce Congestion

Area: Operational and Safety Effects of Highway Design/Cross Section Design

by
Kerstin Lemke
Federal Highway Research Institute (BASt),
Brüderstraße 53,
D - 51427 Bergisch Gladbach, Germany
Phone: +49 2204 43-510,
Fax: +49 2204 43-683,
Email: Lemke@bast.de

Submission date: 2010-02-25
3,166 + 2,750 = 5,916 words

**ABSTRACT**

More than ten years ago the first pilot dynamic hard shoulder running (HSR) scheme was implemented on a German freeway section. Today around 200 kilometers are under operation. This paper presents the findings on road safety as well as on quality of service. These findings have been implemented in a method that enables planning authorities to make decisions on HSR on the basis of the evaluation of economic costs and benefits.

Accident data from road sections with dynamic HSR as well as with permanent HSR have been analyzed. The results show that hard shoulder running can lead to a safety level similar to regular cross sections as long as the prerequisites for such measures (lane width, speed limit, etc.) are taken into consideration.

Empirical data on traffic flow on different sections with dynamic HSR has also been analyzed in connection with the revision of the German Highway Capacity Manual (HBS). This investigation shows that capacity effects are not as substantial as when a regular lane is added.

In order to estimate the economic benefits of HSR compared to the existing cross section a model for the traffic flow over a whole year period was developed. The parameters of traffic flow were transferred to road user costs like vehicle operating costs, time costs and accident costs according to the German guidelines. For practical applications the model was implemented in a software tool provided to German road authorities.

## BACKGROUND

More than ten years ago in 1996 the first pilot dynamic hard shoulder running (HSR) scheme was implemented on a German freeway section on the A 4 freeway near Cologne (1). Based on the experience drawn from this scheme different possibilities to sign and mark such measures were discussed and systematically analyzed. As a result a set of new road signs (FIGURE 1) to direct road users to the hard shoulder was designed by the German Federal Highway Research Institute (BASt), was implemented in the German Road Traffic Regulations, and came into force in 2002.

In parallel, based on the experience of the pilot measures of permanent and dynamic hard shoulder running the Federal Ministry of Transport, Building, and Housing defined a set of guidelines for the implementation of such measures (2). These guidelines contain a set of model design plans showing signing and marking of HSR under different circumstances.

- In accordance with the German Highway Capacity Manual (3) it has to be demonstrated that level of service D could not be reached during peak hours.
- For the heavy vehicle lanes a width of at least 3.50 m has to be provided and at least of 3.25 m for the other lanes. The load capacity of the hard shoulder has to be proven.
- Emergency refuge areas have to be located at intervals of 1000 meters.
- When HSR is intended to run through junctions, additional lanes have to be provided in merge areas.
- In accordance with the General Administrative Instruction concerning the German Road Traffic Regulations for dynamic HSR a speed limit of 100 km/h has to be established. If restriping leads to lane width less than 3.50 m, this speed limit is also advisable in times without HSR.
- When paved shoulders are converted into travel lanes by restriping a speed limit of 120 km/h should be taken into consideration
- Prohibition of overtaking could allow for rescue services to pass through in case of emergencies

Key element of the guidelines is a cost-benefit analysis of all planed measures of HSR and the agreement on the plans with the Federal Ministry of Transport, Building and Housing. Based on the evaluation of the pilot schemes of HSR on the A 4 freeway and some other sections with converted hard shoulders, a framework to assess the economic effects of such measures was developed (4). The framework compares the economic benefits of HSR to the existing cross section by modeling the traffic flow over a whole year period. The model describes free flow as well as congested flow according to the shock wave theory. The parameters of traffic flow are transferred to road user costs like vehicle operating costs, time costs and accident costs according to the German guidelines. For practical applications the model was implemented in a software tool provided to German road authorities which enables the planner to estimate the cost-benefit ratio of a planned measure quite easily. The software allows to change the assumptions whenever new empirical results are available.

## RECENT FINDINGS ON ROAD SAFETY

### Methodology

While the effects of HSR on traffic flow could be described on a reliable basis already shortly after implementation of the pilot schemes, the period under review was too short to develop

consistent results on the safety effects. Therefore, assumptions concerning road safety of HSR had to made when developing the economic assessment framework. An earlier study analyzing road safety with and without shoulder came to the result that without hard shoulder the number of severe personal injury accidents was significantly higher compared to those sections with hard shoulder (5) although the analyzed sections differed in many respects from the sections with planned HSR. At that time somehow pessimistic assumptions were made on the safety effects of HSR as shows TABLE 1.

Therefore, the analysis of road safety on the A 4 freeway with dynamic HSR as well as on the A 6 freeway with converted shoulders continued in a further study (6). A dynamic HSR was perceived as more promising, therefore, two sections on the A 7 freeway in the north of Germany were included in the study. Sections with active traffic management such as overhead gantries to show variable speed limits were excluded from the study to minimize influencing factors.

The starting point of the analysis formed accident data gathered from the responsible police departments for the treatment sites as well as for other reference sites upstream and downstream of the treatment site or in the opposite direction both before and after the HSR implementation. Wherever possible, original handwritten accident report forms were copied. The accident coefficients were estimated separately for accidents involving injury and fatality and property-damage-only (PDO) accidents. Unfortunately, in some areas other PDO accidents do not have to be kept on file by the police.

**Road safety of individual HSR measures**

On the A 4 near Cologne the hard shoulder of a 1.59 km long freeway section is activated in response to traffic volumes as a running lane usually between 6 and 10 a.m. The section is provided with one emergency refuge area. The speed is limited to 100 km/h during the whole day. Travel lanes had to be narrowed to 3.25 m. The shoulder width is 3.50 m. The annual average daily traffic (AADT) exceeds 40000 vehicles per day with almost 10 percent of heavy vehicles.

Accident rates and accident cost rates of the treatment section generally show lower values than those of the upstream and downstream section although they seem to have risen strongly in the last year. As the section is quite short and hard shoulder is opened only a few hours a day the results are not stable enough to derive general conclusions from this case. Therefore, and because of a major work zone downstream the data analysis stopped in 2000.

As a direct result of the HSR the number of collisions between heavy vehicles on the right travel lane and passenger cars on the hard shoulder increased where the heavy vehicles changed lane to the right. In case of regular travel lanes a continuous line between both lanes would help to avoid such situations.

On the A 6 hard shoulders of in total 4 sections were permanently converted into running lanes by restriping. The originally 12 meter wide roadway was restriped in such a way that 3.25, 3.40, and 3.50 m wide lanes were developed from left to right. On the treatment sections Walldorf (5.5 km) and Neckarsulm 1(11.8 km) the unpaved shoulder could be converted in a hard shoulder up to 3 m wide. The treatment sections Neckarsulm 2 (9 km) and Weinsberg (8 km) were provided with emergency refuge areas only. On sections with hard shoulder the speed limit is 120 km/h. On sections with emergency refuge areas it is limited to 100 km/h. The AADT is close to 45000 vehicles per day with heavy vehicles exceeding 20 percent.

Looking at the accident development three out of four sections show a decrease in accident rates concerning fatal and injury accidents as well as PDO accidents (FIGURE 3). Local authorities explain that on section Weinsberg a high-risk road site with extremely high accident rates involving heavy vehicles was under review and therefore this section was excluded from further analysis. Apparently on the other three sections a similar accident rate was reached by the treatment independently of the design and control characteristics.

The A 7 freeway is characterized by commuter traffic to and from Hamburg as well as recreational traffic during summer holidays. Here hard shoulders on three sections in direction to the north (leaving Hamburg) are activated in response to traffic volumes as running lanes. In 2001 the section Quickborn (10 km) was provisionally provided with HSR during holiday traffic. In 2002 this section as well as the one in Neumünster (14 km) was equipped with the necessary facilities. In 2004 the Quickborn section was extended to Kaltenkirchen (additional 12 km). The locations of the emergency phones were converted into emergency refuge areas. The 11.50 m wide roadway had to be restriped. This was done in Quickborn and in parts of Neumünster in such a way that lanes with width of 3.50, 3.80, and 3.60 m were developed. Near the city of Neumüster the section was only partly restriped so the hard shoulder is only 3.45 m wide including the marking. Contradicting the General Administrative Instruction concerning the German Road Traffic Regulations local authorities set a speed limit of 120 km/h during HSR. The AADT reaches up to 35000 vehicles per day. The portion of heavy vehicles is between 10 and 15 percent.

With respect to road safety two (Quickborn and Kaltenkirchen) out of the three sections experienced normal accident numbers already before the implementation of HSR (FIGURE 4). Here a slight improvement or no change were observed. The road safety on the third section (Neumünster) could not demonstrate a similar effect. Although the safety level improved slightly it is still above average. Probably the narrow lanes and the high density of junctions still cause too many accidents.

Accidents that could directly be related to HSR are rare on all treatment sections.

**General Conclusions on Road Safety of HSR**

In order to derive general conclusions on road safety of HSR, as a first step, accident data of the A 6 with hard shoulders permanently converted in running lanes was analyzed. This data shows the most stable results because the measure is not restricted to only few hours of the day and the sections are quite long. FIGURE 5 allows for a comparison of accident rates before and after the implementation of HSR on the A 6.

As explained before treatment section Weinsberg was excluded from the further analysis. The three other HSR sections indicate a significant decrease of accident rates in accident group II (slight injury accidents and severe PDO accidents) while in accident group I (fatal and severe injury accidents) no change is detectable. In contrast to this the reference sections upstream, downstream, or opposite to the HSR sections were characterized by a higher safety level before the implementation of HSR which doesn’t experience the same improvement as on the HSR sections. In any case, the most striking result is that the safety level of all three HSR sections especially for accident group II is very similar with an average accident rate of 0.13 accidents per 1 million vehicle-kilometers independently of the safety level before the implementation of the measure. The corresponding average value for accident group I is 0.03 accidents per 1 million vehicle-kilometers.

These results were compared to accident data from the dynamic HSR on the A 7 although data was extracted from different years. The examination of accident rates before and after the implementation of HSR on the A 7 (FIGURE 6) indicates no significant change in accident group I. For accident group II the safety level on the sections Quickborn and Kaltenkirchen was below 0.13 accidents per 1 million vehicle-kilometers already before the implementation of HSR and does not change much. On the section Neumünster a reduction from 0.20 to 0.13 accidents per 1 million vehicle-kilometers by the treatment can be observed.

As a last step, the findings were related to the general development of road safety on German freeways. Accident coefficients for large parts of the German freeway network of the years 2002 until 2004 were available from a study aiming at developing safety coefficients for different cross section types (7). This data was grouped according to the defined accident groups (TABLE 1). The accident rates were calculated as average values over all cross section types with 2 or 3 lanes on the carriageway. Amazingly, the resulting accident rates were for accident group I 0.03 accidents per 1 million vehicle-kilometers and for accident group II 0.13 accidents per 1 million vehicle-kilometers i. e. exactly the same as on the A 6 with HSR.

As a final result of the analysis it can be stated that a well designed HSR with a speed limit of 100 km/h when equipped with emergency refuge areas or a speed limit of 120 km/h when equipped with small (at least 2.50 m wide) shoulders can reach the same safety level as regular cross sections illustrated in TABLE 2. An important prerequisite for this assumption is a detailed safety analysis of the section at the planning stage in order to eliminate high-risk road sites (especially in junctions) within the section under review. When the safety level is already better than these values before any HSR was implemented assumingly no change has to be expected.

## HSR EFFECTS ON TRAFFIC FLOW

In connection with the ongoing redrafting of the German Highway Capacity Manual (HBS) (3) a study was conducted to investigate recent empirical flow data of German freeways to derive new speed-flow curves and capacities wherever necessary (8). The resulting curves shown in FIGURE 7 are planed to be incorporated in the new HBS 2010.

The curves for the 2-lane carriageway are based on empirical data from the HSR section on the A 4 analyzed before. For the 3-lane carriageways more extensive data from the A 3 freeway near Frankfurt was provided by local authorities. Compared to the capacities of regular cross sections in the current HBS (3) the HSR increases the capacity of the 2-lane carriageway by around 30 % and of the 3-lane carriageway by between 22 and 27 %.

## RECENT DEVELOPMENTS ON HSR IN GERMANY

The new findings concerning the safety effects of HSR have already been implemented in the software tool for the economic assessment of HSR measures. A program update has been provided to the users in the German federal Lander. As a result, the concerns regarding road safety are not relevant any more for the cost-benefit ratio, as long as the prerequisites defined by the German Federal Ministry of Transport, Building, and Housing are taken into consideration and a detailed accident analysis is conducted at the planning stage in order to eliminate high-risk road sites within the planning area.

As a consequence of the revision of the speed-flow relations and capacities for freeways of the current HBS (3) the exchange of a large number of values and diagrams is suggested for the HBS 2010. Especially for grades the recent empirical data demonstrates higher speeds and capacities than assumed in the current HBS. When discussions within the responsible committees have come to an agreement a new update of the software tool will be provided.

So the remaining weak element of the software tool is the modeling of the demand flow pattern over a whole year. Up to now speeds are determined based on empirical flow data considering a growth rate for the expected years under operation. The methodology does not apply to demand conditions in excess of capacity where segments are influenced by downstream queuing. Therefore, the application of the software should be restricted to short planning horizons.

Meanwhile several sections of a total length of around 200 km with dynamic HSR are under operation in Germany. Additional measures are currently being considered (TABLE 3).

In order to explore the potential to increase the capacities of freeways systematically by implementing HSR the Federal Ministry of Transport, Building, and Housing is currently developing a project plan on active traffic management 2009 – 2015. In this context, an analysis of bottlenecks in the freeway network has been conducted. Following the data evaluation possible measures have been derived and assessed by a standardized but simplified evaluation framework. The aim was to develop suitable improvement measures for all bottlenecks with in the network.

Although Germany successfully implemented measures of HSR, hard shoulders are still considered to be a vital element of freeway cross sections. Therefore, all cross section types of the new freeway design guidelines (9) contain hard shoulders. The typical cross section for 4-lane freeways (FIGURE 8), however, was designed in such a way that HSR would be possible without restriping of the roadway. The main design-relevant prerequisites of HSR (2) were integrated into the design guidelines.

**REFERENCES**


1 Rohloff, M. Re-Use of Hard Shoulders at Federal Motorways. In *2nd International Symposium on Highway Geometric Design Conference Proceedings*, 2000, pp. 254 - 266.

2 General Circular Road Construction no. 20/2002 „*Use of the hard shoulder (marginal strip) for flowing traffic* “, Federal Ministry of Transport, Building and Housing, Bonn, Germany, August 5th, 2002.

3 *HBS, Handbuch für die Bemessung von Straßenverkehrsanlagen (German Highway Capaity Manual)*. Forschungsgesellschaft für Straßen- und Verkehrswesen, Cologne, 2001.

4 Arnold, M. *Verfahren zur Wirtschaftlichkeitsuntersuchung einer befristeten Umnutzung von Standstreifen an BAB für Zwecke des fließenden Verkehrs (Economic Assessment of HSR on Freeways)* . Schriftenreihe „Forschung Straßenbau und Straßenverkehrs-technik“, Heft 820, Bonn, 2001.

5 Heidemann, D., M. Bäumer, R. Hamacher, and H. Hautzinger. *Standstreifen und Verkehrssicherheit auf BAB (Hard Shoulders and Road Safety on Freeways)*. Berichte der Bundesanstalt für Straßenwesen, Unterreihe Verkehrstechnik, Heft V 55, Bergisch Gladbach, 1998.

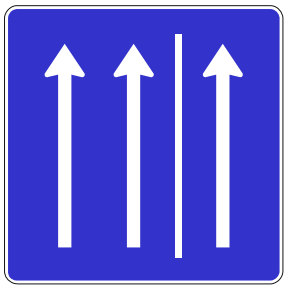
6 Lemke, K. *Standstreifenfreigabe – Sicherheitswirkung von Umnutzungsmaßnahmen (HSR – Safety Effects of Restriping).* Berichte der Bundesanstalt für Straßenwesen, Unterreihe Verkehrstechnik, Heft V 153, Bergisch Gladbach, 2007.

7 Lemke, K. Sicherheitswirkung 2- und 3-streifiger Regelquerschnitte auf BAB (Safety Level of Freeway Cross Section Types with 2 and 3-lane Carriageways). Berichte der Bundesanstalt für Straßenwesen in *Straßenverkehrstechnik*, Heft 8, pp. 427 – 430, 2007.

8 Brilon, W. and J. Geistefeldt. *Überprüfung der Bemessungswerte des HBS 2001 für Autobahnabschnitte außerhalb der Knotenpunkte (Revision of the Speed-Flow Diagrams and Capacities for freeways given by the HBS 2001).* Schriftenreihe Forschung Straßenbau und Straßenverkehrstechnik (unpublished).

*9* *RAA, Richtlinien für die Anlage von Autobahnen (Guidelines on Freeway Design).* Forschungsgesellschaft für Straßen- und Verkehrswesen, Cologne, 2008.

List of Tables and Figures



Z 223.1
„Seitenstreifen befahren“
(Use Hard Shoulder)

Z 223.2
„Seitenstreifen nicht mehr befahren“
(End Hard Shoulder Use)

Z 223.3
„Seitenstreifen räumen“
(Leave Hard Shoulder)

**FIGURE 1 German Road Sign for Dynamic Hard Shoulder Running since 2002**

**TABLE 1 Assumed change of accident numbers by HSR for different accident groups**

| Accident group | Accident category | Commuter traffic or non-commuter traffic and less than 10 % heavy vehicles | non-commuter traffic and 10 % and more heavy vehicles | |
|---|---|---|---|---|
| | | | emergency refuge areas | small shoulder |
| I | Fatal and severe injury accidents | No change | + 80 % | + 50 % |
| II | Slight injury accidents and severe property-damage-only (PDO) accidents | | + 20 % | +12,5 % |
| III | Other property-damage-only (PDO) accidents | | - 20 % for average speeds below 85 kilometer per hour | |

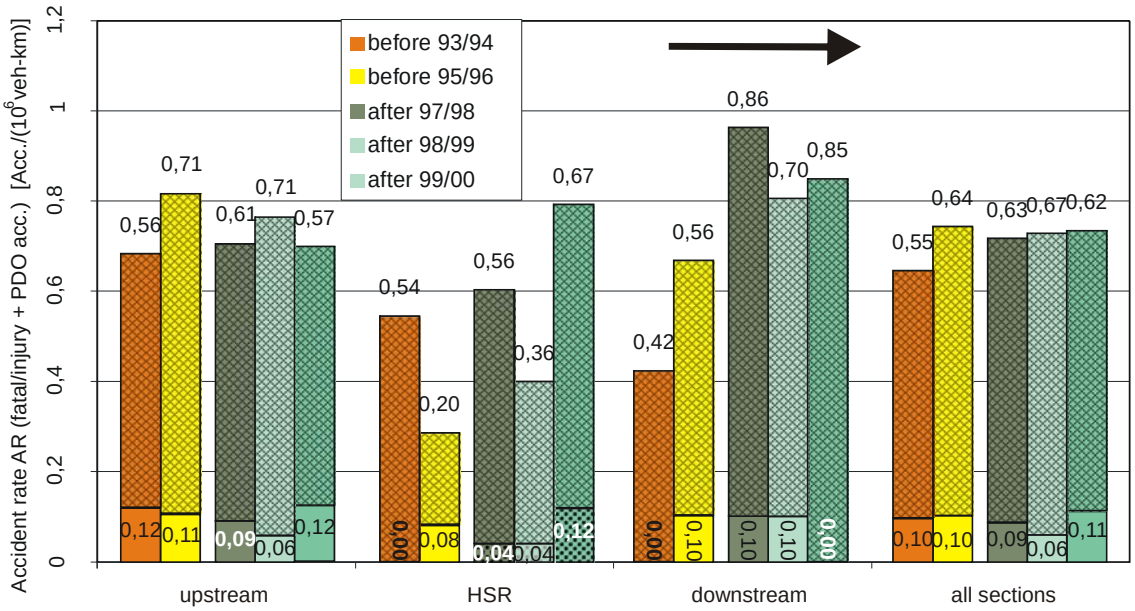



**FIGURE 2 Accident rates in accidents per million vehicle-kilometer on the A 4 freeway before and after implementation of HSR (12 month period from March to February) compared to reference sections (doted = with HSR)**

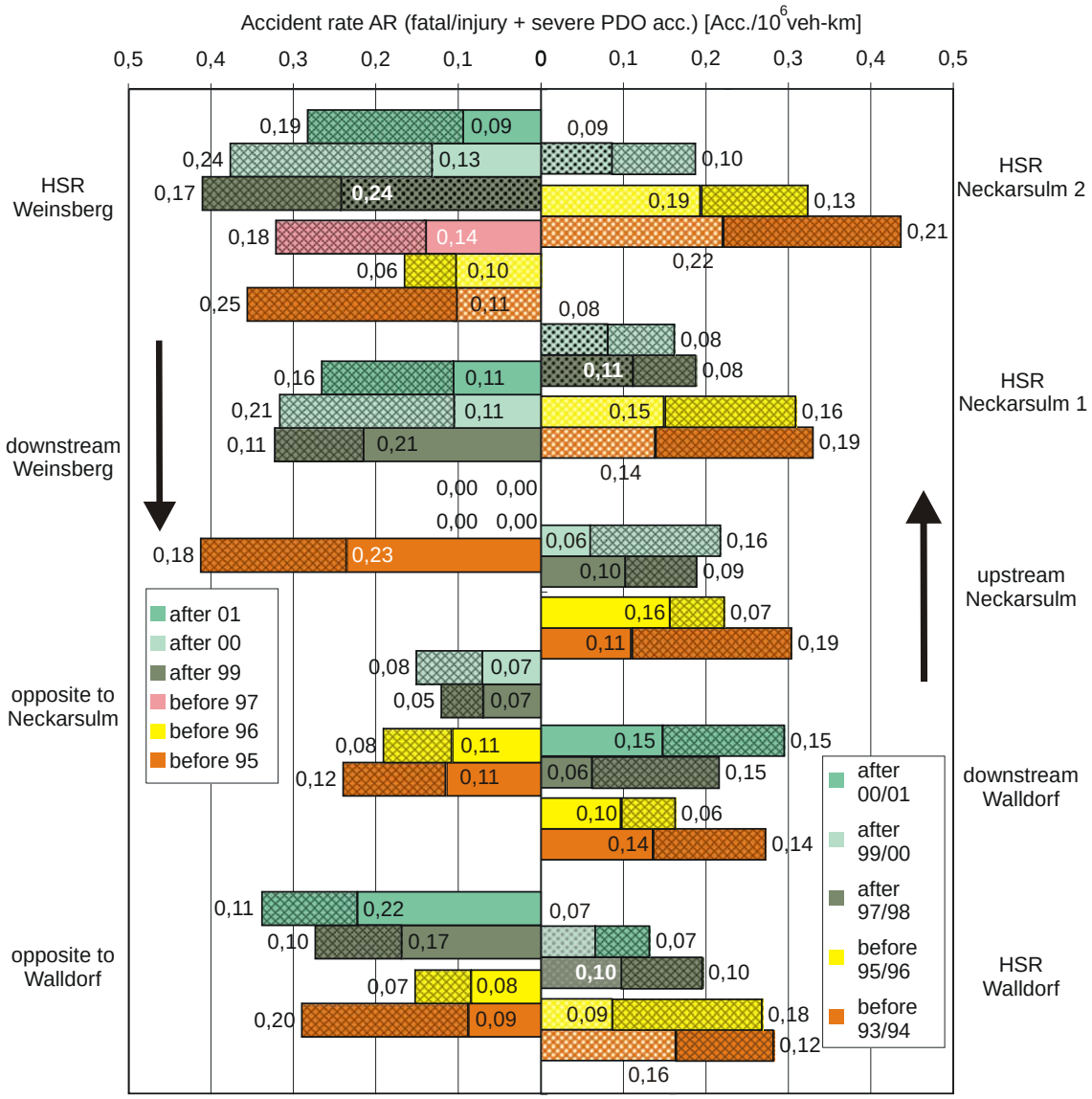



**FIGURE 3 Accident rates in accidents per million vehicle-kilometer on the A 6 freeway before and after implementation of HSR (Walldorf, Neckarsulm: 18 month, Weinsberg 5 month) compared to reference sections (doted = with HSR, squared = severe PDO accidents)**

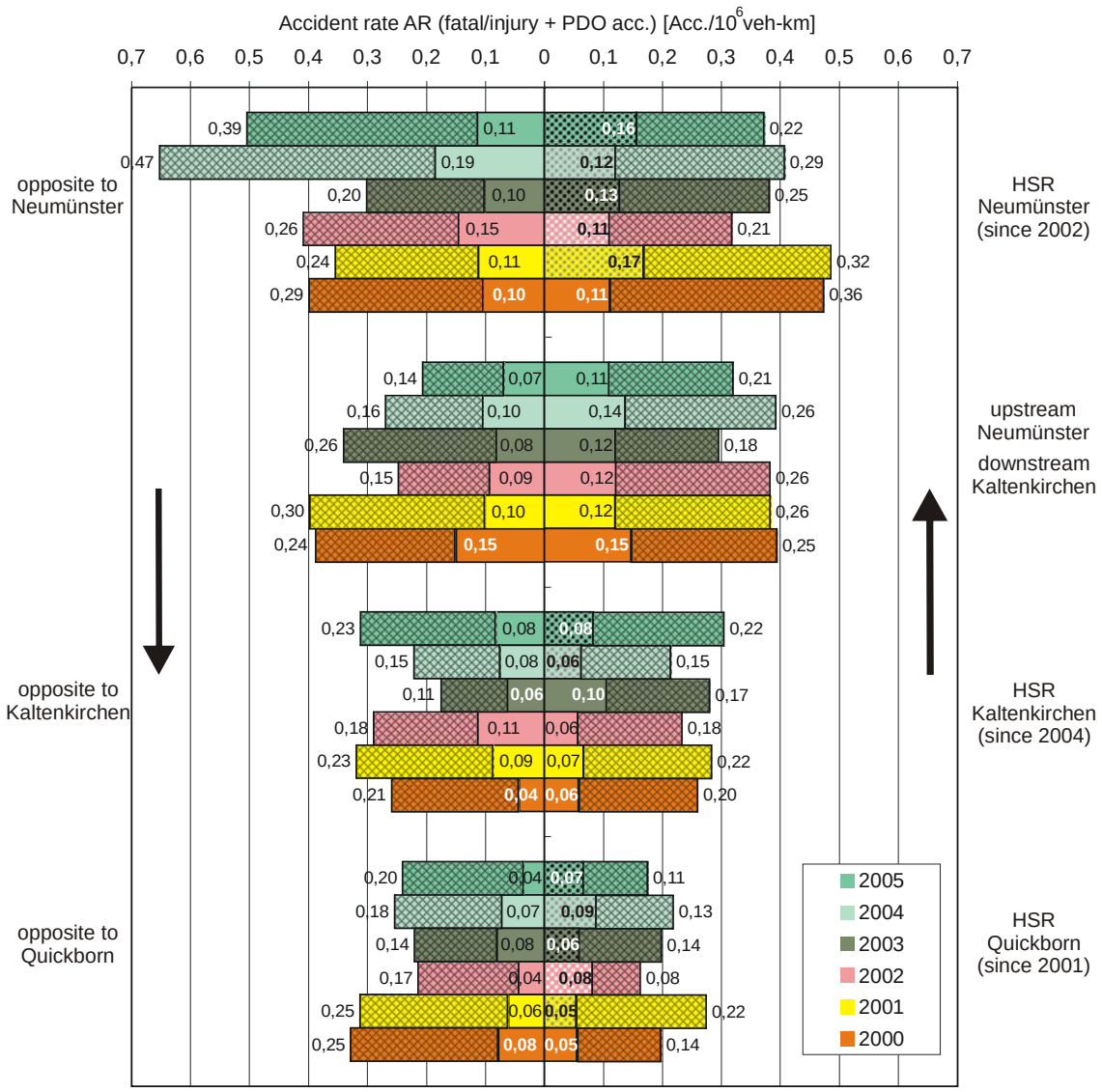



**FIGURE 4 Accident rates in accidents per million vehicle-kilometer on the A 7 freeway before and after implementation of HSR (full years) compared to reference sections (doted = with HSR, squared = severe PDO accidents)**

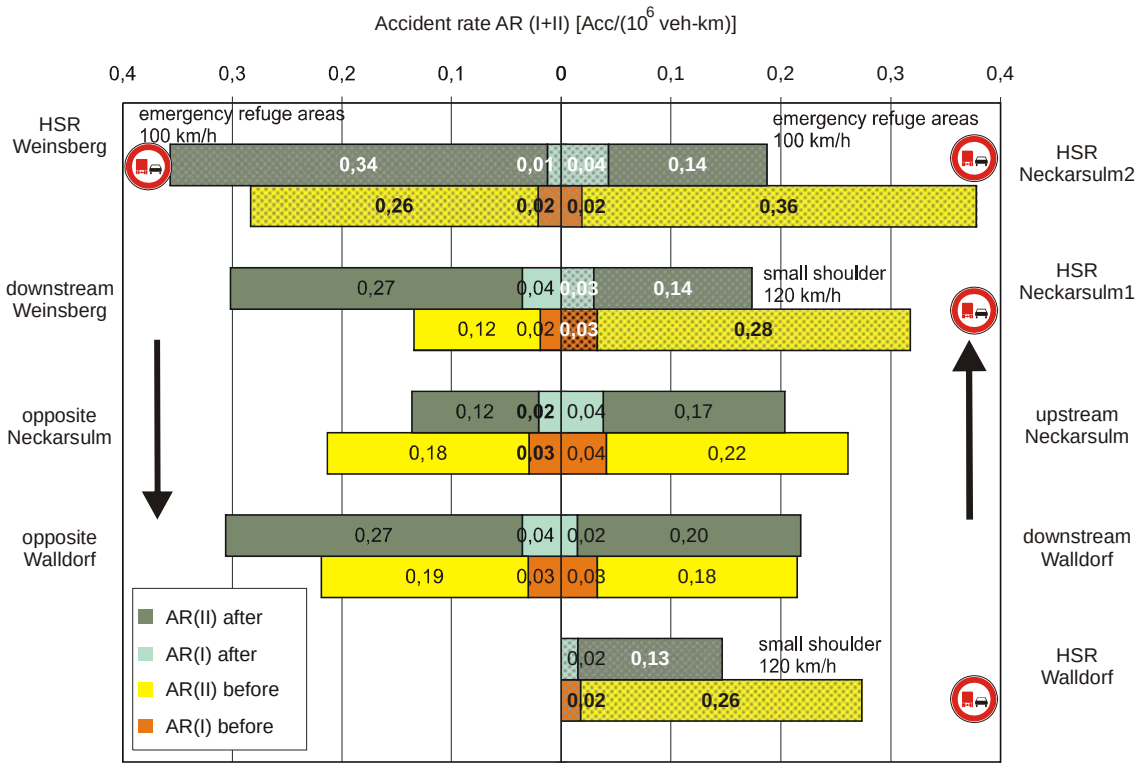



**FIGURE 5 Before-after comparison of accident rates in accidents per million vehicle-kilometer on the A 6 freeway for accident groups I and II (**Error! Reference source not found.**) for different time periods (doted = HSR)**

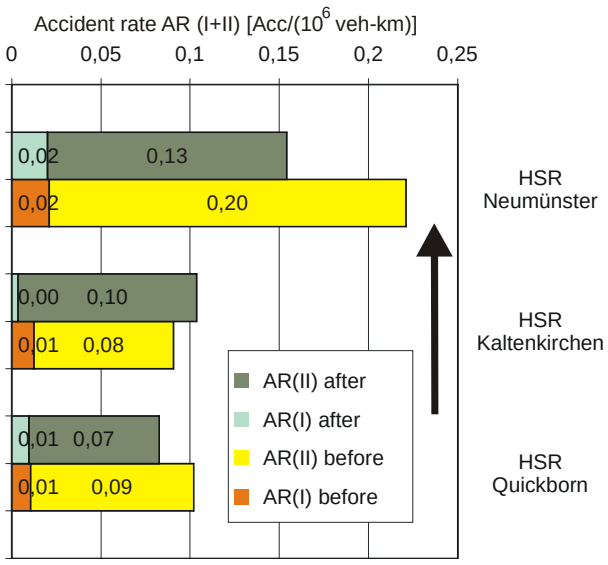



**FIGURE 6 Before-after comparison of accident rates in accidents per million vehicle-kilometer on the A 7 freeway for accident groups I and II (**Error! Reference source not found.**) for different time periods**

**TABLE 2 Accident rate on sections with HSR on German freeways with non-commuter traffic and a speed limit of 100 kilometer per hour when equipped with emergency refuge areas or a speed limit of 120 kilometer per hour when equipped with small (at least 2.50 m wide) shoulders (6)**

| Accident group | Accident categorie | Accident rate [accidents per million vehicle-kilometer] |
|---|---|---|
| I | Fatal and severe injury accidents | 0.03 |
| II | Slight injury accidents and severe property-damage-only (PDO) accidents | 0.13 |

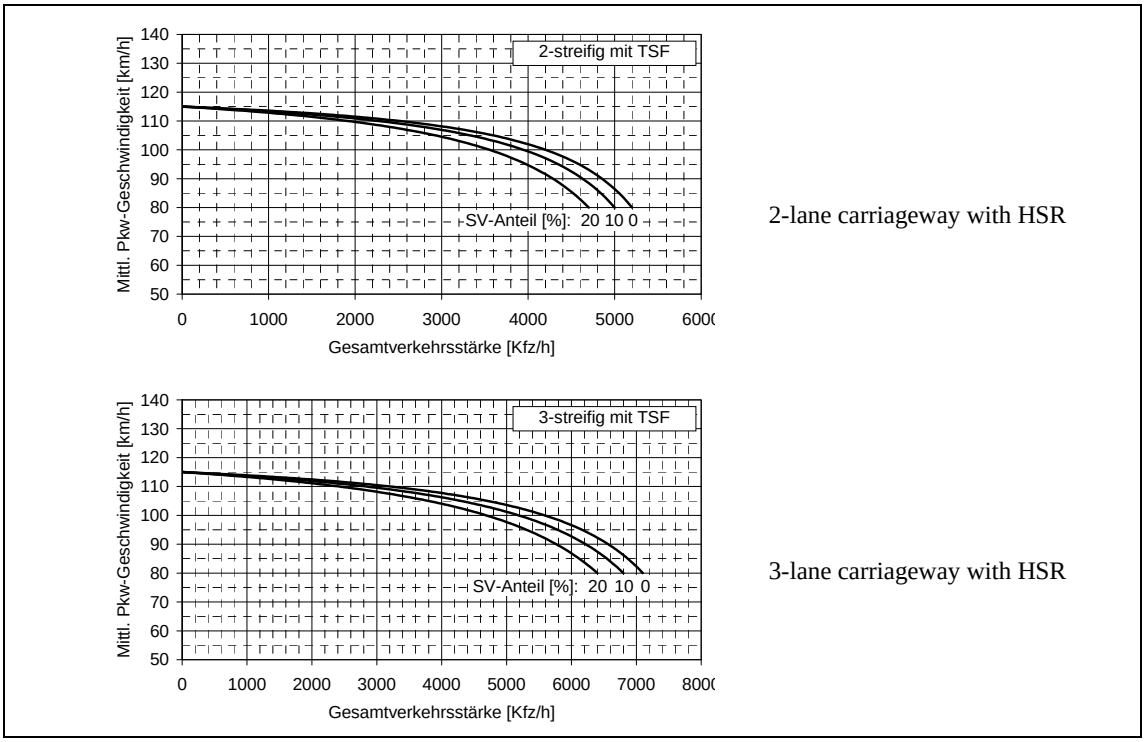



**FIGURE 7 Speed-Flow curves for HSR on German freeways and level terrain to be included in the German Highway Capacity Manual 2010 (8)**
**(Mittlere Pkw-Geschwindigkeit = passenger car speed in kilometers per hour; Gesamtverkehrsstärke = flow rate in vehicles per hour, SV-Anteil = portion of heavy vehicles in percent)**

**TABLE 3 Sections with dynamic HSR in Germany in 2009**

| Freeway | Section | Direction | Length [kilometer] | Lane no. |
|---|---|---|---|---|
| A 3 | Offenbacher Kreuz – AS Obertshausen | both | 5,7+6,0 | 3+1 |
| A 3 | Mönchhofdreieck – AS Kelsterbach | both | 3,3+2,0 | 3+1 |
| A 4 | AS Refrath – AS Köln-Merheim | Köln | 1,6 | 2+1 |
| A 5 | AS Friedberg – Bad Homburger Kreuz | both | 7,2+8,9 | 3+1 |
| A 5 | Bad Homburger Kreuz – Nordwestkreuz Frankfurt | both | 4,8+7,7 | 3+1 |
| A 7 | Border HH – AS Kaltenkirchen | Flensburg | 22,5 | 2+1 |
| A 7 | AS Neumünster-Süd – AD Bordesholm | Flensburg | 14,0 | 2+1 |
| A 7 | AS Soltau-Ost – Dreieck Walsrode | both | 32,4+31,8 | 2+1 |
| A 8 | AS Hofolding – AS Holzkirchen | Salzburg | 9,8+9,8 | 3+1 |
| A 99 | AK München Nord – AS Haar | both | 18,0+18,0 | 3+1 |

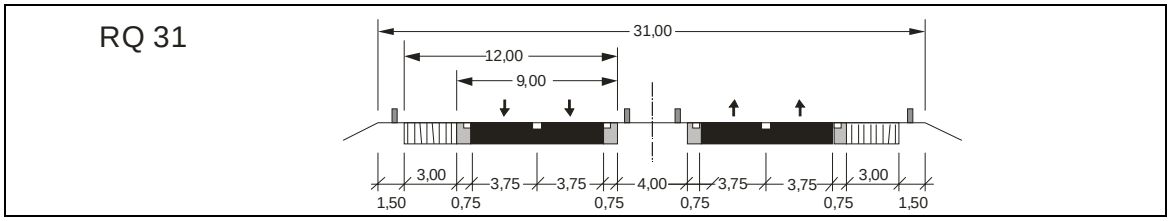



**FIGURE 8 Cross Section for 4-lane German freeways allowing for HSR (9)**