Supreme Building Authority
of the Bavarian Ministry of the Interior
(Oberste Baubehörde im Bayerischen Staatsministerium des Innern)

Accident Blackspots on Rural Roads

Safety Measures

Effectiveness

Version 2011

Aufbruch Bayern
Zukunft Bauen

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Preface

Analysis of accident maps shows that road accidents are not distributed equally throughout the road network but that there are clusters situated at a few clearly defined locations. These so-called "accident blackspots" are only rarely a product of chance. Rather, local flaws in the road and its surroundings make it more likely that accidents will occur. A promising approach consists of using comprehensive analysis to identify safety deficits at such accident blackspots and eliminate them using suitable safety measures. Bavarian accident commissions have been using this approach since their establishment in 2000 and have implemented a great number of improvement measures relating to accident blackspots in a variety of different settings. A standardised evaluation analysing the effectiveness of all measures realized in connection with accident blackspots on rural roads in Bavaria between 2000 and 2006 was performed in order to gain a better overview of the effectiveness of the implemented remedial measures. For this purpose, the incidence of accidents in the years 1997 to 2009 was evaluated. The results of this evaluation are described in this compendium. These results apply exclusively to particularly accident-prone stretches of road which account for a length of approximately 5% of the rural road network.

This compendium presents a newly developed classification system for the evaluation of safety-improving measures at accident blackspots. It is based on a dissertation submitted to the University of the Armed Forces Munich *(Universität der Bundeswehr München)* [10]. Comprehensive and high-quality data material regarding federal and state rural roads in Bavaria was available to enable the area-wide use of the evaluation system. This document describes not just the new evaluation procedure but also the evaluation results in a coherent, comprehensible and practical way. The main purpose of this compendium is to help the accident commissions select those remedial measures that have been proven in practice to be particularly successful and economical and to systematically use them for the treatment of accident blackspots in their daily work. To this end, an interactive computer programme has also been made available to the accident commissions on the intranet of the Bavarian Road Administration *(Straßenbauverwaltung)*. This compendium and the computer programme are intended to pool all resources and use the existing limited resources even more effectively.

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1 Accident Blackspot Management in Bavaria

According to the General Administrative Act *(Allgemeine Verwaltungsvorschrift)* to Sect. 44 of the German Road Traffic Regulations *(Straßenverkehrsordnung)* [1] the responsible authorities are obliged to eliminate particular factors contributing to officially identified accident blackspots in order to reduce the number of traffic accidents. Accident commissions consisting of representatives from the road traffic authority, the road building authority and the police have to perform accident blackspot management. The commissions analyse identified accident blackspots in order to find site-related flaws and, if required, initiate remedial measures. All accident blackspot management is based on the traffic accident data recorded by the police. The site, category and type of accident are the most important accident information for accident blackspot management. The accident site is described using localisation characteristics (road name section, station etc.). The accident category which is defined in the Act on Statistics of Road Accidents *(Straßenverkehrsunfallstatistikgesetz)* [8] is based on the severity of the accident (see Appendix 1). Accordingly, the category is determined by the greatest damage or injury suffered by one of the parties involved in the accident. A total of seven accident types allows for classification according to the traffic constellation or the conflict situation in which the accident occurred. The question of who caused the accident, the misconduct of individual road users or even the question as to whether and how the crash occurred is of no major importance for determining the accident type according to [7]. Appendix 2 contains a short description of the seven accident types with colour code according to [4].

So-called accident type maps (see figure 1) can be used to directly identify accident sites (circle symbols are placed on the road map), the severity of specific accidents (circle diameter) and the type of specific accidents (colour of the circle symbol). The side of the road on which the accident symbol is placed indicates the travelling direction of the road user that is mainly responsible for causing the accident prior to the accident. If the accident symbols overlap each other partially or entirely, they are depicted one after another like pearls on a necklace. The accident type map is the key instrument for accident blackspot management. In addition, in-depth accident analysis by means of lists and diagrams as well as site visits are a fundamental basis needed for the work of the accident commissions.

New findings regarding the distribution of severe accidents within the road network and progress made with regard to accident evaluation and information technology resulted in a regulation regarding the reduction of accidents on Bavarian roads with the title *“Richtlinie zur Bekämpfung des Unfallgeschehens auf bayerischen Straßen“* [2] published on 15 May 2000. This regulation stipulates that stretches of road with an unusual accumulation of severe accidents (accidents with fatalities or seriously injured persons, see Appendix 1) must be centrally identified based on the road accident evaluation leaflet *“Merkblatt für die Auswertung von Straßenverkehrsunfällen“* [4] and that the elimination of such accident blackspots must be given priority.

Accident blackspots on regional roads in Bavaria are consistently identified every three years for the entire state of Bavaria by the Central Office for Road Safety of the Bavarian Road Administration [*Zentralstelle für Verkehrssicherheit der Straßenbauverwaltung* - ZVS]. Due to the considerable differences in legal regulations, road user groups, traffic processes, local conditions and the accident structure resulting therefrom, different criteria for accident blackspots on motorways, rural roads and thoroughfares have been established [3]. On rural roads, safety-relevant flaws mostly concern longer stretches of road. The identification of accident blackspots is therefore based on an investigation length of one kilometre. According to the Bavarian definition applicable since the identification period from 1997 to 1999 an accident blackspot is any stretch of road of one kilometre in length where at least three severe accidents occurred within a period of three years. An accident blackspot starts where the first severe accident occurred and ends where the last severe accident of this blackspot has been identified at a distance of more than one kilometre from another severe accident. Thus, accident blackspots have variable lengths.

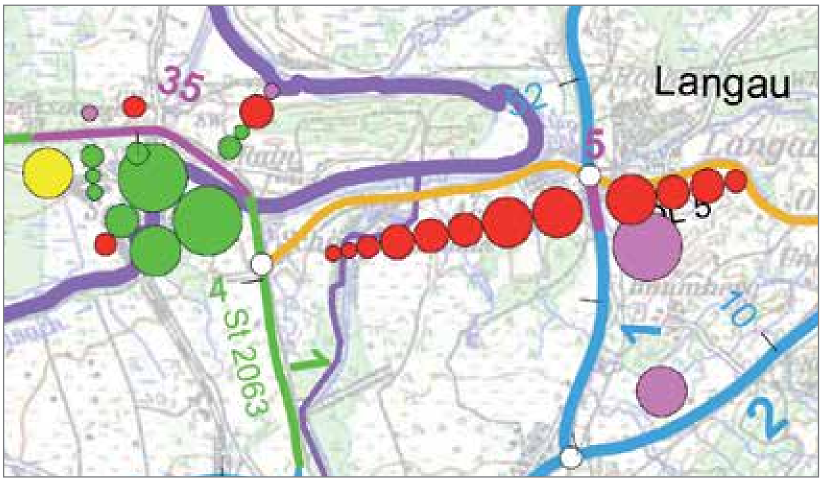


Figure 1: Detail of a three-year accident type map with accident blackspots (magenta-coloured line) 2000-2002 for federal and state rural roads in Bavaria

A total of 107 accident commissions for regional roads in Bavaria were established in 2000. Safety-improving measures at accident blackspots performed in the scope of ongoing projects, e.g. conservation measures, complement the remedial measures initiated by the accident commissions. In order to be able to better analyse the complex interactions between the incidence of accidents, accident causes and remedial measures including their effectiveness, all relevant information relating to accident blackspots is collected by the accident commissions and stored in a central database. This data management strategy substantially facilitates the documentation of implemented improvement measures at accident blackspots. In addition, it constitutes the basis for the effectiveness evaluation of these measures throughout Bavaria (see figure 2).

The information stored about safety measures at accident blackspots can be accessed quickly via the Government of the Federal State of Bavaria's intranet. This data is available both to the accident commissions themselves and their responsible supervisory authorities. Thus, this measure documentation system also provides the basis for effective controlling. In this way it is, for example, possible to identify and remedy deficiencies in the work flow early on.

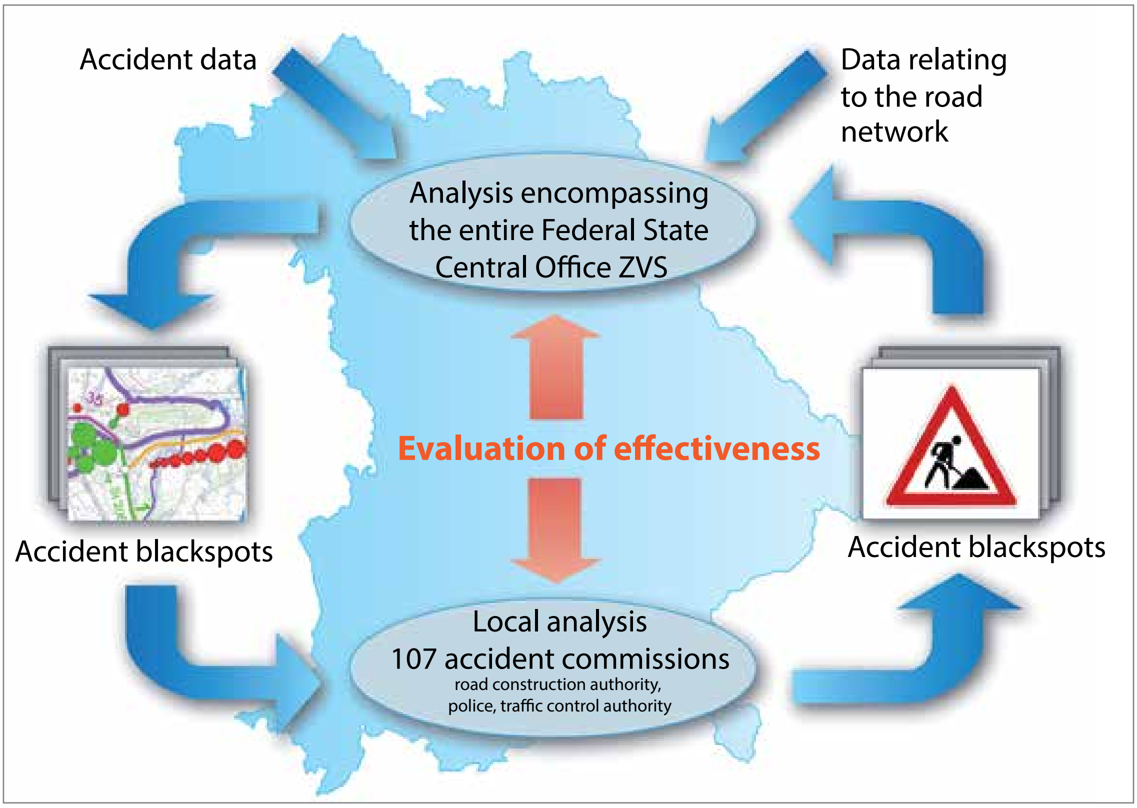


Figure 2: Schematic representation of the procedure for eliminating accident blackspots on regional roads in Bavaria

2 Classification Used for the Evaluation of Measures

The evaluation performed to analyse the effectiveness of remedial measures at accident blackspots is based on comparisons of accident cost rates (see Appendix 3). For this purpose, the difference between the period of the accident blackspot identification (before-period) and the period after the measures have been implemented (after-period) is distinguished. The investigation periods are three calendar years each. The after-period starts no earlier than six weeks after the traffic measures have been implemented. If higher impact measures are implemented, it may be useful to extend this period to six months in order to properly take into account the time needed by all road users to get used to the new situation. It is very important that the investigation periods of the measurement analysis are uninterrupted by construction measures, measures based on traffic regulation or technical measures. In addition, there should be no significant difference in the traffic volume during the before-period and the after-period.

Viewed in the long term, the number of severe accidents is generally subject to random fluctuation - even at accident blackspots. It has been shown that accident blackspots have a lower incidence of accidents in the long-term mean (see figure 3 with an average of 2.25 severe accidents during eight three-year periods 1987 to 2010) than during the period of their identification (see figure 3 with an average of 4.0 severe accidents in the three identification periods 1990 to 1992, 1993 to 1995 and 2005 to 2007 with identified accident blackspots). Thus, the number of accidents at accident blackspots normally decreases even if no measures are implemented. This decrease is called **"bias by selection"** and must be taken into account by means of a well-founded before/after comparison.

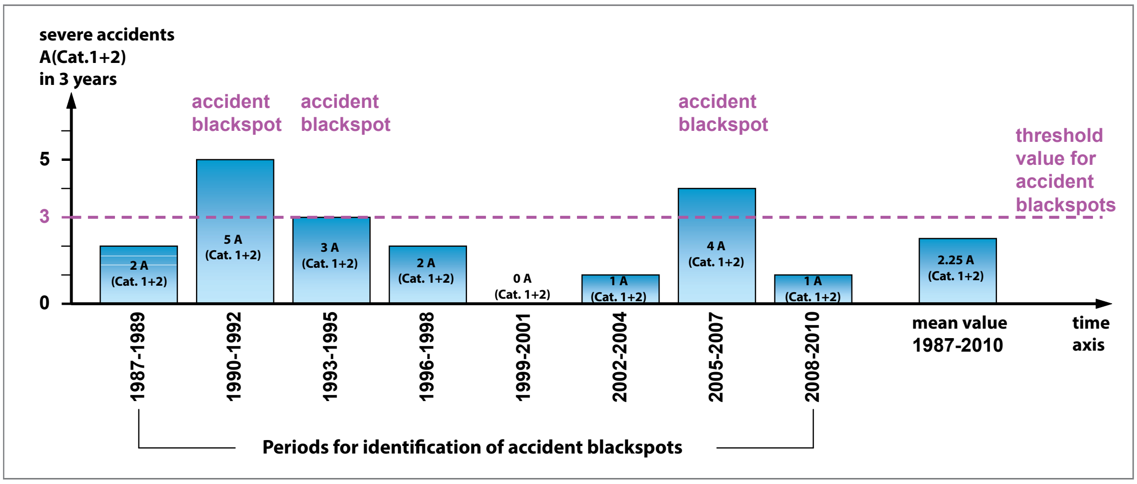


Figure 3: Example of a fictitious accident development on any stretch of rural road with the length of one kilometre

The extent of the bias by selection can be estimated by applying the data of accident blackspots where none of the planned measures have yet been implemented three years after the before-period to similar accident blackspots. By evaluating the implemented measures two main purposes are to be fulfilled: On the one hand successful measures should be effective or cost-efficient (benefit-oriented) and on the other hand their implementation should result in a safe traffic situation (target-oriented).

The analysis of the effectiveness of the implemented measures is based on before/after comparisons of the accident situation taking into account the bias by selection described above. If the **benefit-oriented approach** is used, the applicable economic benefit and cost components derived from the actual accident situation and the remedial measures are compared to evaluate the cost-effectiveness of certain measures [5]. Measures are deemed to be economically viable if the benefit achieved thanks to an improved safety situation exceeds the annual costs of remedial measures. Otherwise the implementation of measures is not economically viable.

Benefit-oriented analyses of economic viability alone are not sufficient for describing the effectiveness of improvement measures. In such analyses, the safety level of accident blackspots after safety-improving measures have been implemented is not assessed and must be taken into account in the course of an additional analysis. Therefore, a **target-oriented approach** is used to determine to what extent the implemented measures have led to the safety level that is achievable according to the local boundary conditions at the treated accident blackspots. Specifically, the measures implemented at accident blackspots are deemed to have resulted in a safe traffic situation in the after-period if the accident cost rates for the after-period are within the range of the achievable safety level (equals the basic accident cost rate, see Appendix 4) or lower. Otherwise, there is still room for improvement even after implementation of the measures.

If the outcome of both benefit- and target-oriented analysis is satisfactory, the effectiveness of the measure is to be classified as "optimal". On the other hand, measures must be regarded as "failed" if they did not lead to any improvement of the road safety situation (and are thus unviable), and if the safety situation is insufficient afterwards on top of that. In this way, all in all three evaluation classes can be defined (see figure 4). There are two procedures for the specific evaluation of the effects brought about by the implemented measures.

Evaluation class	**Description of measure effectiveness**	**Colour code**
Optimal	Measure viable - and thus effective - and sufficient, i.e. safe condition of blackspot after measure implementation	green
Partly effective	Measure either viable or effective or sufficient	yellow
Failed	Measure unviable as no improvement was achieved and the condition remains unsafe	red

Figure 4: Evaluation classes for measure effectiveness with description and colour code

To perform a **differentiated evaluation procedure** the measures' sphere of influence within the analysed accident blackspot must be clearly defined. Apart from a few special cases, these road sections can be classified as one of several standard traffic facilities. The traffic facility "extended stretch of road" is linear and at least 500 m long. It may therefore include (less accident-prone) intersections and bends. The road network elements "intersection" and "bend", however, are limited to specific points. When classifying intersections into standard traffic facilities, the type of the intersection (crossing, junction or offset) and the type of traffic regulation must be considered. The minimum length of "bends" is 200 m. The respective traffic facility determines adjusted accident cost rates and specific basic accident cost rates for further calculating operations. In addition to the incidence of accidents, the traffic load of the corresponding traffic facility in the before- and after-period (including those of the minor road if intersections are concerned) and adjusted annual measure cost rates are used to analyse the effectiveness of the measures. In the differentiated evaluation procedure, the bias by selection value is defined subject to the corresponding traffic facility and the incidence of accidents in the before-period (main accident type and/or accident cost rate) [10]. A program application that can be used to perform a differentiated evaluation of measures is available on the intranet Bavarian Road Administration's intranet which is accessible by all Bavarian accident commissions.

The **simplified procedure**, however, can be easily used without a computer (see Appendix 4) and is based on slightly rougher assumptions. The accident evaluation, for example, takes into consideration the entire accident blackspot. This procedure provides averaged but relatively reliable results.

3 Structure and Underlying Data of the Compendium

The evaluations of measures presented in chapter 4 were performed according to the differentiated procedure. The underlying accident blackspots in Bavaria refer to the network of federal and state rural roads and the investigation periods from 1997 to 1999 and/or 2000 to 2002. The evaluation was thus based on a total of 3,059 accident blackspots, with these blackspot locations partially overlapping. During each of the investigation periods, almost every second severe accident occurred at one of the evaluated accident blackspots on rural roads although all of these accident blackspots together only account for a tenth of the overall length of the road network.

Out of the investigated accident blackspots on rural roads, a total of 2,419 road sections on which safety-improving measures had been performed were selected. Out of these 2,419 road sections 1,793 were suitable for the planned before/after comparison, and therefore suitable for evaluation. Measures were deemed to be unsuitable for evaluation if there was no uninterrupted before/after period of three calendar years, if the time or site of measures could not be determined beyond doubt or if the road section had been downgraded in the meantime. The evaluable measures were implemented on rural roads from 2000 to 2006. Accident data from 1997 through 2009 was evaluated.

When analysing accident blackspots, the accident type is of general importance while the most frequent accident type (main accident type), however, is of crucial importance. Therefore, the main accident type of each site where a measure had been implemented was determined for the identification period of the respective accident blackspot (which is the same as the before-period). The number of accidents with personal injuries and property damage A(Cat.1+2+3+7) was relevant in this respect. If different accident types occurred with the same frequency within an accident group, the main accident type was determined by the accidents of greater severity.

Comprehensive datasets from the Bavarian Road Information System (*Bayerisches Straßeninformationssystem* (BAYSIS)) were available as underlying data. This system contains, amongst others, network-wide information on road design (e.g. bends), traffic data (official road traffic censuses 2000 and 2005), geo-referenced road accidents, accident blackspots for a total of four successive identification periods and data on the accident commissions' analysis and safety measures.

To perform a site-related measure evaluation, all measures that were suitable for evaluation were first classified according to their respective traffic facility. When analysing accidents, statistical fluctuations in the incidence of accidents must be generally taken into account, particularly for smaller accident groups. In order to obtain overall reliable results, only those measures were therefore evaluated for which at least ten similar investigation units (with respect to traffic facility, main accident type and measure) existed, i.e. the number of cases was at least 10. Due to this restriction, 34 different measure-cases remained for analysis. The respective measures that were implemented on single carriageway, state and federal rural roads are treated in chapter 4 "Measure Evaluation and Representation". This chapter classifies the individual investigation units according to their standardised traffic facilities and main accident types. Figure 5 shows the traffic facilities "bend", "extended stretch of road" and "at-grade intersection according to the type of traffic regulation (traffic signs or traffic lights)" which are most commonly used in the measure evaluation and symbols attributed to them.

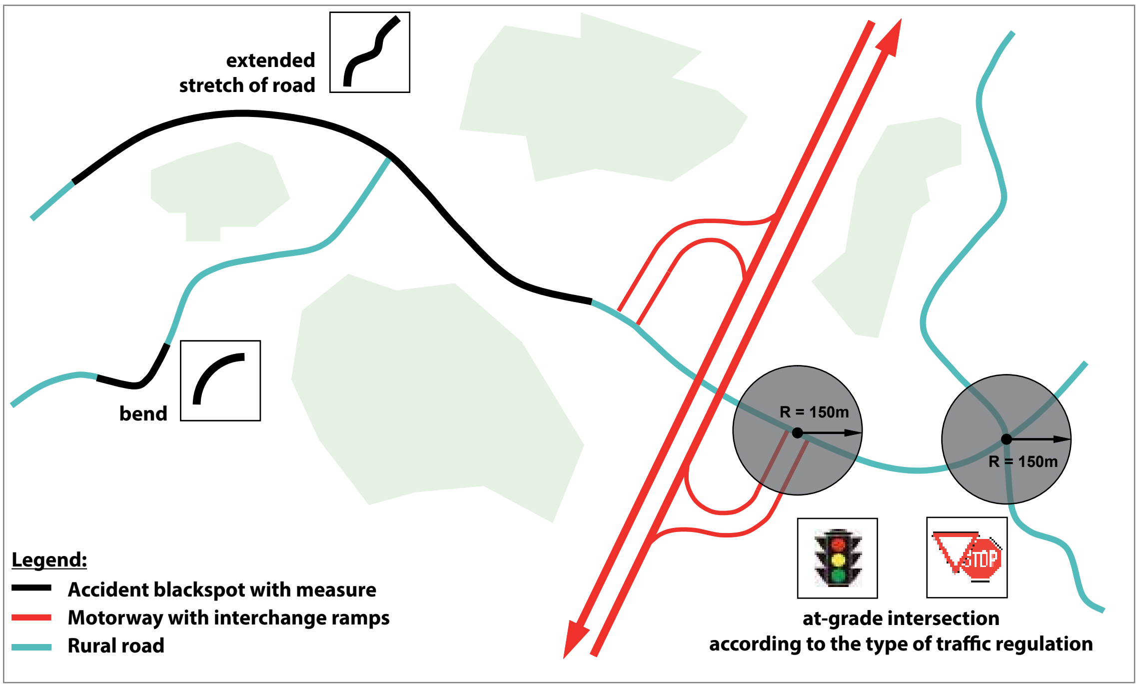


Figure 5: Standardised traffic facilities with symbols according to their position in the road network

Implemented measures relating to similar traffic facilities and to the same main accident type are represented in a light-grey shaded box (see figure 6). In this box, the respective measures are shown line by line.

The effectiveness of the measure(s) is represented by coloured bars. These bars indicate the allocation of the respective measures to the three evaluation classes. The colour code follows the legend according to Figure 4 (green for "optimal", yellow for "partly effective", red for "failed"). Since the measures are placed one on top of the other, their effectiveness can be easily compared (see Figure 6). The mean annual measure costs consisting of the operating costs and the investment costs spread over the entire service life are stated at the end of each line. The estimated service life depends on the type of the evaluated measure. The measures are sorted within the light-grey shaded box according to the level of the measures' costs.

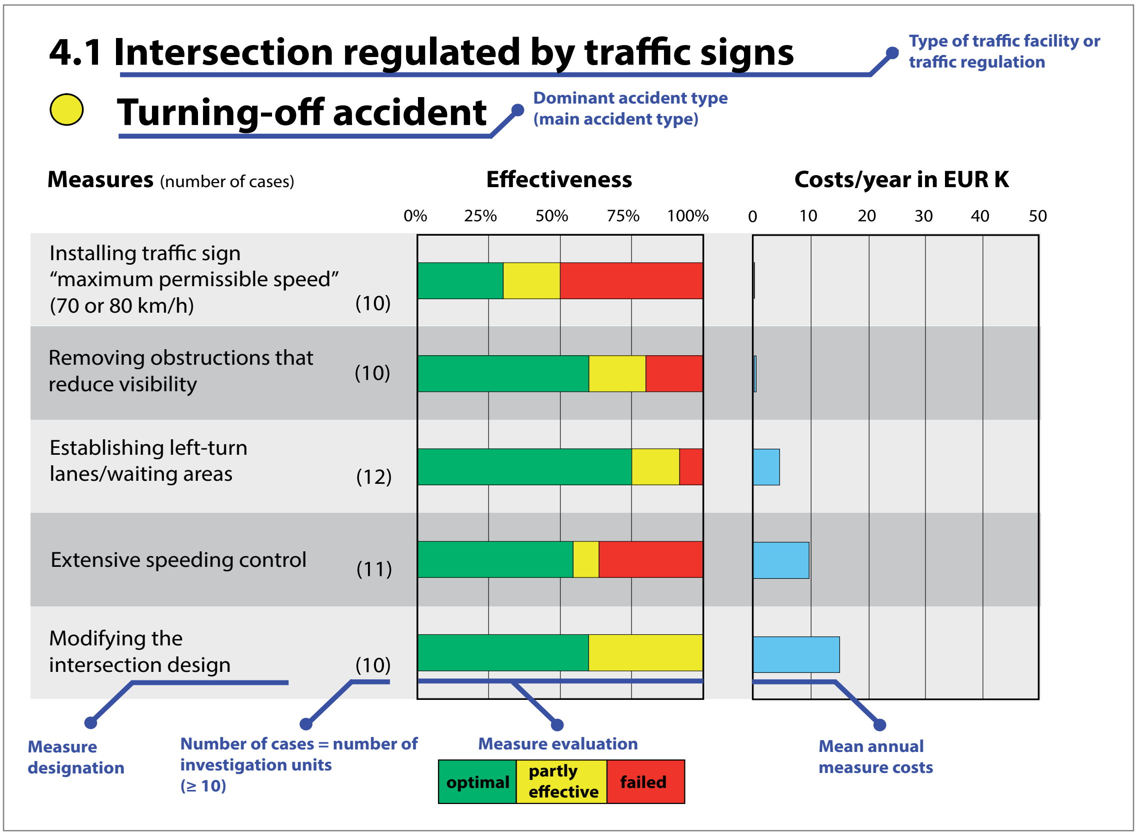


Figure 6: Explanation of terms (dark-blue) regarding measure evaluation

Below the measure evaluation (light-grey shaded box) photos of examples of particularly successful measures are shown. All of the included measures have been classified as "optimal". Pictures of examples have been provided for all evaluated measures except for monitoring by the police (each with a number of cases of at least ten measures). Below the photos of these examples other successful measures which, however, do not amount to a case number of ten (evaluation class "optimal") are shown.

Two photos (see figure 7) are shown for each example of a successful measure. The left photo (**"Problem"**) shows the condition of the traffic facility prior to the execution of the remedial measure(s) including a schematic representation of the dominant accident conflict (main accident type). A short explanation of the identified flaw and the accidents of the respective example are provided as additional information. The right photo (**"Measure"**) shows the condition of the traffic facility after execution of the remedial measure(s). In addition, a short description of how the measure(s) has/have improved the local accident incidence is provided. A reference to any flaws that might (still) persist is added to the caption of the after-situation (**"BUT"**) where applicable.

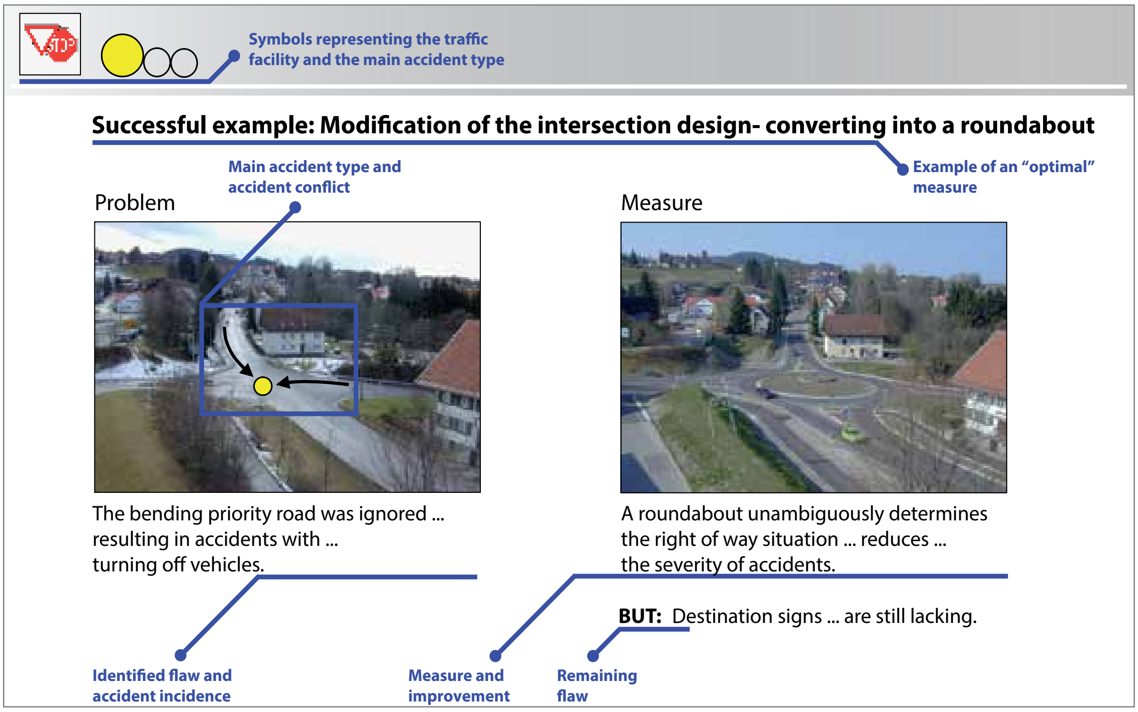


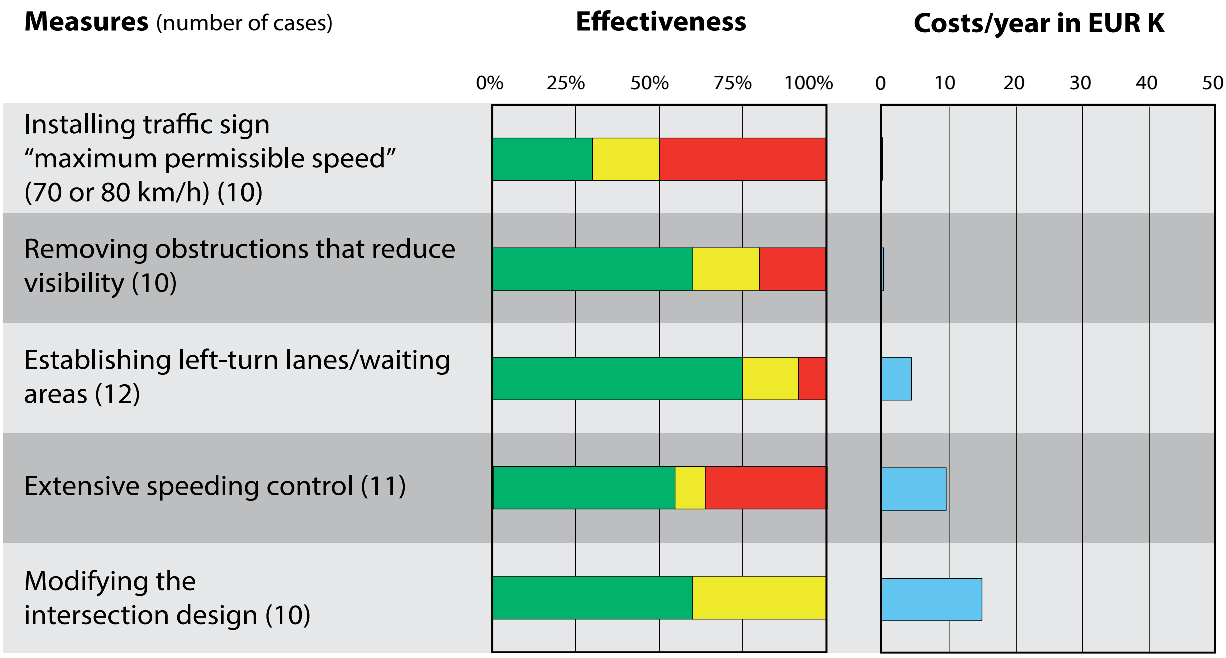
Figure 7: Explanation of terms (dark-blue) regarding pictures of examples

The pictures of the examples make it easier to understand the measures. However, to be better able to assess the effectiveness of measures, any other information that is available (e.g. in form of similar measure profiles, see Appendix 5) should also be taken into account in order to avoid misinterpretations. It must be pointed out that the measure evaluation presented in this document can only provide ideas for future measure discussions within the accident commissions. It cannot replace a well-founded investigation of the site-based accident incidence and an analysis of the local conditions.

4 Measure Evaluation and Representation

4.1 Intersection Regulated by Traffic Signs

Turning-off accident



Successful example: Installing traffic sign "maximum permissible speed"

Problem

The intersection was hard to see. High speeds on the major road made it difficult to turn into the road (short time gaps).

Measure

The speed limit reduces the speed level before the intersection and creates longer time gaps for drivers turning (left) into the minor road.
BUT: A left-turn lane is still lacking.

Successful example: Removing obstructions that reduce visibility - cutting back vegetation

Problem

The vegetation on the side of the road's bend limited the visibility of vehicles coming from the direction of the minor road so that drivers concentrated on gaps between the vehicles in the flow on the major road and collided with oncoming vehicles when turning left.

Measure

Cutting back the vegetation significantly improved the visibility situation at the intersection.

Successful example: Establishing left-turn lanes

Problem

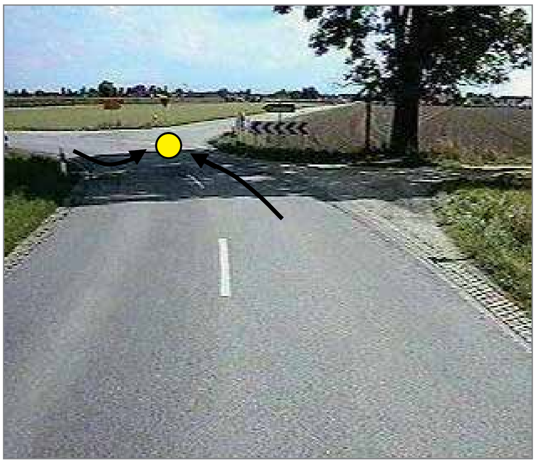
Since the intersection was hard to see, drivers recognized only very late that drivers in front of them intended to turn left. This resulted in rear-end collisions.

Measure

The added left-turn lane improves the visibility of the intersection on the major road and enables left turns without any danger to following straight-through traffic.

Successful example: Modifying of the intersection design - remodelling

Problem



The minor road was connected to the major road in the outer bend. There was no left-turn lane. Drivers on the major road saw left turning vehicles only very late which promoted turning accidents.

Measure

The remodelling of the intersection according to the regulations including a modified right of way creates an unambiguous right of way situation.
BUT: The signpost is not installed according to the regulations.

Successful example: Modification of the intersection design - converting into a roundabout

Problem

The bending priority road was ignored resulting in accidents with following or turning vehicles.

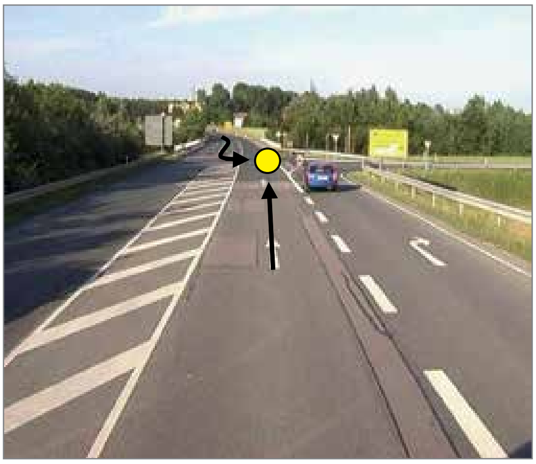
Measure

A roundabout unambiguously determines the right of way situation and reduces the speed level and thus the severity of accidents.
BUT: Destination signs on the centre island are still lacking.

Other examples of successful remedial measures (number of cases < 10)

Installing traffic lights

Problem



Drivers turning left into the minor road ignored the right of way and collided with oncoming or right-turning traffic.

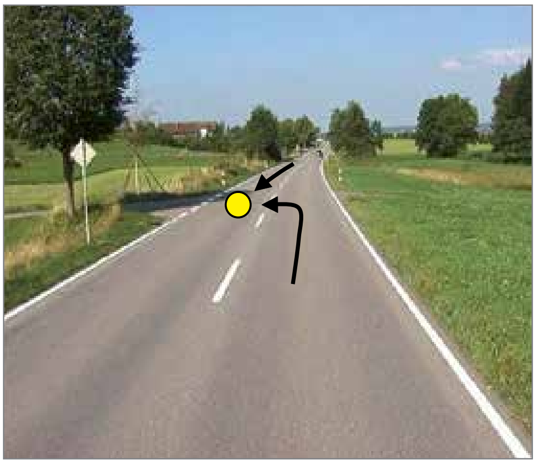
Measure

Traffic lights ensure conflict-free turning.

Other examples of successful remedial measures (number of cases < 10)

Installing signposts

Problem



The intersection was hard to see and, together with the straight road layout, this promoted high driving speeds resulting in severe accidents with turning-off vehicles.

Measure

The installed signpost improves the visibility of the intersection on the major road.
BUT: The font size of the signpost is not sufficient. A left-turning lane is still lacking.

Installing traffic sign "No overtaking for all vehicles"

Problem

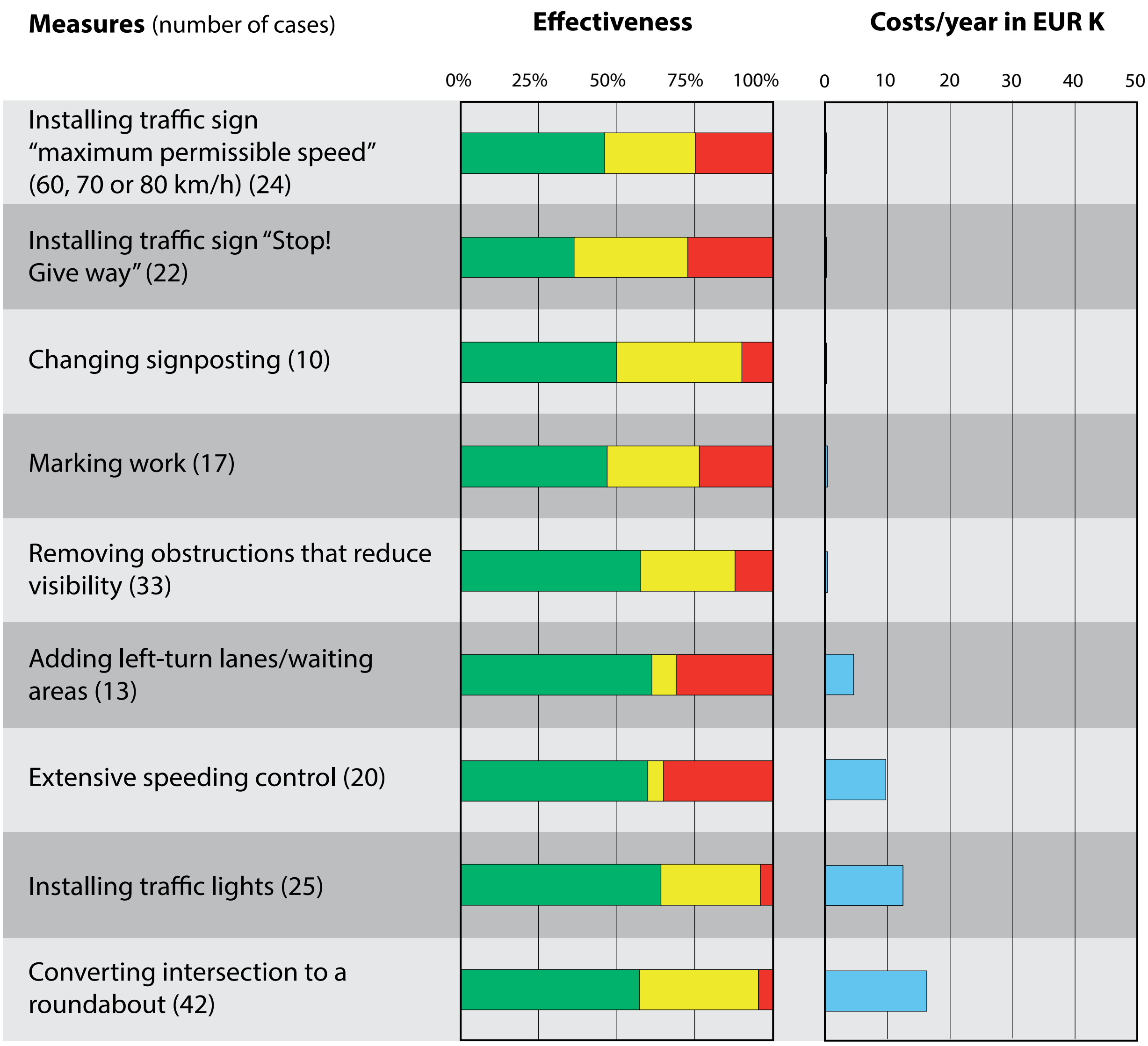
The intersection was hard to see. Drivers overtook other vehicles before the intersection, which caused them to recognize vehicles turning too late and the following traffic collided with the vehicle's rear end.

Measure

The ban on overtaking prohibits overtaking before the intersection.
BUT: This measure could not improve the visibility of the intersection.

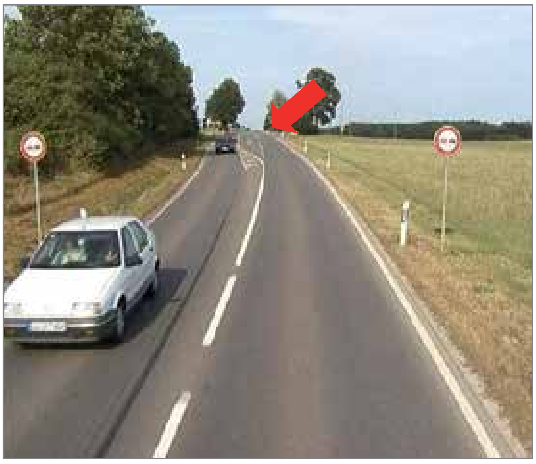
4.1 Intersection Regulated by Traffic Signs

Turning into / crossing accidents



Successful example: Installing traffic sign "maximum permissible speed"

Problem



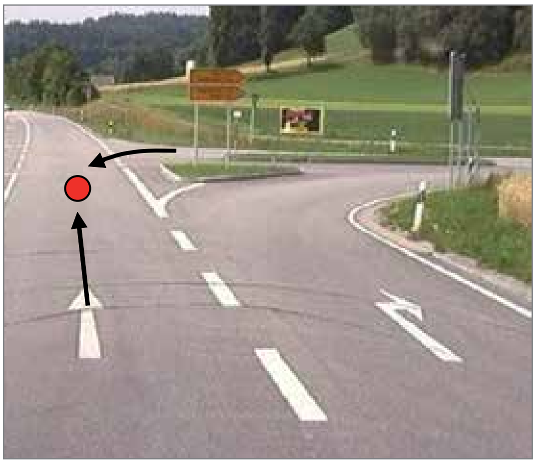
High speeds on the major road made it difficult to turn into the major road from the minor road (short time gaps) causing the vehicles turning into the road to collide with vehicles having the right of way.

Measure

The limitation of the maximum permissible speed reduces the speed level at the intersection and increases the time gaps for turning into the major road.

Successful example: Installing traffic sign „Stop! Give way"

Problem



The obligation to stop on the minor road was often ignored with drivers turning into the major road without stopping resulting in a collision with vehicles having the right of way.

Measure

A stop sign indicates the obligation to stop on the minor road.

Successful example: Changing signposting - installing signposting

Problem

Since the intersection was hard to see, drivers drove too fast in the intersection area which made it difficult for vehicles coming from the minor road to turn into the major road (short time gaps in the main flow).

Measure

The installed signpost gives advance warning of the intersections.
BUT: A left-turning lane is lacking and the row of trees still obscures the intersection and the vehicles in the main flow.

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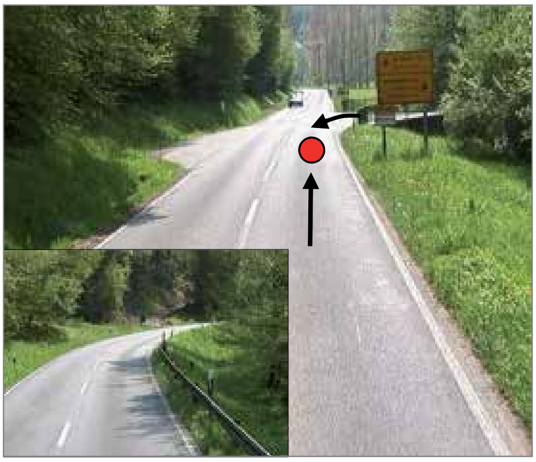
Successful example: Changing signposting - improving signposting

Problem



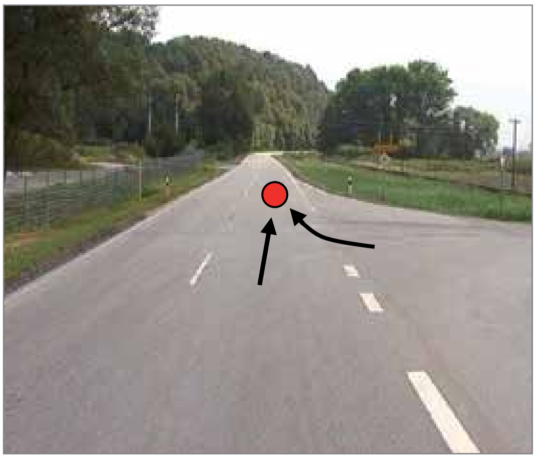
The junction that is located after a bend was not visible from the major road. The destination sign with arrows indicating the directions was installed directly before the intersection and additionally limited the visibility of drivers turning into the major road causing them to collide with vehicles having the right of way.

Measure

The destination sign with arrows indicating the directions is located before the bend and signals the intersection well in advance. This also improved the visibility of drivers turning into the major road.
BUT: A tree is already obscuring the signpost. Visibility of drivers turning into the major road is still limited by the handrail of the bridge.

Successful example: Marking work - adding missing markings

Problem



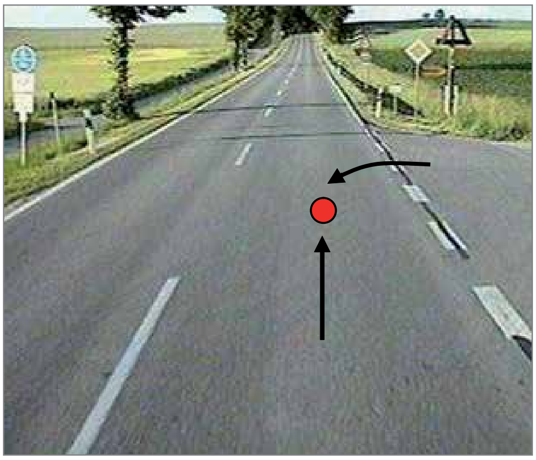
The stop line was no longer visible causing vehicles to turn into the priority road without stopping and colliding with vehicles having the right of way.

Measure

The stop line was renewed to signal drivers turning into the major road in a clearer way that they are obliged to stop.
BUT: A channelizing island (droplet shape) on the minor road is still lacking. The condition of the centre marking is in need of improvement.

Successful example: Marking work - repairing markings

Problem



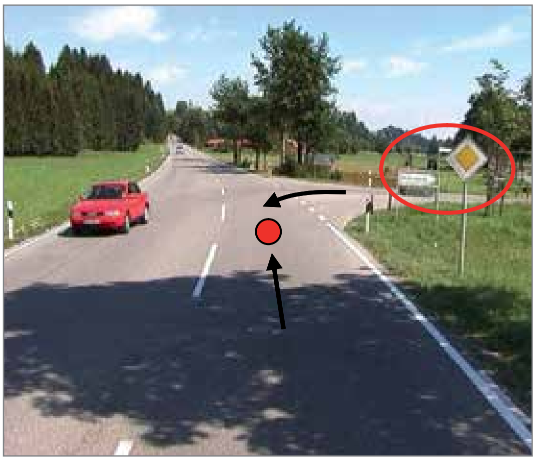
The stop line was no longer clearly visible causing vehicles to turn into the priority road without stopping and colliding with vehicles having the right of way.

Measure

The renewed stop line shows drivers turning into the major road that they are obliged to stop.
BUT: A channelizing island (droplet shape) on the minor road is still lacking.

Successful example: Removing obstructions that reduce visibility - moving signs

Problem



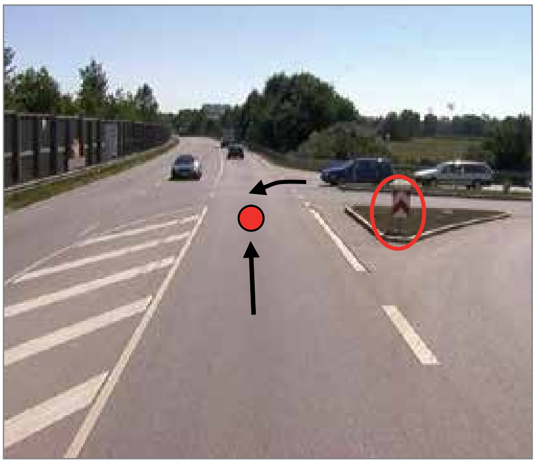
The visibility splay (range of vision required for a driver to safely turn into a major road from a stop) at the intersection was insufficient for both passenger vehicles and lorries. Accidents with vehicles having the right of way occurred as vehicles turned into the major road despite of bad visibility.

Measure

Obstructions reducing visibility for traffic turning into the major road were removed by optimising the installation sites of the signs.
BUT: A channelizing island (droplet shape) on the minor road is still lacking. The signposts are not installed according to the regulations.

Successful example: Removing obstructions that reduce visibility - replacing signs

Problem



The visibility splay (range of vision required for a driver to safely turn into a major road from a stop) at the intersection was insufficient for passenger vehicles. Accidents with vehicles having the right of way occurred as vehicles turned into the major road despite of bad visibility.

Measure

Visibility for traffic turning into the major road was improved by replacing the marker board with posts.

Successful example: Removing obstructions that reduce visibility - cutting back vegetation

Problem

The visibility splay (range of vision required for a driver to safely turn into a major road from a stop) at the intersection was insufficient. Accidents with vehicles having the right of way occurred as vehicles turned into the major road despite of bad visibility.

Measure

Visibility for traffic turning into the major road was improved by cutting back the vegetation. **BUT:** The vegetation has to be cut back at regular intervals.

Successful example: Removing obstructions that reduce visibility - setting back road equipment

Problem

The visibility splay (range of vision required for a driver to safely turn into a major road from a stop) at the intersection was insufficient. Accidents with vehicles having the right of way occurred as vehicles turned into the major road despite of bad visibility.

Measure

The steel crash barrier and the signs were set back from the edge of the road, which improves the visibility for traffic turning into the major road.

Successful example: Removing obstructions that reduce visibility - removing vertical extension rail

Problem

The visibility splay (range of vision required for a driver to safely turn into a major road from a stop) at the intersection was insufficient for passenger vehicles. Accidents with vehicles having the right of way occurred as vehicles turned into the major road despite of bad visibility.

Measure

Visibility for traffic turning into the major road was improved by removing the vertical extension rail.
BUT: The steel crash barrier is in a poor condition. The protection of cyclists is no longer guaranteed.

Successful example: Removing obstructions that reduce visibility - adapting signposting

Problem

The visibility splay (range of vision required for a driver to safely turn into a major road from a stop) at the intersection was insufficient. Accidents with vehicles having the right of way occurred as vehicles turned into the major road despite of bad visibility.

Measure

Visibility for traffic turning into the major road was improved by moving the signposts up, lowering the marker board and removing the marker post.

Successful example: Adding left-turn lanes

Problem

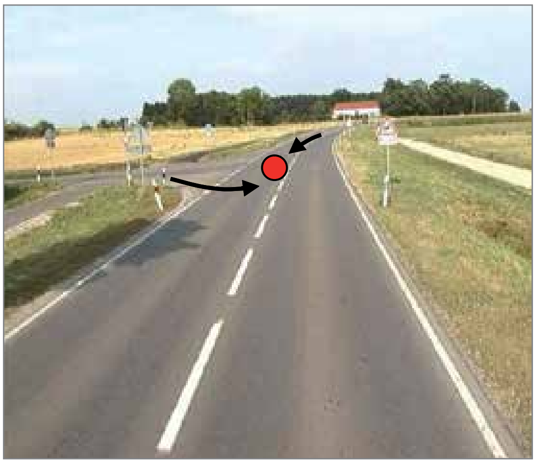
Since the intersection was hard to see, drivers drove too fast in the intersection area which made it difficult for vehicles coming from the minor road to turn into the major road (short time gaps in the main flow).

Measure

The added left-turn lane improves the visibility of the intersection.
BUT: A channelizing island (droplet shape) on the minor road and signposting is still lacking.

Successful example: Adding left-turn lanes

Problem



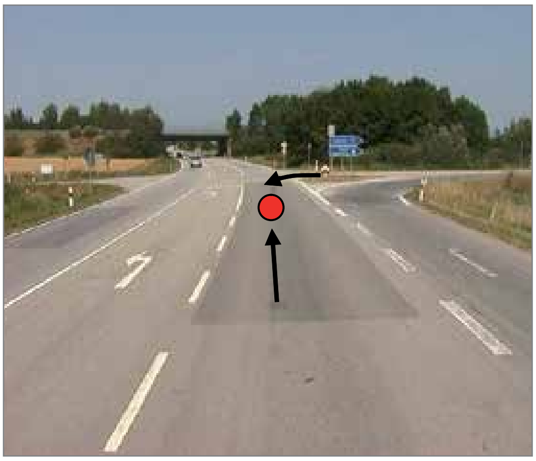
The intersection was hard to see in the dark. In addition, drivers drove too fast, which made it difficult for vehicles coming from the minor road to turn into the major road (short time gaps in the main flow).

Measure

The added left-turn lane improves the visibility of the intersection, especially in the dark.
BUT: A channelizing island (droplet shape) on the minor road is still lacking.

Successful example: Installing traffic lights - installing signals at intersection

Problem



High traffic volumes on the major road made it difficult to turn into/cross the major road coming from the minor road (short time gaps).

Measure

A traffic light system provides sufficiently long time gaps in the main flow for safe turning into/crossing of the major road. In addition, the separate left-turn phase provides increased safety when turning.

Successful example: Installing traffic lights - installing signals at junction

Problem

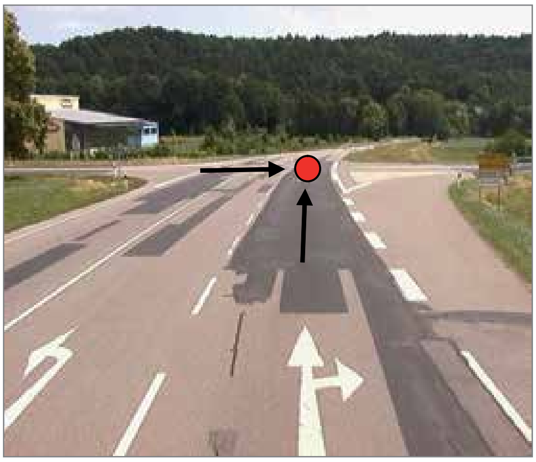
High traffic volumes on the major road made it difficult to turn left into the main flow (short time gaps).

Measure

A traffic light system provides sufficiently long time gaps in the main flow for safe turning into/crossing of the major road from the low-traffic minor road. At the same time, the traffic-actuated light signal control system provides for high throughput.

Successful example: Converting intersection into a roundabout

Problem



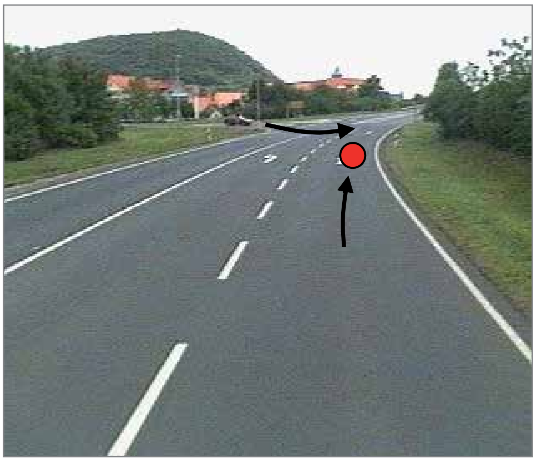
Crossing on the open road was allowed. Increased speed levels led to accidents with severe side collisions at the intersection when turning into/crossing the major road.

Measure

The conversion into a roundabout reduces the speed level at the intersection and makes turning into/crossing the major road easier (reduction of conflict points).

Successful example: Converting junction into a roundabout

Problem



The intersection was hard to see from the minor road, which caused severe accidents when vehicles turned into the major road.

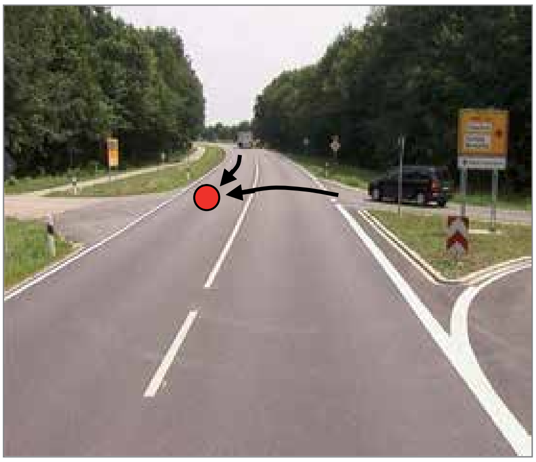
Measure

The conversion into a roundabout reduces the speed level at the intersection and makes turning into/crossing the major road easier. The lighting of the roundabout, especially outside of lit built-up areas ensures better visibility at night.

Other examples of successful remedial measures (number of cases < 10)

Closing access

Problem



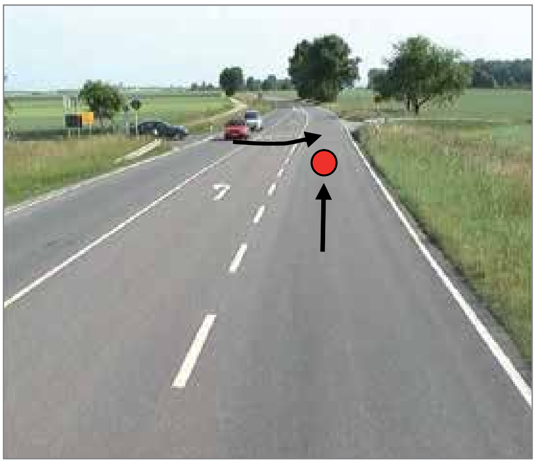
A junction opposite the minor road incited drivers to cross the major road in violation of the crossing ban. Illegal crossing manoeuvres led to accidents with vehicles having the right of way.

Measure

Thanks to the closed access the major road can no longer be crossed.
BUT: Illegal turning manoeuvres to change direction are still possible and have been observed.

Installing a screen

Problem



The range of vision of the traffic turning into the major road was very wide inducing drivers to misjudge distances and speeds, not least due to their own high speeds. Turning into the major road without stopping at the stop line led to severe accidents with vehicles having the right of way.

Measure

The screen "forces" road users turning into the major road to approach the intersection at a reduced speed and, thus, to pay increased attention at the intersection.

4.1 Intersection Regulated by Traffic Signs

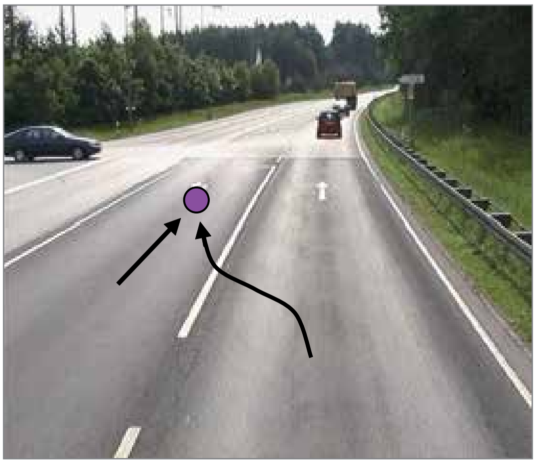
Accident involving longitudinal traffic (rear-end and head-on collisions)

There is no measure evaluation in form of the usual bar diagram for this main accident type as the minimum criterion for the required comparative cases (number of cases ≥ 10) has not been achieved for any of the performed measures. We therefore only present "other" examples of successful remedial measures below.

Other examples of successful remedial measures (number of cases < 10)

Installing traffic lights

Problem



High driving speeds and high traffic volumes on the major road incited drivers to initiate risky lane changes ahead of the intersection which caused rear-end collisions with following vehicles.

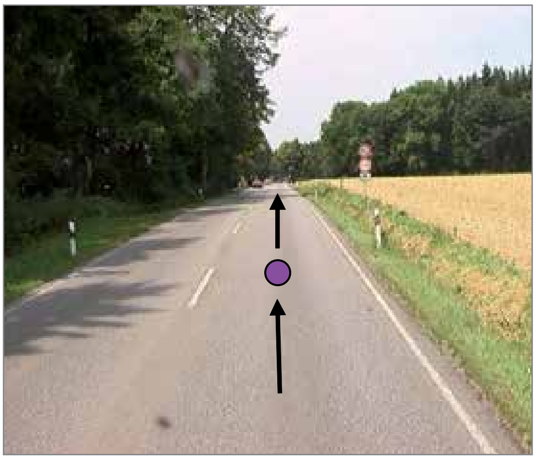
Measure

Traffic lights with separate left-turn phase clearly separates the traffic flow and ensures fast and safe turning.

Other examples of successful remedial measures (number of cases < 10)

Installing signposts

Problem



Since the intersection was hard to see, drivers only recognized slow vehicles in front of them very late. This caused rear-end collisions.

Measure

The new signpost gives advance warning of the intersection.
BUT: A left-turn lane is still lacking. In addition, the signposting is not installed according to regulations.

Installing traffic sign "Stop! Give way"

Problem

The large waiting area on the minor road incited drivers to enter the major road too quickly, which caused conflicts when decelerating and resulted in rear-end collisions.

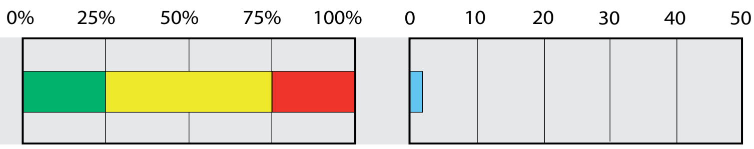
Measure

A stop sign indicates the obligation to stop on the minor road and prohibits entering without stopping at the stop line.
BUT: The entry area is still too wide.

4.2 Intersection Regulated by Traffic Lights

Turning-off accidents

Measures (number of cases)	**Effectiveness**	**Costs/year in EUR K**
Changing signal system (12)		



Successful remedial measure: Changing signal system
Setting up separate left-turn phase

Problem

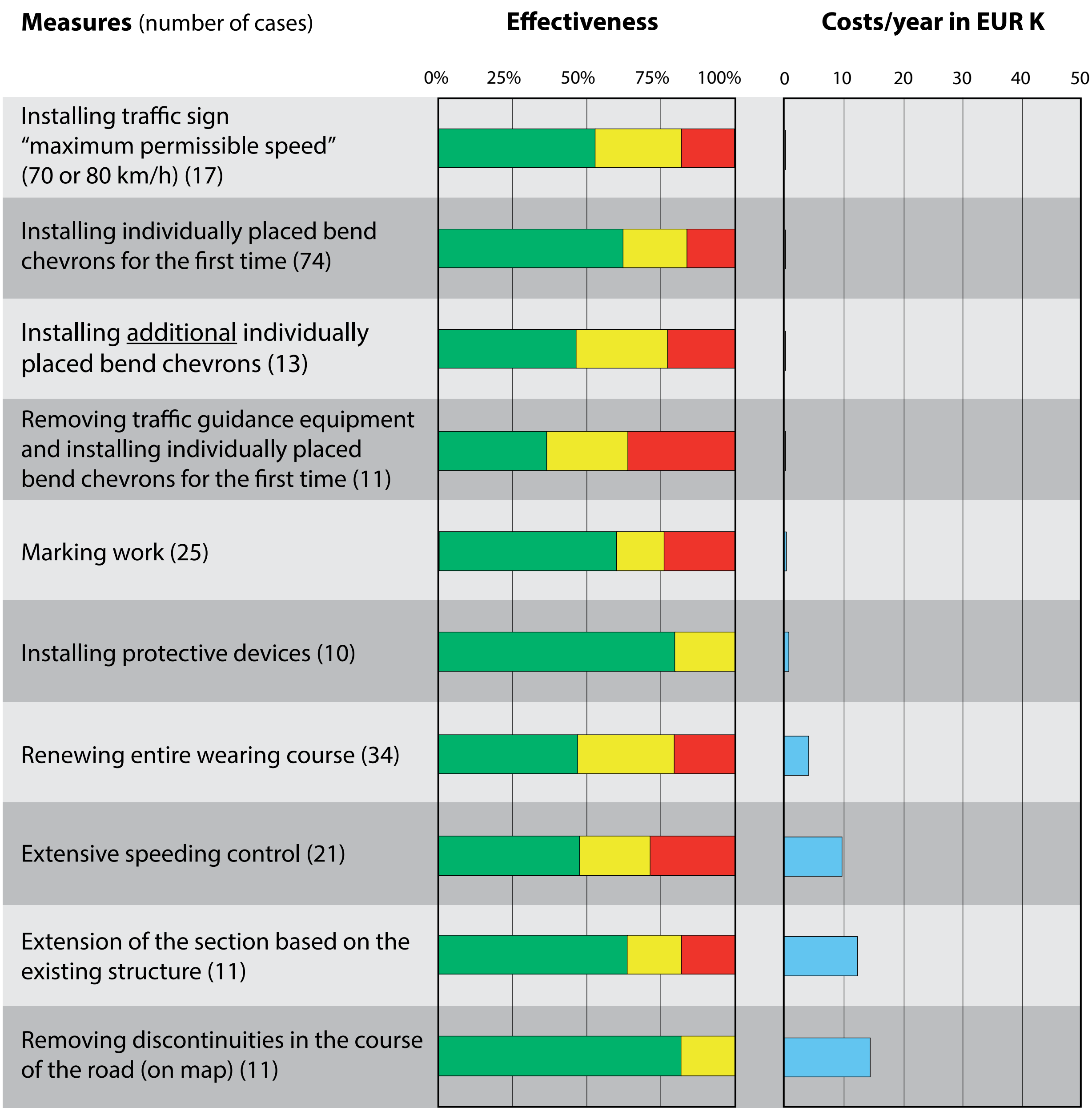
There was no separate phase for vehicles turning left, which promoted accidents when turning left.

Measure

A separate left-turn phase "protects" road users turning left into the minor road from encountering oncoming traffic.

4.3 Bend

Single-vehicle accident



Successful example: Installing traffic sign "maximum permissible speed"

Problem

The direction of the bend was hard to see. High speeds led to single-vehicle accidents.

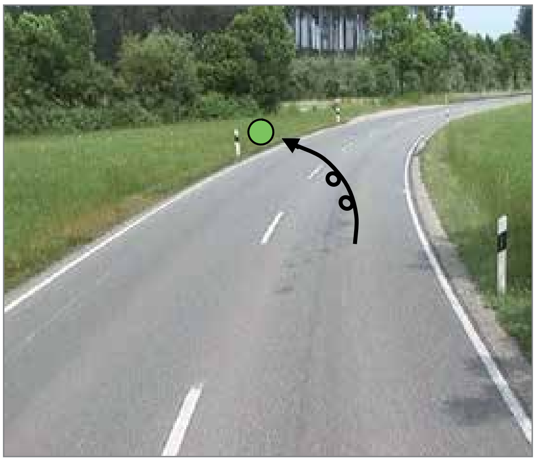
Measure

The speed limit reduces the speed level in the area of the bend

BUT: The direction of the bend must still be made clearer (e.g. by bend chevrons).

Successful example: Installing individually placed bend chevrons for the first time

Problem



The discontinuity of the road's layout and the poor condition of the road promoted many single-vehicle accidents when the road was wet.

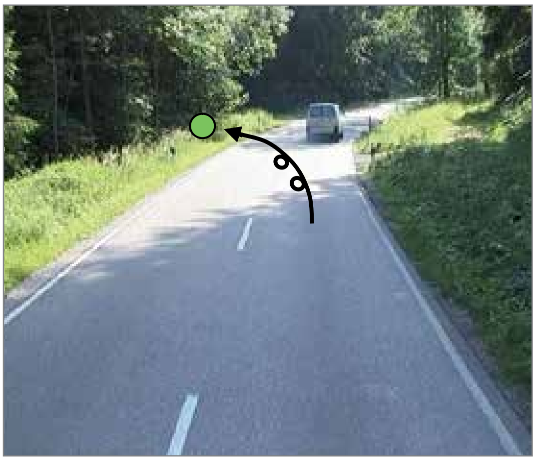
Measure

Individually placed bend chevrons indicate the direction of the bend.

BUT: The road is still in poor condition.

Successful example: Installing individually placed bend chevrons for the first time

Problem



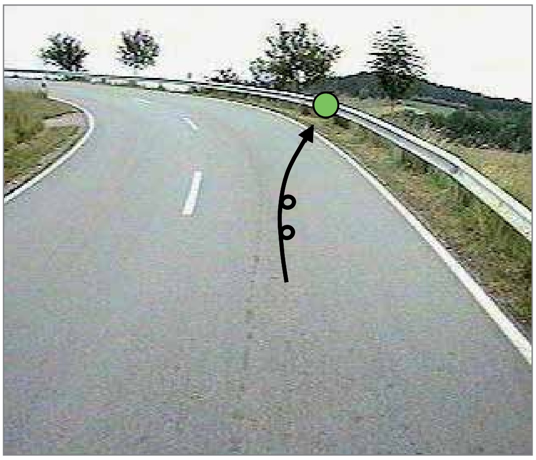
The direction of the bend was hard to see in the wooded area. In some areas visibility was limited due to sudden changes of light and dark patches, which promoted single-vehicle accidents.

Measure

Individually placed bend chevrons (some of which are fluorescent yellow) indicate the direction of the bend.
BUT: Passive safety has not been increased (no steel crash barrier). In addition, visibility is still limited by the vegetation in the inner bend.

Successful example: Installing individually placed bend chevrons for the first time

Problem



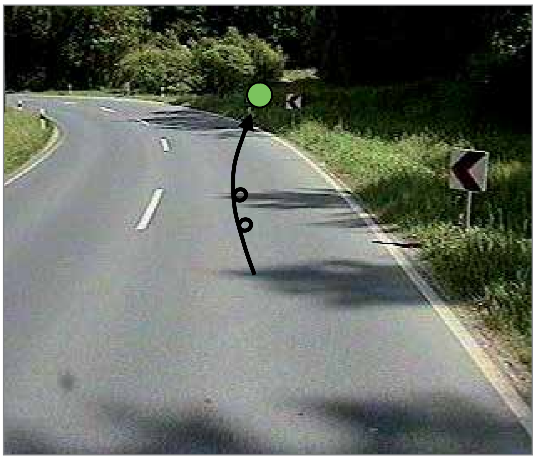
The direction of the bend was hard to see, which promoted single-vehicle accidents

Measure

Individually placed bend chevrons indicate the direction of the bend.

Successful example: Installing <u>additional</u> individually placed bend chevrons for the first time

Problem



The direction of the bend was hard to see despite (some) individually placed bend chevrons, which promoted single-vehicle accidents.

Measure

Additional individually placed bend chevrons make the direction of the bend clearer.
BUT: Visibility is still limited by the vegetation in the inner bend.

Successful example: Removing traffic guidance equipment and installing individually placed bend chevrons for the first time

Problem

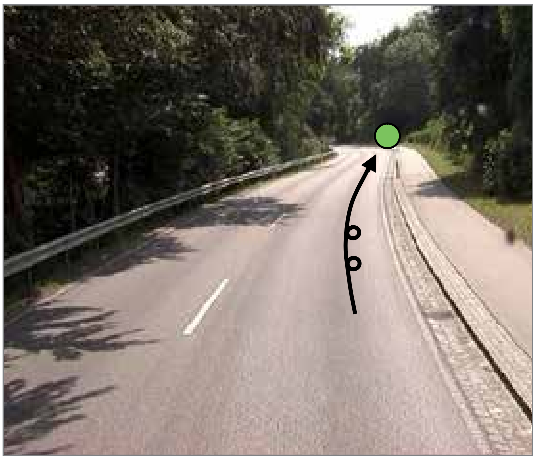
The traffic guidance equipment was insufficient to indicate the direction of the bend, which promoted single-vehicle accidents.

Measure

Individually placed bend chevrons indicate the direction of the bend on an extended stretch of road.
BUT: Visibility is still limited by the slope in the inner bend.

Successful example: Marking work - adding solid white centre line

Problem



The broken line centre road marking was insufficient to indicate the course of the road and promoted high driving speeds and road departure accidents.

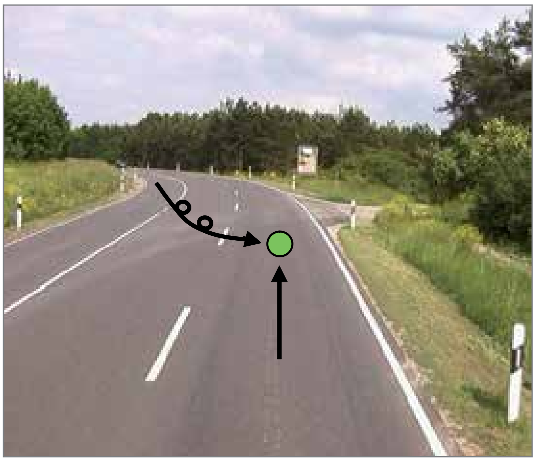
Measure

The solid line centre road marking makes the course of the road and the lane limits clearer. In addition, overtaking is banned.

BUT: The safety distance between the road and the attached pavement and bicycle path is insufficient.

Successful example: Marking work - adding solid white centre line

Problem



The single solid line centre road marking was insufficient to indicate the course and three-lane, single-carriageway layout of the road, which promoted single-vehicle accidents.

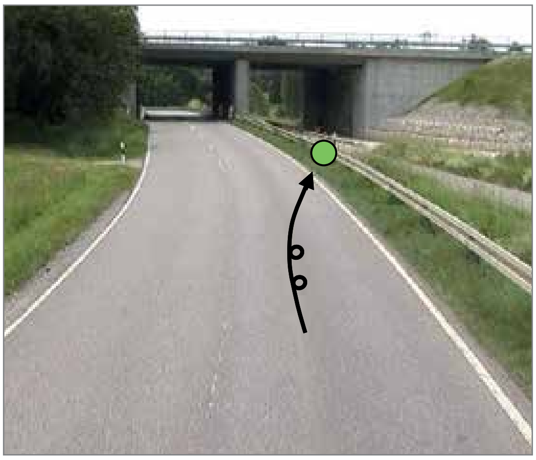
Measure

The double solid line centre road marking makes the lane limits, the course of the road and the three-lane, single-carriageway layout of the road clearer.

BUT: The at-grade access remains.

Successful example: Marking work - repairing the marking

Problem



The centre road marking was in a poor condition and could hardly be seen at all. In addition, it was hard to see the further direction of the road due to a bridge, which promoted single-vehicle accidents.

Measure

The renewed centre road marking makes the course of the road clearer.
BUT: This measure could not improve the limited field of vision caused by the bridge.

Successful example: Installing protective devices - simple steel crash barrier

Problem

The direction of the bend was hard to see. In addition, there were trees at the edge of the road. Single-vehicle accidents where vehicles collided with the trees in the outer bend had severe consequences.

Measure

Passive safety was increased by means of a steel crash barrier.
BUT: The length of the steel crash barrier is insufficient (unprotected trees farther on in the bend). In addition, the bend direction must still be made clearer.

Successful example: Installing protective devices - retrofitting underrun protection

Problem

The road's layout was discontinuous and the marking was hard to see. Motorcycle single-vehicle accidents involving a collision with the posts of the steel crash barrier resulted in severe consequences despite the posts' protective casing.

Measure

Passive safety for motorcycle riders was increased by means of an underrun protection.
BUT: The edge marking is still in need of improvement.

Successful example: Renewing entire wearing course

Problem

The road was in a very poor condition. In addition, it was very hard to identify the direction of the bend, which repeatedly resulted in single-vehicle accidents.

Measure

Thanks to the renewed wearing course, the road is again in a good condition.
BUT: Visibility is still very limited due to the slope in the inner bend.

Successful example: Extension of the section based on the existing structure

Problem

The road had ruts, which promoted single-vehicle accidents when the road was wet.

Measure

Thanks to the extension work based on the existing structure, the road is safe for traffic again. **BUT:** The vegetation in the inner bend is still limiting visibility. In addition, the safety distance between the road and the attached bicycle path is insufficient.

Successful example: Eliminating a discontinuity in the road layout (on map)

Problem

Both the radius and the transverse slope decreased suddenly in the bend, which resulted in an accumulation of single-vehicle accidents.

Measure

The new layout of the right road edge with a continuous radius and an increased consistent transverse slope eliminated the accident blackspot.

Successful example: Eliminating a discontinuity in the road layout (on map)

Problem

The turning line and the further course of the road towards the right could not be anticipated. Numerous drivers lost control of their vehicles for this reason.

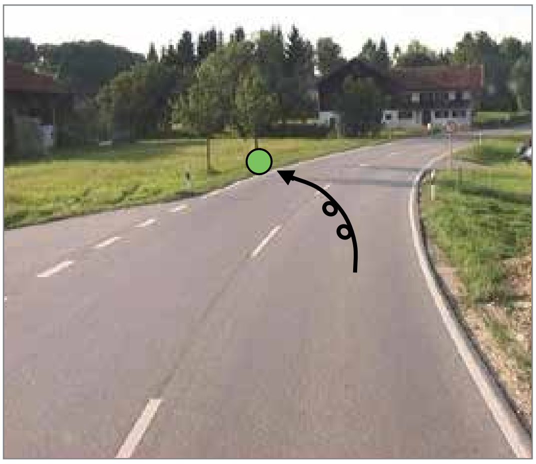
Measure

A bend was removed in the new road layout to make the further course of the road towards the right clear. In addition, the cross-section was widened, the road was resurfaced and its marking was renewed.

Other examples of successful remedial measures (number of cases < 10)

Removing tree

Problem



There were trees at the edges of the road. Vehicles departing from the road collided with these trees, which resulted in serious injuries to the vehicles' passengers.

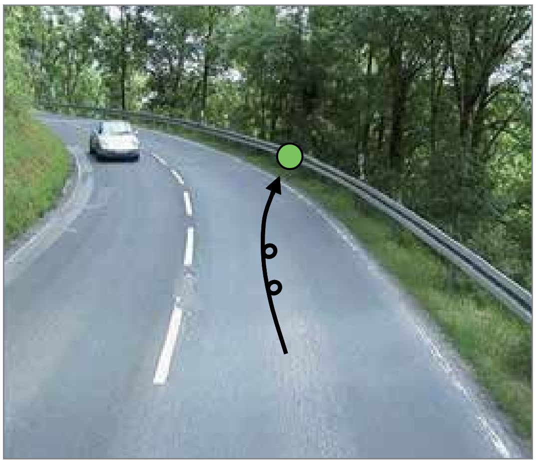
Measure

The area at the road edge which is now free of obstacles provides a large zone for vehicles to come to a standstill. The destination signs were only installed later on.
BUT: The soft shoulder is still in poor condition.

Other examples of successful remedial measures (number of cases < 10)

Installing traffic guidance equipment

Problem



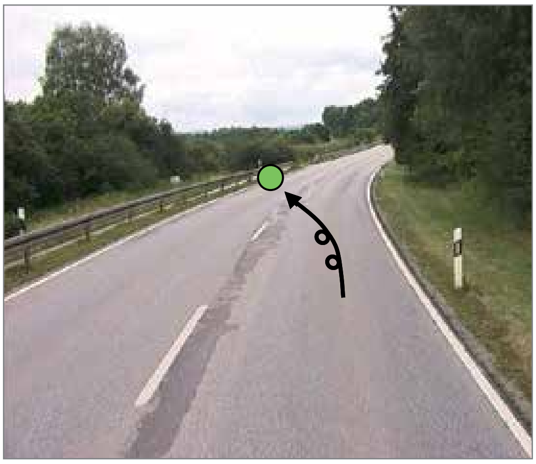
The tight radius of the bend was hard to see, which promoted single-vehicle accidents.

Measure

Traffic guidance equipment installed on top of the steel crash barrier makes it easier to see the direction of the bend.
BUT: The marking and the condition of the road are still deficient.

Renewing entire wearing course and marking to increase night-time visibility

Problem



The road surface was in a very poor condition, which promoted single-vehicle accidents.

Measure

Thanks to the new wearing course, the road has more grip. In addition, the type II marking provides increased night-time visibility.
BUT: The steel crash barrier has a gap.

Other examples of successful remedial measures (number of cases < 10)

Installing steel crash barrier and individually placed bend chevrons

Problem

The road layout was discontinuous. In addition, there were trees at the edge of the road. The direction of the bend was hard to see, which promoted single-vehicle accidents that had severe consequences where vehicles collided with the trees.

Measure

Individually placed bend chevrons indicate the direction of the bend. When a vehicle departs from the road, steel crash barriers prevent it from colliding with a tree which might have severe consequences.
BUT: The vegetation in the inner bend still limits visibility.

Establishing visibility conditions enabling drivers to stop if required

Problem

The intersection situated in the bend was hard to see. Drivers could therefore only react to the new traffic situation when they had already approached the intersection, which promoted single-vehicle accidents.

Measure

The flatter slope improves visibility and makes it therefore easier for the drivers in the main flow to see the course of the road, including the intersection.

Other examples of successful remedial measures (number of cases < 10)

Renewing marking and installing individually placed bend chevrons

Problem

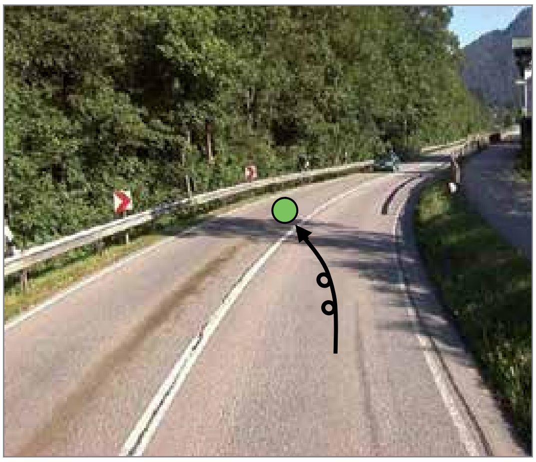
Due to the lack of marking it was hard to see the direction of the bend, especially at night, which promoted single-vehicle accidents.

Measure

Individually placed bend chevrons and renewed road edge markings indicate the direction of the bend.
BUT: The vegetation on the soft shoulder has to be cut back regularly.

Qualified renewal of wearing course

Problem



The transverse slope and the condition of the road were inadequate. In addition, the layout of the road was discontinuous, repeatedly resulting in single-vehicle accidents when the road was wet.

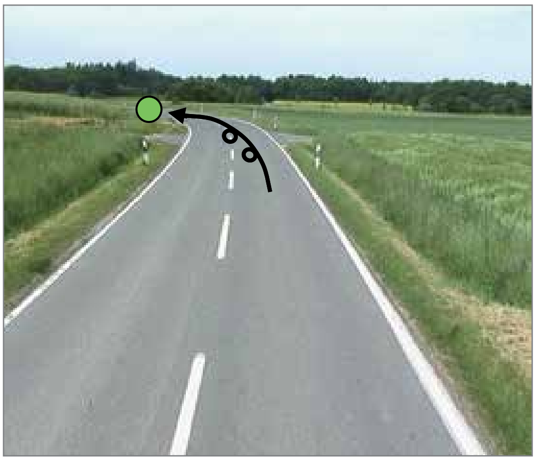
Measure

Thanks to a qualified renewal of the wearing course with an increase of the transverse slope the road now features good grip and drainage conditions again.

Other examples of successful remedial measures (number of cases < 10)

Installing traffic sign "double bend"

Problem



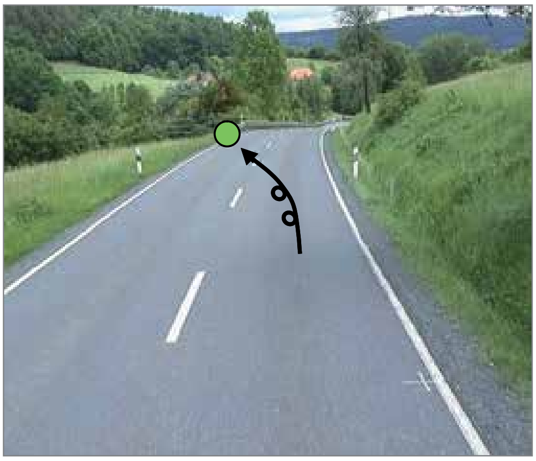
The layout of the road was discontinuous and the double bend could not be seen, which promoted single-vehicle accidents.

Measure

The danger sign gives advance warning of the double bend.

Installing traffic sign "hazard ahead"

Problem



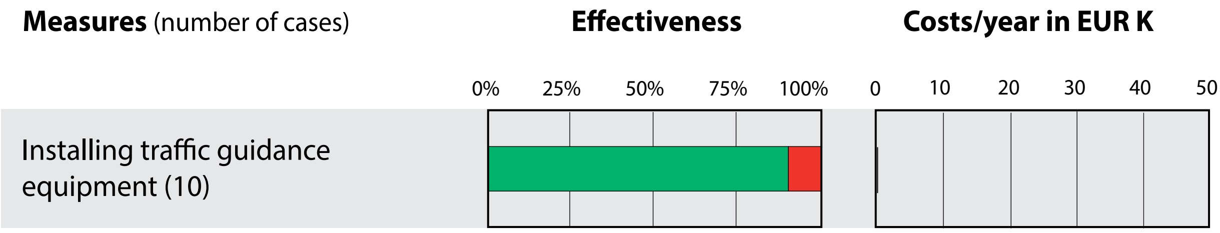
The layout of the road was discontinuous and the road sometimes dipped down, which promoted single-vehicle accidents.

Measure

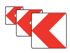
The danger sign gives advance warning of the dangerous layout of the road (additional sign installed later on).
BUT: The condition of the soft shoulder is in need of improvement.

4.3 Bend

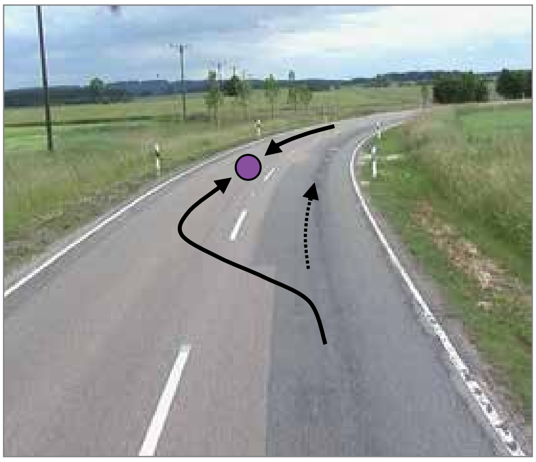
Accident involving longitudinal traffic (rear-end and head-on collisions)



Successful example: Installing traffic guidance equipment installing individually placed bend chevrons



Problem



The course of the road was hard to see which is why the curvature of the road was underestimated. This repeatedly caused accidents involving longitudinal traffic (rear-end and head-on collisions) when overtaking.

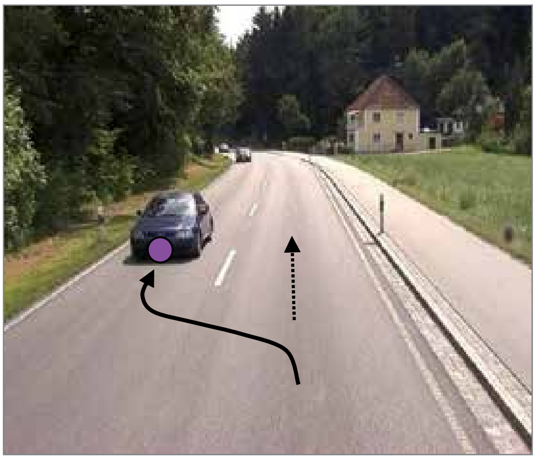
Measure

Individually placed bend chevrons indicate the course of the road and thus reduce the willingness to overtake.
BUT: The road is still in poor condition.

Other examples of successful remedial measures (number of cases < 10)

Adding solid white centre line

Problem



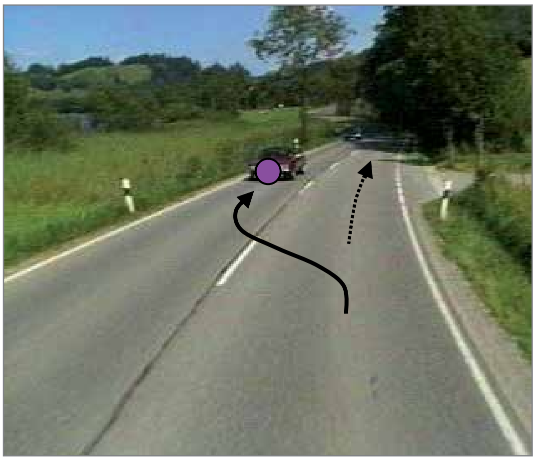
Visibility was not sufficient for overtaking. Due to overtaking manoeuvres performed despite insufficient visibility, accidents involving longitudinal traffic (rear-end and head-on collisions) occurred repeatedly.

Measure

The solid line centre road marking prohibits overtaking.
BUT: The safety distance between the road and the attached pavement and bicycle path is still insufficient.

Establishing visibility for safe overtaking

Problem



Visibility for overtaking was limited by a tree at the edge of the road. Due to overtaking manoeuvres accidents involving longitudinal traffic (rear-end and head-on collisions) occurred repeatedly.

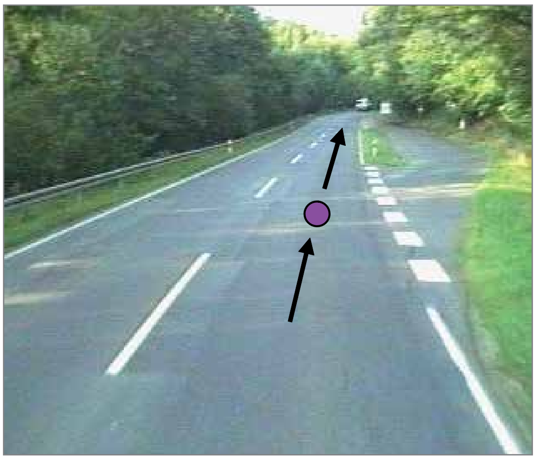
Measure

Visibility was improved by removing the obstacle (tree).
BUT: Passive protection (trees in outer bend unprotected) and the markings are still not ideal.

Other examples of successful remedial measures (number of cases < 10)

Qualified renewal of wearing course

Problem



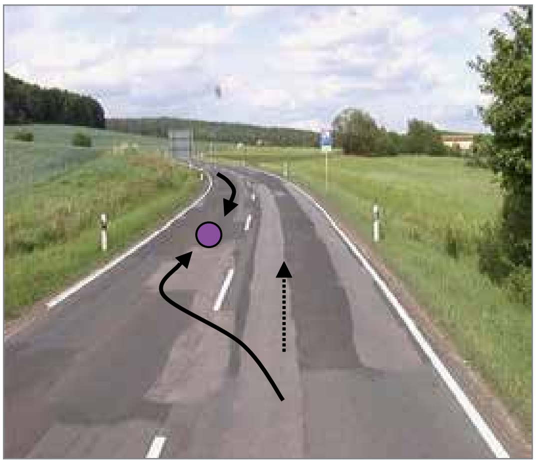
The road was in a poor condition, which promoted rear-end collisions when the road was wet.

Measure

Thanks to the renewal of the wearing course, the road's grip level is satisfactory again.
BUT: It is still possible to leave the parking area (against the direction of the traffic).

New construction of the section according to the regulations

Problem



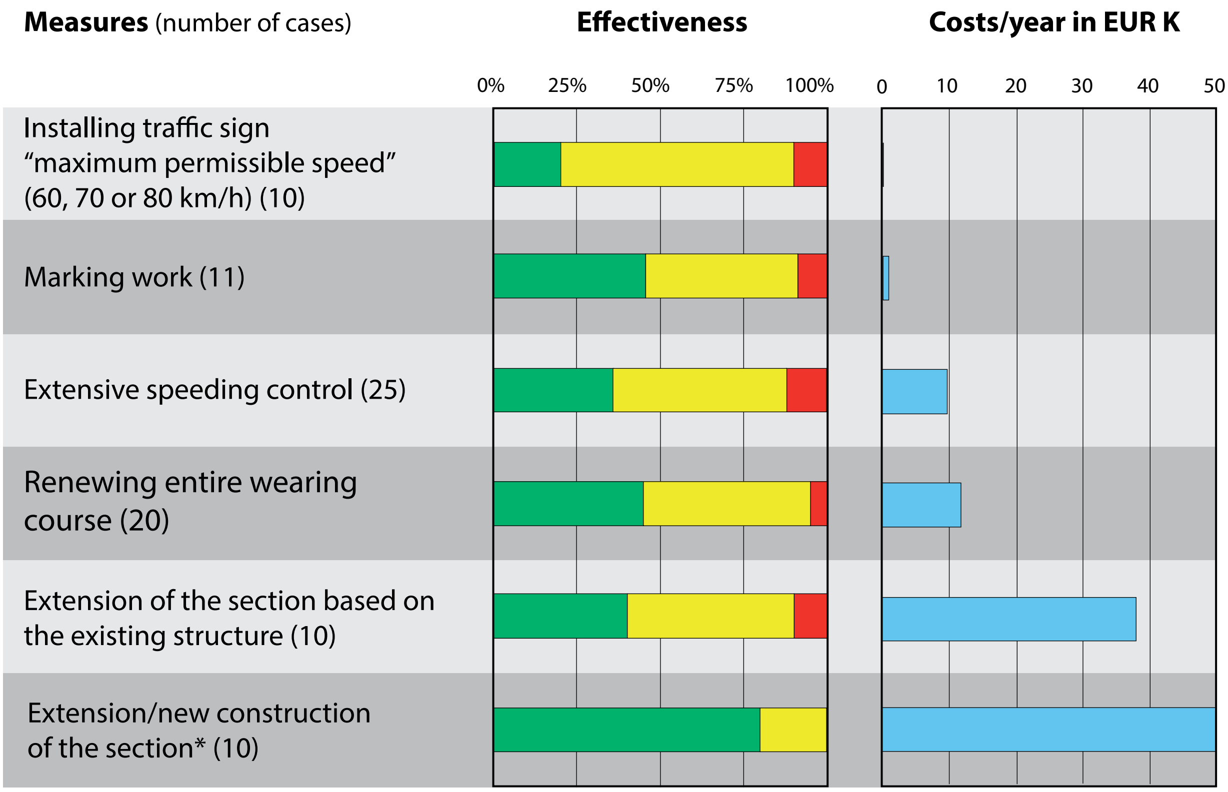
The direction of the bend (turning line) was hard to see. Overtaking manoeuvres in the area of the bend resulted in head-on collisions with severe consequences.

Measure

The changed layout of the road has no turning line and makes the further course of the road towards the right clear.

4.4 Extended Stretch of Road

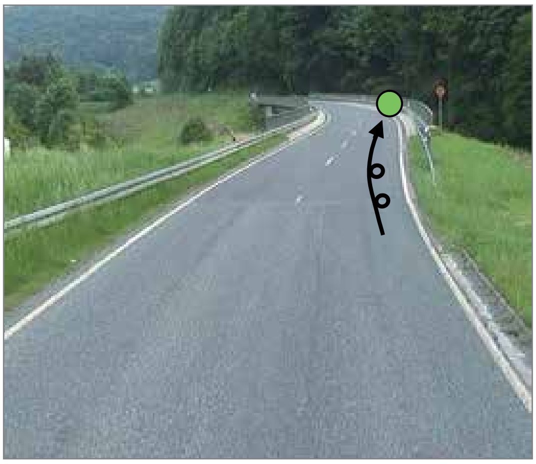
Single-vehicle accident



* The evaluation of the measure only takes into account the benefits resulting from an improved incidence of accidents. Benefits resulting from changed operating costs, travelling times, environmental and climate impact etc. [5] are not considered in this analysis.

Successful example: Installing traffic sign "maximum permissible speed"

Problem



The course of the road was hard to see. High speeds led to single-vehicle accidents.

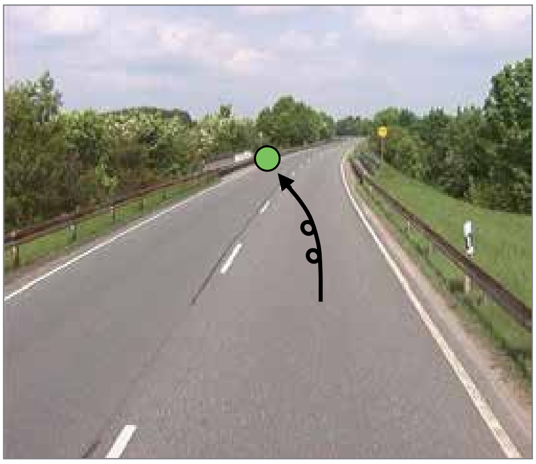
Measure

The speed limit reduces the speed level before the critical section of the road. In addition, the road surface beyond the accident blackspot was repaired.

BUT: Due to the vegetation in the inner bend and the bridge railing it is still hard to see the course of the road.

Successful example: Marking work - adding solid white centre line

Problem



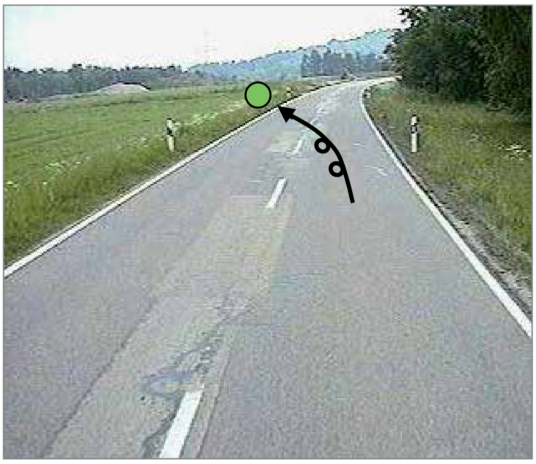
The straight layout of the road incited drivers to drive very fast (speeding). However, visibility was insufficient for overtaking due to the vegetation and the steel crash barrier, which resulted in single-vehicle accidents when overtaking.

Measure

The solid line centre road marking prohibits overtaking and thus reduces the speed level.

Successful example: Renewing entire wearing course

Problem



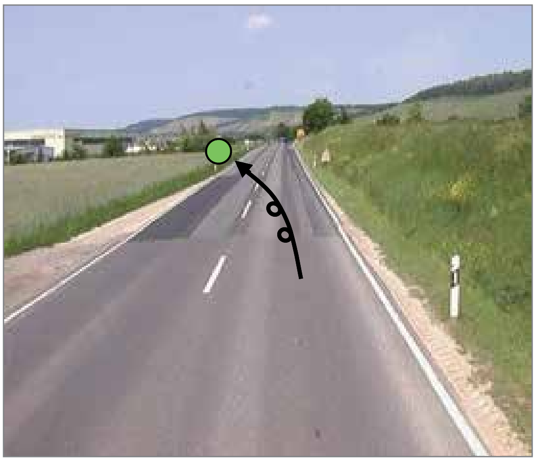
The road was in a very poor condition, which promoted single-vehicle accidents.

Measure

Thanks to the renewed wearing course, the road is again in a mostly safe condition.
BUT: Visibility is still very limited due to vegetation in the inner bend.

Successful example: Extension of the section based on the existing structure

Problem



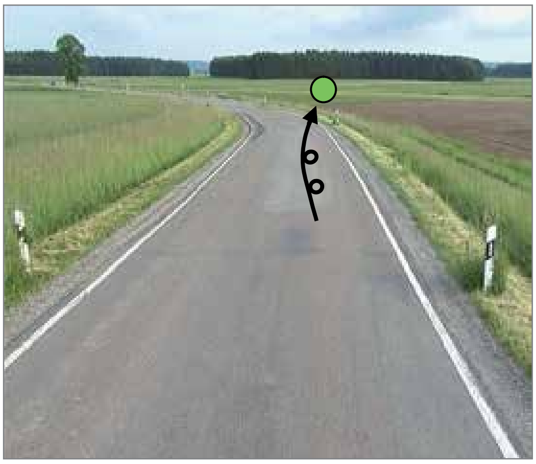
The condition of the road suddenly deteriorated at the end of the extension work, which promoted single-vehicle accidents.

Measure

Since the extension work has been continued the quality standards are adhered to throughout the entire road section.

Successful example: Extension of the section according to the regulations

Problem



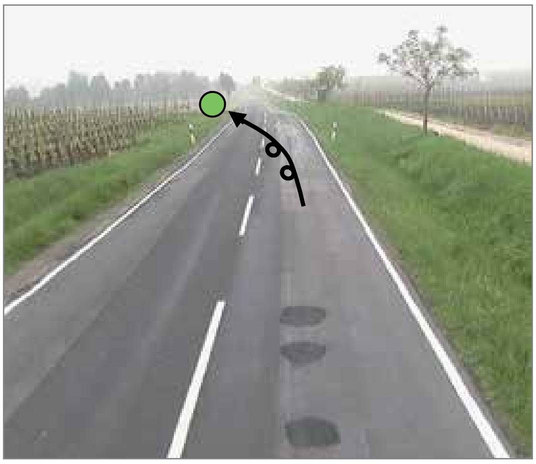
The layout of the road was discontinuous and the road was very narrow, which promoted single-vehicle accidents.

Measure

During the extension of the section according to the regulations, the cross-section of the road has been widened and the layout of the road has been improved. The bicycle paths running parallel to the road also increase road safety.

Successful example: Extension of the section according to the regulations

Problem



The road was in a poor condition and the layout of the road was discontinuous. As the road sloped up, the course of the road behind the slope was hard to see, which promoted single-vehicle accidents.

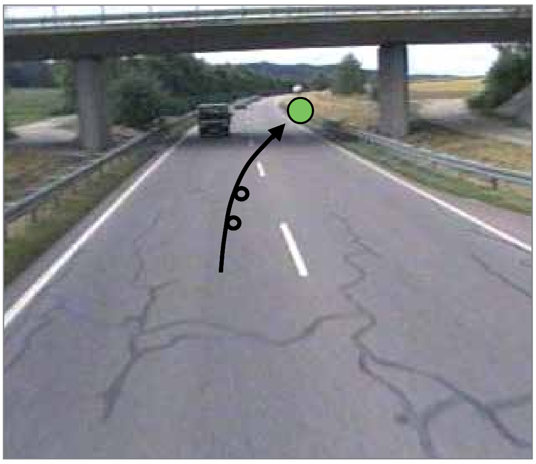
Measure

The position and elevation of the course of the road have been significantly improved during the extension of the section according to the regulations.
BUT: Passive safety has not been improved (still trees at the edge of the road).

Other examples of successful remedial measures (number of cases < 10)

Widening cross-section to three lanes

Problem



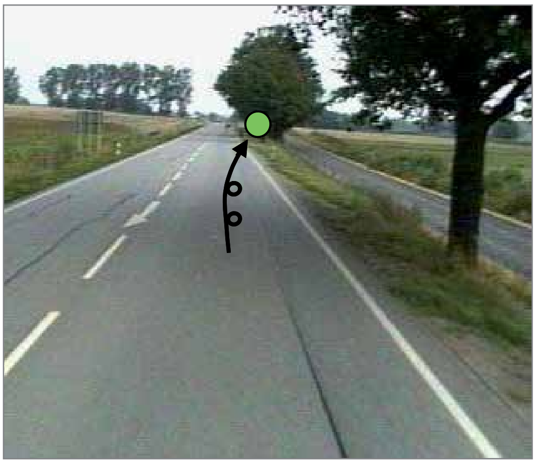
The straight layout of the road incited drivers to drive very fast. However, visibility was insufficient for overtaking due to the bridge. Aborted overtaking manoeuvres caused drivers to lose control of their vehicle.

Measure

The addition of another lane provides for safe overtaking.
BUT: Traverse slope, radiuses and connecting intersections must be adapted to the requirements of driving dynamics.

Installing steel crash barrier

Problem



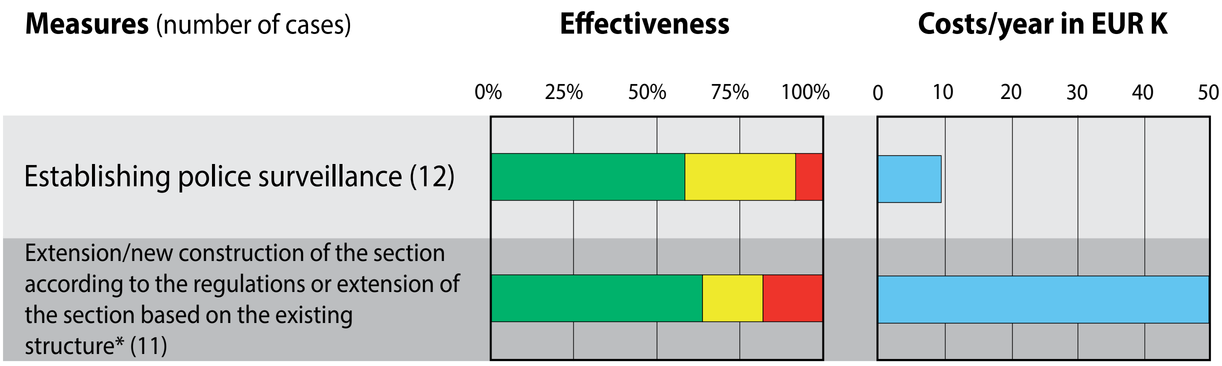
The road was in a poor condition. In addition, there were trees at the edge of the road. Departure accidents where vehicles collided with the trees at the edge of the road had very severe consequences.

Measure

Passive safety was increased by installing a steel crash barrier. This also increased the protection of cyclists on the bicycle path running parallel to the road.

4.4 Extended Stretch of Road

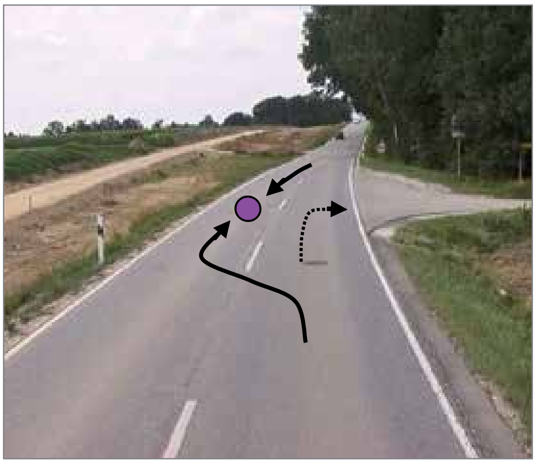
Accident involving longitudinal traffic (rear-end and head-on collisions)



* The evaluation of the measure only takes into account the benefits resulting from an improved incidence of accidents. Benefits resulting from changed operating costs, travelling times, environmental and climate impact etc. [5] are not considered in this analysis.

Successful example: Extension of the section according to the regulations

Problem



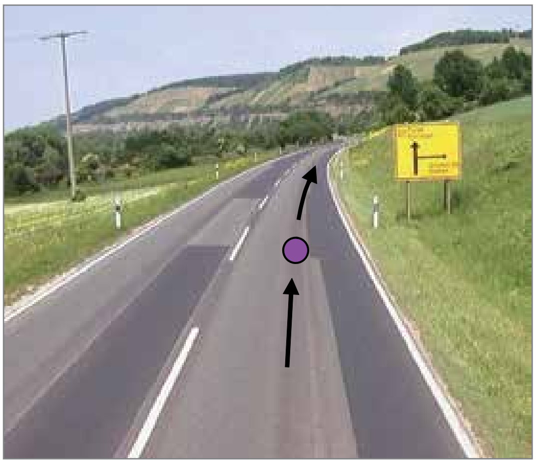
The layout of the road was discontinuous. In addition, this section of the road had numerous access roads and junctions, which promoted risky overtaking manoeuvres of turning vehicles travelling at lower speeds.

Measure

Since the extension of the section according to the regulations, the agricultural road network has been reorganized and the access roads have been merged so that only a few junctions remain.
BUT: The vegetation in the inner bend still limits visibility.

Successful example: Extension of the section based on the existing structure

Problem



The road was in a poor condition, which promoted rear-end collisions when the road was wet.

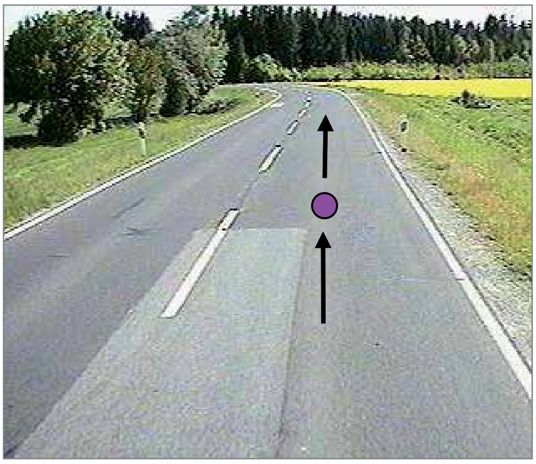
Measure

Thanks to the extension work based on the existing structure the road is safe for traffic again.

Other examples of successful remedial measures (number of cases < 10)

Successful example: Renewing entire wearing course

Problem



The layout of the road was discontinuous and the road was in a poor condition, which promoted rear-end collisions when the road was wet.

Measure

Thanks to the renewed wearing course, the road provides sufficient grip again.
BUT: The discontinuous layout of the road has not been improved by the renewed wearing course.

Other examples of successful remedial measures (number of cases < 10)

Widening cross-section to three lanes

Problem

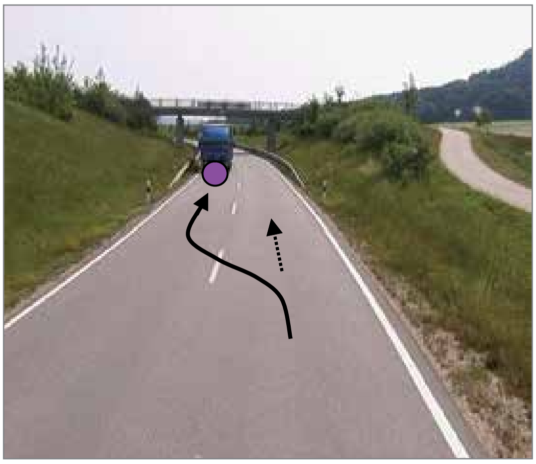
The road provided little opportunities for overtaking while the volume of traffic was quite high. Overtaking despite short time gaps in incoming traffic repeatedly caused severe accidents involving longitudinal traffic (rear-end and head-on collisions).

Measure

The addition of another lane provides for safe overtaking.
BUT: Although the speed level has now increased, passive safety has not been improved (still trees at the edge of the road).

Installing traffic sign "maximum permissible speed"
Installing traffic sign "No overtaking for all vehicles"

Problem



Visibility was insufficient for overtaking due to the slope and the bridge. However, drivers performed overtaking manoeuvres despite insufficient visibility, which caused severe accidents involving longitudinal traffic (rear-end and head-on collisions).

Measure

The ban on overtaking prohibits overtaking in the area of the bend. The speed limit reduces the speed level.
BUT: Visibility is still limited.

Other examples of successful remedial measures (number of cases < 10)

Adding solid white centre line

Problem

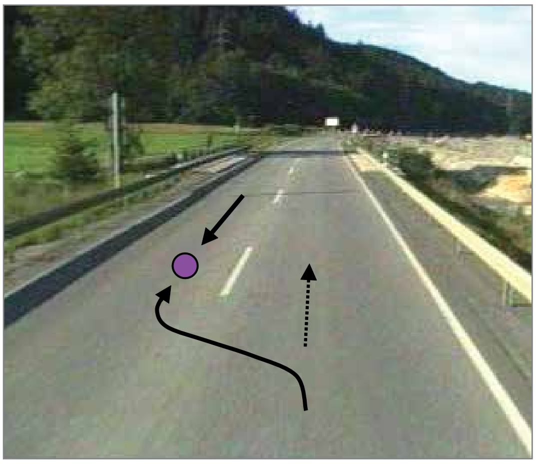
Due to the vegetation at the edge of the road visibility was not sufficient for overtaking, which frequently caused accidents involving longitudinal traffic (rear-end and head-on collisions) during overtaking manoeuvres.

Measure

The solid line centre road marking prohibits overtaking.
BUT: The vegetation on the soft shoulder must be cut back at regular intervals.

Extension to dual carriageway

Problem



The road section provided few opportunities for overtaking while the volume of traffic was quite high. Overtaking despite short time gaps in incoming traffic repeatedly caused severe accidents involving longitudinal traffic (rear-end and head-on collisions).

Measure

The extension of the road to a dual carriageway separates the carriageways for opposite travelling directions and provides for safe overtaking and increases capacity.

5 Network-wide Analysis and Summary of Results

The investigated accident blackspots on federal rural roads had an average traffic volume exceeding that of the remaining road network by approximately one fifth during the identification period. The mean traffic volume of the respective accident blackspots on state rural roads in Bavaria was two thirds greater than outside of these accident blackspots. The overall network of federal rural roads is about half as long as the network of state roads. As the accident density AD(Cat.1+2) on the federal road network is more than 60 % higher than that of state roads due to the significantly higher traffic volume, more accident blackspots were identified on federal roads than on state roads. Correspondingly, federal roads accounted for a greater proportion of the road network and number of severe accidents at accident blackspots. However, the density of severe accidents at the accident blackspots was similarly high for both road categories (federal and state rural roads). The accident blackspots thus had roughly the same characteristics in this respect.

The traffic volume at accident blackspots is normally greater than in the rest of the road network. The conditions with regard to accident analysis and measure determination are roughly the same at the accident blackspots of all road classes.

The number of accidents A(Cat.1+2+3+7) caused by “overtaking” that occurred at the accident blackspots of federal and state rural roads was particularly high. In addition, the police recorded a significantly higher frequency of the accident characteristic “collision with trees at the roadside” and “motorcycle drivers” as drivers who mainly caused the accident (involved party 01) at accident blackspots compared to the rest of the road network. This was also true for the features “crossing” and/or “traffic lights exist” and the accident cause “right of way/priority”.

The number of tree accidents, motorcycle accidents and crossing accidents occurring at accident blackspots is particularly high.

Safety measures were realised at three quarters of all investigated accident blackspots on federal and state rural roads. In order to be able to analyse particularities of accident blackspots where no measures had been realised, they were compared to blackspots where such measures had been implemented. According to our findings, measures were performed more frequently at extended accident blackspots, at blackspots with high traffic volumes or narrow bends and at blackspots with an increased accident density AD(Cat.3+Cat.7) or accident rate AR(Cat.3+Cat.7).

At accident blackspots with main accident type 3 (turning into /crossing major road), measures were taken more frequently than at accident blackspots where mostly other accident types occurred. In addition, the accident structure of accident blackspots where measures had been performed shows certain particularities e.g. in form of an increased proportion of accidents when the road is wet or accidents at "crossings" or "junctions".

Measures are implemented relatively often at long accident blackspots, at accident blackspots carrying a very high traffic volume, at accident blackspots with narrow bends and at accident blackspots where a high number of minor accidents have occurred. In addition, preference is given to measures at intersections.

After measures had been implemented, 83 % of the accident blackspots with evaluable measures showed an improvement in the incidence of accidents - beyond the bias by selection. 99 % of the measures at these critical spots were cost-efficient. Thus, four fifths of all measures implemented at evaluable accident blackspot areas have been effective and economically viable. In addition, 59 % of the evaluable accident blackspot areas had been brought to a safe condition after the execution of the measure. We found the accident cost development to be the determining factor for the cost-effectiveness of measures. The level of the annual measure costs was less important in this respect. Every second accident blackspot where no measures had been implemented was found to be road safe after the identification period.

Four fifths of all measures executed at accident blackspots are useful (effective and cost-efficient). The majority of all accident blackspots (three fifths of all sites) is road-safe after a measure has been implemented. Accident commissions sometimes decide not to use measures and thus fail to tap the full potential for improvement in some cases.

The network-wide accident costs of two reference periods (before and after the implementation of measures) were compared for a summary of the overall economic results. The comparison period for federal and state rural roads was from 1999 to 2007. The bias by selection-adjusted economic benefits of remedial measures at accident blackspots (benefit$_{ABS}$) amounted to approximately EUR 229 m per year during this period [10].

The table below shows the economic benefits in the form of accident cost reduction (benefit$_{network}$) in the area of the entire federal and state rural road network for the period mentioned above. In addition, the table indicates the (bias by selection-adjusted) proportion of safety measures at accident blackspots in the overall benefit (benefit proportion$_{ABS}$).

benefit$_{network}$ [EUR m/year]	benefit$_{ABS}$ [EUR m/year]	benefit proportion$_{ABS}$ [%]
480	229	48

The beneficial effect of the measures implemented at accident blackspots strongly influences the accident cost reduction throughout the entire network. Thus, half of the accident cost reduction (roughly corresponds to the reduction in severe accidents) can be attributed to the remedial measures performed at accident blackspots alone, i.e. taking into account non-local improvements (e.g. rescue service, automotive engineering, traffic law, training).

The traffic commissions alone have caused a reduction in the number of severe accidents by half with non-localised improvements (e.g. rescue service, automotive engineering, traffic law, training) factored out.

Economic efficiency analyses are based on the comparison between expenses and benefits. In this respect, the reduction in accident costs (total benefitsABS of federal and state rural roads: EUR 229 m /year) can be regarded as a component of the benefits. Expense equals the costs. In the scope of an analysis of overall economic viability, all cost components must be taken into account. Thus, the procedure of accident blackspot management in Bavaria causes, in addition to the costs for the safety measure itself, costs for identifying the blackspots, internal cooperation, technical supervision, central coordination and assistance to and qualification of the accident commissions. These direct costs are estimated at a flat rate of EUR 2.5 m per year [10]. Together with the annual measure costs (EUR 15.6 m/year) the total costs for the accident blackspot management of federal and state rural roads in Bavaria amounts to EUR 18.1 m/year. The overall economic benefits thanks to improved road safety at accident blackspots are more than twelve times greater than the overall expenses for local traffic investigation. This shows that the accident blackspot management procedure in Bavaria is highly cost-efficient.

The economic benefits of accident blackspot management are more than 12 times greater than their costs (BCR > 12).

Due to the enormous importance of accident blackspot management for the overall incidence of accidents, the question arises as to what extent this influence can also be seen in a time series analysis of the overall road network. For this purpose, the annual accident costs from 1991 to 2009 for the federal and state rural road network have been compiled. Figure 8 shows a sudden acceleration of the accident cost reduction in 2000 (from an annual reduction to the amount of 1.8 % to 5.0 %). This is the same year in which Bavaria introduced accident commissions which had already initiated and implemented initial safety measures at accident blackspots in the year 2000.

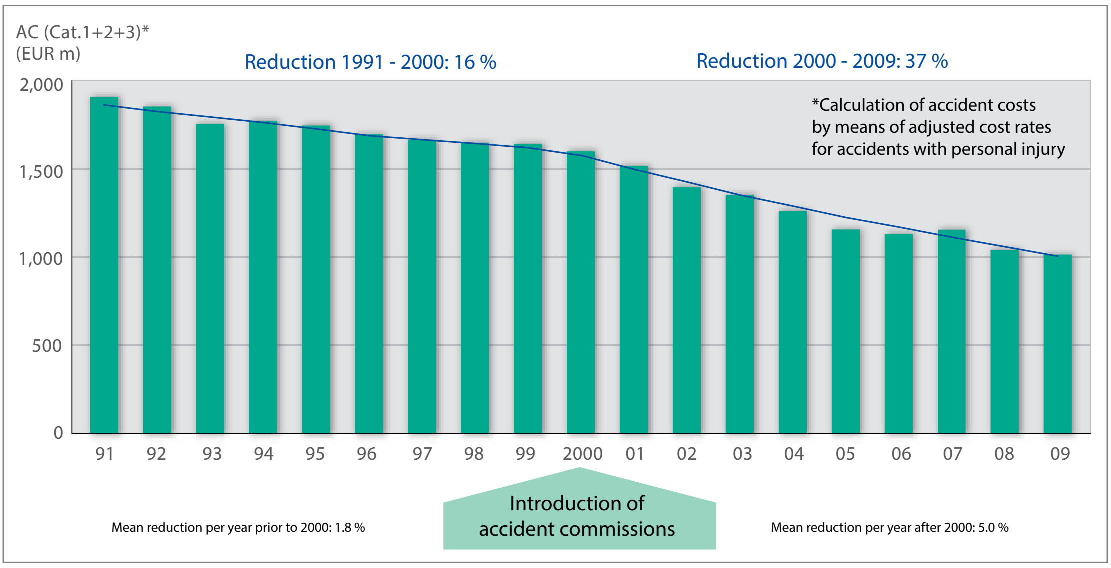


Figure 8: Accident costs 1991-2009 on federal and state rural roads in Bavaria

Thus, the time series analysis also shows that at least half of the accident cost reduction achieved since 2000 can be reasonably attributed to accident blackspot management. Accordingly, the reduction in accident costs at accident blackspots is eight times greater than in the remaining road network.

The annual reduction in accident costs has more than doubled since the introduction of accident commissions. The annual accident cost reduction at accident blackspots where measures have been implemented is eight times greater than in the remaining road network.

Bibliography

[1] "Allgemeine Verwaltungsvorschrift zur Straßenverkehrsordnung" (VwV-StVO) of 22 v. 22.10.1998, neu erlassen v. 26.01.2001, zuletzt geändert v. 20.03.2009

[2] Bayerisches Staatsministerium des Innern (BStMI): „Richtlinie zur Bekämpfung des Verkehrsunfallgeschehens auf bayerischen Straßen", Bek. v. 15.05.2000, München

[3] Böhm, L.; Spahn, V.: „Die Definition von „Unfallhäufungen" als Basis für sicherheitsverbessernde Maßnahmen im Straßennetz", in Straßenverkehrstechnik, Heft 11, 2008

[4] Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV, Hrsg.): „Auswertung von Straßenverkehrsunfällen, Teil 1, Führen und Auswerten von Unfalltypensteckkarten", Köln, Ausgabe 1998

[5] Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV, Hrsg.): „Empfehlungen für Wirtschaftlichkeitsuntersuchungen an Straßen (EWS) – Aktualisierung der RAS-W 86", Köln, Ausgabe 1997

[6] Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV, Hrsg.): „Hinweise zur Methodik der Untersuchung von Straßenverkehrsunfällen", Köln, Ausgabe 1991

[7] Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV, Hrsg.): „Merkblatt zur örtlichen Unfalluntersuchung in Unfallkommissionen (M Uko)", Köln, Entwurf 2011

[8] Gesetz über die Statistik der Straßenverkehrsunfälle; Straßenverkehrsunfallstatistikgesetz (StVUnfStatG) v. 15.06.1990, geändert v. 23.11.1994, geändert v. 29.10.2001

[9] Höhnscheid, K.-J.; Köppel, W.; Krupp, R.; Meeves, V.: „Kostensätze für die volkswirtschaftliche Bewertung von Straßenverkehrsunfällen – Preisstand 2000", in Straßenverkehrstechnik, Heft 1, 2002

[10] Spahn, V.: „Standardisierte Wirksamkeitsanalyse von sicherheitsverbessernden Maßnahmen an Unfallhäufungen auf Außerortsstraßen", Dissertation an der Universität der Bundeswehr München, Schriftenreihe des Instituts für Verkehrswesen und Raumplanung, Heft 56, Neubiberg, 2011

Appendix 1 Accident Categories

The accident category (most severe consequence of the accident) is classified according to the greatest damage suffered by a party involved in the accident. An accident with three involved parties where, for example, two drivers have only been slightly injured, a passenger has suffered serious injuries and a third party involved in the accident has only suffered property damage to the vehicle, will be classified as an accident with seriously injured persons (category 2) as the serious injury of a person is the greatest damage. The classification of accidents with personal injuries is based on the severity of the injuries of individual involved parties.

A(Cat.1) **= Accident with fatalities (category 1)**
At least one road user was killed at the accident site or died within 30 days due to the consequences of the accident

A(Cat.2) **= Accident with seriously injured persons (category 2)**
At least one road user has suffered injuries that are so severe that the respective person had to be immediately admitted to a hospital for in-patient treatment (at least 24 hours).

A(Cat.3) **= Accident with slightly injured persons (category 3)**
At least one road user has suffered injuries. However, in-patient treatment at a hospital was not necessary.

A(Cat.7) **= Accident with property damage (category 7)**
Property damage accident where a criminal offence or traffic offence was committed. In a property damage accident none of the involved road users have been injured. (Accidents where slight traffic offenses are committed or where a warning was issued are not classified in Bavaria.)

The following individual accident categories are frequently combined:

A(Cat.1+2) **= Accident with serious personal injury (categories 1 + 2)**

A(Cat.1+2+3) **= Accident with personal injury (categories 1 +2 + 3)**

A(Cat.1+2+3+7) **= Accident with personal injury or property damage (categories 1 + 2 + 3 + 7)**

Appendix 2 Accident Type Catalogue

Single-vehicle accident, accident type 1

The accident was caused by losing control of the vehicle (due to inappropriate speed or misjudgement of the course or condition of the road or similar) without other road users contributing to the accident. However, a collision with other road users might have occurred due to uncontrolled vehicle movements.

Turning-off accident, accident type 2

The accident was caused by a conflict between a turning-off vehicle and another road user travelling in the same direction or coming from the opposite direction (including pedestrians!) at crossings, junctions or accesses to properties or car parks.

Turning into/crossing accident, accident type 3

The accident was caused by a conflict between a vehicle turning into or crossing a major road and obliged to give way and another vehicle having the right of way at crossings, junctions or exits from properties or car parks.

Pedestrian crossing accident, accident type 4

The accident was caused by a conflict between a vehicle and a pedestrian on the road with the pedestrian not walking in the direction of longitudinal traffic and the vehicle not turning. This category also applies if the pedestrian was not hit.

Accident involving stopped or parking vehicle, accident type 5

The accident was caused by a conflict between a vehicle in moving traffic and a vehicle which was parking/stopping or performing driving manoeuvres in connection with parking/stopping.

Accident involving longitudinal traffic (rear-end and head-on collisions), accident type 6

The accident was caused by a conflict between road users travelling in the same direction or opposite directions unless this conflict is attributed to one of the other accident types.

Other accident, accident type 7

Accident which cannot be classified as types 1 to 6. Examples: Turning to change direction, reversing, accidents of vehicles parking, obstacle or animal on the road, sudden vehicle damage or similar.

Appendix 3 Key Accident Characteristics

The purpose of analysing key accident characteristics, in the sense of a risk variable, instead of absolute accident figures (A) is to take into account the influence of the corresponding reference parameters on the accident figures. The most crucial reference parameters for safety analysis of roads are "length" of and "vehicle kilometres" on the analysed stretch of the road. The accident density (AD) is a risk variable related to the length of the corresponding stretch of road (L). It measures the frequency of accidents that have occurred during a certain period on a certain stretch of road (t refers to the analysed period in years):

AD	**=**	**A / (L * t)**	**[A / km*a]**

The accident costs (AC) indicate the economic loss caused by road accidents. The accident costs account for the number and the severity of the accidents. They enable comparisons of road safety at a price level. In this compendium, the accident cost rates [9] as of the price level 2000 indicated in EUR per accident have been used.

ACD	**=**	**AC / (L*t)**	**[EUR 1,000 / km*a]**
ACD	=	accident cost density	

The accident rate (AR) or the accident cost rate (ACR) is a key accident characteristic related to the vehicle kilometres. The accident rate measures the risk of the driver of a motorised vehicle being involved in an accident or having an accident in relation to the kilometres travelled. It rates the road extension standard:

AR	**=**	**10^6*A / (365*ADT*L*t)**	**[A / 10^6 vehicle km]**
ACR	**=**	**10^3*AC (365 * ADT*L*t)**	**[EUR / 10^3 vehicle km]**
ADT	=	average daily traffic	

Key accident characteristics can be determined for road sections and road networks (combined road sections and intersections), for road sections between high-volume intersections and for spots such as intersections, railway crossings, stops and bridges. For the evaluation of single spots such as intersections on rural roads, the length is set to "1" without dimension. When investigating intersections, it is useful to include accidents that have occurred on the road sections directly adjoining the spot [6]. For this purpose, an intersection area has to be analysed which stretches 150 m in each direction at out-of-town intersections (i.e. 300 m of a continuous stretch of road should be included in the area of investigation).

Appendix 4 Simplified Evaluation Procedure

In contrast to the more differentiated variant, the simplified evaluation procedure does not take into account the measure costs (which are of minor importance for the effectiveness of the measure) and does not include an exact definition of different accident blackspot subareas. Thus, only the accident blackspot as a whole is analysed. In addition, it is assumed that the vehicle kilometres are always similar. However, the basic approach of the evaluation system described in chapter 2 is still applied in the simplified procedure. According to this approach, safety-improving measures are used at accident blackspots to achieve the aims listed below. When both aims have been fulfilled, the use of the measure can be classified as successful or optimal. The aims, their formulas and entry values are as follows:

Aim 1: Improvement of road safety

$\mathbf{AC_{after} < AC_{before} * (1\text{-}BSR_{flat})}$ **[EUR/3*a]**

BSR_{flat} = flat bias by selection rate

Aim 2: Establishing safe traffic conditions in after-period

$\mathbf{ACR_{after} < bACR_{ABS}}$ **[EUR/ 10^3 vehicle km]**

$bACR_{ABS}$ = basic accident cost rate of accident blackspot

The before-period is identical to the identification period of the accident blackspot. The after-period equals three continuously successive calendar years after the measure has been implemented (excluding familiarisation stage). For the investigation stages before and after the measure, the number of accidents A(Cat.1+2), A(Cat.3) and A(Cat.7) is determined (using accident type maps or the intranet of the Bavarian Road Administration). Based on this data, the accident costs (AC) which are indicated in EUR for a period of three years (3*a) are calculated according to the following formulas:

$$AC_{after} = A(Cat.1+2)_{after} * aACR(Cat.1+2) + A(Cat.3)_{after} * aACR(Cat.3) + A(Cat.7)_{after} * aACR(Cat.7) \text{ [EUR/3*a]}$$

$$AC_{before} = A(Cat.1+2)_{before} * aACR(Cat.1+2) + A(Cat.3)_{before} * aACR(Cat.3) + A(Cat.7)_{before} * aACR(Cat.7) \text{ [EUR/3*a]}$$

aACR [EUR / accident]	aACR(Cat.1+2)	aACR(Cat.3)	aACR(Cat.7)
Accident blackspots on federal roads	290,000	18,600	7,000
Accident black spots on state roads	249,000	18,500	7,000

Adjusted accident cost rates (aACR) for accident blackspots on rural roads in Bavaria

Flat bias by selection rates (BSR_{flat}) are used to take into account the bias by selection and compensate for chance fluctuations in the incidence of accidents at accident blackspots. To determine the flat bias by selection rate (BSR_{flat}), it must be verified whether the incidence of accidents A(Cat.1+2+3+7) was dominated by intersection accidents during the identification period. For this purpose accident type maps can be used.

Accident blackspots on	**BSR_{flat}**
Rural roads, intersection - The majority of accidents A(Cat.1+2+3+7) at the accident blackspots occurred at intersections	15 %
Rural roads, non-intersection - The majority of accidents A(Cat.1+2+3+7) at the accident blackspots did not occur at intersections	30 %

Flat bias by selection rates for the simplified evaluation of the effectiveness of measures at accident blackspots in Bavaria

When calculating the accident cost rate of the after-period (ACR_{after}), it must be taken note of the fact that a length of 300 m is generally used in the accident cost rate calculation formula for accident blackspots that are limited to a specific point (bend or intersection), even if the accident blackspot itself (L_{ABS}) is actually shorter. In this way, the distortion of results due to very low lengths can be prevented. For accident blackspots consisting only of one rural road intersection, the traffic volume of the minor road(s) must be taken into account as well when determining the ADT_{ABS}. The ACR_{after} is calculated as follows:

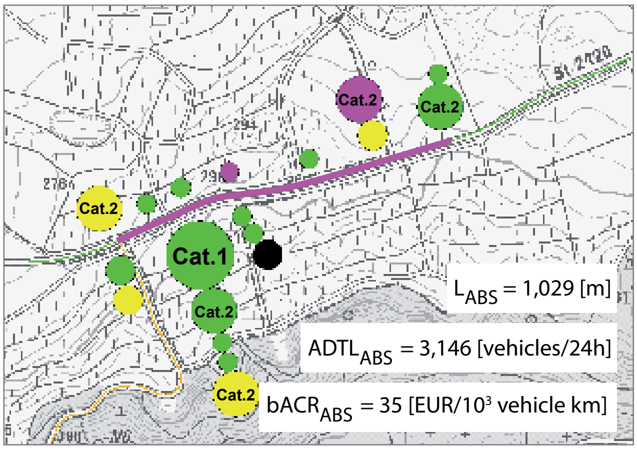
$$\mathbf{ACR_{after} = 10^3 * AC_{after} / (365 * ADT_{ABS} * L_{ABS} * 3 * a) \qquad [EUR / 10^3\ vehicle\ km]}$$

The road-safety condition of a traffic facility is expressed by the basic accident cost rate ($bACR_{ABS}$). This key characteristic indicates the accident cost rate which is to be expected even if the traffic facility has been constructed according to the regulations. This characteristic which depends on the class of the road and the length of the accident blackspot is listed in the following table:

$bACR_{ABS}$ [EUR / 10^3 vehicle km]	**straight line ($L_{ABS} > 300$ m)**	**limited spot ($L_{ABS} \leq 300$ m)**
Federal rural road	27	50
State rural road	35	50

Basic accident cost rates for the simplified evaluation of the effectiveness of measures at accident blackspots in Bavaria

Example of calculation for the simplified procedure (measure p. 54 bottom):



Accident situation before, detail of accident type map 2000-2002

Accidents before (2000-2002):

A(Cat.1+2) = 6

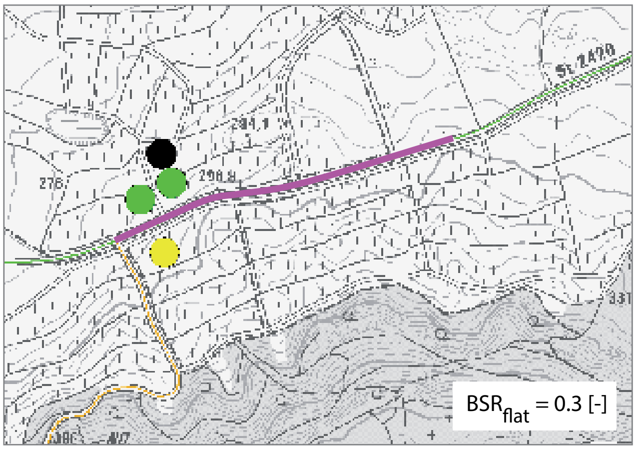
A(Cat.3) = 4

A(Cat.7) = 9

Accident costs before:

AC_{before} = 6 + 249,000 + 4 * 18,500 + 9 * 7,000 = 1,631,000 [EUR/3*a]

Measure: Extension of the section according to the regulations in 2005



Accident situation after, detail of accident type map 2006-2008

Accidents after (2006-2008):

A(Cat.1+2) = 0

A(Cat.3) = 4

A(Cat.7) = 0

Accident costs before:

AC_{after} = 0 + 249,000 + 4 * 18,500 + 0 * 7,000 = 74,000 [EUR/3*a]

Aim 1: Has road safety been improved?

$AC_{after} = 74,000 < AC_{before} * (1-BSR_{flat}) = 1,631,000 * (1 - 0.3) = 1,141,700$ [EUR]

→ Aim 1 has been achieved!

Aim 2: Is the traffic situation safer in the after-period?

$ACR_{after} = 10^3 * AC_{after} / (365 * ADT_{ABS} * L_{ABS} * 3 * a)$

$ACR_{after} = 10^3 * 74,000 / (365 * 3,146 * 1.029 * 3) = 20.9$ [EUR/10³ vehicle km]

$ACR_{after} = 20.9 < bACR_{ABS} = 35$ [EUR/10³ vehicle km]

→ Aim 2 has been achieved!

Result: The measure "Extension of the section according to the regulations" was optimal.

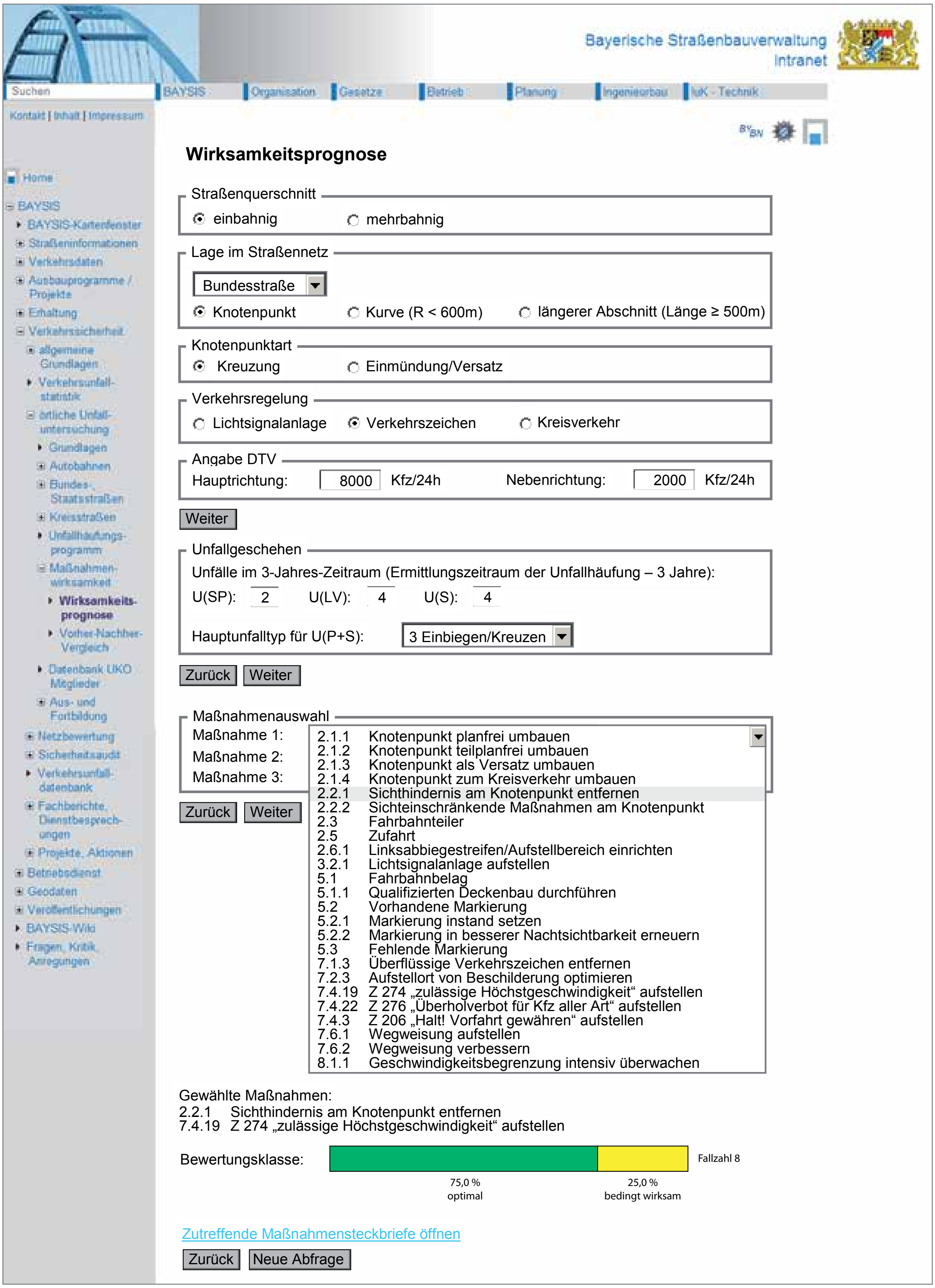
Appendix 5 "Effectiveness Prediction" Computer Program

The effectiveness of a planned measure is predicted on the basis of previously performed before/after investigations. To be able to take into account specific local conditions, certain input data is required which has to be entered into a form on the intranet of the Bavarian Road Administration by the user (accident commissions). The menu navigation for this entry is shown on the next page. Based on the data entered by the user, the corresponding traffic facility and the associated relevant key evaluation characteristics can be determined.

Of all investigated accident blackspots on rural roads, 2,419 road sections where safety-improving measures have been implemented were identified. Of these 2,419 road sections 1,793 were suitable for the intended before/after comparison, i.e. evaluable (see chapter 3). Only those individual measures or combinations of measures for which a certain volume of records from comparable situations are available can be selected under "Maßnahmenauswahl" (selection of measures). According to the current status, the prediction is based on 126 different comparative cases for rural roads with each comparative case consisting on average of seven different investigation units. Every fifth case relates to a combination of measures.

Now, suitable comparative cases are selected based on the entry data. On the basis of the selected comparative case and the matching entry data, the program then provides a prediction regarding the presumable effectiveness of a planned measure (measure proposition) to the program's user. The effectiveness of the measure is indicated, as explained in chapter 2, by means of evaluation classes and bars that are coloured accordingly. In this context, "green" means that a measure has optimal effectiveness and "yellow" means that its effectiveness is limited while "red" indicates a failed measure.

The reliability of this prediction increases as the number of comparative cases or evaluated individual measures rises. Thus, the program application is designed so as to enable the continuous enlargement of the data base with newly evaluated measures. In addition, the user is able to view and analyse further data sheets regarding the selected comparative case ("zutreffende Maßnahmensteckbriefe" - relevant measure data sheets).



Program application “Wirksamkeitsprognose” (effectiveness prediction) on Bavarian Road Administration intranet

Erhobene Daten

Lokalisierung

Bauamt: StBA Kempten	Landkreis: Ostallgäu	Straßenklasse Nebenrichtung: G
Straße: St 2008	von Abschnitt / Station: 100 / 3,815	bis Abschnitt / Station: 100 / 4,215

Unfallhäufung

Nummer: 2	Ermittlungszeitraum: 1997–1999

Raumtypisierung

Ortslage:	Landstraße		Querschnitt:	einbahnig
Lage im Straßennetz:	Knotenpunkt		Länge [m]:	400
Knotenpunktsform:	Kreuzung	Verkehrsregelung: Verkehrszeichen	Radius [m]:	300

Verkehrsbelastung

Hauptrichtung:	DTV 2005 [Kfz/24h]: 4.586		DTV 2000 [Kfz/24h]:	4.918
Nebenrichtung:	DTV 2005 [Kfz/24h]: 500			

Auffälligkeiten Unfallgeschehen:
Auffällig viele Unfälle mit Ursache (27-33) "Vorfahrt, Vorrang" 2.1.8

Auffälligkeiten Strecke:
Streckenverlauf schlecht erkennbar/begreifbar 1.2.1
Sichtdreiecke am Knotenpunkt nicht ausreichend vorhanden 2.1.3

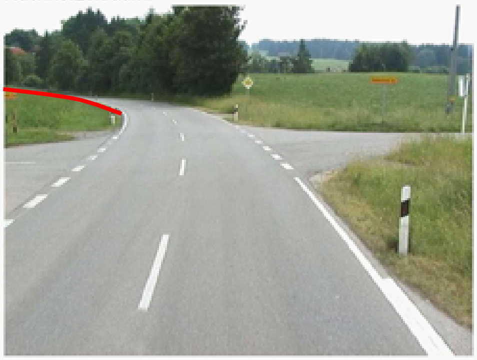
Maßnahmentypisierung

Code	Beschreibung	Jahr der Verkehrswirksamkeit	Kosten [Euro]
2.2.1	Sichthindernis am Knotenpunkt entfernen	2002	10.000
7.4.19	Z 274 "zulässige Höchstgeschwindigkeit" aufstellen	2002	300

Beschränkung der zulässigen Höchstgeschwindigkeit [km/h]: 70

Vorherzeitraum:

Nachherzeitraum:



Unfallgeschehen

Zeitraum	U(SP)	U(LV)	U(S)	U(P+S):	HUT	Jahr 1	Jahr 2	Jahr 3
1997-1999	4	1	1		4			
2003-2005	0	1	0		0	0	1	0

Hauptunfalltyp für Ermittlungszeitraum: Einbiegen / Kreuzen

Abgeleitete Daten

Zeitraum	Unfallkosten [Euro/3a]	DTV[Kfz/24h]
1997-1999	1.098.200	5.675
2003-2005	19.200	5.233

Summe der annualisierten	
Maßnahmenkosten [Euro/a]:	384,52

Bewertungsklasse: optimal

Bemerkung: Böschung wurde an der Innenkurve abgeflacht.

Bemerkung: Böschung an der Innenkurve abflachen

Example of a selected measure data sheet on the Bavarian Road Administration intranet

Imprint

Publisher

Oberste Baubehörde im Bayerischen Staatsministerium des Innern (Supreme Building Authority of the Bavarian Ministry of the Interior)

http://www.strassenbau.bayern.de

Sources

The pictures of the examples in chapter 4 were taken by members of Bavarian accident commissions or during roads inspections for road condition analyses and evaluations.

http://baysis.bybn.de/

The basic concept, tables, diagrams and other figures are taken from or based on a dissertation submitted to the Universität der Bundeswehr München (University of the Armed Forces Munich) [10].

Editors

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*Autobahndirektion Nordbayern (*realization, Northern-Bavarian Motorway Authority)