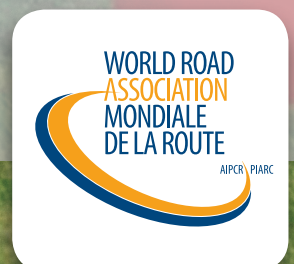


# HUMAN FACTORS GUIDELINES FOR A SAFER MAN-ROAD INTERFACE

Technical Committee 3.2.  
*Design and Operation of Safer Road Infrastructure*  
World Road Association



# STATEMENTS

*The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.*

*The study that is the subject of this report was defined in the PIARC Strategic Plan 2012 – 2015 and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated by the member national governments for their special competences.*

*Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organisations or agencies.*

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Frontcover © Comité 3.2*

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This report has been prepared by the Human Factors Working Groups of the PIARC *Technical Committees 3.1 Road Safety (2004-2007), C.1 Safer Road Infrastructure (2008-2011) and 3.2 Design and Operation of Safer Road Infrastructure (2012-2015)*. The work is based on a literature study of experimental proofs about road characteristics that triggers accidents. It draws on a unique method of accident analysis with a Human Factors Evaluation Tool, which has been developed by Intelligenz System Transfer GmbH, Dr. Sibylle Birth, Germany. This has been refined through investigation of about 1,400 accident locations and validated within a double blind test design. The results were discussed and adapted to international requirements in the above mentioned PIARC's Human Factors Working Group.

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## HUMAN FACTORS GUIDELINES FOR A SAFER MAN-ROAD INTERFACE

### BACKGROUND AND GOAL

Whilst physical factors are conditions of geometry and dynamics at the interface between vehicles and the road it is well known that Human Factors of the Man-Road-Interface have an enormous influence on the safe handling of technical systems. Human Factors are stable psychological and physiological limits that influence the performance and safety of technical systems used by humans. It is a well-established scientific term in the safety community of man-machine-interaction. Human Factors is defined as those psychological and physiological threshold limit values which are verified as contributing to operational mistakes in machine and vehicle handling.

In the case of road safety, the Human Factors concept considers road characteristics that influence a driver's right or wrong driving actions. It understands the causes of road users' operational mistakes as the first step in a chain of actions which may proceed to an accident. Many often observed operational mistakes result from a direct, subconscious interaction between road characteristics and road users' threshold limit values of perception, information processing and action. Because the driver's reaction characteristics cannot be changed, attention should be focused on a self-explaining road design.

This guideline explains the relationship between several road characteristics that trigger wrong perception and therefore also wrong driving reactions, most of which happen subconsciously. Detailed examples and sketches allow the engineer to understand the relationship between misleading and irritating road characteristics and operational mistakes. They can be used as a kind of checklist in "on-the-spot" investigation of black spots or single vehicle accidents or in road safety inspections (RSI). They can also be used to qualify planning and design processes in road safety audits (RSA).

### THREE CLASSES OF HUMAN FACTORS-ACCIDENT TRIGGERS IN THE MAN-ROAD-INTERFACE

#### 1. The 6-Second Rule: The road should give the driver enough time to react

The time it takes an average driver to adapt from one traffic situation to the next or to adjust to new requirements, takes much longer than what is stated in current guidelines. Instead of fractions of a second ("*simple stimulus-reaction time*" – Stopping Sight Distance SSD), it takes the average driver at least 4 to 6 seconds to adapt to a new driving requirement ("*perception-decision time – Decision Sight Distance DSD*", [1], [2]).

When driving at a speed of 100 km/h, drivers will cover a distance of up to 300 m during this 4-6 second period (including breaking time).

A user-friendly road will give drivers the necessary time to adapt to new and unexpected situations. It will give them the time they need to safely re-organise their driving programme. A user-friendly road and its environment will allow an appropriate adjustment of the driving programme to a new situation. That is why it is not enough to provide the driver with a reaction time of 2-3 seconds (Stopping Sight Distance, SSD with manoeuvre section and response section). The design should also provide an anticipation section with a minimum of 2-3 seconds to identify an unexpected or unusual situation with more complex decision demands (Decision Sight Distance, DSD). In more complex situations or higher speed it is recommended to offer the driver also an advance warning section with proper signing and instructions.

It is necessary to arrange transition zones, remove visibility restrictions, and make junctions perceptible or use signings or markings to indicate at least 6 seconds before any critical location (e.g. junctions, curves, railway crossings, bus stops, bicycle paths, entrances of villages and towns and end of newly upgraded road sections or the change of road hierarchy...).

## **2. The Field of View Rule: The road must offer a safe field of view**

Motorised driving changes the field of view much more than any other movement. Monotonous or high-contrast periphery (optical flow), optical misguidance or optical illusions, deceptive or distracting impressions affect the quality of driving. The road, together with its surrounding offers an integrated field of view. The field of view can either stabilise or destabilise drivers, it can tire or stimulate them. It can also result in either increased or reduced speed. Speed, lane-keeping and reliability of direction are functions of the quality of the field of view.

A good-quality field of view safeguards the driver and keeps him from drifting to the edge of the lane or even leaving it. Misleading eye-catching objects in the periphery of the field of view activate subconscious changes in direction. The most serious consequences arise from eye-catching objects that differ from the road axis. They lead in extreme cases to a horizontal swing of the complete field of view: The driver has the feeling that the road and its surroundings are moving while it is in an unmoved position. Such objects lead to gross mistakes in steering. At minimum they lead to disturbances in lane-keeping, though these can mostly be corrected.

A user-friendly, self-explaining road will give drivers a well designed field of view with sufficient contrasts to increase the activation of the nervous system and thereby the alertness. It will provide good optical guiding and orientation facilities with a symmetrical and orthogonal impression. A self-explaining road design will avoid optical illusions or misleading eye-catching objects that destabilise drivers and negatively impact their driving, especially at adverse visibility conditions.

## **3. The Logic Rule: The road has to follow driver's perception logic**

Drivers follow the road with an expectation and orientation logic formed by their experience and recent perceptions. Unexpected abnormalities disturb a mostly automated chain of actions and may cause drivers to “*stumble*”. Several critical seconds pass before the disturbance can be processed. Therefore planners should try to keep road characteristics flowing in a logical sequence. They should introduce inevitable changes as early and clearly as possible and exclude any sudden changes that would confuse the driver.

## PERSPECTIVES

PIARC's Human Factors Working Group has been developing this guideline over the past nine years. It is based on the Human Factors Guideline of Brandenburg, Germany [11]. Traffic accident commissions can use it for a new approach in determining accident causes or for road safety inspections (RSI). Road design-ers can use it to demonstrate compliance of their designs in road safety audits (RSA). The next step should be to transfer this knowledge into design recommendations and in the education of road engineers.



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## 1. INTRODUCTION

### 1.1. THE TWO-WORLD DILEMMA IN ACCIDENT ANALYSIS: THE DAMAGE- AND PREVENTION-ORIENTED APPROACH

#### Damage-orientated approach

Traditional accident research plays an important role in the review of road design. It begins with the consequences assessed at each accident location. An accident location is considered to be the crash location where the car movement comes to an end or where the collision or the damage occurs.

In this case, black-spot analysis starts with searching police data for correlations between accident features and “*suspicious*” road characteristics (e.g. grip, geometry, wheel rut) or “*suspicious*” driver features (e.g. performance deficits, drunkenness, abilities, age, sex). On the one hand, this method is convenient, but on the other it is fraught with difficulties.

The high percentage of incorrect data sheets and unreported cases, as well as the abundance of tautological explanations (“*loss of control*”) makes it impossible to develop any testable hypotheses for investigating the causes of accidents. Furthermore the fixation on the crash location prohibits a systematic method to search and identify the trigger of the wrong driving action 300m-500m ahead of the crash location.

Traditional black-spot analysis evolves into an “*on-the-spot*” investigation to find effective countermeasures. But, until now, there has been a lack of a validated inspection method that takes into consideration the background of Human Factors operational and driving mistakes. Sometimes it is obvious that the road should be reconstructed. But very often the analysis ends without reaching sufficient conclusions as to what can be done. As a result, the recommendations try to minimise the consequences of accidents in general – this leads to a forgiving road design. So the favourite measures are for instance additional warning signs, speed limits or – very often – traffic lights.

This scenario is comparable to hosts whose house has stairs with steps of differing heights. Again and again their guests stumble and injure themselves. The hosts want to improve the situation: they mark all final locations of collisions, analyse them and the consequences. Finally, they decide to cushion the impact locations (steps) and the handrail with soft cushions.

This damage oriented approach (*illustration 1*) promoted until nowadays many changes in terms of minimising the consequences of accidents. These changes have contributed to fewer seriously injured persons and fewer damages. But what triggers the accidents remains largely unknown.

## Prevention orientated approach

By contrast, the Human Factors concept takes into consideration the triggers of driver's reactions which may result in an accident.

In applying the Human Factors concept to traffic accidents the road safety expert asks for the reasons that led to a driver's operational mistake which finally resulted in an accident. This approach is not new to road design. In the 1930s basic ideas from the Human Factors concept were taken into account in planning major roads and motorways.<sup>1</sup>

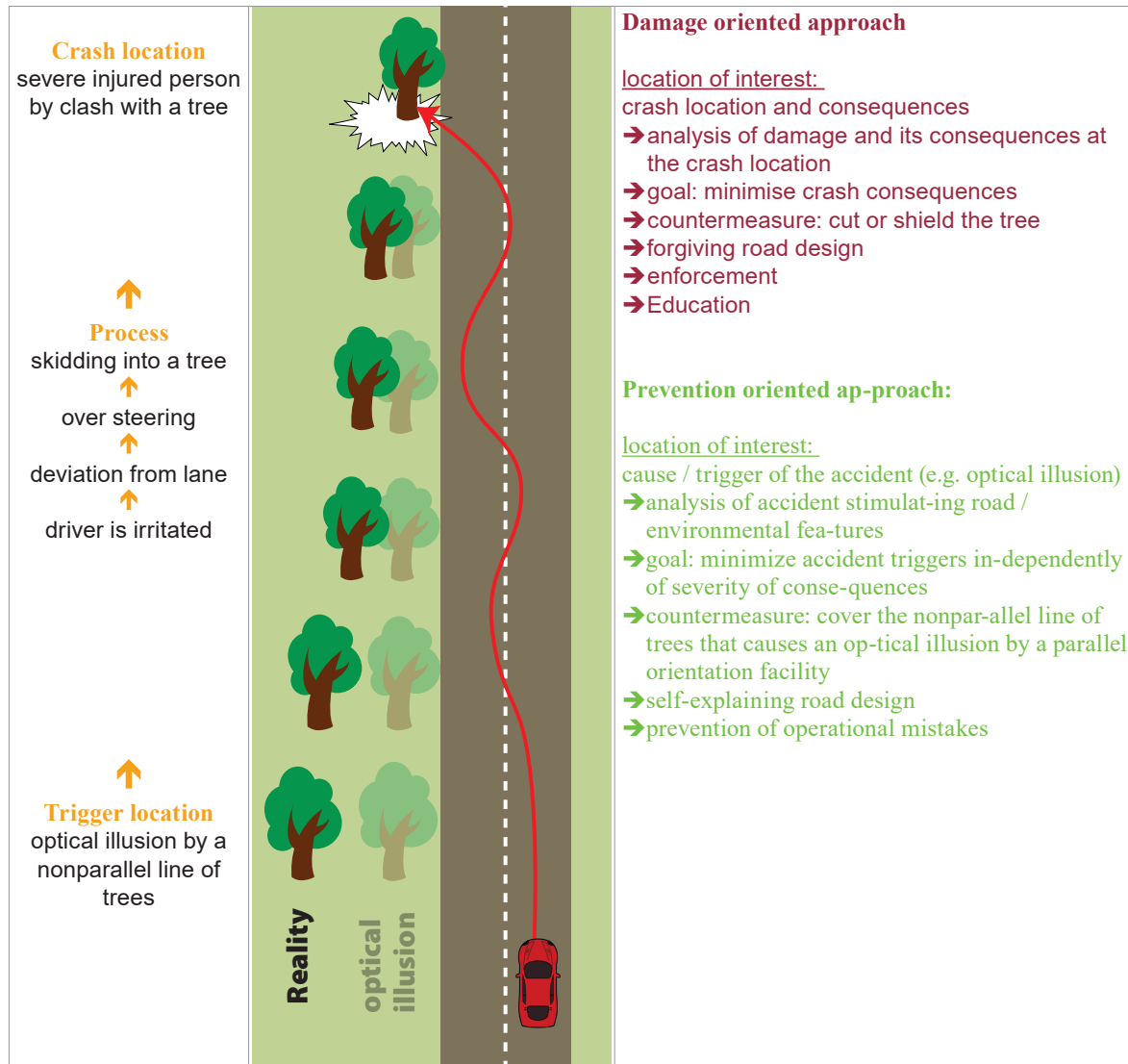


Illustration 1 : Damage- and Prevention-oriented accident approaches [11]

The Human Factors concept considers the driver's operational mistake as the first step in a chain of events that may lead to an accident. Many often-observed operational mistakes result from the direct interaction between road and driver's reaction characteristics. Road characteristics determine subconscious driving reactions. Since the driver's reaction characteristics cannot be

<sup>1</sup> The origin of Human Factors research goes back to the development of controlling and operating parts/devices in weapons technology. It was subsequently applied to the aircraft industry and the development of nuclear power plants. It is only now that it is beginning to be systematically applied to road planning and design. The highway planner Alwin Seiffert (1934) is considered to be the pioneer in this field.

changed, attention should be focused on improving the road characteristics according to driver's psychological and physiological limits. This conclusion makes it possible and mandatory to take into consideration the laws of driver's perception, information processing and action regulating for road planning and design.

The Human Factors concept aims to reduce the probability of operational mistakes and ultimately of driving mistakes by promoting a user-friendly and self-explaining road design including its surrounding. This means that the road and its surrounding has to be designed for clarity and that sections have to be designed so as to be easy understandable, perceptible and recognisable. The road user should neither be confused nor invited to take risks. The goal of the notion of self-explaining road design is to increase the unmistakable "*legibility*" of road characteristics without any signing. Such a user-friendly, self-explaining road design should directly result in a reduction in accident frequency and severity.

Of course, the Human Factors concept cannot completely control the extent of accident damages as they are dependent on many other variables (the vehicle's technical condition, weather, animals, driver's experience and personal traits like aggression/alcohol/medication, car/road interaction, etc.).

The installation of traditional passive safety measures leads to "*forgiving roads*". On the one hand, the design of a "*forgiving road*" implies advanced hazard warnings for the driver, e.g. in the form of rumble strips. On the other hand, it gives the driver enough time and/or space to correct driving mistakes. One example for this praxis is the obstacle free zone [35].

As an approach to accident prevention, the Human Factors concept integrates both the damage and the prevention oriented approach.

## 1.2. TERMINOLOGY

The Human Factors concept uses certain words and terms that are normally not used in road accident research and analysis. These are explained below.

An operational mistake is the first unintended action within a chain of actions, which may result in a driving mistake (*illustration 2*). It is caused by a lack of information or a misinterpretation of information in the interaction between driver and road. In most cases it can be corrected spontaneously.

In most cases, operational mistakes are not observable and can only be detected by special measuring instruments (deviations in heart rate, blinks of the eyelids, perspiration of fingertips, changes in driving parameters like steering, lane-keeping or braking).

An operational mistake left uncorrected could develop to a driving mistake. Often the driver is able to correct the driving mistake. If not, it could develop to an accident. Generally, the driving mistake is the possible result of an operational mistake. The driver has subconsciously e.g. brought the vehicle to an undesirable position. The driver may be able to correct this driving mistake by steering, speeding up or braking and the driving mistake could have no consequences. On the other hand it could cause an accident.

Driving mistakes can be detected by skid marks on the road and on the shoulders; remains of mirrors/bumpers and other car pieces; damage, traces of paint or mud on safety barriers or other road equipment.



*Illustration 2: The context of operational mistake – driving mistake – accident [11]*

### 1.3. DEFINITION OF HUMAN FACTORS

#### What does “*Human Factors*” mean?

Human Factors (HF) ever has been a technical term since the 1930s. It is defined as the contribution of stable psychological and physiological limits of the human nature to the development of a technical dysfunction or failure in handling machines and vehicles.

It is the generic term for those psychological and physiological threshold limit values which are verified as contributing to operational mistakes in machine and vehicle handling. Human Factors is not human behaviour or human performance. It has nothing to do with personalities like aggressiveness; the will to violate traffic rules consciously or mistakes because of medication/age. It deals with general and stable subconscious reactions of common road users and excludes temporary individual reactions and conditions.

#### Human Factors:

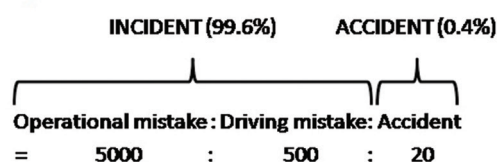
Stable natural psychological and physiological threshold limits that contribute to operational mistakes in machine/vehicle handling

- Included: psychological/physiological threshold limit values that contribute to damaging events
- Excluded: temporary mental/physical conditions (intoxication, circulatory collapse, heart attack, alcohol, panic attack, depression, age)
- Objective: identification of road characteristics that are not according to human threshold limit values and therefore trigger accidents

#### What are the relative proportions of operational mistakes, driving mistakes and accidents?

Operational and driving mistakes are called “*incidents*” and amount to about 99.6% of all relevant traffic offences. Only 0.4% of operational and driving mistakes lead to accidents (*illustration 3*). That is why effective accident prevention is focused on the identification of accident triggers that come out of the man-road-interface. The following sketch shows the proportion of incidents and accidents (data based on a reasonable estimate):

#### Proportions Incidents and Accidents



*Illustration 3: Relative proportions of operational mistake – driving mistake – accident [11]*

### **How is the Human Factors concept used in practice?**

Accident research uses the Human Factors concept to identify road characteristics that trigger accidents. If these are eliminated the probability of accidents will be reduced.

Furthermore the Human Factors concept allows Road Safety Audits and Road Safety Inspections to be completed with a special Human Factors Evaluation-Tool. The planned or realised road characteristics can be compared with the Human Factors demands for self-explaining road design.

### **Does the Human Factors concept make other safety measures superfluous?**

Even a proper technical road design in accordance with Human Factors demands cannot replace proper road safety management, road safety education, measures for safer vehicles nor a good post-crash response. Nor can the Human Factors concept compensate for the risks of designing triggers for incidents and accidents.

### **Does the Human Factors concept obviate the need for analysis of accidents in the damage oriented approach?**

In the damage oriented approach the psychological and physiological triggers of the accident and their effects are often not checked. That is why it is necessary to complete it with a Human Factors evaluation. The need for speed limits, ban of overtaking and similar measures can be fully explained by applying the Human Factors concept. Furthermore innovative and cost effective countermeasures can be developed.

## **1.4. TEST YOUR UNDERSTANDING OF HUMAN FACTORS**

Which of the following issues are parts of Human Factors? Please identify the psychological and/or physiological items that trigger an operational mistake and may result in an accident:

1. Alcohol level above the legal norm
2. Overlooking a red traffic signal
3. Underestimating a road's curve
4. Loss of steering control
5. Heart attack
6. Irritating insect in the vehicle
7. Overestimating road width
8. Underestimating distance
9. Surprised by road curve
10. Risky overtaking manoeuvre
11. Overlooking a yield sign
12. Wrong estimation of the road course

Answer: 2, 3, 7, 8, 9, 11 and 12

## 2. FIRST CLASS OF HF-ACCIDENT TRIGGERS – THE 6-SECONDS RULE

### 2.1 HF REQUIREMENT NO.1: THE ROAD SHOULD GIVE THE DRIVER ENOUGH TIME

Everyone is a road user and most drive cars. Only few people are excluded from participating in motor-operated road traffic. Completely fit users share the road with those who are physically and/or mentally impaired or are distracted, with those who are too slow to react, tired, overexcited, angry and impatient or have a lack of concentration. Road users comprise the entire spectrum of abilities.

Road users and so also drivers are not exceptional people. They have limited capabilities to act and react. The time it takes an average driver to adapt from one traffic situation to the next or to adjust to new requirements takes much longer than what is stated in current guidelines.

Instead of fractions of a second (“*simple stimulus–reaction time*”), it takes the average driver at least 4 up to 6 seconds to adapt to a new driving requirement (“*perception–decision time*”, [1], [2]) (*illustration 4*).

When driving at a speed of 100 km/h drivers will cover a distance of up to 300 m during this 4-6 second period (including braking time). A user-friendly road will give drivers the necessary time to adapt to new and unexpected situations. It will give them the time they need to safely re-organise their driving programme.

That is why it is not enough to provide the driver with a section that allows a reaction time of 2-3 seconds (Stopping Sight Distance, SSD, with manoeuvre and response section).

The design should also provide an anticipation section with a minimum of 2-3 seconds to identify an unexpected or unusual situation with more complex decision demands (Decision Sight Distance, DSD). In situations that are more complex or involve higher speeds, it is recommended that there should also be an advance warning section with proper signing and instructions like it is already practised on motorways.

### Minimal adapting time: 4-6 sec

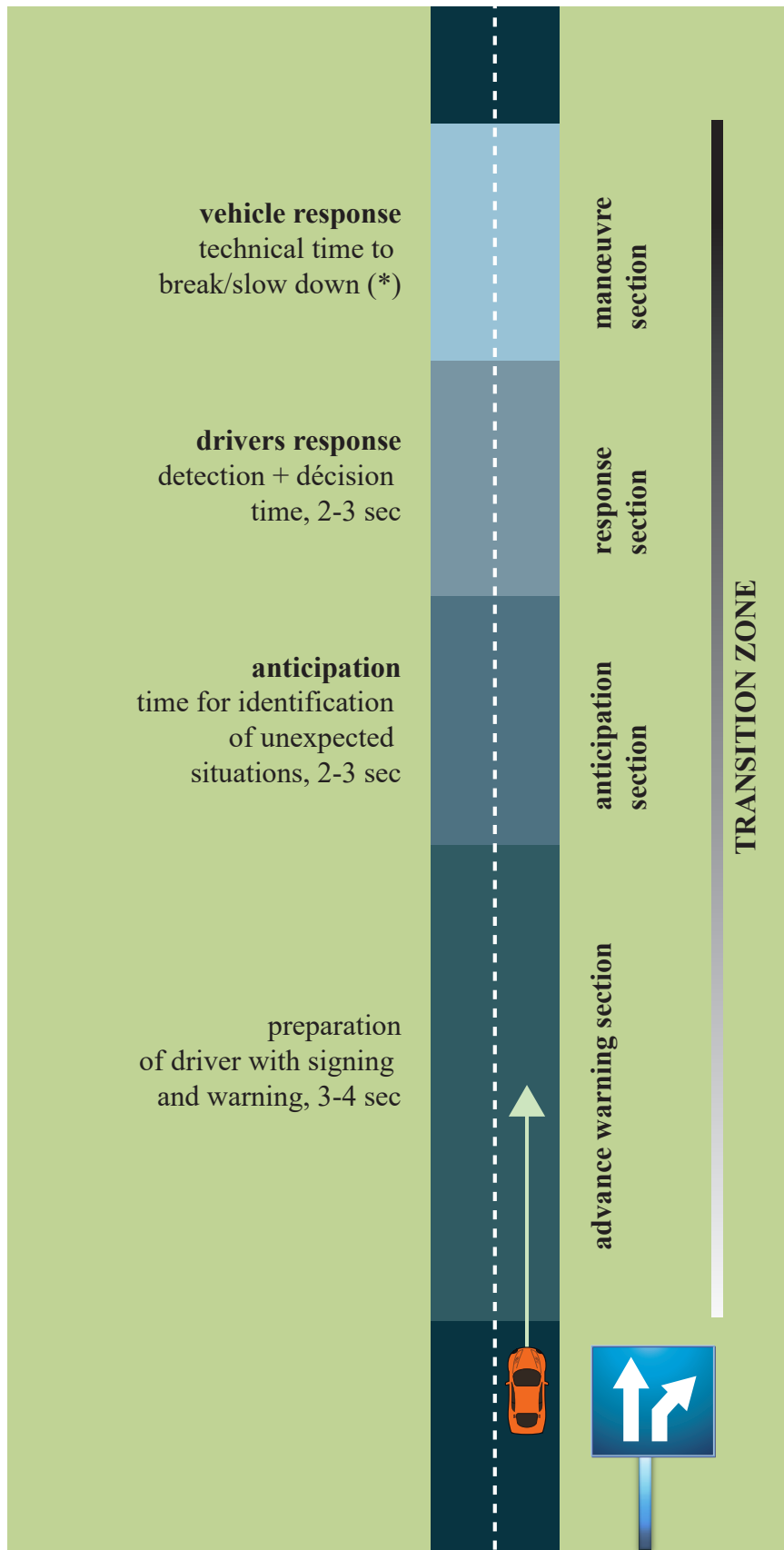


Illustration 4: Sketch of 6-Seconds Rule [38]. Minimum adapting time: 4 – 6 sec

\* Refer to [Table 1](#) (depends on speed, gradient, surface friction, wind resistance).

## 2.2. CONCLUSIONS AND PRACTICAL EXAMPLES

It takes average drivers 4–6 seconds to adapt their driving programme completely to a new requirement. At a speed of 100 km/h, this results in a distance of up to 300 m. This is the minimal distance of the transition zone.

<b>Example: stop at a junction: <math>V_{\text{admissible}}</math></b>	→	100 km/h
Distance of anticipation section: 2–3 s x 28 m/s	→	56 – 84 m
+ Distance of response section: 2–3 s x 28 m/s	→	56 – 84 m
+ Distance of manoeuvre section (to decelerate from 100 km/h to 0 km/	→	115 m
<b>= Minimal distance of the transition zone</b>	→	225–285 m

The driver changes the driving programme in three easily distinguishable, consecutive logical phases:

### 1. Anticipation.

- Identification of the critical location. The critical location is any requirement to adapt the driving programme.



### 2. Response (detection, decision)

- Detection of the precise kind of the required driving action (steering, braking, acceleration, ...)
- Decision for the appropriate driving programme
- Start of the new driving programme (“change”)
- Checking, testing and correction of the driving action



### 3. Manoeuvre.

- Technical time to brake / slow down (it depends on the car’s technical condition, weather and interaction between car and road).

Since the process may take up to 6 seconds, the necessary change in the driving programme has to be conveyed to the driver 6 seconds ahead to the critical location.

**Frequent critical locations requiring an adaptation of the driving programme are e.g.:**

- Junctions or crossings, e.g. crossings with/without traffic signals (railway, bicycles, pedestrians) (*illustration 5*);
- Access from private streets/parking places/ farm tracks to main roads;
- Road curves;
- Cross section narrowing (e.g. at road works or narrow bridges);
- Lane losses/merges;
- Bus/tram stops;
- Motorway entrances/exits;
- Entrances to towns/villages;
- Changes from a mono-functional road to a road with several mixed functions.



Illustration 5: Junction, perceptible only at 100 m distance: the minor road seems to be the main road; unexpected braking and high speed at this location cause rear end and sideswipe collisions [10].

TABLE 1: APPROXIMATED BRAKING DISTANCES AHEAD OF CURVES AND CROSSINGS [45]			
Initial speed $v_1$ (km/h)	Final speed (*) $v_2$ (km/h)	Total braking distance (*) $s_b$ (m)	Total braking time (*) $t_b$ (s)
100	90	30	1.5
	80	55	2.5
	70	70	3.0
	60	85	4.0
	50	95	4.5
	40	105	5.5
	0	115	7.5
80	70	20	1.0
	60	35	2.0
	50	45	2.5
	40	55	3.5
	0	65	5.5
70	60	15	1.0
	50	25	1.5
	40	35	2.5
	0	45	4.5
60	50	15	1.0
	40	20	1.5
	30	25	2.0
	0	35	3.5

\* Conditions: longitudinal gradient 0%, wet surface, non-linear deceleration, consideration of wind re-sistance. Other conditions might result in different braking distances and conditions. If there are sig-nificant differences in road conditions, braking distance and time should be recalculated.

TABLE 2: LENGTH OF ORIENTATION AND DECISION SECTIONS (ROUNDED) [45]

Speed	Driving time and driving distances in correlation to speed				
	2 s	3 s	4 s	5 s	6 s
50 km/h ( $\approx 14$ m/s)	28 m	42 m	56 m	70 m	84 m
60 km/h ( $\approx 17$ m/s)	34 m	51 m	68 m	85 m	102 m
70 km/h ( $\approx 20$ m/s)	40 m	60 m	80 m	100 m	120 m
80 km/h ( $\approx 22$ m/s)	45 m	65 m	90 m	110 m	130 m
90 km/h ( $\approx 25$ m/s)	50 m	75 m	100 m	125 m	150 m
100 km/h ( $\approx 28$ m/s)	55 m	85 m	110 m	140 m	170 m

A user-friendly road will give drivers the necessary time to adapt to new and unexpected situations. It will give them the time they need to safely re-organize their driving programme.

Missing transition zones before changes of function (e.g. town entrance, crossings, access from private roads) or road curves are the most critical cases in the application of the 6-Second Rule. They should be systematically checked according to the following criteria:

1. Design of the transition zone (see sketch: 6-Second Rule)
  - an advance warning section exists;
  - sufficient time for anticipation, response and manoeuvre.
2. Perception and visibility of the critical location
  - Critical locations should not be restricted by plants, buildings, traffic signs or roadside furniture;
  - Critical locations should be visible and clearly identifiable (e.g. junctions, crossings, driveways, bus/tram stops etc.) (*illustration 6, 7 and 8*);
  - Curves should be visible (curve is not behind a crest, the inner curve should provide an unobstructed view on the course) (*illustration 9*);
  - Minor road: the visibility triangle from minor road should be not obstructed (priority traffic should be visible for at least 6 sec, the critical location should be not over a crest / in a sag / in a curve);
  - Minor road should instruct an unmistakable right of way (main road should be not narrower than the minor road, surface of minor road should not have a higher quality than the major road, surface of minor road should be clearly distinguishable from the main road's surface, lay-out of main and minor road should be not similar).



*Illustration 6: Minor road is not visible early enough: unexpected braking and high speed cause rear-end collisions [7]*



*Illustration 7: Improved situation by optical countermeasures of space perception (simulation) [7]*



*Illustration 8: The course of the curve is not perceptible: the view over the inner curve is restricted, the outer curve has no clear optical setting [46]*



*Illustration 9: Intersection not visible 125 m ahead: unexpected braking and high speed cause rear-end collisions [10]*

### 2.3. COUNTERMEASURES

Optimally in order to ensure the required change in the driving programme the critical location should be made clearly perceptible using design measures. However, this is often limited by surrounding conditions or budget constraints. In such cases corrective measures have to be applied. Warning devices should only be installed if design or corrective measures are not possible. Countermeasures are prioritised as follows:

1. **Eliminate:** Don't surprise the driver!
  - Ensure the perception and visibility of the critical location by road alignment and design, allowing an unobstructed view of the critical location.
  - Or, if this is impossible: ↓
2. **Reduce:** Ensure visibility by corrective measures!
  - Implement treatments that guide driver's attention directly to the critical driving demand.
  - Or, if this is impossible: ↓
3. **Minimise:** Give advice by warning measures!
  - Forewarn and seek to change driver's programme by installing traffic control devices.

#### Measures:

Remove visual obstacles such as crests, curves, vegetation and buildings prior to critical locations. If useful, construct traffic islands.

#### Measures:

Use attention guiding visual clues such as coloured are-as, pavement changes and special markings or crash

#### Measures:

Install speed limits, prohibit overtaking, set up warning signs.

The 6-Seconds Rule is fundamental to road safety as it offers drivers enough time to adapt their driving programme. Driving reactions can specially be guided by road equipment, control devices or special attention guiding optical facilities in the field of view.

Additional good solutions and best practise examples can be found in the PIARC's Report "Human Factors in Road Design. Review of Design Standards in Nine Countries" [38].

### 3. SECOND CLASS OF HF-ACCIDENT TRIGGERS – THE FIELD OF VIEW RULE

#### 3.1. HF ROAD REQUIREMENT NO. 2: THE ROAD MUST OFFER ROAD USERS A SAFE FIELD OF VIEW AND PRE-PROGRAMME THE CORRECT CHOICE OF SPEED

Motorised driving changes the field of view much more than any other everyday movement. Changes in the field of view cause pleasurable and stimulating emotions in most people. These emotions are involuntary and cannot be suppressed.

Changes in the field of view and the associated positive feelings are among the main motives for motorised driving. This basic Human Factor leads to a design of the field of view that is sufficient for a speed of 80-100 km/h in rural roads or motorways. Monotonous, clouded, deceptive or dis-tracting impressions affect the quality of driving. The road, together with its surrounding field, offers an integrated field of view. This can either stabilise or destabilise the driver; it can tire or stimulate him. It can also result in either increased or reduced speed. Speed, lane-keeping (tracking) and reli-ability of direction are functions of the quality of the field of view.

The well-calculated design of the field of view is described as “*field of view management*”. It takes into consideration road’s optical “*Gestalt*” – the impression of content of perception that is clearly distinguishable from its background of scenery and the details of which are so integrated as to con-stitute a functional unit with properties not derivable by summation of its parts [46].

#### Gestalt and Gestalt psychology

‘*Gestalt psychology*’ (also: ‘*Gestaltism*’) is a term used by Max Wertheimer (1880-1943) to sum-marize contemporary results of experimental research in the field of perception. The groundwork for today’s prevailing neurological cognition research was done by the Berlin pioneers of experi-mental psychology (‘*Berlin school*’) like Wolfgang Köhler (1887-1969), Kurt Lewin (1890-1947) and Kurt Goldstein (1878-1965).

The term ‘Gestalt’ labelled the new understanding that immediate (visual, haptic, acoustic, gustato-ry, olfactory) perception does not provide a direct image of ‘the reality’. Instead, the perceiver dis-cerns a substantially redesigned ‘picture’ of reality (*illustration 10*). The causes of this perceptive rear-angement were mostly found in optical experiments. Psychologists described the underlying prin-ciples as Gestalt heuristics or Gestalt principles. Soon it became part of the knowledge of design professionals that perception is biased due to some cognitive rearrangement of the ‘actual’ situa-tion. Over the time, the term Gestalt became extremely popular although only few had the neces-sary understanding of its origin and context.

Architectural planning, especially road and landscape architecture, must take Gestalt effects into consideration. In many cases, these are the causes of serious accidents because they result in misjudgement of routes, curves or gradients. A suggestive design of the road, a supposed narrow-ing or widening of a lane - in any case, the Gestalt principle affects the field of view and irritates the driver. On the

other hand, taking advantage of the Gestalt principle in a smart manner can turn a racing track into a promenade. Usually, already a first sketch of a road design reveals to what extent it is supported by a thorough understanding of Gestalt psychology. Pursuing related training can avoid casualties and save lives.

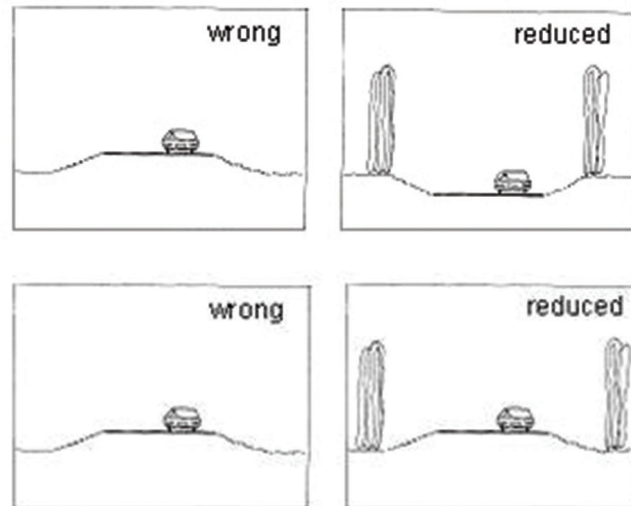


*Illustration 10: Dynamic Gestalt: two faces or a vase?*

A user-friendly road will give drivers a well-designed field of view with sufficient contrasts to increase alertness. It will provide good optical guiding and orienting facilities and with symmetrical and orthogonal impression.

A good-quality field of view safeguards the driver and keeps him from drifting to the edge of the lane or even leaving it. It will provide an unambiguous Gestalt to instruct the driver how, how fast and where he has to drive. Misleading eye-catching objects in the periphery of the field of view activate subconscious changes in direction and may lead to run-of-road. A road running along the top of a plateau for instance disturbs the balance of the driver and will lead to drive more towards the centreline.

Although a planting after the obstacle free zone improves the situation (*illustration 11.a*) a road running along a trough (*illustration 11.b*) gives the better stabilisation and prevents the driver from drifting towards the centreline.



*Illustration 11: Destabilisation (left) and stabilisation (right) of lane-keeping depends on road design [11]*

*11.a - above - full stabilisation*

*11.b - below - partial stabilization*

### 3.2. CONCLUSIONS AND PRACTICAL EXAMPLES

By adapting their driving programme, drivers involuntarily - and in most cases instinctively - optimise their field of view. They achieve a sufficient amount of stimuli (information) by acceleration, braking and/or change of direction.

Drivers continuously strive to optimise their field of view as long as they are not diverted by operational actions, offers of information or communication. The steering wheel, accelerator and brake pedals become control elements which contribute to the achievement of the comfortable field of view situation. Drivers correct their field of view by a single intense or several driving operations:

- Acceleration (often)
- Steer towards / across the centre of the road
- Swinging between road's centre line and edge (often, especially bikers)
- Swerve to the left lane
- Cutting corners
- Spontaneous adjustment of direction.

Driver's correcting or optimising behaviour has been under scrutiny for decades. Analysis of very serious accidents has revealed inexplicable changes in speed, lane and direction. These have been gradually identified as inevitable reactions to deficits in the field of view. Clear connections could be proven: speed, lane-keeping and reliability of direction are functions of the quality of the field of view.

Characteristics of the field of view allow predictions to be made of average driving reactions. Dependencies between field of view characteristics and driving reactions can be divided into three classes:

- density of the field of view;
- lateral space structure;
- depth of the field of view.

### 1. Density of the field of view

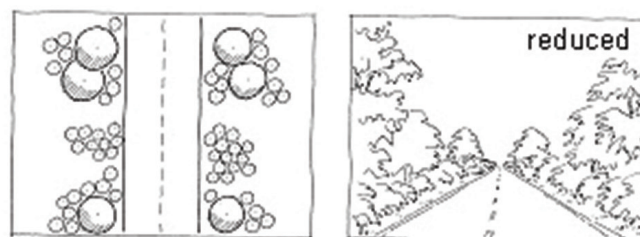
Drivers adapt their speed to the given road situation. It is well known that the amount of information that has to be processed influences the quality of driving (Yerkes-Dodson Law) (48). The amount of information also influences driver's speed. The term used for this is density of the field of view. It is a function of the number of objects that contrast with the background.

The presence of very few contrasting objects leads to monotony as well as reduced performance and reactivity (*illustration 12*). To avoid monotony the driver subconsciously changes his driving activities in order to increase information input: he swerves, brakes or – in most cases – increases speed.

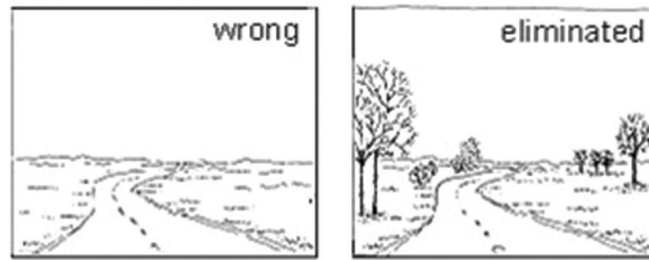
Consequently, it is desirable to achieve an optimal level of brightness and colour-contrast (optical density) to support the correct choice of speed. That is why efficient speed management relies on changing brightness and colour contrasts to avoid subconscious speeding up. So the number of objects that contrast with the background determines the density of the field of view (*illustration 13 & 14*). It affects  $V_{85}$  (the speed at or below which 85% of vehicles travel) [4], [31], [32], [33].



*Illustration 12: Density of the field of view is low; monotonous and long straight-ahead section stimulates subconscious speeding up [11]*



*Illustration 13: Density of the field of view is improved: diversified plantings with variation in heights and distances lead to a higher number of contrasts; the driver subconsciously slows down [11]*



*Illustration 14: Density of the field of view and the alignment is sufficient [11]:*  
 - sinuous rhythmic curvature;  
 - diversified planting with variation in heights and distances;  
 - the road environment is well structured.

A design feature that also influences the speed perception is the curvature of the road. A regular “swinging” sinuous alignment with a good curvature leads to an increase in attentiveness and a decrease in speed [40]. This can be explained by the increased workload out of steering and the increased amount of information from the 39 balance organs, which react to the change of position and curve acceleration.

Situations creating an inadequate density of the field of view should be avoided such as:

- Monotonous approaching sections/surroundings (*illustration 15*), including:
  - Monotonous planting without variation in height/distances in tree-lined country roads, sags;
  - Monotonous design in tunnels without contrasts by graphical design or eye-catching objects in accordance to the view axis;
  - Monotonous buildings along arterial roads;
  - Monotonous landscapes or uniform roads without alteration in planting or side objects.



*Illustration 15: Monotonous field of view leads to subconscious acceleration and fatigue. [13]:*

- Long/far visible approaching sections before critical locations (*illustration 16*), which can be corrected by:
  - creating a sinuous rhythmic road alignment;
  - using fixation objects that attract driver’s attention but do not distract it;
  - planting diversified vegetation along the road (*illustration 17*);
  - using markings with decelerating effects.



*Illustration 16: Optical orientation to the horizon: distant focus and monotony decreased workload and cause sub-conscious acceleration. [13]*



*Illustration 17: A field of view with high contrast leads to deceleration, increased attention and full peripheral field of view. [13]*

## 2. Lateral space structure

Tracking, braking and accelerating are largely performed subconsciously. The perception of position and speed derive from the perception of the road and its surroundings. In addition to the central part of the field of view, people subconsciously process peripheral information in the lateral part of the field of view in order to orient themselves. This is what enables people to walk through a forest in the twilight without hitting trees — a feat which is almost impossible by trying to consciously fixate on all the trees. It is also proven, that the lateral field of view and its information provide the most important information to master the difficult task to hold balance on the road like on a balance beam.

If designers fail to take this fact into account, they may not make the right prediction about how the finished design will influence lane-keeping. To hold balance on the road (as on the balance

beam) drivers need a clear orthogonal orientation out of objects in their periphery. Orthogonal objects or structures calibrate the equilibria-perception of road users that is needed for lane-tracking. Structures over the road like bridges, advertising, signalling and toll facilities should be symmetrical, of equal height, and the angle of skew to the own road should be less than 15° from perpendicular.

It was found at accident spots that asymmetrical posts of a bridge or pitched bridges/advertisements confuse and disorientate drivers with regard to lane-keeping and result in run-off-road accidents.

### Optical setting of curves: curve illusions by non-parallel optical guidance

Driving reliably through a curve also critically depends on the quality of the field of view and a clear distinguishable Gestalt of the curve. Best driving results are achieved when the driver has an unobstructed view over the inner curve and the outer curve has a closed optical setting that provides with its Gestalt a clear instruction that there is a curve at all. It provides also clear information about the sharpness of the curve.

Driver's responses to inner curves which are obstructed and/or responses to a fragmentary or even non-existent setting of the outer curve are spontaneous speed changes and inadequate steering manoeuvres. The cause is a misperception of the sharpness of the curve (in the best of cases) or a missing perception of the curve at all (in most of the cases).

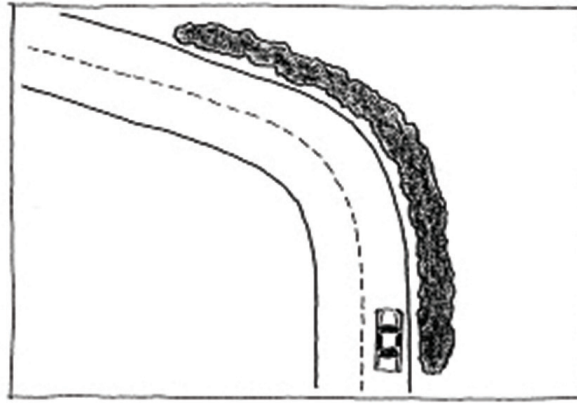
If the setting of an outer curve is not parallel to the road's edge, a curve illusion is created and will misinform the driver about the sharpness of the curve. He will follow subconsciously rather the dominant guiding of the outer curve than the subdominant guiding by the marking of road's edge (*illustration 18*).

It was found at black spots that an absence of these three characteristics (unobstructed inner curve, parallel setting of the outer curve and closed setting of the outer curve without optical gaps) causes subconscious swerving and technically "*unexplainable*" run off-road accidents.

This is because the motion in a curve causes two supplementary perceptions:

- the change in the structure of the field of view is accompanied by pleasant feelings,
- they are intensified by acceleration and further increased by the change of direction. The driver receives lasting, positive, optimistic and pleasant feelings from the sensation of driving round the curve.

These positive feelings result from the release of pleasure hormones and cannot be suppressed. They often reduce the conscious registration of possible dangers. The driver can then be particularly susceptible to operational mistakes in road curves. These mistakes may be caused by deficits in curve design, especially right-hand curves, which are more difficult to drive because of the left-hand-phenomenon.

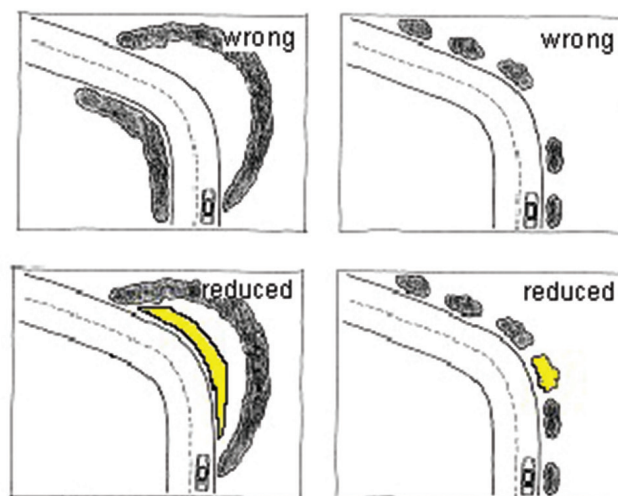


*Illustration 18: Complete setting of the outer curve and unobstructed view of the inner curve stabilise the driver. [11]*

Therefore, designers will not only try to design a curve with a constant radius according to the guidelines, they will also try to design the field of view safely. Even a curve which has been correctly designed from a technical perspective can become hazardous as a result of the following two optical characteristics [19], [20], [49] :

- when the sight distance on the inside of curve is obstructed (e.g. by buildings, vegetation or geological formations);
- when the lateral optical guidance of the outer curve is partially or completely missed (without setting) or non-parallel (*illustration 19, illustration 20*).

Many accidents happen when one or both of these optical characteristics are present. They trigger spontaneous changes of direction and speed. No matter how much drivers try to correct their reactions, vehicle will lose stability in function of the intensity of the correction. This can range from an unintended change of lanes, to swerving, driving on the shoulder, skidding into safety barriers or run-off-road accidents.



*Illustration 19: Driver's destabilisation in a curve [11]*

- left: by misleading lateral optical guidance in the outer curve and obstructed inner curve; corrected by a parallel setting to road's edge;
- right: by gaps in the lateral optical guidance on the outer curve; corrected by covering the optical misguidance with a dominant optical guidance parallel to road's edge.



*Illustration 20: Tendency towards the outer curve by misleading gaps in the setting and obstructed inner curve [12]*

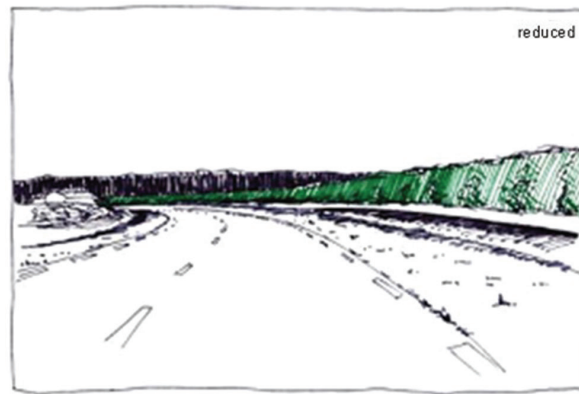
**The following road characteristics should be avoided.**

Incorrect optical setting of outer curves

- Lateral optical guidance on the outer curve is missing (*illustration 21 and 22*) or is non-parallel to road's edge (planting lines, safety barriers);
- Gaps in the optical guidance;
- Obstructions of the inner curve;
- Invisible edge line markings.



*Illustration 21: Curve without setting leads to destabilisation of the driver especially in the night. [26]*



*Illustration 22: Setting in the outer curve stabilises the driver. [26]*

Optical guiding with illusions by non-parallel lateral optical guidance in curves, such as

- Non-parallel safety barriers, snow and wildlife fences;
- Non-parallel plants, bicycle, riding and rescue paths;
- Non-parallel public maintenance routes.

#### Roadside objects should appear vertically

The non-orthogonality of the surrounding environment affects the balance and thereby lane-keeping. Trees, posts or buildings can create a non-orthogonal impression that especially affects field-dependent drivers who tend to swerve and make spontaneous steering manoeuvres to compensate the optical misperception (*illustration 23, illustration 24*).

#### Field-dependency

Degree to which human perception depends on the holistic perceptual field so that perception performance cannot be separated from the overall impression of the environment.

Field-dependent drivers are more dependent on a reliable designed field of view. They need more time for orientation and their rate of failures, slips and lapses is higher than that of field-independent drivers. They cannot define their own position in the space of the road independently from the structure of the field of view.

Psychological tests concerning field-dependency are used to select pilots that are able to separate the perception of their own position independently from the visual information they get from the field of view.

Because it is not possible to exclude field-dependent drivers from the participation on motorised traffic it is mandatory to offer a reliable, stabilising field of view to all drivers. That's why roadside objects like trees and delineators as well as architectural constructions like posts of bridges or traffic control devices should provide an orthogonal appearance to stabilise lane-tracking.



*Illustration 23: Destabilisation by non-orthogonal impression: field-dependent drivers spontaneously swerve and cause accidents [13]*



*Illustration 24: Destabilisation by a non-orthogonal and unsymmetrical suspension: balance is disturbed and field-dependent users tend to swerve to the right [18]*

Non-vertical appearance of roadside objects should be avoided, such as

- Trees, delineators, or Single objects, e.g., buildings, trees, traffic control devices.

#### Structures over the road should support lane-tracking

The orderliness of objects in the roadside determines the symmetry and rhythm of the lateral road space, the lateral space structure. It supports or consequently disturbs optimal lane-tracking. [22], [45].

Structures over the road that are asymmetrical and/or of different height and those with an angle of skew more than 15° from perpendicular should be avoided (fig. 25 to 30):

- Bridges, advertising, signalling and toll facilities;
- Groups of plants.

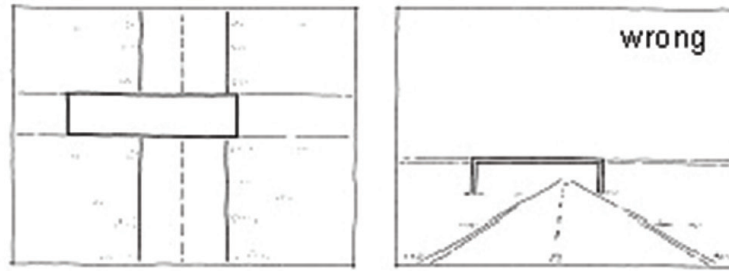


Illustration 25: Wrong asymmetrical structure over the road shifts the optical middle of the road to the middle of the asymmetrical structure, driver drifts to the left lane. [11]

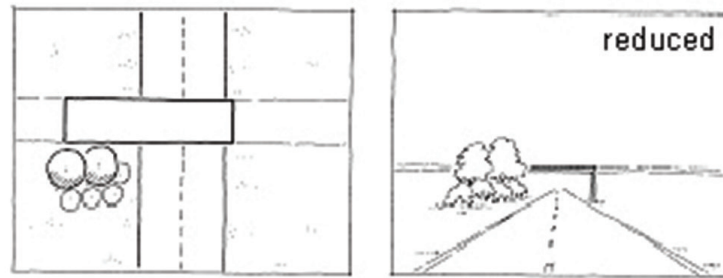


Illustration 26: Corrected asymmetrical structure over the road by planting. The perceived middle of the road matches with the middle of the structure [11]:

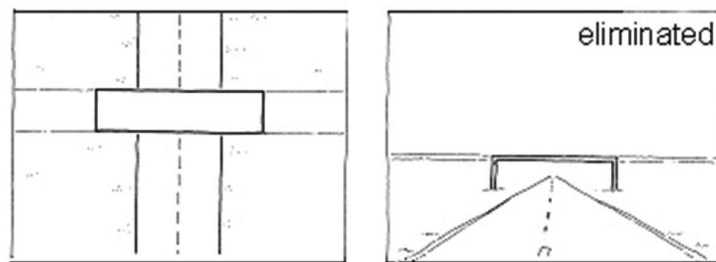


Illustration 27 : Asymmetrical superstructure is eliminated: Symmetry achieved, no tendency to drift towards the left lane. [11]

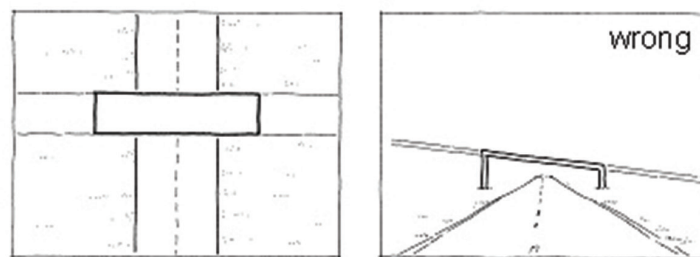
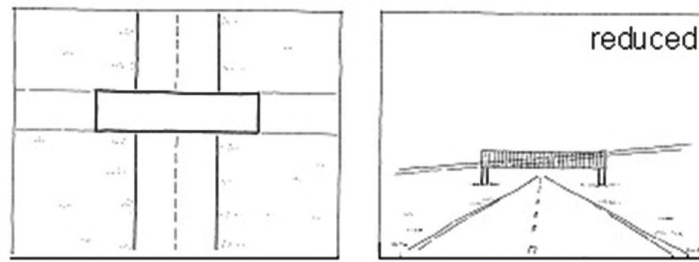
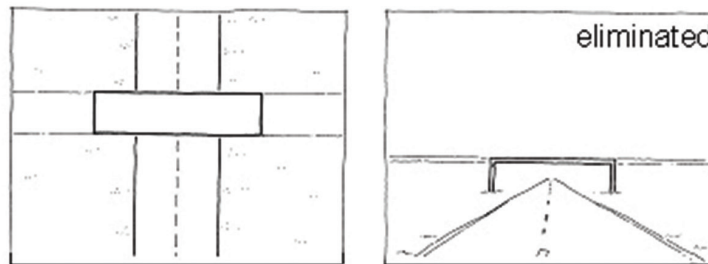


Illustration 28: Skewed superstructures result in a tendency to veer left, because the higher left side of the superstructure dominates the orientation. [11]



*Illustration 29: Unequal height of the structure is covered. [11]*



*Illustration 30: Unequal height of the structure is eliminated: Symmetry achieved, no tendency to drift towards the left lane. [11]*

### Depth of the field of view

Space is perceived by humans as an oval. To perceive this space and identify relevant sensory information the eye scans this oval automatically in small interior circles of  $15^\circ$  in a counter-clockwise direction and forms a three-dimensional space.

This three-dimensional space ends after 8 m and beyond this space can only be perceived in two dimensions. Despite this people can still judge distances and estimate which of two objects is nearer to the observer. However, this is the result of information processing of the brain - based on knowledge about regular sizes of objects, perspective relations and characteristics of textures. These are the reasons why the visual perception of space is very mistake-prone and susceptible to optical illusions and thus needs clear and unambiguous spatial information (*illustration 31; illustration 32*).

The driver orientates himself in the environment that surrounds him. To estimate his position relative to the road, to the surrounding and to other drivers, he depends on his changes of position, his changing view axis and the changing locations/lines of reference in the environment.

All this information has to be set in relation to the drivers' coordinate system, which is working sub-consciously. While a moderate change of position keeps attentiveness high and reduces mistakes, there is also an opposite effect caused by sudden and frequent changes in drivers' surrounding. In this case, the information load cannot be processed accurately and operational and though driving mistakes can result. As a result drivers are susceptible to optical illusions or other perceptual traps.



*Illustration 31: Best practice example from Canada: well-structured field of view with clear lines of reference [13]*



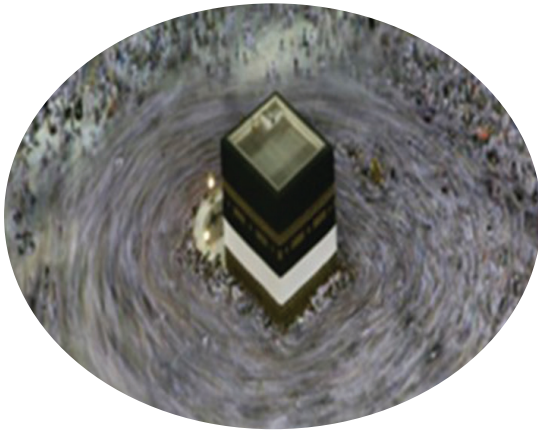
*Illustration 32: Best practice example from Denmark: well-structured field of view with clear lines of reference [3]*

The most serious consequences arise from eye-catching objects that differ from the road axis. These lead in extreme cases to a horizontal swing of the complete field of view.

### **Left-hand phenomenon**

A not very well known stereotype of human orientation and space movement is the so called left-hand phenomenon. It is evident in humans as well as mammals and can be described as a genetically determined movement to circular, counter-clockwise movements. For example, wild game separated by a hunter or any other incident will run after a short spin to the right in a long left-handed circle counter-clockwise back to the starting location. Counter-clockwise movements are often much easier for mammals, so also for humans. Moving clockwise causes dizziness, stumbling, enhanced orientation-urge, lower speed and hesitating in the movement action.

The left-hand phenomenon explains why right-hand curves are more difficult for drivers. For road designers this means that the difficulties in driving through a curve are even more crucial for right-hand curves.

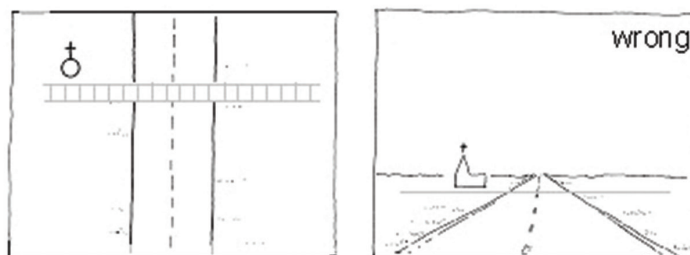


*Illustration 33:  
Left-hand phenomenon: Circumnavigation of the  
Kaaba, Mekka, counter clockwise. [18]*

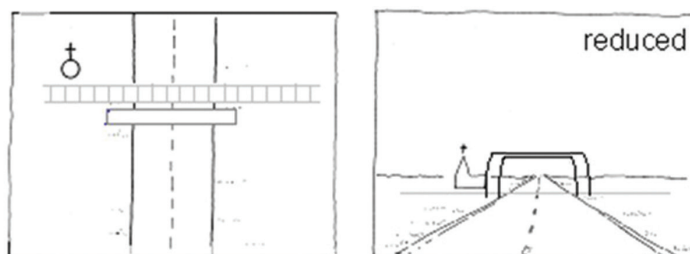
### Dominant eye-catching objects should support lane tracking and detection of critical locations

The most serious consequences arise from eye-catching objects that differ from the road axis (*illustration 34*). These lead in extreme cases to a horizontal swing of the complete field of view: The driver has the feeling that the road and its surrounding are moving while he is in an unmoved position. Such objects lead to gross mistakes in steering. At minimum they lead to disturbances in lane-keeping, though these can mostly be corrected (*illustration 35*).

The shape of the space in the driving direction determines the perceived spatial depth structure. Together with the depth of field of view, it has an influence on the reliability of direction and the speed  $V_{gs}$  ([27], [29], [32], [41]).



*Illustration 34: Depth of space structure: Dominant eye-catching object (church) in competition to a subdominant railway crossing. [11]*



*Illustration 35: Correction of the dominant eye-catching object by using perspective-forming objects, possibly with traffic control devices [11]*

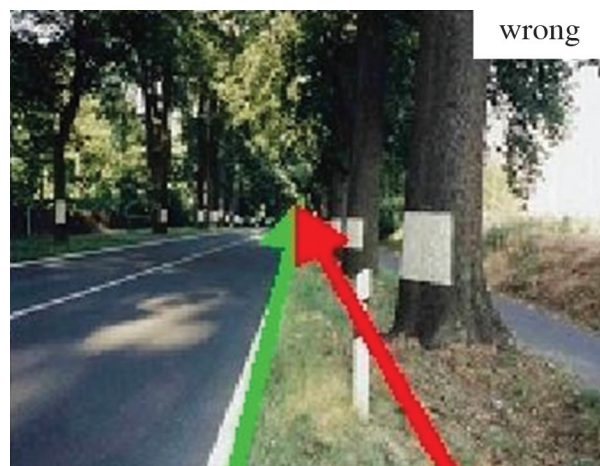
**The following road characteristics should be avoided:**

- Eye-catching objects disturbing optimal lane-tracking by disruption of the view, asymmetry or non-alignment with view axis, such as trees, buildings, technical facilities or other single objects;
- Dominant eye-catching objects that distract the view from the road axis or from critical locations such as: church towers, other buildings, lighting, plants, windmills.

**Illusion-free optical guidance should support optimal lane-tracking**

All lateral orientation clues should be parallel to the road edge, regularly spaced and equally sized to stabilise lane-tracking. This is important for markings, hard shoulders, side strips, safety barriers, snow and wildlife fences, plantings, bicycle ridings and rescue paths and also for public maintenance roads.

It was found at black spots that non-parallel orientation lines lead to the impression of prolonged (if lines are converging) or shortened (if lines are diverging) distances up to critical locations. Optical illusions<sup>2</sup> cause subconscious swerving, sudden driving manoeuvres and technically “unexplainable” run-of road accidents (*illustration 36*).



*Illustration 36: Distance illusion:  
Road edge and planting line are not parallel after a reconstruction [6]*

The non-parallel road edge in relation to the line of trees causes a perspective illusion. Drivers over-estimate the distance up to the oncoming curve. As a result their speed is too high in the beginning of the curve and run-off-road / hit obstacle accidents occur (*illustration 37*).

<sup>2</sup> The word illusion comes from the Latin verb *illudere* meaning “to mock.” Illusions are the result of the complex information processing of the brain and the visual system that tricks us into perceiving something as different from what it actually is. Thus what we see does not correspond to physical reality.



Illustration 37: Distance illusion at an accident location [11]

- Optical illusions by non-parallel lateral orientation/guidance lines, concealed parts of the lane or sharp curves co-located with vertical curves:
  - Distance illusion (*illustration 38 to 41*) ;
  - Perspective illusion (*illustration 42*) ;
  - Curve illusion (*illustration 43*).
- Partially obstructed course of the road in the following situations:
  - Overtaking;
  - Driving in a curve;
  - Driving with high speed.



Illustration 38: Unintended distance illusion at an accident location in the Netherlands: safety barriers suddenly swing to the left. [38]

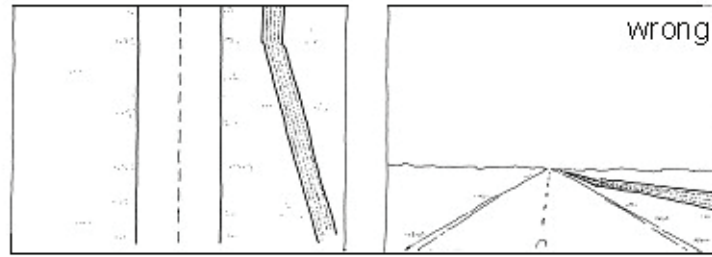


Illustration 39: Distance illusion: non-parallel spatial line of orientation (such as fences, planting lines, safety barriers, or similar) leads to an overestimation of distances. [11]

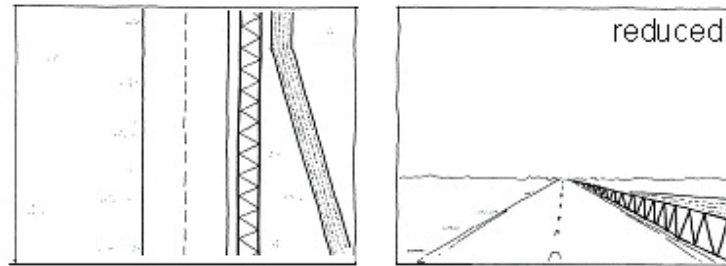


Illustration 40: Distance illusion corrected: deficit concealed. [11]

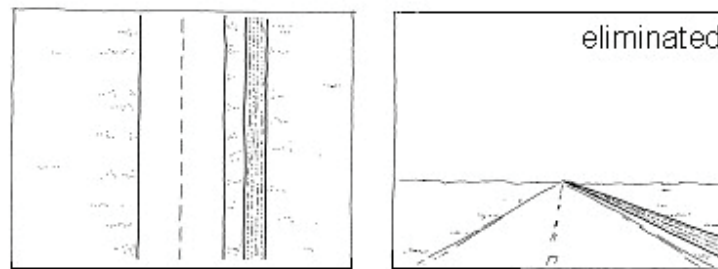


Illustration 41: Distance illusion eliminated by strictly parallel orientation lines. [11]



Illustration 42 :Perspective illusion: at night signs sometimes give a wrong expectation of the direction of a curve first impression left, after 100m – right. [13]

Another optical illusion is caused by a curve in combination with a sag or in combination with a crest (*illustration 43*). This leads to underestimation / overestimation of curve's radius.



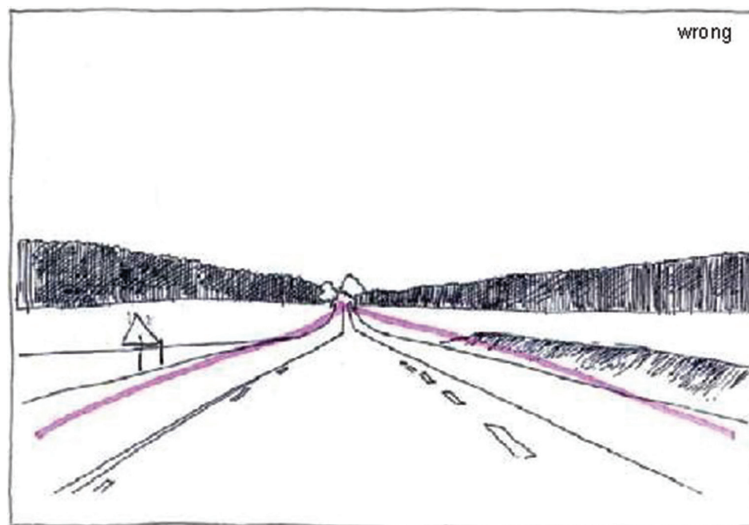
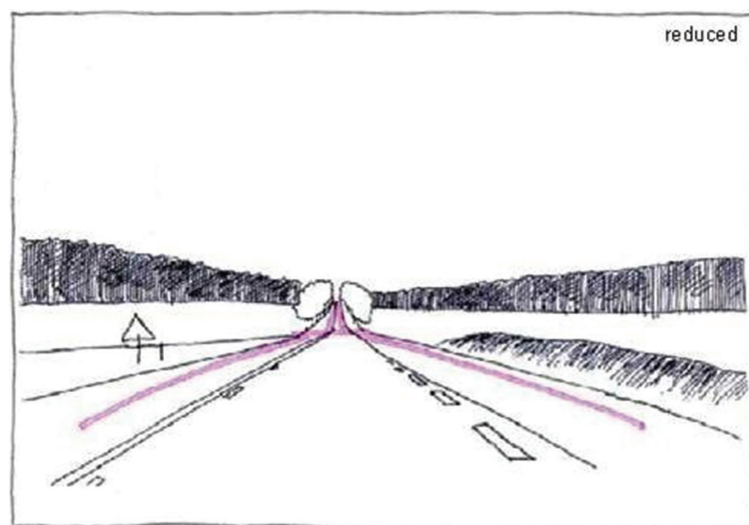
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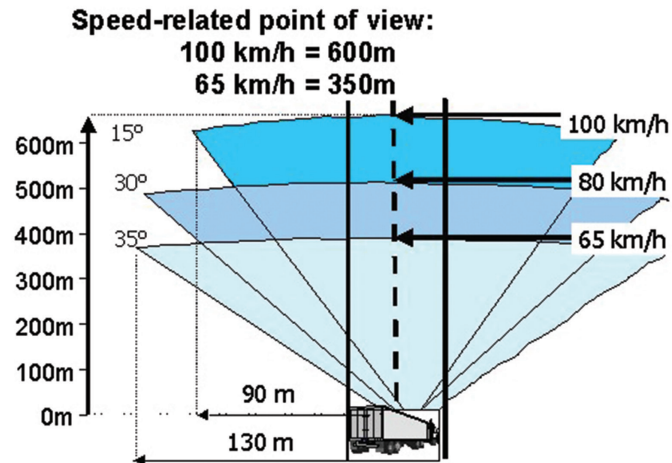
*Illustration 43:*

*Optical illusion resulting from combination of curve with sags/crests:*  
 - Top: curve in a sag: overestimation of the radius, driving too fast;  
 - Below: curve on a crest: underestimation of the radius, driving slows down. [23]

*Illustration 44: Optical irritation by a difference in beginning of a sag and a planting [24]**Illustration 45: Improved situation by beginning planting and sag at the same location. [24]*

### The field of view depends on the speed – and vice versa

The longer a straight ahead section of a road is the farther the driver will have his fixation location on the horizon (*illustration 46*). The automatic effect of that condition is a subconscious speeding up. That's why a Human Factors experienced designer will limit the length of straight sections especially before intersections or other critical locations to avoid subconscious speeding up.

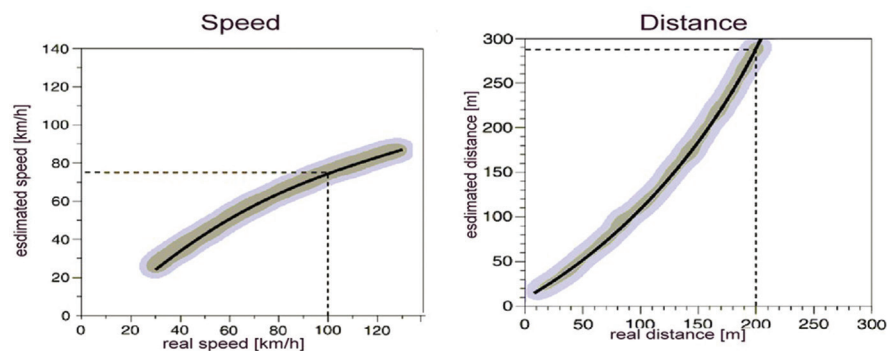


*Illustration 46: Speed-related focus and field of view [31]*

The average driver will almost certainly react in a predictable way to an unsatisfactory quality of field of view. In most cases, his subconscious, spontaneous reaction will be the following:

- acceleration and/or
- deviation from the lane and/or
- inadequate change of direction.

The estimation of speed and distances of road users is very failure-prone (*illustration 47*). Especially if they are moving the estimation is not correct. If the sight distance on crossing vehicles is too long, a mis-judgement can lead to wrong actions and to crashes. So at unsignalised intersections or railway crossings road users expect a safer situation as it really is. That's why designers should ensure that the sight triangles are correct but not allow a sight on the crossing traffic that is longer than 6 seconds.



*Illustration 47: Speed-related focus and field of view [31]*

### 3.3. THE STORYBOARD METHOD: HOW TO CHECK THE QUALITY OF THE FIELD OF VIEW

Investigation of the quality of field of view should be carried out by checking it in regular 50 m intervals along the road. Options for improving the quality of the field of view should be implemented, because sections of road with high perception quality are much safer than those with poor perception quality.

When the 50 m sections are being examined, they should be checked systematically according to the above mentioned criteria which are the most common deficiencies in the quality of field of view.

The quality of the field of view of a planned road section can always be determined by reference to these items. Remedial treatments can generally be identified during planning and design.

A photo documentation/simulation of the road at 50 m intervals (storyboard method) can be used to guarantee an efficient management of the field of view. The field of view is outlined as it would appear to the road user – either in a two-dimensional photo-story, a three-dimensional model or a simulation. Generally, serious hindrances in the predictability of a road section can be identified without using three-dimensional models or simulations.

In existing roads instead of using simulations it is possible to use photographs from Google Earth's Street View or similar facilities. The zoom should be chosen so that the impression on the picture is similar to that of the road user. In most cases a higher zoom has to be used than the normal photo provides.

### 3.4. COUNTERMEASURES

Deficits in the field of view which have been identified in this way can be addressed systematically. Prioritisation of the countermeasures is the same as that applied for the 6-Seconds Rule:

1. **Eliminate:** design the field of view!
  - Remedy the identified deficits in the field of view by de-sign / constructive measures
  - or ↓
2. **Reduce:** correct the field of view!
  - Permanently remedy the identified deficits in the field of view by improving the optical guidance,
  - or ↓
3. **Minimise:** place warnings in the field of view!
  - Address the identified deficit in the field of view by
  - signs and instructions.

#### Measures:

Create sinuous “*rhythmic*” road alignment against monotony; create symmetry of superstructures by constructive measures, etc.

#### Measures:

Use eye-catching objects, create a complete setting of outer curves, cover non-parallel optical guiding lines that lead to optical illusions, etc.

#### Measures:

Install speed limits, ban overtaking, set up warning signs.

A few examples of measures that can be used to improve the optical density of the field of view are provided here.

Interrupt the unobstructed overview to the horizon in long straight road sections, create fixation points that guide drivers' attention

- use varying types or colors of pavement;
- apply colored signs or graphics on the pavement (*illustration 48*);
- plant diversified vegetation alongside the road;
- use reflecting markings, signs, etc.
- create artificial bottlenecks or use roundabouts;
- use fixation points along the view axis of the driver (reflecting safety barriers, signs, artwork, etc.) (*illustration 49*);
- structure the roadside with light in different colors, brightness, or with several eye-catching objects (*illustration 50, illustration 51*).



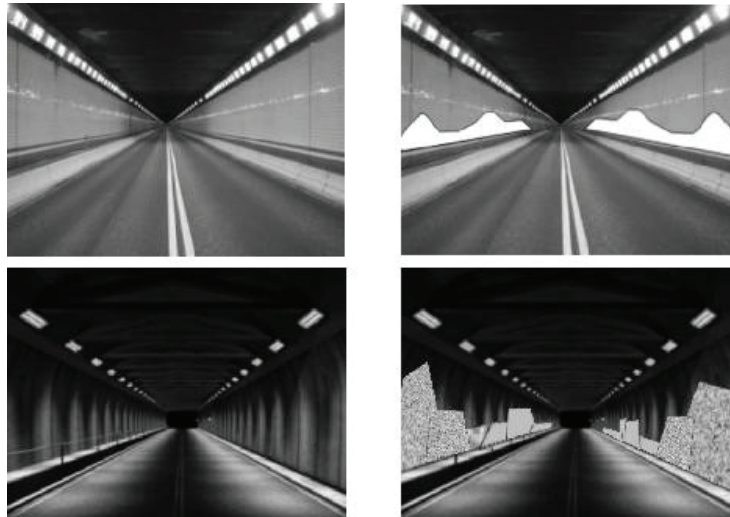
*Illustration 48: Application of colored markings to guide drivers' attention to an invisible intersection (OU Forst. Source: Steffen Wenk, MIL Brandenburg, Germany)*



*Illustration 49: Example of fixation points along the view axis of the driver. [22]*



*Illustration 50: Noise walls with differently coloured and sized windows. [38]*



*Illustration 51: Tunnel walls with little contrast (left) and increased contrast (right) to influence speed. [38]*

Inform drivers of critical points early enough and use optical illusions to reduce speed:

- Decrease speed by use of an optical break (sequence of cross markings in logarithmical decreasing intervals of width and length on both sides of the road) (*illustration 52*) [21]
- advanced visual cues of approaching intersections by use of chevron patterns (herringbone) and crossing markings (32)
- advanced visual cues of approaching curves by dashed edge markings (*illustration 53*) [21]
- advanced visual cues of approaching curves by Hering's illusion (*illustration 54*) [32]
- advanced announcement of curves by edge marking broadened till apex of curve [32].

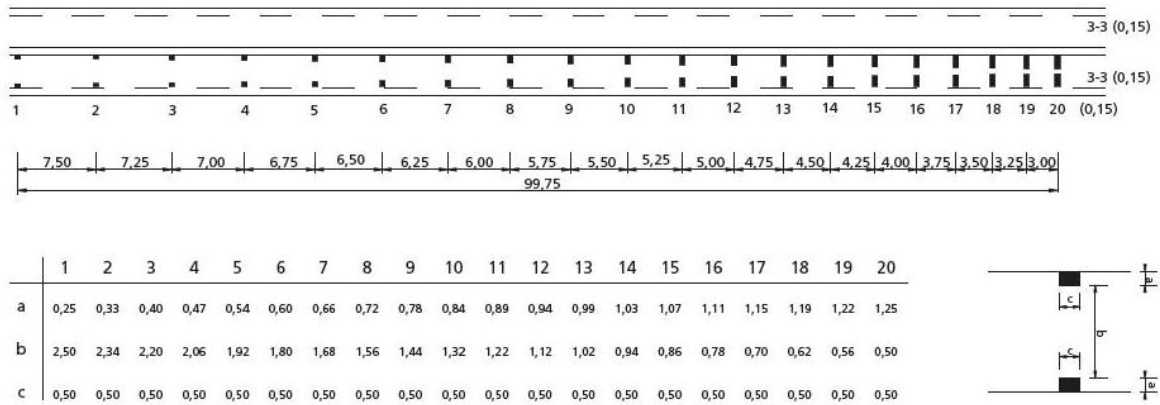


Illustration 52: Optical break to reduce speed of vehicles approaching a town entrance [37]



Illustration 53: Example of advanced visual cues of approaching intersections by use of optical break in Belgium [37]

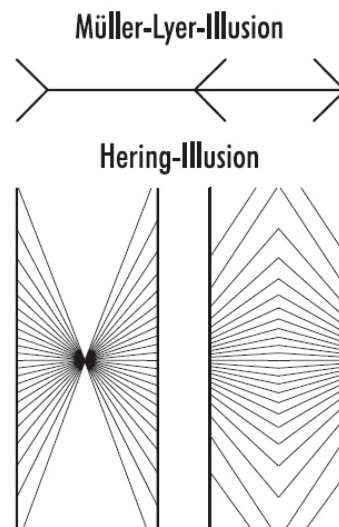


Illustration 54: Optical Illusions to decrease speed. [29]

Support the estimation of speed at intersections:

- support the estimation of speed/distance by markings/other objects on the sides of the road
- support the identification of the drivers position relative to others by markings/posts/other objects on the crossing road

Other solutions and best practise examples can be found in the PIARC’s report “Human Factors in Road Design. Review of Design Standards in nine Countries” [38].

## 4. THIRD CLASS OF HF MISTAKES – THE LOGIC RULE

### 4.1. HF-ROAD REQUIREMENT NO. 3: THE ROAD HAS TO FOLLOW DRIVER'S PERCEPTION LOGIC

Drivers follow the road with an expectation and orientation logic formed by their experience and re-cent perceptions. These affect their actual perception and reactions.

The same principle applies when climbing stairs. After only a few steps the motion balance adjusts to the sequence of steps just perceived. In most cases, this is a subconscious process. However, if one step is of a different height, the motion balance will become considerably disordered - possibly resulting in a stumble or fall. Adjustment of driving programme on the road is similarly subconscious.

The perception of the lane, the edge of the lane and the lane periphery produces a general sensual impression. Drivers react to these road elements with their actions, in the same way as the person climbing stairs reacts intuitively to the height, depth and width of the steps. Unexpected objects disturb the automatic sequence of operations, possibly causing the driver to “*stumble*”. After several critical seconds the disturbance can be handled.

Therefore planners and designers try to keep road characteristics flowing in a logical sequence. They should introduce inevitable changes as early and clearly as possible and exclude any sudden changes that would confuse the driver.

Many international guidelines demand continuity (consistency) for the layout of roads and contain design principles for continuous spatial alignment management (*illustration 55*). Discontinuous radii of consecutive curves increase the risk of accidents.

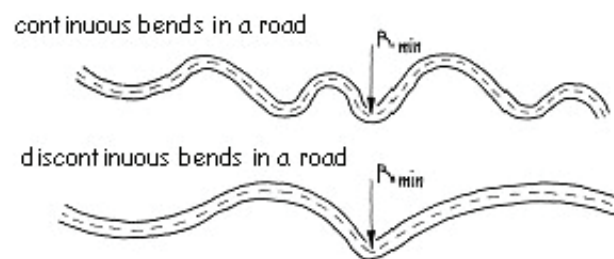


Illustration 55: Continuous and discontinuous curves in a road. [23]

Therefore, in order to exclude unexpected changes the modification of critical locations (“*stumble and tumble locations*”) as well as planning new sections of road always has to be adjusted to the existing road characteristics before and after these locations (*illustration 52*).

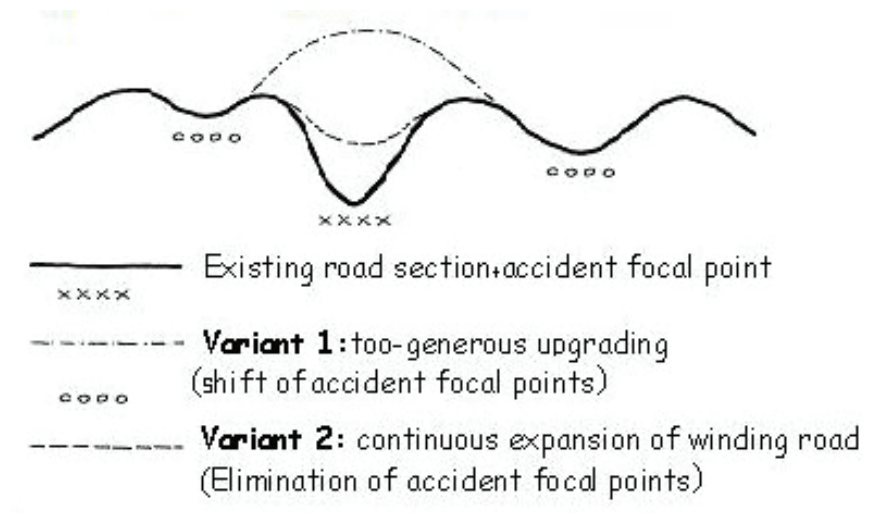


Illustration 56: Elimination of dangerous locations by consistent adaptation of road curves. [11]

The principle of the consistency of successive radii of curves and the usage of transition curves are nowadays integrated in most national design guidelines [37].

## 4.2. CONCLUSIONS AND PRACTICAL EXAMPLES

When choosing their speed, drivers rely on their previous and recent sensory impressions of the last driven 5-10 minutes. Breaks in the consistency and the experienced logic of the design trigger operational mistakes which can result in driving mistakes and accidents.

**This particularly applies to the following seven situations:**

### 1. Change of road function without corresponding change in design and optical characteristics (e.g. town entrance)

Drivers need to adapt their driving programme when entering a built-up urban area or when road functions changes significantly. They need to decrease speed and be more attentive as more decisions and reactions are required.

There should be offered unambiguous visual clues to recognize the change of function, for instance by a horizontal swing of road's course, optical sight barriers, planted central islands, special speed-reducing markings or a combination of these instructions. A clear guiding Gestalt has to instruct the driver how to adapt the driving programme.

The absence of visual clues to reinforce a change of function of the road (e.g. change from tree-lined country road to town entrance) or other situations with the necessity to adjust the speed should be avoided, instead:

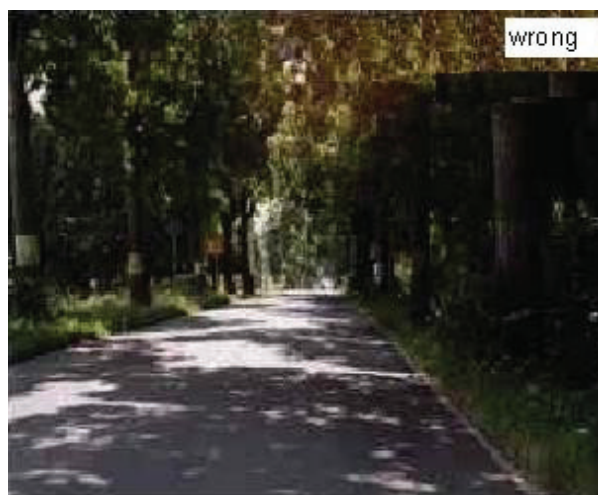
- Use changes of road characteristics (e.g. by kerbstones, pavement, bottlenecks, eye-catching objects) (*illustration 57*);
- Use changes of roadside and landscape characteristics;
- Use transition zones with clear optical signals.



*Illustration 57: Use of bottleneck and optical illusions in South Africa to instruct the pedestrian walk and to re-duce speed [9]*



*Illustration 58: Invisible crossing in a tree-lined country road (300 m ahead). [12]*



*Illustration 59: Invisible town entrance in a tree-lined country road (150 m ahead) [12]*

## 2. Change of road's direction is contrary to eye-catching objects in another direction (e.g. city by-pass dilemma)

Drivers need eye-catching objects to realize that there is a change in road direction despite other dominant eye-catching orientation structures or objects. The change of direction has to be supported by covering the wrong view axis or optical misguiding (*illustration 60*).

It has been found at black spots that dominant eye-catching objects such as a line of trees, buildings or straight road sections impede the correct anticipation of a road's course even though correct signing is present. Road characteristics that mislead spatial perception cause technically “*unexplainable*” accidents.

The following road characteristics should be avoided.

A change of road direction contrary to eye-catching objects in another direction should be avoided, such as:

- New road layout is neither visible nor clearly perceived;
- Transition zone is not adequate;
- Misleading visual clues along the old road alignment (if so, are they covered by planted embankments, placement of fixation objects etc.) (*illustration 61 to 63*).



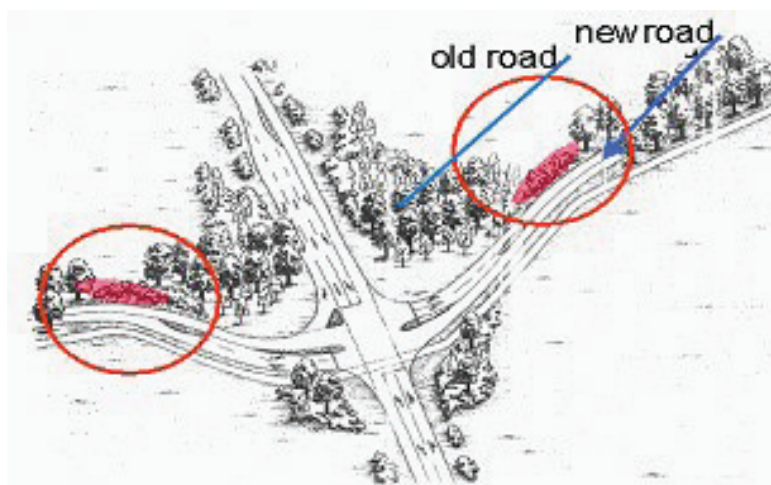
*Illustration 60: Changed road direction is not unambiguously visible, the anticipation of the road course is disturbed. [12]*



*Illustration 61: Optically misleading view axis: road curves to the right contrary to the view axis leading straight ahead (150 m before the critical location). [12]*



*Illustration 62: Misleading view axis is covered [12]*



*Illustration 63: A changed direction contrary to the old, dominant eye-catching view axis can be corrected by a planted embankment [45]*

### 3. Requirement for a new driving program recognized and changes are introduced to “re-programme” driving habits and expectations

Changing the right-of-way or altering the course of the road - such as a new alignment - will challenge driver's habits and expectations. Appropriate and timely signals or visual clues are required to inform the driver and provide an adequate time for correct anticipation. The required reaction could be significantly different from the habitual one! In order to avoid surprises, various design principles need to be considered.

It has been found at black spots that newly built intersections that are not introduced properly lead to incorrect anticipation of the situation and therefore to accidents even though correct signing is pre-sent.

Sudden changes of road characteristics that are contrary to normal driving habits, e.g. new cross-ings, changes in the right of way, etc. (“*effects of pre-programmed habits and expectations*”) should be avoided, such as:

- Requirement for new driving programme cannot be recognised (*illustration 64*);
- No changes introduced to “re-programme” driving habits and expectations, such as:
  - change of alignment;
  - provision of adequate transition with appropriate anticipation and response section (at minimum);
  - ensuring clear visibility of modified road or traffic control devices;
- Road alignment does not conform with drivers' expectations;
- Transition zones and critical locations: not visible, lacking overview, not understandable and/or not progressively implemented (*illustration 65, illustration 66*).



*Illustration 64: Sudden change of road characteristic: the new intersection is not introduced by progressively implemented transition zone (150 m ahead). [10]*



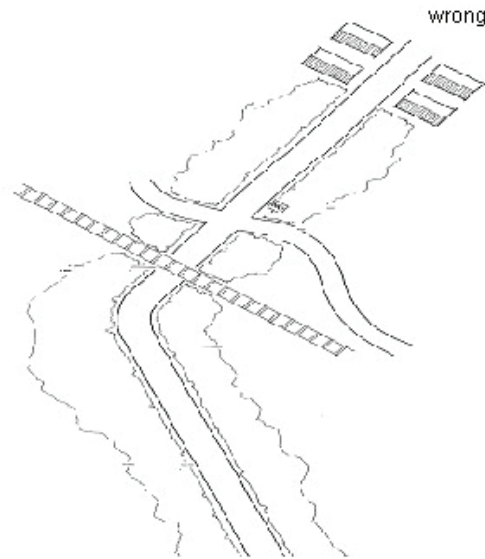
- Multiple critical locations / overload of information processing not avoided (*illustration 67 to 69*);
- Not all critical locations are visible / more than 3 decisions are necessary at the same time;
- Driver not progressively informed of multiple critical locations;
- Critical locations like sharp curves, intersections, traffic signs etc. not avoided directly after tunnels.



*Illustration 67: Three critical locations: maintenance location, starting a curve and exit road without transition and/or progressive information (150 m ahead). [12]*



*Illustration 68: Three critical locations on the left lane: end of acceleration lane, end of climbing lane and end of intersection's median. (C. de Almeida Roque)*



*Illustration 69: Cumulative effect of non-visible railway crossing, road crossing and town entrance after a dangerous curve and a long, monotonous straight section. [11]*

## 5. Deficiencies in traffic control devices

Due to higher traffic volumes, roads need to be equipped with traffic control devices for safety. Along with rules, traffic control devices organise the driving reactions of road users. Under all light conditions and within all optical backgrounds, traffic signs should be visible, legible and detectable. They should never be covered by plantings or other structures. That is because the effect of mime-sis may make even bright, oversized signs invisible to the driver (*illustration 70*).

Signs should be in accordance with driver's expectations, and the road alignment should be consistent and in accordance with the traffic control devices. Otherwise there will be a risk of misleading and confusing drivers, leading to accidents.



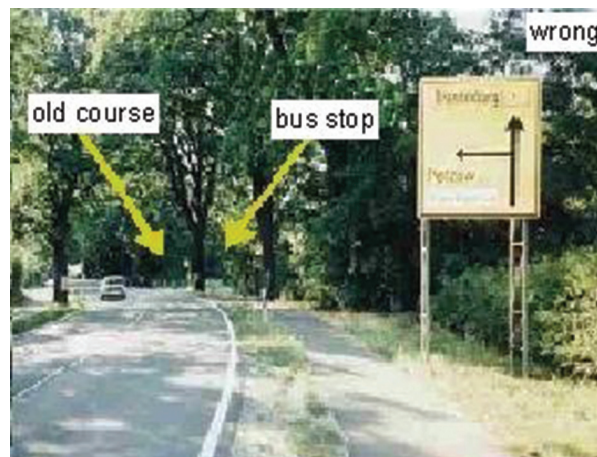
*Illustration 70: Three oversized chevron signs are not visible against the background in an accident curve. [8]*

*Illustration 71* shows clearly that the detection of left sign's Gestalt (red arrow on yellow) is much easier than the sign with the white arrow on red background. Human eyes have a special sensibility to colours: Yellow-green and yellow-orange are more easily detected than other colours – especially in all conditions (day, twilight and night). A yellow frame or background make them more visible.



*Illustration 71: Improved visibility of signs by use of yellow background instead of red.  
(source: photo from Austria, Hans-Joachim Vollpracht, 2008)*

Drivers can also get confused if the direction of a sign differs significantly from the perceived road course (*illustration 72, illustration 73*). It has been found at black spots that such illogical signing causes irritations and accidents (*illustration 74, illustration 75*).



*Illustration 72: Direction of a traffic sign differs from road course.  
Drivers try to follow the old course. [12]*



Illustration 73: Corrected direction of the sign is compatible with the road course and marking old course is concealed. [12]



Illustration 74: Incorrect expectation of the situation caused by misleading signs at an accident location. [10]

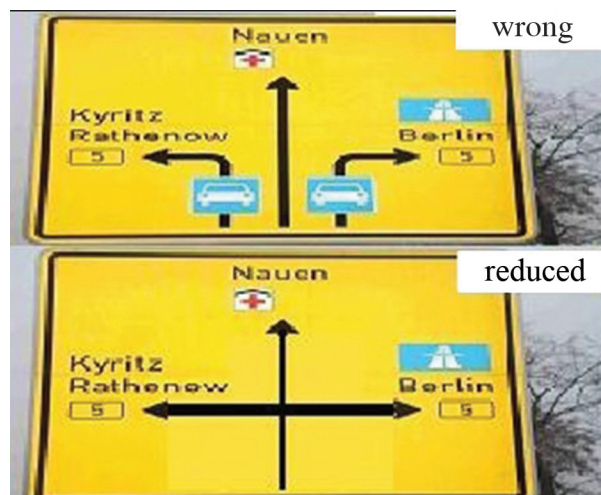


Illustration 75: Corrected signing on the accident location. [10]

Deficiencies in traffic control devices should be avoided, such as:

- Traffic control devices not visible against background (size, contrast, brightness not sufficient);
- Traffic control devices not appropriate and consistent with road characteristics;
- Traffic control devices not in accordance with drivers' expectation and perception;
- Road alignment not consistent with the traffic control devices.

## 6. Deficiencies in direction signing

Often direction signs are crammed with information or the information is not visible or legible.

- Deficiencies in direction signing should be avoided, such as:
  - more than 5 +/-2 destinations per approach to intersection;
  - more than 3 destinations per direction
  - insufficient sight distance provided to detect sign
  - chosen letter size too small; less than:

v = 60-70km/h:	140 – 160 mm
v=80-100 km/h:	175 – 240 mm
v ≥ 110kmh:	320 – 400 mm.

## 7. Deficiencies in settlement planning

Divided settlements create safety problems with unexpected crossings by vulnerable road users.

**The following road characteristics should be avoided.**

- settlements divided by a road (*illustration 76*);
- crossing habits of users not investigated before planning the road (*illustration 77*);
- increased difficulty for vulnerable road users to cross the road:
  - distance between crossings more than 200m,
  - crossings not on ground level,
  - using bridges or tunnels.



*Illustration 76: Settlement divided by a road: crossing habits of users are neglected. [18]*



*Illustration 77: Barriers are too low and can't prevent crossing. [18]*

The examination requires an integrated understanding of a road section and crossing behaviour of vulnerable road users. The road sections are examined to find out whether they are user friendly and offer sufficient crossing facilities or they neglect the needs of the inhabitants.

### 4.3. COUNTERMEASURES

If logical inconsistencies are detected in the design of the road and its surrounding, there are three corrective strategies available:

1. **Eliminate:** design logical road sections!
  - Ensure early visibility and clear comprehension of critical locations where road characteristics require a change of driving programme, including parking lot exits, entrances and other gateways. or
  - ↓
1. **Reduce:** correct illogical road sections!
  - Announce critical locations early enough by special road surfacing, changes of road's course (e.g. traffic island). Offer eye-catching objects that guide the attention to the critical situation. or
  - ↓
2. **Minimise:** place warnings in illogical road sections!
  - Forewarn drivers of the logical inconsistencies by traffic control devices and instructions.

#### Measures:

Avoid logical breaks in sections with the same function. Indicate change of function by change of alignment, cross section and roadside facilities.

#### Measures:

Use special road surfacing such as coloured areas, pavement changes and special markings to indicate critical locations.

#### Measures:

Install speed limits, ban overtaking, erect warning signs.

Additional good solutions and best practise examples can be found in the PIARC's Report "*Human Factors in Road Design. Review of Design Standards in nine Countries*" [38].

## 5. PRACTICAL SOLUTIONS WITH HUMAN FACTORS

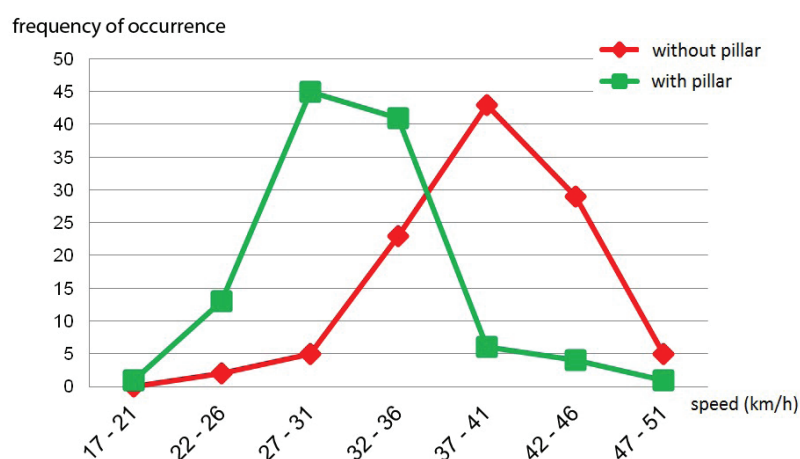
### 5.1. HUMAN FACTORS CORRECTION OF A DANGEROUS SCHOOL

In a little town in Brandenburg (Germany) an accident commission had a problem with high speed on a road section with a school. Although a speed limit was enacted, the speed of drivers was still high. The reason for that was the invisibility of the school and the entrance itself. Instead of announcing children that could surprisingly cross the road offered a large visible section that invited drivers for speeding up subconsciously.

It was decided to install an optical brake to signalise that children can enter the street on their school way. The children designed a “Stop” Pillar (*illustration 78*) and the speed was controlled before the installation and after. The results are shown in *illustration 79*.



*Illustration 78: Attention-guiding pillar designed by children to call for attention before a school entrance. [16]*



*Illustration 79: Effect of an attention-guiding pillar ahead of school entrance. [16]*

The level and statistical spread of speed before and after installing the attention-guiding pillar show a clear reduction of  $V_{85}$ . A reduction of about 3-9km/h in average from all directions was statistically significant (level of significance = 0.05). But the special effect was not only the

overall reduction of speed. While before the installation 98% of the sample violated the speed limit of 30km/h after the installation only 48% of the sample violated the speed limit.

In an evaluation two years after the effect was found to stable. The speed reduction is reliable and not only temporary.

## 5.2. HUMAN FACTORS CORRECTION OF A FATAL ACCIDENT CURVE BY AN OPTICAL

In a sharp curve with many fatal accidents, it was not possible to re-design the road course (*illustration 80*). So the accident commission decided to try an innovative optical countermeasure: instead of setting more (mostly invisible) chevron signs and speed limits they developed 200 cm high optical setting that works like an optical break and installed it in the outer curve (*illustration 81*).



*Illustration 80: Before: the course of the curve is discontinuous, drivers underestimate the radius. The speed is too high, about four fatal accidents/year. [15]*



*Illustration 81: After: the course of the curve has a clear guidance, the coloured setting guides the driver, sig-nalises the course and reduces speed. The alternative colours work like an optical break. [15]*

The level and statistical spread of speed before and after installing the optical setting show a very clear reduction of  $V_{85}$  from 61-65 km/h to 46-50 km/h – a reduction of 15 km/h at all (*illustration 82*). The results are statistically significant (level of significance = 0.05). The result is stable over 2 years (2011 and 2012).

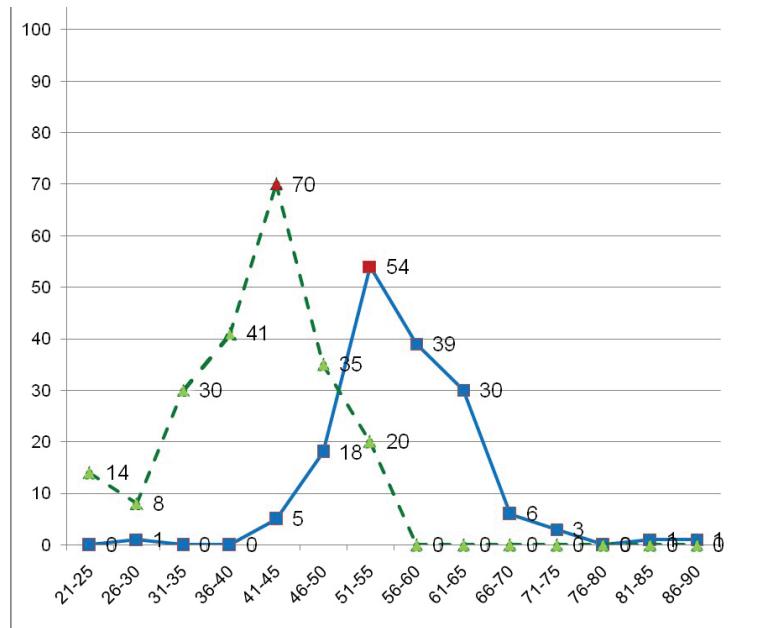


Illustration 82: Speed before and after installation of an optical setting with optical brake in an accident curve in Germany. [15]

### 5.3. HUMAN FACTORS PRINCIPLES FOR THE ANNOUNCEMENT OF A TOWN ENTRANCE

A town legally begins after the town sign. From this location on, a speed limit of 50 km/h general applies. Whoever exceeds the speed limit risks fines or worse. Nevertheless actual speeds are often much higher than the speed limit. Many of the town signs do not have the expected impact on driving programme because their Gestalt has not clear guiding quality and they are not visible in contrast to their background (illustration 83). This should prompt engineers to implement design measures or - as a minimum - corrective measures. However, many places do not have any kind of warning and instead rely upon infrequent enforcement to change driver reactions. Most drivers do not feel particularly guilty, but rather perceive themselves as victims.

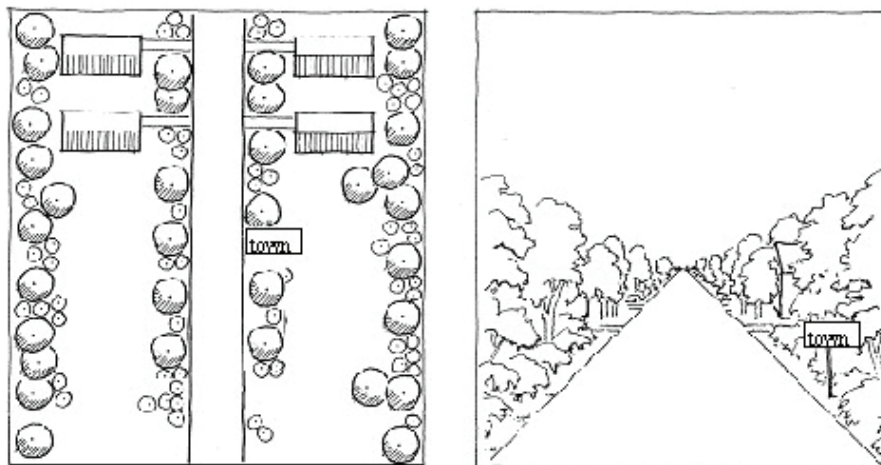
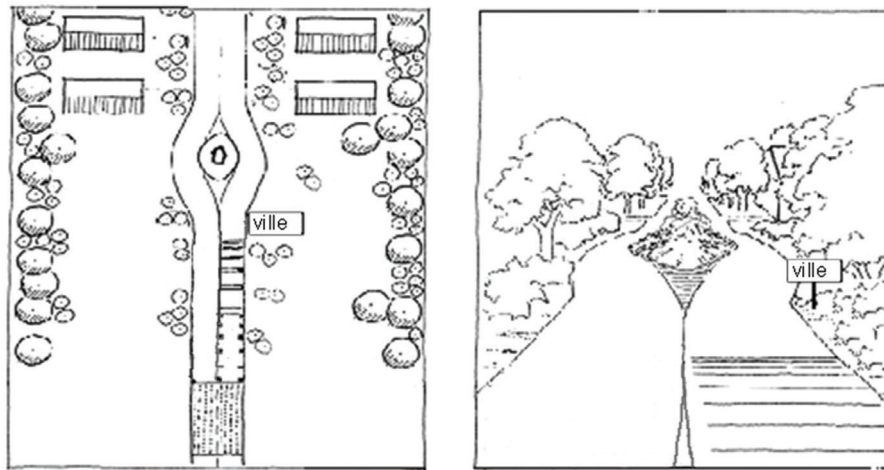


Illustration 83: Continuing road characteristics despite change of function [11]:  
 - Change of function / town entrance is not visible  
 - Town sign is not visible and change of function cannot be identified.

Planners who have been trained in Human Factors place great reliance on traffic islands as they create an optical break in the course of the road. Consequently the driver is instructed to change his driving programme. While this procedure is usually successful, it is not reliable in each and every case. Often the  $V_{85}$  rises again beyond the traffic island. This is because the island has only a temporary and not a lasting effect on drivers' programme.

Indeed, having both a traffic island and a town sign would be much more effective as they would complement and mutually strengthen each other. The effect can be further improved by giving the road beyond the town sign and traffic island a distinctively different look to what is in place up to that location (*illustration 84*). Kerbstones, sidewalks, footpaths, illumination, totally different plantings, build-ings along the street as well as a change in the roadway surface – this is what makes a town entrance perceptible (*illustration 85*). With these sorts of visual clues drivers “understand” that they are inside the town limits. They will be prepared for speed reduction to 50–60 km/h and do not rise again as easily.



*Illustration 84: Correction of the illogical road section [11]:*

- Traffic island with a minor shift in alignment conveys the change of function;
- Eye-catching objects guide the driver to the critical location;
- Change in function supported by special paving (brightness/bumpiness of coating, audible road-markings, and the like);
- Association of the town sign with the change of function is more readily identified by drivers.

To create an effective and secure town entrance, town signs must open onto the town ‘scenery’. This not only infers, announces or indicates the end of the rural speed limit, but convincingly supports the change of driving programme to reduce speed.



*Illustration 85: Town entrance combined with a middle island and marking to signalise the change of driving programme [38]*

## 6. CONCLUSIONS

### 6.1. LEARNING RATES OF ROAD ENGINEERS IN IDENTIFYING HUMAN FACTORS RELATED ACCIDENT-TRIGGERS IN ROAD DESIGN

It was observed from five Human Factors training courses held for road planners, designers and accident investigators that the Human Factors accident triggers of road design are completely new for road engineers.

The training course was developed and subsequently delivered over 21/2 days, consisting of:

- basic training,
- three half-day units, each with “*on-the-spot*” investigation, documentation, discussion, feedback, and
- final examination.

The key questions were

- which Human Factors accident triggers could participants identify before and after the Human Factors training;
- what conclusions could be drawn for the training.

The participants comprised 63 road engineers from Germany, Japan, India, China, Australia, France, Spain, Netherlands, Slovenia, Finland, Sweden and Portugal. A competition was held between the investigation teams to enhance the learning environment. An overview of the learning re-sults is provided in *Table 3*.

**TABLE 3: IDENTIFICATION OF HF ACCIDENT TRIGGERS OF ROAD’S GESTALT, BEFORE AND AFTER HUMAN FAC-TORS TRAINING**

	BEFORE	AFTER
6-Seconds Rule	36 %	66 %
Field of View Rule	12 %	28 %
Logic Rule	25 %	43 %

The table shows that with the training course a considerable increase in identifying Human Factors related triggers of wrong driving actions can be achieved. The three half-day units with “*on-the-spot*” investigation and feedback ensured a good level of practical learning.

It was easiest for traffic engineers to identify road design deficits associated with the 6-Second Rule. This result was predictable because the need for clear announcement of critical locations and the use of transitions is well known internationally. It is also often implemented in design standards.

The overview also shows that the training led to a doubling in the detection rate of accident triggers associated with the Field of View Rule. Engineers naturally do not have basic knowledge about the laws of space perception and Gestalt, information processing and activity regulation. So it was not surprising that the detection rate remained at a lower level.

Nevertheless, the participants stated they had learned to look at the road from a different perspective.

The improved detection rate of design deficits associated with the Logic Rule is acceptable because the essential deficits were identified.

It can be concluded that knowledge about user demands and Human Factors related design can be quickly and easily integrated into road safety improvement.

## 6.2. RESULTS OF HUMAN FACTORS EVALUATION

More than 1,400 accidents were analysed on the basis of Human Factors accident triggers in road design in Brandenburg, Germany, between 2001 and 2012. The accident triggers were condensed in a “*Human-Factors Evaluation-Tool*”. It is a complex diagnostic instrument for the prediction of the accident probability of road sections. It contains some 100 reliable items with a correlation of 0.61 to the real accident occurrence.

The Human-Factors Evaluation Tool contains about 100 validated Human Factors accident triggers that were derived from an extensive literature search focused on reliable experimental studies and about 1,400 road safety inspections at accidents spots in Brandenburg (Germany) that were technically unexplainable. During these road safety inspections, it was found that often the limitations to react and the specific natural laws of space and Gestalt-perception of road users were neglected. Specific mistakes in optical guidance and mismanagement of the field of view as well as serious mistakes in pre-programming driver’s habits, routines and expectations were found.

The Human Factors Evaluation-Tool has been validated in the European research project RANKERS (39). It allows a reliable prediction of the probability of accident spots and accident sections. This was tested in a double blind test-design within the RANKERS project. The blind test was started on two roads in Brandenburg, Germany. Two representative roads (“*L982-10*” and “*L98-30*”) were defined - one with few accidents and one with many accidents – based on BASTA, an expert system for registration of roads with high accident rates.

The aim was to identify accident spots and accident lines in on-the-spot investigations by using the Human Factors Evaluation-Tool. The results of the blind test confirmed the predicted accident probability and the actual number of accidents. Out of 28 road segments, 20 were predicted correctly; 8 were predicted to be dangerous, but did not have any accidents registered for them. No road segment with registered accidents was predicted to be “*safe*”. The correlation between HF-Score and registered accidents was 0.61 ( $\alpha$  0.01).

The statistical analysis shows that the more Human Factors accident triggers can be identified the higher is the number of registered accidents. Furthermore, the analysis shows that the Human Factors Evaluation-Tool is valid for the prediction of accident probability of road sections. It also allows a systematic check of Human Factors demands in Road Safety Audits (RSA) and Road Safety Inspections (RSI).

It is called now “*Human Factors Evaluation-Tool*© (2015)” (before: “*IST-Checklist*”).

Out of the 1,400 accidents, between 2001 and 2006, 27% were classified as having causes not able to be influenced by road design. They were caused by regional characteristics such as crossing deer (16%), weather, technical malfunction or road works (8%). Only 3% were caused by driver deficits such as alcohol, aggression, inattention or pharmaceuticals.

At least 68% of accidents were caused by Human Factors related accident triggers in road design and are therefore able to be influenced by a self-explaining, user-friendly road design.

**TABLE 4: HUMAN FACTORS RELATED ACCIDENT TRIGGERS OF 1,400 ACCIDENTS, BRANDENBURG (GERMANY)**

		Accidents	%
<b>I. Not Influenced by Road Design</b>		<b>383</b>	<b>27 %</b>
1.	Animals	219	16 %
2.	Weather, techniques, road works	117	8 %
3.	Driver deficit (alcohol, aggression, ...)	47	3 %
<b>II. Influenced by Road Design</b>		<b>953</b>	<b>68 %</b>
1.	6-Seconds Rule	451	32 %
2.	Field of View Rule	228	16 %
3.	Logic Rule	274	20 %
<b>III. Unexplained</b>		<b>64</b>	<b>5 %</b>
<b>Sum of accidents</b>		<b>1,400</b>	<b>100 %</b>

These results indicate that a sustainable integration of the Human Factors approach into road design and maintenance is necessary. They support the demand to consider the psychological and physiological limitations of driver’s perception, information processing, act regulation and decision-making into road design and accident analysis.

To reduce the probability of operational mistakes and ultimately the number of driving mistakes road design and standards has to be adapted to the needs and limitations of road users.

Accident investigators can draw on the Human Factors accident triggers referred to in this Guide-line to identify a new approach to accident causes. Road designers can use them to qualify their planning processes. The possibilities are various and promising.

### 6.3. COMPARISON OF NINE CURRENT NATIONAL DESIGN STANDARDS OF ROADS: TO WHICH DEGREE DO THEY INCLUDE HUMAN FACTORS DEMANDS?

In the work-cycle 2008-2011, PIARC *Technical Committee TCI.1 “Safer Road Infrastructure”* reviewed 9 national design standards to identify the degree to which the above described Human Factors items are addressed in 9 currently used design standards and guidelines for distributor roads. The results are summarised in *Table 5* and below.

TABLE 5: GENERAL VOTING TABLE OF HF-AUDIT OF 9 NATIONAL DESIGN STANDARDS OF DISTRIBUTOR ROADS [38]			
« Yes »: HF-demand is integrated - « P »: HF-demand is partly integrated - « No »: HF-demand is not integrated			
Human Factor demand	Yes (%)	P (%)	No (%)
I.1. Transition zone long enough for anticipation, response and manoeuvre distance	58%	20%	22%
I.2. Perception and visibility of intersections, curves and right-of-way is provided	39%	36%	25%
<b>∑ Safety Rule No.1: Give road users enough time!</b>	<b>49%</b>	<b>28%</b>	<b>23%</b>
II.1 Field of View with sufficient brightness and colour contrasts length visible approaching sections avoided	0%	50%	50%
II.2 Fixation objects and visual cues on lateral roadside give optical guidance and support optimal lane tracking	13%	18%	69%
II.3 Eye-catching objects support lane tracking and detection of critical locations, optical illusions are avoided	15%	26%	59%
<b>∑ Safety Rule No.2: Ensure appropriate speed + lane-tracking!</b>	<b>9%</b>	<b>32%</b>	<b>59%</b>
III.1 Change of function is signalled by a change in road’s optical characteristics	22%	22%	56%
III.2 Change of direction is visible despite dominant eye-catching orientation	0%	37%	63%
III.3 Changes in road characteristics that require re-learning of pre-programmed habits/expectations are signalled early and clearly	39%	28%	33%
III.4 Multiple critical locations and/or overload of information processing capacity is avoided	41%	26%	34%
III.5 Traffic control devices are legible and in accordance with driver’s expectation	69%	22%	09%
<b>∑ Safety Rule No.3: Pre-programme driver’s reactions correctly!</b>	<b>34%</b>	<b>27%</b>	<b>39%</b>
<b>∑ ∑ Fulfilled Human Factors demands in 9 current standards</b>	<b>31%</b>	<b>29%</b>	<b>40%</b>

**I. The need for the driver to anticipate any critical location in the driving environment** eand adequately respond to that is well described in the most standards of developed countries. Of the Human Factors demands, 49% were met, 28% were partly met and 23% were not met.

**II. Management of the field of view to ensure appropriate speed and lane tracking** is poorly addressed in the design standards. Of the Human Factors demands, 9% were met, 32% were partly met and 59% were not met. The subject of spatial perception – the Gestalt principles underlying the Human Factors demands - seem to be a blind spot in the field of road design:

- The value of parallel planting and guiding structures for lane-keeping and to avoid optical illusions is fully described in only one design standard, partly described in two and not described in seven.
- The need for contrasts in the visual periphery to avoid monotony and manage the speed perception of drivers is not addressed in the standards (50%) or only addressed in a rudimentary way (50%).
- The possibility of using eye-catching objects to support lane-tracking and the detection of critical locations is not addressed in the standards (69%) or only partly addressed (18%). Only 13% of the standards mention the need to avoid misguiding and misperception. But even then, there is no clear specification for engineers about how to do that.

**III. The Human Factors demands to pre-programme driver's expectations and reactions** are addressed in guidelines differently. Of the Human Factors demands, 34% were met, 27% were partly met and 39% were not met.

In most guidelines, driver's expectations are not well covered. Changes of function or direction despite dominant optical characteristics of the road are not mentioned (56%), or only in a rudimentary way (22%). There is broad agreement in saying "*Never surprise the driver*". However, it seems to be difficult to include this along with practical requirements in standards, because the underlying principles of space and Gestalt perception as well as the subconscious regulation of driving actions, reasoning and learning are not well known.

From the above we may conclude that management of the field of view in particular, as well as the pre-programming driver's reactions and expectations, are not well incorporated in design standards and in RSIs and RSAs. This may hinder the application of such knowledge by road engineer.

The following recommendations are made to help spreading the knowledge and improving road safety:

- Train future road engineers and auditors in subjects like spatial and Gestalt perception, management of the field of view and pre-programming of driver's actions.
- Train them also in the basics of self-explaining road design, design-for-all and the basic principles of a hierarchical system of road categories.
- Use best practices from other countries' design standards/guidelines to supplement one's own guidelines with Human Factors demands.
- Develop proposals for missing links. The design guidelines need systematic improvement concerning the Human Factors principles of spatial perception, the management of the field of view to ensure appropriate speed and lane tracking as well as the principles how to pre-programme driver's reactions and expectations correctly.

It is now up to the responsible governmental parties, road safety experts and road engineer to use these results to avoid preventable accidents, save human lives and ensure that state-of-the-art science and technology will be used in the field of road design and accident prevention.

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