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Transportation Research Procedia 14 (2016) 4364 – 4373

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th Transport Research Arena April 18-21, 2016

Influence of human behaviour on geometric road design

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Abstract

Regarding the annual accident statistics, it becomes evident that the amount of deadly accidents decreased steadily throughout the last decades, whereas the amount of accidents itself remained fairly constant. Therefore one can draw the conclusion that the improvement of passive safety systems is the crucial, impact-inhibiting factor. Hence the next step should take us to the contemplation on how we can eliminate the occurrence of accidents. Taking the psychology into account may be one possible approach on this subject.

The content of the thesis, which is the foundation of this abstract, is a capacious, international literature research. More than 450 sources have been analysed, containing the scientific fields of road design, behavioural psychology, gestalt psychology, ergonomics and the evolution of the technical codes.

First and foremost, it is necessary to understand the concept of decision-making during a driving-task. The idea of a conscious and rational decision-making while driving is merely wishful thinking and has nothing to do with the actual processes. When we take the performance-model of Rasmussen into consideration, then we have to admit that the actual human performance is taking place in the skill-based area (Rasmussen, 1983), i.e. human operators do not think deliberately about every single action by considering every single possible input, but rather scan unconsciously their environment for hidden signals, which are supporting a certain type of action – human operators are always prone to errors (Kahneman would call this conceptual pair “heuristics and biases”). As a consequence, the road space should be designed according to the expectation the driver has about the forthcoming characteristics. In order to describe gestalt-psychological weaknesses of spatial road alignments, the driver’s perspectival view was analysed and divided into several key points and key directions, whose arrangement allow conclusions on how the imperfections emerge and how they influence the driver’s evaluation of the road space ahead.

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Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.358

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Keywords: road design; human factors; Gestalt psychology; road safety; heursitics

1. Introduction

The process of driving is a constant process of interaction. The human within the vehicle takes in sensory perceptions and processes them. Besides the visual perceptions of the surrounding road space (road, planting, traffic, buildings, interior), the driver is also exposed to other perceptions (auditory, vestibular, sensory, olfactory, gustatory), whereby the visual perception dominates over the other perceptional input. The amount of incoming information is enormous. The amount is approximately 10^{11} bit/s, but only 16 bit/s reach the awareness (Durth, 1974). This flow of data is being visualised in the following figure:

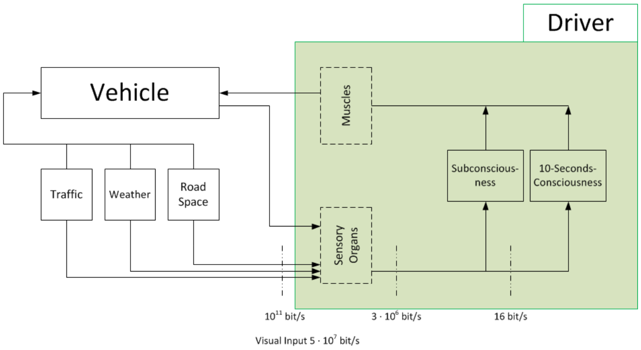

Fig. 1. Flow of information and its volume (Durth, 1974).

Considering the enormous amount of incoming information, the question arises, whether and in how human beings are capable of completing complex and prolonged actions, e.g. driving, without making errors. In order to answer this question, a citation of Dawkins (2006) can be considered:

“When a man throws a ball high in the air and catches it again, he behaves as if he had solved a set of differential equations in predicting the trajectory of the ball. He may neither know nor care what a differential equation is, but this does not affect his skill with the ball. At some subconscious level, something functionally equivalent to the mathematical calculations is going on. Similarly, when a man takes a difficult decision, after weighing up all the pros and cons, and all the consequences of the decision that he can imagine, he is doing the functional equivalent of a large ‘weighted sum’ calculation, such as a computer might perform.” (Dawkins, 2006)

Thus, the human being is subconsciously able to identify and solve many problems. Therefore, there is no need for the entire amount of the incoming information. The human brain differentiates between necessary and unnecessary information and initiates the correct measures.

Concerning the geometric design of roads it has to be stated that the multi-dimensionality of the external influences is characterising the driver behaviour. The main purpose of this paper is therefore to characterise the process of human behaviour – in general and within the context of the driving situation. After this brief characterisation, the essentials are being transferred into the field of geometric design by postulating some general principles that should be followed, in order to enable a “psychological geometric design of roads”. These general principles are then specified by giving hints to an assessment-technique of the spatial alignment of roads.

2. Human behaviour

2.1. Traffic as an exceptional, behavioural situation

The road itself can be understood as a path of transportation, but also as a communication channel. Human actions are being performed within this channel or path, therefore there are consequences for human beings – it can be seen as a social space of human interaction. But the kind of communication differs markedly from other social spaces, as every single communication partner is located in an isolated vehicle and cannot communicate directly with other participants. Furthermore there is a communication channel between the road space and the driver. The road space has to transmit its properties, so that the driver can choose the correct style of driving. If this is not the case, a latent danger of an accident can emerge that remains unknown for the driver. For this reason a thorough analysis of this communication channel is crucial, in order to improve the unambiguousness of the information transmitted by the road space and, simultaneously, the road safety.

2.2. Model-assisted description of human behaviour

In order to describe human decision-making, one has to be clear about the process behind it. In economics, one could take a decision-theoretical approach into account, in order to describe situations, criteria and alternatives. But during driving situations, the infinite amount of criteria and alternatives makes it impossible for the driver to survey them and to make a decision. The process of decision-making is not based upon a thorough consideration but can be described as a gut decision or, more scientific, heuristics. These rules can be interpreted as categorical imperatives and could be formulated as follows:

- Act in such a way that you reach your destination quickly.
- Act in such a way that you diminish risks.
- Act in such a way that you maximise your driving pleasure.

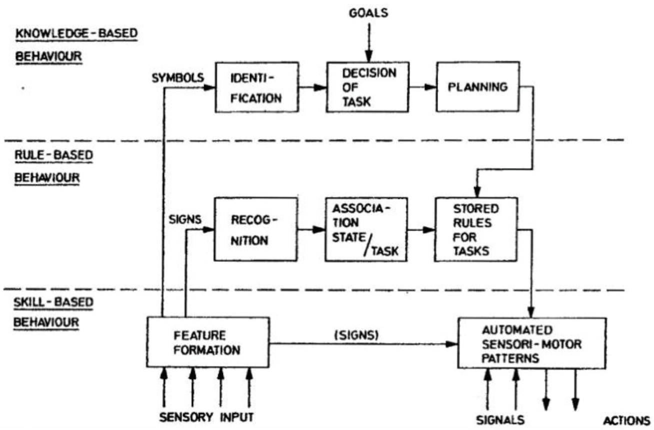

Fig. 2. Three-layer-model of performance of human operators (Rasmussen, 1983).

This enumeration is endless, but the point of it is that during driving there is no decision tree and thorough consideration, on which the driver bases his decision. These imperatives are maxims that can be seen as guidelines or headings of each decision the driver makes while driving. Therefore the driver is also prone to biases, i.e. the amount of information is limited in such a way, that important information could remain hidden or misinterpreted – errors are the result. This is the reason why information that is important for the driver, has to be highlighted. Additionally information must not be ambiguous or misleading.

The process of driving can, for the most part, be understood as an automated process (Groeger, 2000). The vehicle is being controlled subconsciously and "reflectively" (Schmitz, 1958). Reflectively in this context means, that the measures taken by the driver are only caused by sensory impressions and are restricted to the process of driving and do not imply other measures or actions.

Behaviour itself can be simplified to a three-layer-model, with regard to human consciousness. Rasmussen (1983) elaborated this three-layer-model, by dividing the process of behaviour according to its amount demand for consciousness in order to make a decision (see Fig. 2).

Hale, Quist & Stoop (1988) describe this model as follows: The highest layer (knowledge-based behaviour) demands the highest amount of consciousness in order to make a decision, because the task given is new and/or highly complicated, so that the human operator is not capable of accomplishing it in an automated mode. The second layer (rule-based behaviour) demands slightly less consciousness as the task given has been solved in the past, but not often enough, so that the human operator needs to find a solution in order to accomplish the task. Consciousness is therefore not directly needed to solve the problem itself, but to categorise the problem and find tasks that have been solved in the past that could help solving the new one. The third layer (skill-based behaviour) can be described as an endless if-then-loop. Tasks and actions are being accomplished using memorised workflows and take place subconsciously. Driving therefore can be characterised as a skill-based behaviour, as the driving task is merely a routine-task and demands only in emergency situations human consciousness.

Charlton & Starkey (2013) examined the impact of driving on familiar roads on the quality of driving. They prepared a simulator-course, in which the test subjects drove on the same track for a couple of times. After a certain amount of passages, the track was changed in a slight manner (buildings were removed, landscape was modified, warning signs were removed or added. The results were as follows:

- after a couple of passages, the test subjects reported that they find themselves in an automated condition
- speed-variance decreased
- average speed increased
- modifications of the road space have not been noticed

Due to the multiple passes of the test-track, the test subjects underwent an automatisation of their behaviour. Their decisions were made on the skill-based level, in which their consciousness was absent. This experiment can be seen as a first indicator, how human driver react to repetitions and how the proceduralisation of the driving task influences its quality.

3. Psychological implications on geometric road design

3.1. Contradictory nature of geometric road design

"Whereas the leading-principle of geometric road design has the aim of promoting appropriate driving behaviour, the inhibition-principle has the aim of diminishing inappropriate driving behaviour." (Klebelsberg, 1982)

The main task of geometric road design is therefore to consider these two contradictory principles, as there is no uniform driving behaviour. In addition to control equipment, traffic signs and marking, it is the geometric road design that has to comprise this tension field.

The leading-principle can be equated with the optical guidance and is primarily ensured by marking, traffic signs and other vertical elements (Bitzl, 1963; Bringiotti, 1967). But the geometric road design is also crucial, as only the road itself can "tell" the driver, what kind of difficulties he could or should expect. Road equipment should remain the ultima ratio, when the alignment is of contradictory nature.

The antipode of the leading-principle, the inhibition-principle, is also achieved partly with the help of road equipment. But the geometric road design is also capable of establishing an inhibiting effect on the driver, e.g. by creating "walls", as humans have a natural inhibition that keep them from running against walls. In road design these walls can be created for example by twisting the road around the inside edge of the road or by combining hollows and curves. Such a combination leads to a higher inner perspective angle and experiments have shown that curves with a higher inner perspective angle have a lower accident ration than curves with rather small inner perspective angles.

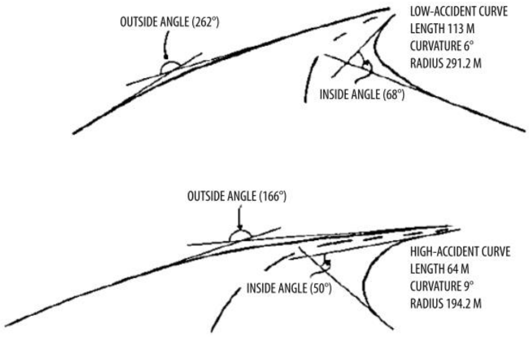

Fig. 3. (a) Curve with a high inner perspective angle; (b) Curve with a low inner perspective angle (Shinar, Rockwell, & Malecki, 1980).

3.2. Accidents – mistakes do not lead automatically to an accident

Every accident has its cause in an error, but not every error leads automatically to an accident. This rule makes accident analyses very difficult, as only a small percentage of driving errors manifest themselves in accidents and become evident. In order to understand the origin of errors, Bringiotti (1967) reduced this problem into a simple inequation between input entropy (driver's receptiveness) and output entropy (available amount of information) (see Fig. 4. (a)).

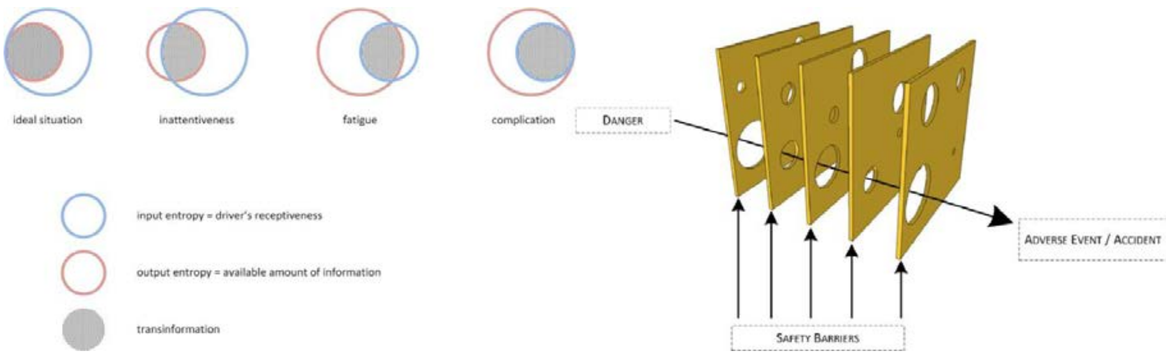

Fig. 4. (a) Inequation between receptiveness and available amount of information as a Venn diagram (Bringiotti, 1967); (b) Swiss-cheese-model of safety barriers.

But it is also clear that there is not only a human barrier that prevents accidents. There are also technical barriers that absorb the effects of an error. Reason (1992) depicts this system of barriers as a Swiss-cheese-model, i.e. there are several safety layers, which have holes in them (see Fig. 4. (b)). But only if the given error passes a hole in every single one of those safety layers, an adverse event can take place – in the case of an error on the road, this would mean an accident. Additionally, there is also the absorbing effect of coincidence. The same exact sequence of actions and errors taken, can lead to differing results concerning the fatality of the result – accident or not. So we have a system that is very forgiving (Vollrath & Krems, 2011).

But still, errors occur and consequently accidents. But why? This question is very hard to answer, as there is no black-box inside of cars. Accordingly, nobody knows exactly what happens before the accidents and what is the salient factor that triggers the accident. Treat et al. (1979) tried to examine the main causes for accidents. In this report it becomes evident that major human induced accidents are caused by wrong interpretations of the road space ahead (recognition errors). This leads to the conclusion that, due to wrong expectations on the road space ahead, the examined drivers were not able to evaluate their situation correctly and therefore made mistakes, which led to an accident. This finding is being confirmed in numerous other researches, e.g. concluded Rumar (1990) that the main cause of accidents is the tardy or wrong recognition of situations (see Fig. 5).

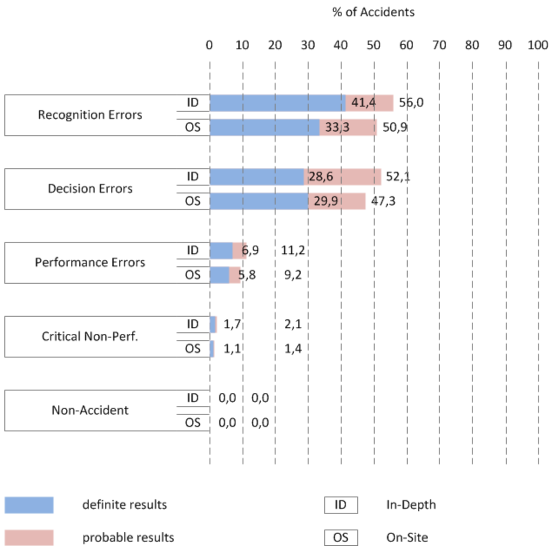

Fig. 5. Major human causes of accidents (Treat, et al., 1979).

3.3. Expectations while driving

As already pointed out, expectations on the road space ahead should be in congruency with the actual design. Several experiments have shown that a correct expectation of events leads to an appropriate action:

Näätänen & Summala (1976) have shown in their experiment that the human reaction time increases, when an event seems improbable to the experimentees (see Fig. 6. (a)). Nagayama (1978) has shown that the quality of the action taken as a reaction to an event decreases, when the experimentees have the wrong set of information as the basis of their decision (see Fig. 6. (b)). Therefore one can conclude that the information presented to the driver is highly important for the quality of driving. If information remains hidden or is presented in an ambiguous manner, reaction times will increase and the measures taken are probably going to be the wrong ones.

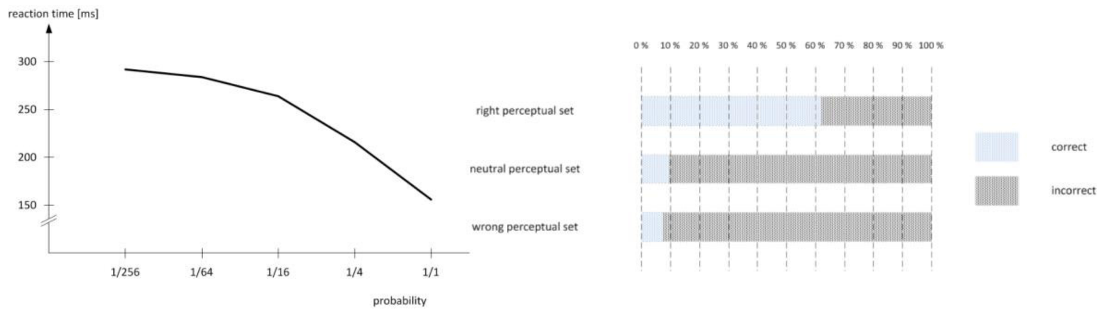

Fig. 6. (a) Impact of the probability of an event on human reaction time (Näätänen & Summala, 1976); (b) Role of perceptual set on the quality of human action (Nagayama, 1978).

Alexander & Lunenfeld (1986) defined two kinds of expectation that determine the driving process: a priori expectancies and ad hoc expectancies. A priori expectancies are being formed throughout a long period of time, they are omnipresent and therefore they can be compared with routine. Ad hoc expectancies establish themselves throughout a rather short period of time and are very soon forgotten. Examples for these kinds of expectancies are e.g. the curvature of the road or, formulated in a general manner, the characteristics of the road alignment. This is the reason, why we shall focus on these kinds of expectations, as the a priori expectations are more part of learning processes and cannot be manipulated by the geometric design of roads.

Ad hoc expectancies are nothing more than heuristics. Based on experiences from the past, we try to anticipate properties of the road in the future. Some of these heuristics have found their way into the design guidelines, e.g. the relationship between the radii of two consecutive curves. But the implemented restrictions, based on heuristics are not enough to respect human behavior and decision-making. This is how gestalt-psychological approaches come into play.

3.4. Gestalt-psychological approach

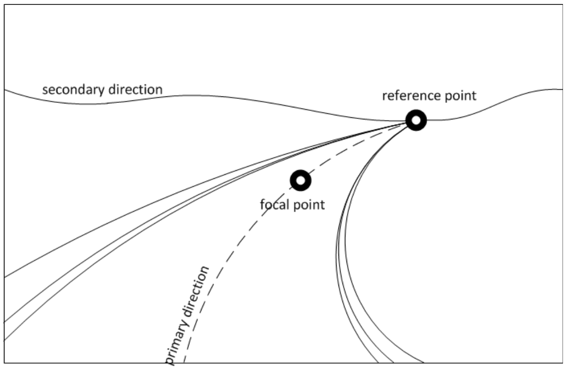

Fig. 7. Road space defined as a gestalt-psychological space (Durth, 1972).

As a consequence, the whole environment, including the geometric design of the road itself, should be designed according to the expectation the driver has about the forthcoming characteristics – there has to be a congruency between expectations and reality in order to guarantee a flawless driving-process.

Durth (1972) has picked up an unconventional approach, by drawing connections with the field of gestalt psychology (Durth, 1972). He created two crucial points in the road space, which are most important for the driver, in order to interpret the forthcoming road space and based upon that, choose his preferred type of action:

- reference point (Leitpunkt)
- focal point (Blickpunkt)
- primary direction
- secondary direction

These two points and two directions are corresponding to the gestalt-psychological idea of Metzger, who introduced the idea of these two points (Metzger, 1968; Čičković, 2014) and directions. The primary direction is the direction, in which the driver travels. The secondary direction is orthogonal to the primary direction and is the boundary of the forthcoming road space (horizon). The reference point is the furthermost point of information for the driver and therefore the primary source of information, whereras the focal point functions as the fixation point and is depending on the driving speed. During the driving task, the driver switches from one point to another to be certain about his present location and future actions. In order to ensure a, from gestalt-psychological point of view, safe geometric design, there can be postulated these following principles:

- only one reference and focal point
- reference and focal point should both be in the visual field of the driver in order to minimise saccadic eye--movements
- steady course of the primary direction
- certain distance between focal and reference point – they must not concur

With the help of these rules, several imperfections of spatial road alignment can be explained. The German guidelines have a compilation of several imperfections, two of those shall be discussed and analysed in a gestalt--psychological way.

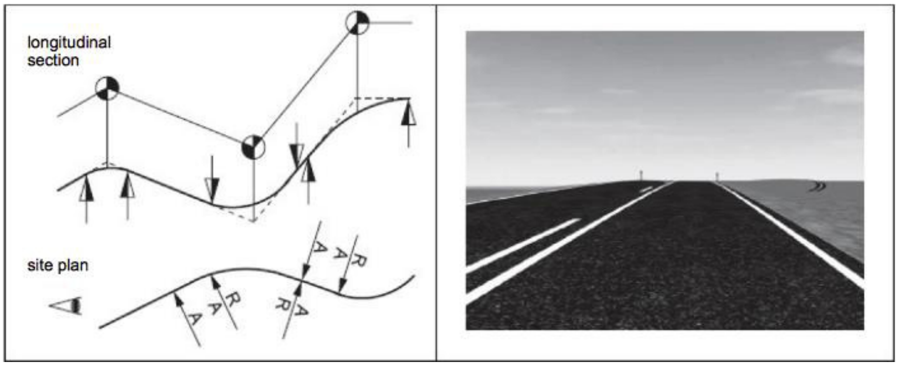

Fig. 8. (a) Site plan and longitudinal section of the imperfection "bouncing" (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012); (b) Perspective view (driver's point of view) of the imperfection "bouncing" (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2012).

Table 1. Description and gestalt-psychological interpretation of the alignment imperfection "bouncing".

description	gestalt-psychological interpretation
• crest radius too low, therefore a vast area of obstructed vision • perception of change in direction obstructed • more fatal if there is a part beyond the area of obstructed vision that is visible for the driver, as it evokes the feeling of control over the road space ahead	• proximity or concurrence of focal point and reference point, if the road space ahead is majorly within the area of obstructed vision • if there is a visible area after the area of obstructed vision, then there are two reference points and there is a discontinuity of the primary direction

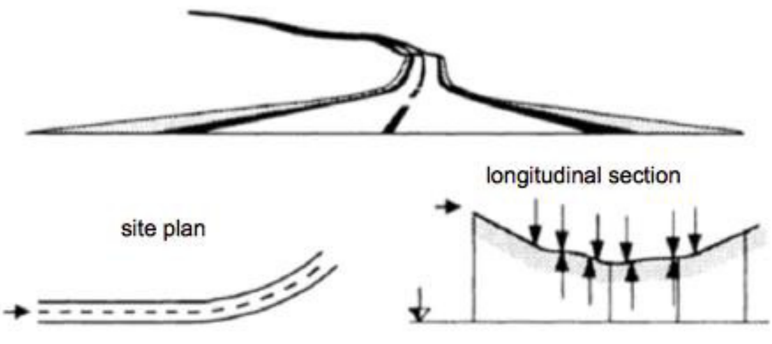

Fig. 9. (a) Perspective view (driver's point of view) of the imperfection "fluttering" (Forschungsgesellschaft für Straßen- und Verkehrswesen, 1995) (b) Site plan and longitudinal section of the imperfection "fluttering" (Forschungsgesellschaft für Straßen- und Verkehrswesen, 1995).

Table 2. Description and gestalt-psychological interpretation of the alignment imperfection "fluttering".

description	gestalt-psychological interpretation
• immoderate changes of direction within the longitudinal section, curvature within the site plan remains nearly constant • road alignment seems restless • evitable by connecting curvature-elements of the site plan with curvature-elements of the longitudinal section	• discontinuity of the primary direction due to many changes in curvature • multiple reference points – driver does not know, which reference point is the most important one, as every single one of them holds important information about the further characteristic • plurality of crucial points leads to a large occupied area of interest and exceeds the visual field of the driver

4. Conclusion

The thesis described in this paper dealt with the impact of human behavior on driving and how this impact could be implemented in design guidelines, regarding the several imperfections of spatial road alignment and their influence on the decision-making process (Čičković, 2014). The main problem connected with this aim is that a quantification of design parameters according to human traits is impossible and pointless, as human behavior varies very much. The approach chosen concentrates on gestalt psychological ideas, because gestalt psychology has a large overlap with heuristics, which are the main basis of human decision-making. Also the point of dividing pictures into relevant points and directions seems plausible, as this is a subconscious process driver undergo while assessing the road space ahead.

The examples that were discussed at the end of this paper have shown clearly that imperfections of spatial road alignment can be analysed by utilising gestalt-psychological tools. The flaws of the two imperfection types are closely connected to the technical explanations of their imperfection, so that it can be assumed that this approach can prove its validity in other cases, too. The Master's thesis contains more examples of imperfections and their associated gestalt psychological analysis. Therefore further research seems advisable, not only in order to assess the spatial road alignment of new roads, but also to investigate the impact of the road on the process of an accident.

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