AN INTEGRATIVE MODEL FOR THE PREDICTION OF OVERSPEEDING

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ABSTRACT: Over-speeding is a great problem for traffic safety. Therefore, it is surprising, that well evaluated theoretical models of speed choice are quite rare in transportation research. The current paper critically examines established models and discusses open questions within the traffic safety domain. Also a new and promising approach is explained and evaluated using empirical data and mathematical modelling.

1 INTRODUCTION

Why do people over speed? Statistics say, that regulations regarding the speed limit are the most important, but mostly overridden rules in traffic (Goodwin et al., 2006). Stepping over the speed limit is still the most important reason for traffic accidents (Tay et al., 2003; Machin & Sankey, 2008). For example, more than 3500 deaths were directly due to over-speeding in Germany, in 2008 (statistisches Bundesamt).

In research literature a long history of effects influencing the probability of over-speeding has been established. Remarkably, as many effects have been found in empirical studies, as hterogeneous these effects are. For example, Atawa et al. (2006) and Van Schagen & Van Nes (2007a) found environmental factors like the development of the roadside or lane with as affecting the chosen speed. But also credibility (Van Schagen & Van Nes, 2007b; Van Nes et al., 2008), personality traits (Goldenbeld & Van Schagen, 2007; Tay et al., 2003), personal and normative rules (DePelsmacker & Janssens, 2007), emotions (Levelt & Swov, 1998) and even culture (Ötzkan et al., 2005) has been shown to have an influence on speeding behaviour. At this point, the need for a theory, which incorporates and therefore explains at least the majority of these effects, becomes apparent (Ranney, 1994). In addition, there are few effective countermeasures for over-speeding existing. Commonly, legislature uses safety-advertising campaigns to influence public attitudes, subjective norms, and perceived behavioural control regarding speeding Stead et al. (2005). An example for the little effect of these undertakings is the five year "Foolspeed" campaign in Scotland, which started in 1999 (z.B. Machin & Sankey, 2008). Using different types of media (e.g. TV, newsletter, advertisement) "[…] neither subjective norms nor perceived behavioural control altered, although changes occurred on attitude towards speeding and affective beliefs, particularly among those who speed frequently." (Machin & Sankey, 2008; p. 546). In contrast to advertising campaigns, the regulatory effect of the police penalization system seems to be quite large. Heydecker (2006) reports many studies showing that the installation of radar altimeters results into a lower accident rate at these places. However, this effect might be locally restricted to the area of the radar altimeter where these studies were conducted. For example, Stern et al. (2006)

shows, that this effect does not generalize onto the general driving behaviour for a longer period than three to four months. Explanations for the smalllong-term effect of these regulatory approaches are mostly found on the personal side of the driver. Tay et al. (2003) point out, that drivers with maladaptive personality traits (like the type A personality) do simply not respond to the content of current advertising campaigns or penalties. Kanellaidis et al. (1995) put up a possible self-serving bias as reason why drivers do not adapt their behaviour according to the proposals of the campaign or the police penalty. Following their line of argumentation, drivers do not consider themselves but others to be addressed by the topic. However, a theoretical framework is needed to address these questions and to formulate effective countermeasures (Ranney, 1994). This paper firstly gives a short introduction to the most common theoretical and empirical approaches for the over-speeding phenomenon. Further, one of these theoretical approaches, the Task Capability Interface model (Fuller, 2005) was chosen, as the basis for the integration of other theoretical models. Subsequently, hypothesis with respect to over-speeding where derived from the conjoined theoretical model and tested with empirical data. Finally, the first version of a mathematical model and first modelling results are presented, allowing precise predictions about the time and the amount of over-speeding due to personal, situational and environmental factors.

2 THEORETICAL PART

Despite the multi-facet appearance of the over-speeding phenomenon, few theoretical approaches have been developed, which treat speeding in a multi-facet view. Common approaches can be classified in at least two categories: cognitive and integrative approaches. Representative models for the cognitive domain are cost-benefit analysis (Tay et al., 2003), the theory of risk homeostasis (Wilde, 1994) and the Theory Of Planned Behaviour (TOPB, Ajzen & Madden, 1986) and its modifications (DePelsmacker & Janssens, 2007; Stern et al., 2006). Within this domain, the theory of planned behaviour is the most prominent (and mostly used) theoretical conceptualization. Therefore, this approach is highlighted. Using the TOPB major advantages become apparent. First, it is a well-validated and widely accepted theoretical framework, which can be assessed by questionnaire measures. Within these advantages disadvantages become visible as well. Gabany (1997) for example states, that most questionnaires are not tested on their psychometric properties. Therefore the TOPB constructs cannot be measured reliably and valid. Further more, the predictive power of studies using TOPB is very limited, partly because of low association coefficients. Several studies examined self-reported driving behaviour in rural areas. Most found coefficients of association for the intention to speed between -0.18 – 0.64 (Parker et al., 1992; DePelsmacker & Janssens, 2007; Elliot et al., 2003; Stern et al., 2006). Only few investigations delivered coefficients for the prediction of self-reported behaviour: 0.47 – 0.50 DePelsmacker and Janssens (2007) or -0.2 – 0.46 Elliot et al. (2003). Additionally, low predictive power of the TOPB emerges from the type of behavioural data, which is used as target behaviour. Most often the behavioural data is self-reported (Parker et al., 1992; DePelsmacker & Janssens, 2007; Elliot et al., 2003; Stern et al., 2006) and therefore prone to bias (Sedlmeier &

Renkewitz, 2008). Finally, TOPB only captures one, the conscious, aspect of driving. According to different researchers (e.g. Michon, 1985; Summala,1985; Wille, in press) with successive practice "[…] driving becomes a habitual activity, which is based on largely automized control of safety margins […] "(Hale et al., 1990; p.633). These authors describe the driving task as conglomerate of conscious cognition and (procedural) action, which are differently emphasized on the three (knowledge-, rule- and skill-based) levels of driving (see also Rasmussen, 1987). Building upon these assumptions, integrative theoretical approaches have been formulated, which incorporate conscious cognition as well as skill-based behaviour. Within these theoretical concepts, the least amount of cognition is implemented in tracking-loop models (e.g. Wickens & Hollands, 2000). There, a driver only monitors the current speed and regulates it with respect to an ideal value. More detailed assumptions about the interplay of non-/ cognitive driver behaviour are integrated in stages of driving models (e.g. Adler et al., 1993; Michon, 1985). Within these models, conscious planning of the route or time of travel is performed at the knowledge-based level. The actual navigational performance, like changing lanes, takes place in the rule-based level of driving involving a minimum amount of conscious effort to check the situational circumstances and match the best fitting behavioural procedure. Almost no amount of conscious effort is needed at the skill-based level. Here, largely automated behavioural patterns, like changing gears, are executed (Michon, 1985; Hale et al., 1990). Maybe the highest integration of personal and environmental factors (including cognitive processes, personality traits, etc.) is provided by the Task Capability Interface Model (TCI; Fuller, 2005). It incorporates most of the models mentioned above and relates personal characteristics like constitutional features (i.e. tiredness), attitudes and norms, declarative and procedural knowledge or simply (driving-) experience to the actual influences of the environment such as road characteristics (i.e. wide or narrow lanes) visibility, road signs and others (see also Fuller, 2005). The core component of his model is the continuous comparison of capability (C; e.g. personal factors) and task demand (TD; environmental factors). At each sampling point in time, the result of the comparison can be either positive with C being larger than TD, neutral with C resembling TD or negative with C being smaller than TD. In case of a positive difference, the driver maintains stable and safe control over the vehicle. C paralleling TD constitutes the turning point where the driver starts loosing control over the vehicle. "At the threshold, where task demand begins to exceed capability, we need not necessarily expect a sudden and catastrophic breakdown of control but rather a more fragmented degradation." Fuller (2005, p.463). Since Fuller (2005) distinguishes between perceived (recognized by the driver) and objective capability and task demand, the core assumption described above substantially parallels the perceived behaviour control component of the TOPB (Ajzen & Madden, 1986). As demonstrated in various studies (Elliot et al., 2003; Stern et a., 2006; Kannellaidis et al., 1995; DePelsmacker & Janssens, 2007; Parker et al., 1992), perceived behaviour control was the best predictor of the intention towards behaviour and the behaviour itself. Fuller (2005) proposes this concept as most important element determining the speed chosen on a particular road. Additionally, the TCI model relates the result of the internal comparison of perceived capability (C) and task demand (TD) to measurable behaviour. Following Fullers line of argumentation, the amount of adjustment of the acceleration depends on the difference of C and TD. In line with the Yerkes – Dotson law (Wickens & Hollands, 2000), the difference between C and TD is related to the driving performance with an inverted U – shaped function. This implies that perceived performance is best, when C is reasonably larger than TD. In the TCI terminology, the current difference of C – TD lies within an optimal interval, which is put up in advance through route planning at the knowledge based level and can be adjusted while driving due to changes in driving tactics at the procedural level. In contrast, if the difference of C – TD is either very large (because of high capability or low task demand) or very low or negative (because of very low capability or high task demand) driving performance is low. The perceived driving performance itself nicely translates into acceleration behaviour. Figure 1 displays these presumptions.

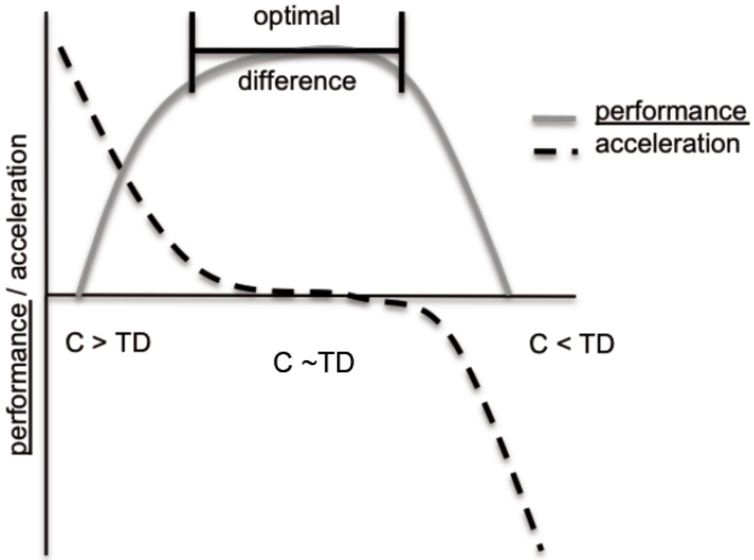

Fig.1. assumptions regarding the comparison of capability (C) & task demand (TD) and its implications to perceived performance and acceleration behaviour

The third advantage of the TCI model becomes actually visible (see Fig.1) when translating the intra-personal comparison of C and TD and the corresponding acceleration behaviour into graphical representations. Both variables follow functions, which enable researchers to draw precise predictions based on the assessment of personal variables and environmental factors. The perceived performance can be computed using equation (1):

$$f(x) = ax^2 + bx + c \tag{1}$$

where f(x) is the perceived performance, x the difference of C & TD and a, b and c the parameters, which set up the location of the function within the coordinate system. In addition to the perceived performance, the acceleration behaviour can be computed using the equation (2):

$$f(x) = \left(-\frac{1}{3}\right)x^3 \tag{2}$$

In equation (2), f(x) is the amount of acceleration, (-1/3) sets up the form of the function and x is again the difference of C and TD. Utilizing these presumptions, two exemplary implications for empirical research can be derived. First, subjects chose their speed depending on their capability and the current task demand. This implies, that subjects' chosen speed differs from the speed limit but not from the desired, safe or credible speed. Second, participants should accelerate less, when facing a more complex driving situation. Thus, the differences between the speed limit and the desired, safe or credible speeds should be largest for the highway environment, smaller for interurban road and smallest for urban roads.

3 EMPIRICAL PART

A very first inspection of the previously named assumptions was performed, using a reanalysis of a previously collected survey data.

3.1 Participants

A total N = 218 subjects with a mean age of M = 23.4 (SD = 3.1) took part in the survey. A majority of the sample was male (76%). In average, participants had about 5 years of driving experience (SD = 3.5), about half of the sample (61%) drove less than 100 km. All subjects participated voluntarily and did not receive any incentives for their participation.

3.2 Method

For the data collection, a German version of the driver questionnaire of Fildes et al. (1991) was used. The task for the subjects was to recall the last time they could remember traffic surveillance, independently from their behaviour (over-speeding yes or not) at that moment. After recalling a situation, participants were asked to complete the questionnaire without time pressure.

3.3 Results

For the analysis of the survey data, ANOVAs and paired t-tests with Bonferroni adjustment were computed. With respect to hypothesis one, subjects report a significant difference between the speed limit compared to their estimation of safe speed, $t(212) = -17.87$, $p < 0.001$, credible speed $t(212) = -15.87$, $p < 0.001$ and desired speed, $t(212) = -18.70$, $p < 0.001$. In contrast, no significant differences between the driven and the safe speed ($t(212) = -1.87$, $p = 0.66$) as well as the driven and the credible speed ($t(212) = -0.43$, $p = 0.86$) were obtined. Only the desired was significantly higher than the driven speed, $t(212) = - 9.04$, $p < 0.001$. Figure 2 exemplary shows the probability – density functions of the speed limit, the driven and desired speeds, reflecting the estimation of the population distributions.

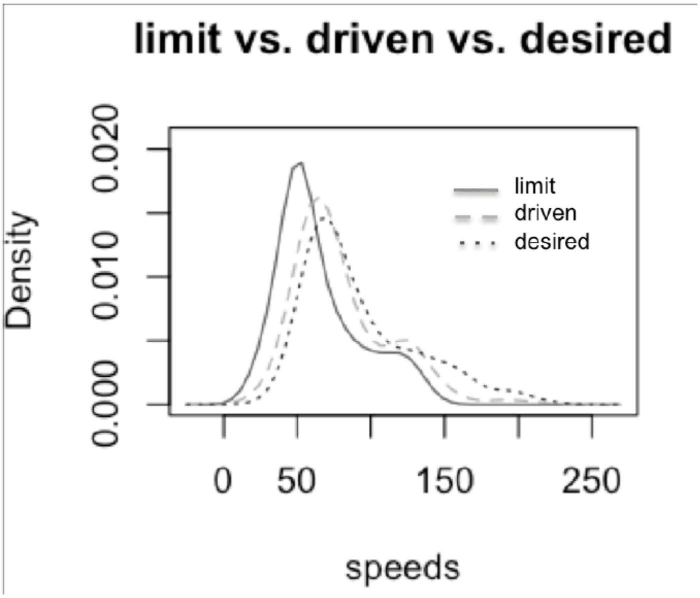

Fig.2. the probability - density function for the speed limit, the driven and the desired speed

For the test of hypothesis 2, the dataset was decomposed into different driving conditions (highway, interurban- and urban road). For each of the speeds in question (desired, safe and credible) the largest significant difference was obtained for the highway condition. There, the smallest effect was found for the credible speed, $F(1,211) = 5.95$, $p < 0.01$. Paralleling this result, credibility showed the smallest effect on the interurban road ($F(1,211) = 4.42$, $p = 0.03$) and the urban road, $F(1,211) = 4,37$ $p = 0.04$ as well. Again, al of these differences did not reach significance when the speeds in question (desired, safe and credible) were compared to the driven speed. For these comparisons, the largest effect was for the desired speed, $F(1,211) = 1.01$, $p = 0.31$. In addition to the speeds in question, personal reasons for over-speeding were assessed in an open question at the end of the questionnaire. These reasons mapped onto most of the variables (e.g. environmental and personal reasons), which were proposed by Fuller (2005). Frequencies of these personal reasons were computed and used for the mathematical model.

3.4 Discussion

The first empirical results seem to support Fullers model in its core assumptions. Nevertheless, the facts that the analysis occurred post hoc and only self reported data was analysed puts up the demand for further exploration of the models assumptions with experimental methods. To examine the model assumptions and the empirical data using a different method a mathematical model was constructed and tested qualitatively.

4 MODELLING PART

Two objectives motivated the construction of a mathematical model resembling the theoretical assumptions made before. First, the influence of the self reported personal reasons for speeding were examined. Second, precise predictions for an experimental test of the proposed interrelationship of variables influencing the capability (C) and task demand (TD) were derived. Starting point for the model is the core assumptions made by Fuller (2005), namely the difference of C – TD and its relation to performance as specified in equation (1) and the acceleration, which was specified in equation (2). In addition to these two specifications, a third assumption, which was not yet mentioned explicitly, was incorporated in the computation of TD – the dependability of the task demand from a persons' behaviour. This means: an increase in acceleration also increases task demand and vice versa.

4.1 Model input

The model input consists of two vectors – one for capability and one for task demand – including the presence (and if possible the magnitude) or absence of four features each.

According to Kanellaidis et al. (1995) capability is determined by age, driving experience in years, sex and educational level ranging from 1 = elementary school to 4 = university education. In contrast, the task demand features were not extracted from literature but from the empirical data presented in this paper. Since, the four most frequently mentioned personal factors for over-speeding mimic Fullers (2005) components of task demand, these personal factors constituted the features of the task demand vector.

4.2 Model computations and output

After defining the input vectors, it has to be specified how the present features are weighted. Analogous to the extraction of the features, weights for the capability vector were extracted from the article of Kanellaidis et al. (1995). Again, the weights for the task demand vector were estimated from the survey data, computing the proportion of subjects naming a featureas relevant. Calculating the scalar product of the feature vectors for C and TD with the corresponding weights, one global measure for C and one for TD is obtained. Finally the computations for the performance and the acceleration are done, using the equations (1) and (2). The output for each combination of input vectors is one value for the difference of C and TD, one value for the performance and a third value for the acceleration. Figure 3 visualizes exemplary results for an increase in task demand, while capability is stable.

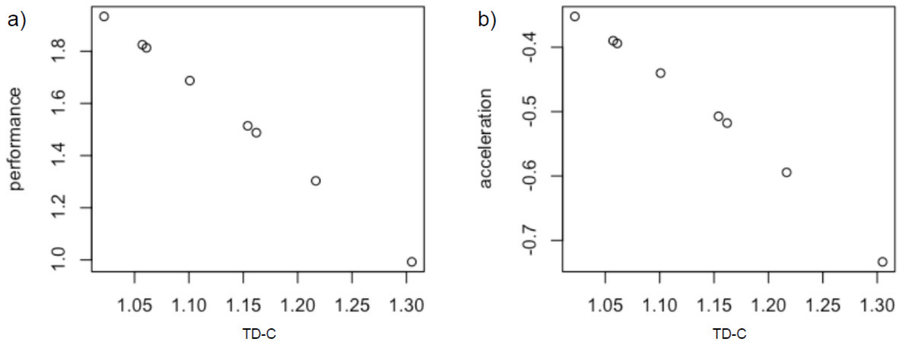

Fig.3. a qualitative evaluation of the model assumptions

Examining Fig. 3 visually, it is noticeable that performance and acceleration are decreasing with an increasing gap between capability (held stable) and task demand (increasing). Also, the range of the decrease in performance is located above the x-axis and the range of decrease in acceleration is located below the x-axis. Finally, the shape of the functions resembles the safety-critical part (right hand side of the optimal interval) in Fig. 1.

4.3 Discussion

The first modelling results seem to support the assumptions of the mathematical model. The location of the performance function in the first quadrant and the acceleration function in the fourth quadrant of the coordinate system as well as the shape of both, supports further exploration of the model properties. Future research should explore the models properties depending on changes in the input vectors C and TD.

5 GENERAL DISCUSSION

There were two main issues addressed in this paper. First, salient gaps in the current speeding research were discussed. Here, the missing link between empirical findings and an underlying theory was mentioned. Often, empirical influences are explained with single concepts like the type of personality (Tay et al., 2003), type of speed limit (Van Nes et al.,2008a, Van Nes et al., in press) or the conscious part of cognition (Ajzen and Madden, 1986). Testing the influence of separate variables on speeding surely helps to gain knowledge about the bandwidth of influences on the over-speeding phenomenon on the side of drivers' capability as well as the task demand. A deeper understanding of the interactions and dependencies among those factors cannot be reached with this type of research. Second, a profound knowledge of over-speeding is necessary. The little long term effect of countermeasures on speeding as reported by researchers (e.g. Stead et al.,2005; Kanellaidis et al.,1995) might be due to the maladaptive theoretical basis from which the countermeasures are derived. Normally, available theories (e.g. TOPB; Ajzen & Madden, 1986) or models (e.g. Stages of driving behaviour; Michon, 1985) are used to derivate countermeasures to over-speeding (e.g. Stead et al.,2005). Depending on the theoretical focus of the model the countermeasure focuses either on conscious or environmental influences on the driving task. This task itself is considered to be largely visual (Wickens & Hollands, 2000), highly automated (e.g. Hale, 1990) and mainly without any involvement of conscious cognition (Wille, in press). At some point within the driving task, attitudes and norms will play an influential role. These influences might be strongest while planning the trip (Michon, 1985), during the actual performance (Hale et al., 1990), or they might serve as moderator variables as suggested by Fuller (2005). By now, theorists do not know. Within the scope of this paper, two reasons were addressed: (a) the limited focus of existing models and (b) the gap between the quality of data and the aspiration of the related theoretical approaches. With respect to the narrow focus of theoretical models, a consolidation and integration of well-known concepts from different areas of research might enhance their scope. But the second reason might be even more important. The quality of data and data analysis differs with respect to dependencies among factors influencing capability and task demand compared to the theoretical ambitions. In some cases even reliability of data is questionable (Gabany et al., 1997). One way to determine the interplay between different influencing variables as well as the effects of non-reliable data lies within the realm of basic research. Using experimental and modelling methods, it is possible to examine interactions and dependencies of different variables on speeding. The integrative model, used in this paper, bears the potential to connect personal factors (i.e. constitution, experience, attitudes) to environmental influences (i.e. lane width, visibility of the road). Using the mathematical approach to examine the models' properties, forces theorists towards precision in the definition of their proposed concepts and their relationships. And precise models predicting over-speeding are urgently needed if we want to avoid putting up radar altimeters every couple of hundred meters. Therefore, further research has to have the objective to specify the single components of capability and task demand and their inter-relationships on the basic research level.

6 REFERENCES

Adler, J. L., Recker, W.W. & McNally, M.G. (1993). Conflict model and interactive simulator (FASTCARS) for predicting enroute driver behavior in response to real-time traffic condition information. Transportation, 20, pp. 83-106.

Ajzen, I. & Madden, T.J. (1986). Prediction of goal-directed behavior: Attitudes, intentions, and perceived behavioral control. Journal of Experimental Social Psychology, 22, pp. 453-474.

Attawa, M., Hassan, Y. & Sayed, T. (2006). Quantitative evaluation of highway safety performance based on design consistency. Advances in transportation studies an international journal. Section A 9.

DePelsmacker, P. & Janssens, W. (2007). The effect of norms, attitudes and habits on speeding behavior: Scale development and model building and estimation. Accident Analysis and Prevention 39 , pp. 6–15.

Elliot, M. A., Baughan, C. J. & Armitage, C. J. (2003). Drivers' Compliance With Speed Limits: An Application of the Theory of Planned Behavior. Journal of

Applied Psychology. Vol. 88, No. 5, 964 –972.

Fildes, B.N., Rumbold, G. & Leening, A. (1991). Speed behavior and drivers' attitude to speeding. Research documentation. Accident research centre Monash University.

Fuller, R. (2005). Towards a general theory of driver behaviour. Accident Analysis and Prevention 37. pp. 461–472

Gabany, S.G., Plummer, P. & Grigg, P. (1997). Why Drivers Speed: The Speeding Perception Inventory. Journal of Safety Research, Vol. 28, No. I, pp. 29-36.

Goldenbeld, C. & VanSchagen, I. (2007). The credibility of speed limits on 80km/h rural roads: The effects of road and person(ality) characteristics. Accident Analysis and Prevention39, pp.1121–1130

Goodwin, F., Achterberg, F & Beckmann, J. (2006). Intelligent Speed Assisstence – Myths and Reality: ETCS position on ISA. European Transport Safety Council, Brussels.

Heydecker, B. G. (2006). Einsatz von Geschwindigkeitsüberwachungskameras in Großbritannien. In:Effekte von Tempo 80 auf Freilandstraßen. Bericht zur FSV-Veranstaltung "Tempolimit auf Freilandstraßen für Verkehrssicherheit und Umweltschutz" (Symposion + Workshop) in Wien 30.11. - 01.12.2006. p.19-27.

Hale, A. R.; Stoop, J. & Hommels, J. (1990). Human error models as predictors of accident scenarios for designers in road transport systems. Ergonomics 33. pp. 1377-1388.

Kanellaidis, G., Golias, J. & Zarifopoulos, K. (1995). A survey of drivers' attitudes toward speed limit violations. Journal of Safety Research. 26,31–40.

Levelt, P.B.M., Swov (1998). Speed and motivation: established and newly developed ideas about the content of questionnaires and the designing of campaigns. Working paper.

Machin, M., A. & Sankey, K.,S. (2008). Relationships between young drivers' personality characteristics, risk perceptions, and driving behaviour. Accident Analysis and Prevention 40 .pp. 541–547.

Michon, J.A. (1985). A critical view of driver behavior models: What do we know, What should we do? in: L. Evans & R. C. Schwing (Eds.). Human behavior and traffic safety. pp. 485-520. New York: Plenum Press

Ötzkan, T., Lajunen, T., Chliaoutakis, J.E., Parker, D. & Summala, H. (2006). Cross-cultural differences in driving behaviours: A comparison of six countries. Transportation Research Part F 9. pp. 227–242.

Parker, D., Manstaed, A., S., R., Stradling, S. G. & Reason, J.T. (1992). Determinants of intention to commit driving violations. Accident Analysis & Prevention. Vol. 24, No. 2. pp. 117-131.

Ranney, T., A. (1994). Models of driving behavior: A review of their evolution. Accident Analysis and Prevention, Vol. 26 (6), pp. 733-750,.

Rasmussen, J. (1987). The definition of human error and a taxonomy for technical system design. In: Rasmussen, J.; Duncan, K.; Leplat, J., eds. New technology and human error. Chichester, U.K.: Wiley.

Sedlmeier, P. & Renkewitz, F. (2008). Forschungsmethoden und Statistik in der Psychologie. Pearson: München.

Statistisches Bundesamt (2009). http://www.destatis.de/ (letzter Abruf: 22.01.2009).

Stern, J., Schlag, B., Rößger, L., Fischer, T. & Schade, J. (2006). Wirkungen und Akzeptanz polizeilicher Verkehrsüberwachung. Verlag für Polizei und Wissenschaft: Frankfurt.

Stead, M., Tagg, S., MacKintosh, A. M., & Eadie, D. (2005). Development and evaluation of a mass media Theory of Planned Behaviour intervention to reduce speeding. Health Education Research, 20(1), 36-50.

Summala, H. (1985). Modeling driver behavior: A pessimistic prediction? In: Evans, L.; Schwing, R. C.; eds. Human behavior and traffic safety. New York: Plenum Press.

Tay, R., Champness, P. & Watson, B. (2003). Personality and speeding – some implications. International association of traffic and safety science. Vol. 27(1), pp.68-74.

Van Nes, N., Brandenburg, S. & Twisk, D. (2008a). Dynamic speed limits: Effects on homogeneity of traffic flow. In: Proceedings of the IEEE conference of intelligent vehicles. 04-06 August, Eindhoven, Niederlande.

Van Nes, N., Houtenbos, M. & Van Schagen, I. (2008b). Improving speed behaviour: the potential of in-car speed assistance and speed limit credibility. Intelligent Transport Systems (4).

Van Nes, N., Brandenburg, S. & Twisk, D. (in press). Improving dynamic speed limits by dynamic speed limits. Accident analysis and prevention.Special issue on simulator studies.

Wickens, C.D. & Hollands, J. G. (2000). Engineering psychology and Human Performance. Prentice Hall.

Wille, M. (in press). Self induced Speed Oscillation and Speed Production.