# From adaptive control to adaptive driver behaviour

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*Summary*

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Progress in the field of driver behaviour modeling has been limited during the last ten years. One of the main problems arises from the emphasis on traffic accidents and accident causation instead of everyday driving. Also, the partiality of the various approaches involved in driver modeling has impeded progress. Existing models are exclusively directed at either the operational level or the tactical level of the driving task. Moreover, existing models focus either on individual differences or on situational factors. In contrast, the approach advocated in this thesis emphasizes the integration of behavior on the operational and the tactical level together with a relation between individual differences, vehicular and situational factors on the one hand and operational performance on the other hand in a systems approach that stresses the interactions between man, machine and environment. Starting from a discussion of a number of important models and approaches in traffic psychology, the adaptation model is developed in chapter 2. In this model, several factors are assumed to affect performance on the operational level. For example, drugs and alcohol affect skills involved in vehicle handling. These skills are affected by the process of aging as well. Yet, there is little evidence for a relation between skill level and traffic safety. It is suggested that this is caused by a compensation or adaptation of behaviour on the tactical level for deteriorations of skill level and operational performance. This means, for example, that when steering performance is negatively affected by whatever reason, drivers take account of this by lowering their speed. Operational performance is not only determined by skills. Vehicular factors and situational factors related to the road, sight distance and weather affect operational performance as well. In chapter 2 a number of experimental results are discussed that suggest the existence of a process of adaptation of behaviour on the tactical level under these circumstances. Behavioural adaptation then appears to be a general phenomenon that normally occurs when operational performance is affected and when this is perceived by the driver. However, this process of adaptation appears to be prevented in some conditions, for example after alcohol ingestion or in the case of young male drivers. This results in a dramatic increase of accident risk. Motivational models play an important role in contemporary traffic psychology. Some elements of the 'Zero Risk Theory' and the 'Threat Avoidance Model' are integrated with the adaptation model.

An important starting-point of the adaptation model is that car driving is essentially a self-paced task. The driver determines how to drive and makes the decisions on the tactical level of driving behaviour. When the driver has little choice, the task is forced paced. Deteriorations of operational performance have to be handled differently in that case as discussed in chapter 2.

Paragraph 2.5 discusses time-related safety margins such as the time-to-collision (TTC) and time-to-lane-crossing (TLC) as control mechanisms for the extent to which behaviour on the tactical level is adapted to operational performance.

In paragraph 2.6 the research questions are discussed of six experiments that examine an important aspect of the adaptation model: the extent to which individual differences in operational performance result in individual differences in behavior on the tactical level. The two

different driver tasks of curve negotiation and car-following are examined in detail. Curve negotiation was selected because the lateral control task, and especially the quality of operational steering performance, affects the choice of speed in curves. Car-following was selected because it was expected that the longitudinal control task, and more specifically braking performance, determines choice of time-headway. This research then tries to answer the questions why some negotiate curves at higher speeds than others and why some drivers follow at a small time-headway while other follow at larger headways.

The experiments discussed in this thesis were performed in the TRC driving simulator. The author has, together with a colleague, developed the software for this research instrument. Because the design and implementation of components of the simulator constituted an important element in the preparation of this thesis, the functionality of the simulator is discussed in some detail in chapter 3.

Chapter 4 discusses an experiment in which the relation between speed choice in curves on the one hand and steering competence and road radius on the other hand is examined. Road radius affects required steering angle and, thus, required performance. The magnitude of the steering error is determined by both required steering angle and steering competence. It is found that both factors determined both operational performance and speed choice in curves such that the minimum TLC to the inner lane boundary is constant. This confirms the hypothesis that several factors affect operational performance and that behaviour on the tactical level is adapted to this. It also confirms that, in lateral control tasks, adaptation is controlled by safety margins.

In the chapters 5 to 9 five experiments are discussed that examine the relation between choice of time-headway (THW) during car-following and operational performance in braking. Chapter 5 studies the relation between choice of THW and the ability to brake as fast as possible. No differences are found between short and long followers in this ability, in the speed at which they perceive that the lead vehicle brakes, or in the speed of response preparation. However, there appear to be differences in the response execution of braking. These differences are restricted to situations where the driver does not know in advance that the lead vehicle will brake or how hard it will brake.

Chapter 6 examines the relation between the use of time-to-collision (TTC) information during braking and choice of THW. Both the initiation and the control of braking appear to be determined by the TTC at the moment the lead vehicle starts to brake. It is found that the intensity of braking is more sensitive to TTC information for short followers compared to long followers. This suggests differences between short and long followers in perceptual-motor skills involved in the response execution of braking. However, a confounding factor may have affected the results: absolute differences in TTC may have forced the short followers to brake more efficiently.

In the experiment discussed in chapter 7 this confounding factor is controlled. Three sequential phases of braking are distinguished: the reaction time (RT) phase, the open-loop ballistic phase and the closed-loop phase. It appears that the duration of the open-loop phase is strongly determined by the TTC at the moment the driver detects the deceleration of the lead vehicle. The duration of the closed-loop phase is related to the number of movement corrections during the process of braking. Short followers exhibit a faster open-loop and a faster closed-loop response compared to long followers. The results suggest that drivers with a smaller preferred THW are more sensitive to task requirements than drivers who prefer to follow at a larger THW.

In the chapters 8 and 9 two experiments are discussed in which the hypothesis is tested that short followers differ from long followers in the sensitivity of the braking response to TTC. In the experiment discussed in chapter 8 the RT, open-loop and closed-loop phases are manipulated separately. Although the manipulations specifically affect the different phases of the braking response, the predicted interactions between following group (short vs long followers) and the manipulations of the open- and closed-loop phases are not statistically significant. The results suggest that task-specific factors evoked undesirable startle and vigilance effects that preclude confirmation of the hypotheses. Therefore, the final experiment, discussed in chapter 9, is designed such that these task-specific effects are prevented. The open-loop phase is manipulated with the level of deceleration of the lead vehicle. A larger deceleration of the lead vehicle results in a smaller TTC at the moment the driver detects the deceleration. This effect speeds up the open-loop phase. If response execution of short followers is more sensitive to TTC information compared to long followers, a statistical interaction is expected between following group and level of deceleration of the lead vehicle on the duration of the open-loop phase. The results confirm this hypothesis. It is also investigated whether short followers differ from long followers in other tasks requiring a dynamic perceptual-response coupling by measuring performance on a lateral tracking task and a longitudinal tracking task. It is found that performance on the two tasks is significantly correlated and short followers perform better on both tasks compared to long followers. These results support the hypothesis that long followers choose a larger THW during car-following because they are less skilled in dynamic tasks requiring a perception-response coupling.

Chapter 10 discusses the extent to which the results of the experiments support the adaptation model together with a number of general conclusions.