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Modelling Driver Behaviour in European Union and International Projects

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1.1 Introduction

Human (or operator) modelling has been an extensive area of research in many application areas, such as artificial intelligence, aviation, probabilistic risk assessments, system safety analysis and human performances in working contexts (Cacciabue et al., 1993; Baron et al., 1980). Still, human behaviour is fairly contextual and substantially different from one person to another. Thus, the initial linear models have been gradually replaced by nonlinear and even probabilistic models, based upon artificial intelligence (AI) principles, such as artificial neural networks or genetic algorithms. This becomes even more intrigued if we consider a complex behavioural task such as vehicle driving.

The traffic system as a whole can be seen as being composed of three interactive parts: vehicles, road users and the road environment. Any traffic situation is the result of the interaction between these three systems. Normally, the traffic situation develops as planned, but, in certain circumstances the resulting interaction will result in a critical situation or in a crash.

The driver is a critical component of the traffic system. Attempts have been made to estimate the importance of the driver as an accident cause (Evans, 1985). It has been estimated that road user factors are the sole or contributory factors in a great majority of road crashes.

There is no generally accepted model of the complete driving task. There are detailed descriptions focusing on perception and handling aspects and reporting what drivers really do in every possible ('normal') situation from the beginning to the end of a journey (see McKnight and Adams, 1970). There are also more analytical approaches focusing on driver behaviour in relation to task demands, with the purpose of trying to explain and understand the psychological mechanisms underlying human behaviour (Rasmussen, 1984; Michon, 1985).

Usually, car driving is described as a task containing three different levels of demands. At the strategic level, the general planning of a journey is handled. For example, the driver chooses the route and transportation mode and evaluates resulting costs and time consumption. At the tactical level, the driver has to exercise manoeuvres, allowing him/her to negotiate the 'right now' prevailing circumstances, for instance, turning at an intersection or accepting a gap. Finally, at the control (stabilisation) level the driver has to execute simple (automatic) action patterns, which together form a manoeuvre, for example, changing the gear and turning the wheel.

The demands imposed on the driver are met through his/her driving behaviour. Also, the performance of the driving task is usually assigned to three different levels: knowledge-based, rule-based and skill-based behaviour. Skill-based behaviour is described as data-driven, meaning that skills are performed without conscious control and use of attention resources. They are immediate and efficient. Rule-based behaviour on the other hand occurs under conscious control and requires attention. Therefore, it is less immediate and efficient. Knowledge-based behaviour involves problem solving and is relevant when it is not given how to act in a specific situation. Thus, an important aspect of knowledge-based behaviour is that reasoning is required.

1.2 Evaluation of Driver Behaviour Models

Analysing the driving task requires consideration of the dynamic interaction between drivers and the traffic system. Driver-specific factors include performance aspects, individual dispositions and transient driver states. Driver behaviour models attempt to formalise the complex relation between the driver and the traffic system.

1.2.1 Michon's Hierarchical Control Model

Michon (1985) proposed a simple two-way classification of driver behaviour models: One dimension distinguished between behaviour, i.e., input–output-oriented models and internal-state-oriented models. The second dimension differentiates between functional models and taxonomic models, where model components do or do not interact, respectively.

According to Michon (1985), all models lack in one or more respect: they are generally bottom-up controlled, internal models. Corresponding top–down processes are hardly specified or they tend to be too simplistic. Michon regards cognitive process models as the most encouraging step towards a valid model of driver behaviour because these types of models combine elements of driving task analysis with an information-processing approach. Therefore his Hierarchical Control Model subdivides the driving task into three coupled and hierarchically ordered levels, namely the strategic, the manoeuvring and the control levels. Adapting this model, to incorporate the GADGET fourth level (see next section), one more level is added, i.e., the 'behaviour level' (Fig. 1.1).

The strategical level includes trip planning, route choice and other general principles including time constraints. This level is little involved in actual driving. However, it sets criteria for factors at the lower levels, like speed control and associated subjective risk levels. At the manoeuvring level, drivers interact

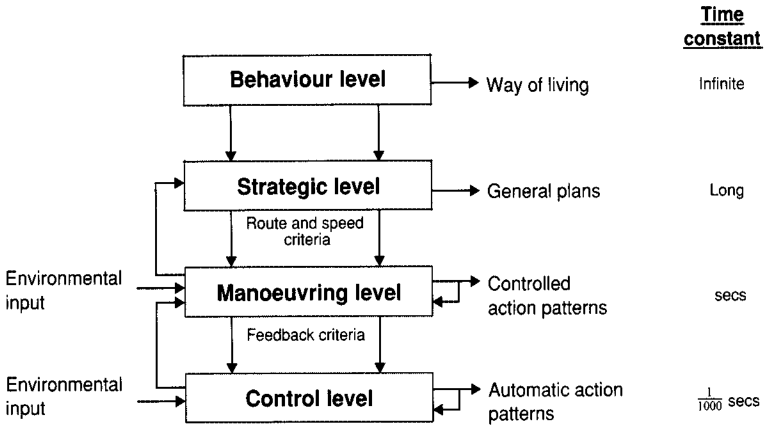

FIGURE 1.1. The hierarchical structure of the driving task (adapted from Michon, 1985).

with the traffic system. The control level, finally, refers to basal car control processes. Although a dynamic relationship between the concurrent activities is assumed, the different levels require different types of information: The strategical level is mainly top–down (knowledge) controlled. The manoeuvring and control levels require in addition bottom-up (data) input from the traffic environment.

Closely associated to Michon's hierarchical model of driver behaviour is Rasmussen's division of operative behaviour into three levels: skill-based behaviour refers to automatic procedures, rule-based behaviour to application of learned rules and knowledge-based behaviour to conscious problem solving (Rasmussen, 1984). Skill-based behaviour is applied in Michon's model mainly at the control level in the form of automatic action patterns. Ranney (1994) relates Michon's control hierarchy to Rasmussen's taxonomy of operative behaviour. Skill-based behaviour is applied in all familiar situations. Rule-based behaviour dominates during standard interactions with other road users as well as in some rare situations like driving a new car, where automatic routines have to be transferred to a new system. Knowledge is applied when driving in unfamiliar traffic networks, in difficult environmental conditions or when skills are not fully developed as in novice drivers.

1.2.2 The GADGET-Matrix: Integrating Hierarchical Control Models and Motivational Models of Driver Behaviour

Motivational models of driver behaviour 'propose a general compensatory mechanism whereby drivers adjust their driving (e.g. speed) to establish a balance between what happens on the road and their level of acceptable subjective risk (Ranney, 1994). An important assumption of motivational models is that drivers establish a constant level of risk by activating risk-compensation mechanisms when a subjective threshold is exceeded (e.g., Summala, 1988). The opportunity to compensate risks by adjusting subjective risk levels indicates that drivers' personal motives are as well a crucial factor for safe driver behaviour. For this reason, a fourth level corresponding to individual dispositions has been added to hierarchical control models of driver behaviour within the European project GADGET (Christ et al., 2000). The new level refers to *personal preconditions* and *ambitions in life,* and as such has the highest priority inside the matrix because such dispositions heavily influence driving decisions at lower levels. The four levels of the so-called GADGET-Matrix are as follows (Table 1.1):

(a) *Goals for life and skills for living:* An individual driver's attitudes, lifestyle, social background, gender, age and other personal preconditions that might influence driving behaviour and accident involvement.
(b) *Driving goals and context:* Strategical planning of a trip; the focus is on why, where, when and with whom one is driving.
(c) *Mastery of traffic situations:* Actual driving in a given context, resembles Michon's manoeuvring level.
(d) *Vehicle manoeuvring*: Overlaps despite a different terminology with Michon's car control level. The focus is on the vehicle, its construction and how it is operated.

A safe driver has, however, not only developed skills but also knowledge about his/her own abilities, preconditions and limits. Experienced drivers have, in addition, cognitive driving skills, such as anticipation and risk perception. In order to cover these higher-order aspects of driver behaviour, vertical columns are added to the so far horizontal structure of hierarchical control models (see Table 1.1). The columns of the GADGET-Matrix are as follows:

(a) *Knowledge and skills*: Routines and information required for driving under normal circumstances.
(b) *Risk-increasing factors*: Aspects of traffic and life associated with higher risk.
(c) *Self-assessment*: How good the driver reflects his/her own driving skills and motivations.

Levels and cells of the GADGET-Matrix are not mutually exclusive – there is large vertical as well as horizontal overlap due to the complex and cyclic nature of the driving task, where subtasks usually have to be carried out in parallel at different levels (e.g., routing, turning left, gap acceptance, speed control, steering, braking, etc.).

1.2.3 DRIVABILITY Model

The most recent evaluation in driver modelling concerns the notion that driver behaviour is not necessarily static, but evolves dynamically with time, as well as is context-related. It is subjected not only to permanent but also temporary

TABLE 1.1. The GADGET-matrix (adapted from Hatakka et al., 1999).

Hierarchical levels of driver behaviour		Knowledge and skills	Risk-increasing factors	Self-assessment
	Goals for life and skills for living	Awareness about • relation between personal tendencies and driving skills • lifestyle/life situation • peer group norms • motives • personal values	Risky tendencies like • acceptance of risks • high level of sensation seeking • complying to social pressure • use of alcohol and drugs	Awareness of • impulse control • risky tendencies • dangerous motives • risky habits
	Driving goals and context	Awareness about • effects of journey goals • planning and choosing routes • effects of social pressure by passengers inside the car	Risks associated with • physical condition (fitness, arousal, alcohol, etc.) • purpose of driving • driving environment (rural/urban/highway) • social context and company	Awareness of • personal planning skills • typical driving goals • alternative transport modes
	Mastery of traffic situations	Knowledge about • traffic regulations • traffic signs • anticipation • communication • safety margins	Risks associated with • wrong expectations • vulnerable road users • violations • information overload • unusual conditions • inexperience	Awareness of • strong and weak points of manoeuvring skills • subjective risk level • subjective safety margins
	Vehicle manoeuvring	Skills concerning • control of direction and position • vehicle properties • physical phenomena	Risks associated with • insufficient skills • environmental conditions (weather, friction, etc.) • car condition (tyres, engine, etc.)	Awareness of • strong and weak points of car control skills

contributors, which may or may not be independent. The DRIVABILITY model (Bekiaris, Amditis, Panou, 2003) introduced as most important the following ones:

1. *Individual resources*, namely physical, social, psychological and mental conditions of the specific driver. Physical conditions include motor, sensoric and coordination functions. Mental status depends also on the actual level of stress, concentration to the task and vigilance level.
2. *Knowledge/skills level*: This refers not only to actual driver training and experience, but also to generic knowledge, as basic education greatly influences motivations and behaviour of the driver. This level also considers the self-awareness of the own skills and it includes all the four levels of the GADGET model.

3. *Environmental factors:* This includes the vehicle status, the existence of traffic hazards, the weather, road and traffic conditions. The combinations of these may generate a risky situation, which certainly influences DRIVABILITY.
4. Two common denominators between driver resources and environmental status, namely *workload* and *risk awareness.*

The two intermediate factors between driver resources and the environment, namely workload and risk assessment, are among the key issues in order to understand and analyse driving performance. Risk awareness depends on three major contributors:

1. Risk perception, namely the ability to understand/recognise the specific risk at the specific time moment.
2. Level of attention, the ability to spot the risk in time.
3. Possible external support so as to spot the risk in time, i.e., by advanced driver assistance systems (ADAS).

In contrast to the risk awareness level, which is rather discrete and may change arbitrarily, the other factor, workload, is continuous and evolves with time. Even temporary input, i.e., use of mobile phone, may have high impact on workload for limited time periods. The major contributors to DRIVABILITY are depicted in Fig. 1.2.

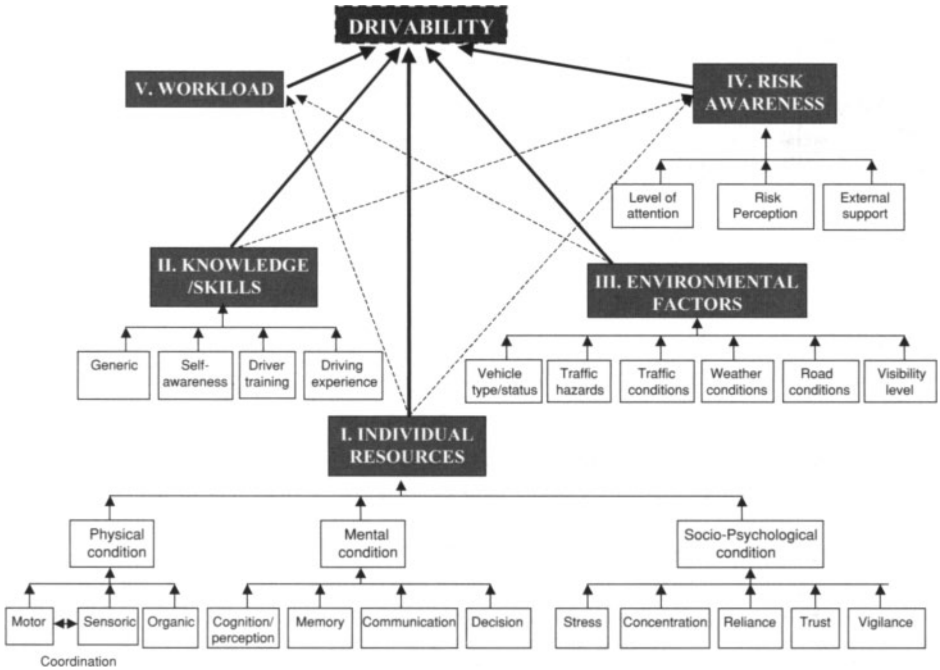

FIGURE 1.2. Contributors to DRIVABILITY.

The contributors shown in Fig. 1.2 are combined in a mathematical formula, which comprises the DRIVABILITY index (DI) of each individual driver at any given moment in time. Considering that the individual resources are the most significant contributor, the knowledge/skills and workload are of equal importance, while environment and risk awareness are third in importance, the overall DI is calculated through the following empirical formula:

$$\mathrm{DI} = \mathrm{IRI} \times \frac{\mathrm{KSI}}{2} \times \frac{\mathrm{WI}}{2} \times \frac{\mathrm{EFI} + \mathrm{RAI}}{6}$$

where IRI is the individual resources index, KSI the knowledge/skills index, WI the workload index, EFI the environmental factors index and RAI the risk awareness index.

The DRIVABILITY model contributors validity are being proved within the AIDE IP, where five modules are being developed, as components of one model, that monitor whether the driver is engaged and/or distracted by a secondary task and his/her availability/unavailability (related to the contributor V of Fig. 1.2), his/her inattention/fatigue (related to contributor IV of Fig. 1.2), his/her personal characteristics (related to the contributors I and II of Fig. 1.2) as well as the monitoring of the traffic and environment (related to the contributor III of Fig. 1.2). In a few words, the Cockpit Activity Assessment (CAA) module in AIDE is intended to monitor the activities of the driver to detect workload by visual distraction, cognitive distraction, and signs of lateral manoeuvring intent. Furthermore, the Driver Availability Estimator (DAE) module aims to assess the driver's 'level of availability/unavailability' to receive and process information, according to the requirements of the primary driving task (depending on the nature of the road infrastructure, the goal followed at this time, the current driving actions carried out, etc.). The Driver State Degradation (DSD) module intends to detect and to diagnose in real-time the driver hypo-vigilance state due to drowsiness and sleepiness situations, giving an indication about the driver's ability to execute the driving task. The Driver Characteristics (DC) module personalises the warning and/or information provision media, timing and intensity according to driver's profile (experience, reaction time, average headway, etc.), explicit and implicit preferences. The Traffic and Environment Risk Assessment (TERA) monitors and measures activities outside the vehicle in order to assess the external contributors to the environmental and traffic context and also to predict the driver's intention for lateral manoeuvre (Boverie et al., 2005).

1.3 Driver Behaviour Adaptation Models and Their Relation to ADAS

ADAS are currently being developed and installed within vehicles at an increasing rate. These systems aim to improve driving safety by automating aspects of the driving process, through information, warnings and support to the driver, hence reducing driver workload.

TABLE 1.2. Driver behaviour issues when introducing ACC (Bekiaris et al., 2001).

Short term	Long term
Mistrust: distrusting the ACC system	Spare capacity: using spare capacity for other in-vehicle tasks
Over-reliance: relying too much on the ACC system	
Brake pedal forces: increasing brake pedal forces Imitation: unequipped vehicles imitate equipped vehicles Reliance on vehicle in front: vehicle in front might have poor driving behaviour	Fatigue: ACC could take over too many driving tasks causing fatigue Quick approach to vehicle in front: the development of new behaviour Time-headway: driving with smaller time-headways Indication for overtaking: use ACC as an indication of when to overtake
Overtaking: difficulties with overtaking and being overtaken	

Automation can reduce driver workload in areas of decision choice, information acquisition and information analysis. This reduction in workload should then reduce driver error and stress, thereby increasing road safety. However potential problems exist with the introduction of automated systems. The reduction of mental workload may not always occur under conditions of system failure or when a user is unfamiliar with the system. Under these conditions, workload may in fact increase rather than reduce (Stokes et al., 1990). Also, changes in driver skills, learning and behaviour, which may occur due to the shift in locus of control, may prove detrimental and therefore predictions as to how drivers will react when locus of control shifts between the driver and the vehicle are required. Short- and long-term driver behavioural changes with the use of an advanced cruise control (ACC) system, from six research projects are summarised in Table 1.2 (Bekiaris et al., 2001).

The introduction of ADAS, as with any changes to the driving environment, may lead to changes in driver behaviour. However, the nature of these behaviour changes in response to changes in the driving environment and has on occasions proved to be the opposite of that which was intended. Grayson (1996) pointed out that 'people can respond to innovation and change in ways that are unexpected, unpredictable, or even wilfully perverse'. For example, Adams (1985) claimed that the introduction of seat belts in vehicles leads to a perception of greater safety, in turn leading to drivers increasing their speed on the road.

It has been suggested that improved safety cannot be predicted directly from the efficiency resulting from improved technology, as people adapt to some kinds of improved efficiency by taking more risks (Howarth, 1993). The introduction of safety measures may lead to compensatory behaviours that may reduce the benefits of the measures being implemented. This phenomenon has most recently been described as 'behavioural adaptation' (OECD, 1990). However, previous models explaining the behaviour have termed it as 'risk compensation' and 'risk homeostasis'.

The most important relevant theories and issues related to driver behavioural adaptation because of an external stimuli (ADAS introduction in our case) are summarised below (Bekiaris etal., 2001)..

1.3.1 Automaticity

Automation refers to the mechanical or electrical accomplishment of work. Some of the automatic components provided by ADAS act as a substitution for tasks that humans would otherwise be capable of performing. In other cases, ADAS provides automatic components, which carry out additional tasks that humans would not have been capable of but will also assist in the overall driving task.

Introducing automation into the driving task offers several potential advantages in aspects of both efficiency and safety. For example, the use of dynamic route guidance systems will assist drivers in taking the most cost-effective route, in terms of fuel and time, for current traffic conditions. Furthermore, automation can reduce driver workload in areas of decision choice, information acquisition and information analysis. This reduction in workload should then reduce driver error and stress, thus increasing road safety.

Overtrust on a system also brings problems. Drivers may become complacent and may not detect when a system fails. Drivers are left with a false sense of security, thereby failing to monitor the system leading to the added disadvantage of loosing system awareness. Drivers may also lose the opportunity to learn and retain driving skills. Furthermore, the role of the driver may be reduced to such an extent that their manual driving skills may degrade. This concept has been termed 'out-of-the-loop familiarity'.

Bainbridge (1987) discusses what she terms the 'ironies of automation', which occur with the changing role of the human in the human–machine relationship when a system is automated. She points out that the more advanced a system is, the more crucial the contributions of the human operator become. Automation aims to eliminate the human factor; however, ironically, the human operator is required to carry out those tasks that cannot be automated. The human operator is therefore required to monitor the system and to take over and stabilise the system manually in situations of system failure. However, as previously discussed manual control skills deteriorate when using an automated system, leading an experienced user to become inexperienced.

Bainbridge points out the loss of cognitive skills that an operator using an automated system, such as ADAS, is likely to suffer. As the retrieval of knowledge from the long-term memory is dependent on the frequency of use, operators will loose the benefit of long-term knowledge concerning processes. This practical knowledge can be used to generate strategies in emergency or unusual situations. It is difficult to teach practical knowledge without experience; it is thus of great concern that when automating a system this practical experience and the reinforcement by frequency of use will be taken away from the operator.

1.3.2 Locus of Control

Locus of control is the location of control over a situation or system. The implementation of ADAS will, in many cases, move the locus of control away from the driver and instead will lie with the vehicle. It is therefore necessary to consider the impact of this change in locus of control both on driver behaviour and also in terms of safety. The level of control left to the driver must be carefully considered (e.g., will drivers be given the opportunity to override vehicle decisions and vice versa?).

Once level of control is decided upon, it is still important to consider the likely consequences of implementation. Several concerns exist, including those discussed in the previous section. First, drivers may feel mistrust in the system and experience problems in handing over control to the vehicle; this factor is dependent on the confidence a driver has in the capabilities of the system. Secondly, drivers may overtrust the system; drivers may become dependent on the system. This may be problematic both in cases where the system fails; the driver may not detect failure due to reduced monitoring. Also, in situations when the driver is handed back control, driver's skills and learning may have been diminished due to out-of-the-loop familiarity.

Finally, driver behaviour and safety during the handover of control between the driver and the vehicle needs to be considered. De Vos et al. (1997) investigated safety and performance when transferring control of the vehicle between the driver and an Automatic Vehicle Guidance (AVG) system. Drivers were found to be able to leave the automated lane even when high-speed differences and traffic-density differences between lanes were present. Unsafe interactions were observed in the scenario of a low-speed manual lane. As expected, increased trust in the reliability of the system increased driver comfort. However, as headway decreased drivers were observed to experience greater discomfort, implying that total trust in the system did not exist.

1.3.3 Risk Homeostasis

One of the most considered and debated models in the area is Wilde's risk homeostasis theory. The model bears similarities to earlier models such as that of Taylor, and Cownie and Calderwood's. Taylor's risk-speed compensation model (1964) claims simply that the larger the perceived risk, the lower the chosen speed will be. Cownie and Calderwood (1966) proposed that drivers drive in a way that will maintain a desired level of anxiety, leading to the self-regulation of accidents within a closed-loop; feedback from the consequences of driver decisions will affect future decisions.

In a like manner, Wilde's risk homeostasis theory holds that drivers have a target level of risk per unit time that they attempt to maintain. He proposed that drivers make adjustments that ensure perceived subjective risk is equal to an internalised target level of risk. The theory asserts that if a driver is provided with additional safety measures, such as information concerning traffic ahead or the installation of a seat belt, the driver will exhibit more risky behaviour to compensate and return to the target level of risk.

Wilde also posited what he named the 'principle of preservation of the accident rate'. This principle implies that the number of accidents within a given population is dependent solely on the number of accidents that population is willing to tolerate.

1.3.4 Risk Compensation

As with other risk compensation theories, Näätänen and Summala propose a zero-risk hypothesis, stating that drivers normally avoid behaviour that elicits fear or anticipation of fear. Avoidance behaviour is motivated by subjective risk, which according to the theorists is not high enough, thereby leading to accidents. The main addition to the theory is its focus on the drivers' desired action. The theory contends that driver behaviour is motivated not only by perception, expectancy and subjective risk, but also by the relative attractiveness and benefits of carrying out a behaviour in a given situation. Furthermore, Näätänen and Summala (1973) postulate that the motivation of desired action is the most important route leading to a driver's decision to take action. The model proposes that a decision-making process occurs, weighing up the motivating and inhibiting factors, before a decision is made for action, such as overtaking. According to the model, driver adaptation occurs when perceptions concerning motivations and subjective risk are altered, hence altering the balance of the decision-making process.

1.3.5 Threat Avoidance

Fuller's (1984) threat-avoidance theory is developed both from Wilde's theory of risk homeostasis and the zero-risk model of driver behaviour proposed by Näätänen and Summala. The theory presupposes that drivers opt for zero risk of accident and that they make avoidance, competing or delayed avoidance responses depending on a wide number of factors. These factors are the rewards and punishments associated with the response, the accuracy of discriminative stimuli recognition, the subjective probability of a threat, the effectiveness of avoidance responses and finally the driver's level of arousal. The theory differs from the other theories in that it is not based on a motivation variable. Instead it views the driving task as involving learned avoidance responses to potentially aversive stimuli.

Fuller argues against the presupposition that drivers are capable of monitoring the probability of an accident. Instead, he proposes that drivers consider the subjective probability (or likelihood) of an accident. He proposes that the discriminative stimulus for a potential aversive stimulus is a projection into the future formulated through the integration of drivers' perceptions of their speed, the road environment of the intended path and their ongoing capability. Their expectations of the threat posed by each of these factors combine, leading to either a discriminative stimulus or no discriminative stimulus. This model also considers the influence of rewards and punishments. He proposes that when a discriminative stimulus is detected, the anticipatory avoidance response is not only determined by the subjective probability of expected threat, but also by the rewards and punishments associated with the various response alternatives. The theory also differs from that of Wilde, and Näätänen and Summala in that it highlights the role of learned responses.

1.3.6 Utility Maximisation

The utility maximisation model proposed by O'Neill (1977) assumes that the driver has certain stable goals and makes decisions to maximise the expected value of these goals. Some of these goals are achievable more effectively through risk-taking behaviour, for example, speeding to save time or gain social status. These motivating factors are counteracted by the desire to avoid accidents as well as by fear of other penalties such as speeding tickets. Balancing goals with the desire to avoid accidents therefore derives driving behaviour choice. O'Neill claims that the balance, which affects the decision made, is shifted when a safety measure is introduced. An assumption made by the theory, which has been questioned (OECD, 1990), is that the driver is 'rational'. In other words, the driver is an accurate judge of the accident probability resulting from each mode of behaviour.

Blomquist (1986) also presented a utility maximisation model, which claimed to illustrate that risk compensation is a natural part of human behaviour when individuals pursue multiple goals with limited resources. He claimed that drivers choose target levels of accident risk, based on the perceived net benefits of safety effort. Again the model proposes that, under plausible conditions, a change in safety, which is beyond driver control, causes a compensatory change in driver effort in the opposite direction. Blomquist (1986) likens this theory to Wilde's theory of risk homeostasis in that utility maximisation focuses on the choice of safety goals and risk homeostasis focuses on maintenance of those goals.

1.3.7 Behavioural Adaptation Formula

Evans (1985) proposes a human behaviour feedback parameter by which the actual safety change in traffic systems is related to that which was expected. A mathematical representation of the process dictates that feedback can occur through physical changes to the system, adjustments in user behaviour for personal benefits and adjustments in behaviour to re-establish previous risk levels. Evans suggests that human behaviour feedback is a pervasive phenomenon in traffic systems, which may greatly influence the outcome of safety measures to the extent that in some cases the opposite effect to that which was intended may occur.

In a review of driving behaviour theories, Michon (1985) commented that although behavioural adaptation theories explain the behaviour, and the motivations, attitudes and factors affecting that behaviour are detailed, the actual processes by which the behaviour occurs are not explained. Similarly, an OECD report found the models to be vague. The report states that risk compensation theories do not explain how or which cognitions lead to the expected compensation of objective risk. The report also points out the problem of how the objective risk can be accurately assessed by the driver; again models fail to explain this process.

1.4 Use of Driver Behaviour Models in EU and International Projects

The field of application of such models in EU projects is vast and is gaining pace over the last decades. Rather than attempting to meticulously cover this extensive area, we will provide an in-depth overview of characteristic examples, showing the related difficulties as well as benefits in applying such models.

1.4.1 Driver Models Use for Driver Training and Assessment

Indeed, many of the driver models have been developed, not aiming at driver behaviour and support but at facilitating better, theory-based, driver training model. A characteristic example is the GADGET-Matrix developed with the EC project GADGET in order to structure post-license driver education.

This model as well as different extension of the Michon model have been used as basis in nearly all recent EC projects dealing with driver training. In TRAINER project (GRD1-1999-10024), the different layers of the GADGET-Matrix have been further detailed and correlated to the problems of novice drivers, following a relevant accident analysis end experts opinion survey. This work resulted in the adapted GADGET-Matrix that correlates key subtasks of the different GADGET layers to the needs of driver trainees, with support by multimedia tools and/or driver simulators (Table 1.3). Thus, the development of appropriate new training tools and scenario was based upon the relevant theoretical model of novice drivers' needs.

Another training (in fact re-training) and assessment application is that of AGILE project (QLRT-2001-00118), regarding the assessment of driving ability and eventual re-training of elderly drivers. In this project, a mapping has been attempted of the age-related deficits and benefits to the different levels and cells of the GADGET-Matrix (Breker S. et al., 2003). The second level of the adapted GADGET-Martix is presented in Table 1.4.

This resulted in the prioritisation of specific driving scenaria, where elderly drivers would need more thorough assessment and/or support (re-training or aiding).

1.4.2 Evaluation of Driver Models' Use for Safety Aids

1.4.2.1 Use of Seat Belts

Evans (1982) observed that unbelted drivers drive at higher speeds and with smaller headways in comparison to drivers wearing belts. This evidence supports the theory that an adaptation in behaviour has occurred; however, the reduction in risk-taking behaviour does not support the risk compensation hypothesis. In contrast, Streff and Geller (1988) found that go-kart drivers wearing seat belts drove faster than non-wearers, suggesting that the seat belt leads to a sense of security, enabling drivers to feel safe in increasing vehicle speed. The experimental validity is questionable

TABLE 1.3. Findings of the analyses made in TRAINER D2.1.

	Literature survey	Existing training	Experts' proposals	
			Multimedia	Simulator
Starting		O		X
Shifting gears		O		X
Accelerating/decelerating		O		X
Steering/lane following		O		X
Speed control		O		X
Braking/stopping		O		X
Use of new cars control aids (ABS, ACC, etc)	X	X		X
Insufficient skills and incomplete automation	X			
Realistic self-evaluation	X			
Following	X	O		X
Overtaking/Passing	X	O	X	X
Entering and leaving the traffic	X	O		X
Tailgating	X			X
Lane changing	X	O	X	X
Scanning the road (eye cues)	X	Ø	X	X
Reacting to other vehicles	X	Ø X		X
Reacting to pedestrians	X		X	X
Parking		O		
Negotiating intersections	X	O	X	X
Negotiating hills/slopes	X	O		X
Negotiating curves	X	O	X	X
Road surface (skid, obstacles)	X	Ø X		X
Approach/exit of motorways	X	O		X
Turning off/over		O		
Railroad crossings, bridges, tunnels		Ø		
Reacting to traffic signs and traffic lights	X	O	X	X
Reacting to direction signs (including in-car devices)	X			
Emergency brake		Ø X		
Urban driving		O	X	X
Rural driving		O		
Convoy driving		X		
Motorway driving		Ø X		X
Weather conditions	X	Ø X		X
Night driving	X	Ø X		X
Insufficient skills and incompletely automation	X		X	X
Information overload	X		X	X
Insufficient anticipating skills and wrong expectations	X		X	X
Risky driving style	X		X	X
Realistic self-evaluation	X		X	X
Awareness of personal driving style	X	X		X
Determination of trip goals, route and modal choice				
Preparation and technical check		O	X	
Safety issues	X	O	X	
Maintenance tasks		O	X	

TABLE 1.3. (*Continued*)

	Literature survey	Existing training	Experts' proposals	
			Multimedia	Simulator
International legislation		X		
First aid		Ø X		X
Economic driving	X	Ø	X	
Driver's condition (stress, mood, fatigue)	X	X		X
Motives for driving	X			
Awareness of personal planning skills				
Awareness of typical driving goals and risky driving motives	X			
Knowing about the general relations between lifestyle/age/gender and driving style	X			
Knowing the influence of personal values and social background	X			
Knowing about the influence of passengers	X			X
High level of sensation seeking	X			
Consequences of social pressure, use of alcohol and drugs	X	X		X
Awareness of own personal tendencies (risky habits, safety-negative motives)	X			

O: the task is trained in all or nearly all European countries as the analysis of the questionnaires showed; Ø: the task is trained only in few or at least one country; X: the driving authorities and driving instructors questioned indicate that the task is not trained, but should be trained in the particular country.

because of the generalisation of go-karting to real life driving, as well as due to the differences in overall behavioural patterns of drivers using seat belts versus those that do not.

1.4.2.2 Use of Motorcycle Helmet

The retraction of these laws in some states of the USA during the late 1970s made it possible to compare repeal and non-repeal conditions in a natural environment. However, results from accident studies suggested that wearing helmets provided a safety benefit; those states that had revoked laws requiring helmets to be worn suffered an increase in fatalities (Grayson, 1996). These findings were opposed by the analysis of Adams (1983), where higher fatality rates were found in those states that had retained helmet-wearing laws. Adams argued that these results support the risk compensation theory: motorcycle riders who wore helmets felt less vulnerable to injury, thereby exhibiting riskier driving behaviours. The findings of Adams in favour of the risk compensation theory have again been disputed by the work of Chenier and Evans (1987). In their re-analysis of the USA accident statistics, they found that fatalities were increased in the states that had retracted compulsory crash helmet wearing laws. Their results imply that any increase of caution due to

TABLE 1.4. GADGET-Matrix level 2 (Mastery of Traffic Situations): Situation of older drivers (Breker et al., 2003).

Knowledge and skills		Risk factors		Self-assessment	
Pro	Contra	Pro	Contra	Pro	Contra
Knowledge about traffic regulations/traffic signs/anticipation/communication/safety margins, etc.		Risks associated with wrong expectations/vulnerable road users/violations/information overload/unusual conditions/inexperience, etc.		Awareness of strong and weak points of manoeuvring skills/subjective risk level/subjective safety margins, etc.	
	–priority (esp. right before left, right-hand driving) –signalling –reduced perception of road signs –dementia –cataract –diabetes + associated –glaucoma –cardiac & cardiovascular condition –seizure disorders –back pain	–slower on motorways –uniform driving style on country roads –larger gaps, especially when turning left –less overtaking –less night driving –slower approach of junctions –early speed reduction at junctions –smooth slow down at junctions –less driving on low friction –early observation of situations –tolerance towards other road users	–interpreting movement of other drivers –judging other drivers movement –junctions/intersections –yield right of way –right-angle (side) collisions –left turns (right-hand driving) –right turns (left-hand driving) –multiple vehicle accidents –merging onto motorways –risky merging in traffic flow –running over red –railway crossings –too early observation of situations (it might changed) –situation complexity especially in urban settings –late detection of other road users –judgement of gaps –underestimation of speed of vehicles at higher speeds –problems with reappearing situations when new information becomes available –problems with interrupting actions when necessary –problems with situation complexity –skill decline by compensation –lateral safety margins –dementia –cataract –diabetes + associated –glaucoma –cardiac & cardiovascular condition –seizure disorders –back pain	–larger safety margins (headway etc.) –lower risk level –avoiding complex settings –avoiding give-way or stop junctions –avoiding heavy traffic –awareness of difficulties at intersections –general awareness of age-related skill declines	–over estimation of one's own driving abilities –less sensibility to changes in performance and capacities –insufficient awareness that oneself is subject to general age-related skill declines –dementia

the removal of helmets was not great enough to compensate for the loss of safety benefits that the helmets provide. Overall, research into motorcycle helmet wearing has been found to provide a safety benefit and offers little support to any of the behavioural adaptation theories. However, as Grayson (1996) pointed out these findings are not surprising and more relevant to the theories are those mechanisms which protect one part of the anatomy and lead to disregard for safety of other parts of the body.

1.4.2.3 Studded Tyres

Studded tyres have been developed to improve safety in icy and snowy conditions; they provide better track-holding properties and shorter breaking distances under these conditions. Evidence from studies investigating the behavioural effects of fitting vehicles with studded tyres have often been cited in support of both behavioural adaptation (OECD, 1990) and risk compensation (Adams, 1985). The most greatly cited study is that of Rumar (1976). Results from this study indicated that in icy (low friction) conditions drivers of vehicles equipped with studded tires drive at faster speeds when negotiating curves in the road. However, it was determined that this increase in speed does not lead to a reduction in safety. It should therefore be noted that the observation of higher speeds in itself is inconclusive. Lund and O'Neill (1986) argue that the increased feedback provided by studded tyres allows vehicles to be driven at higher speeds without reducing safety. The Rumar study therefore provides evidence that the behavioural effect of driving faster with studded tyres reduces the safety benefits; however, an overall increase in safety is still achieved through their implementation.

1.4.2.4 Antilock Braking Systems

Antilock braking systems (ABS) are a recent safety feature introduced to the vehicle, and studies concerning their effect on driver behaviour are cited to support some of the theories of behavioural adaptation. ABS are designed to make breaking distances shorter and to allow vehicles to be steered during breaking manoeuvres. Rompe (1987) conducted a series of tests to investigate the benefit of these systems. Results showed that when simulating high-risk manoeuvres drivers without ABS made 2.4 times more errors. Real life evidence does not support this sizeable predicted benefit and therefore support theories of behavioural adaptation. A study conducted by Aschenbrenner (1994) is one of the only studies designed to specifically investigate the risk compensation theory; their hypothesis being that ABS will fail to reduce accidents despite its technical benefits. The study looked at two fleets of taxis in Munich: one fitted with ABS and the control one without. Aschenbrenner concluded that since it was not possible to prove a universal increase in safety, the results indicated the occurrence of behavioural adaptation in the form of risk compensation. The overall accident rate was unchanged, but inconsistencies such as decreases in blameworthy accidents and increases in parking and reversing accidents for fitted vehicles were observed. These inconsistencies were described as indicating a tendency to riskier driving by drivers of fitted vehicles when reviewed in the OECD report.

More supporting evidence has been provided by a US study (HLDI, 1994). Findings from this study indicated that the introduction of ABS has failed to reduce the frequency or cost of insurance claims. However, this does not necessarily imply that ABS does not provide a safety benefit, as Grayson (1996) points out, the circumstances under which ABS could prevent accidents are quite rare. Kullgren (1994) supplied evidence that ABS is effective in reducing accidents. This analysis of Swedish accident statistics indicated an overall effectiveness of 15% for ABS vehicles under snowy or icy conditions. It was also found that fitted cars were more likely to be struck from behind in rear-end accidents.

Evidence for the occurrence of behavioural adaptation is both inconsistent and conflicting. The OECD report reviewed empirical evidence concerning behavioural adaptation. It was concluded that behavioural adaptation does occur although not consistently, and the magnitude and direction of its effects on safety cannot be precisely stated. The studies reviewed suggested that behavioural adaptation does not eliminate safety gains from programmes but tends to reduce the size of the expected benefits.

1.4.3 Driver Models Use for ADAS Design and Impact Assessment

Few studies have been carried out investigating behavioural effects of future automated systems, and many of these have revealed the occurrence of negative behavioural effects.

A study conducted by Winsum et al. (1989) provides support to the theory that drivers will exhibit behavioural adaptation in response to ADAS. Winsum et al. suggested that the use of a navigation system, in place of a map, leads to a reduction in workload, which in turn leads to drivers increasing vehicle speed, implying that drivers demonstrate behavioural adaptation in response to the implementation of automated navigation.

Similarly, Forward (1993) reviewed the evidence concerning the effects of dynamic route guidance (DRG) systems, concluding that benefits such as reduced workload and stress exist as do undesirable effects such as increased speed. However, Forward noted that the real effect of the system cannot be fully comprehended until its use becomes more extensive.

Focus mainly tends to concentrate on the negative effects of introducing automation to the vehicle. However automation benefits have also been observed during evaluation of future systems.

In the case of AWAKE (IST-2000-28062), the DRIVABILITY model has been employed to design its warning levels and strategy. AWAKE was a project aimed to develop an unobtrusive and personalized, real-time driver monitoring device, able to reliably predict driver hypovigilance and effectively and timely warn the driver. AWAKE has recognised the importance of actual traffic risk level as well as driver status, type and key environmental factors, and worked towards a

TABLE 1.5. Correlation of AWAKE (driver vigilance monitoring and warning system) use cases and warning strategy with overall DRIVABILITY Index (Bekiaris et al., 2003).

AWAKE use cases	Values of DRIVABILITY Indexes	Overall DRIVABILITY Index	AWAKE warning levels/strategy
• Driver is hypovigilant;	IRI = 3.5	4 (the system closely monitors the driver, without any action)	No action but monitoring system parameters are strengthened to cautionary case
• Rural environment, with sufficient traffic density (normal workload);	WI = 2		
• No major environmental risk identified;	EFI = 3		
• Standard type of driver;	KSI = 2		
• No sign that the driver missed any risk.	RAI = 3		
	Thus DI = 3.5		
• Driver is hypovigilant;	IRI = 3.5	3 (the system provides warning)	Driver warning by audio and visual means (warning level 1)
• Urban environment, with normal traffic density (normal workload);	WI = 2		
• No major environmental risk identified;	EFI = 3		
• Standard type of driver;	KSI = 2		
• Driver seems to miss some risks (i.e. rather small TTC or headway).	RAI = 2		
	Thus DI = 2.9		
• Driver is hypovigilant;	IRI = 3.5	2 (the system intervenes)	Driver warning by audio and haptic means (warning level 2) (intervention is excluded from AWAKE, due to liability issues)
• Highway environment, with low traffic density (low workload);	WI = 1.4		
• High speed, cautionary case;	EFI = 2		
• Standard type of driver;	KSI = 2		
• Driver seems to miss some risks (i.e. lane deviation or swerving).	RAI = 2		
	Thus DI = 1.75		

multi-stage driver monitoring and driver warning system that takes such parameters into account. Table 1.5 correlates the overall DI and the indexes of the DRIVABILITY contributors to the different AWAKE driver warning levels and media. It should be noticed that the sensors included in the AWAKE system (such as driver eyelid and steering grip force monitoring, frontal radar, lane recognition system, etc.) allow for sufficient, real-time estimation of all DRIVABILITY indexes (except KSI, which is however included in the system by the driver at its initiation as the system adapts itself to the driver profile). This is done by storing driver's, vehicle and environmental data on the system and automatically processing them. Further processing off-line is also feasible.

TABLE 1.6. Driver model and rules for implementation.

PIPE driver model	Type of process	Rules or governing assumptions
Perception of signals	Sensorial process	– Haptic – Visual – Aural
Interpretation	Cognitive process	– Similarity Matching – Frequency Gambling
Planning	Cognitive process	– Inference/reasoning
Execution	Behavioural process	– Performance of selected actions/iterations

This is indeed one of the very few cases where such a direct relation between a driver behaviour model and the development of the HMI of an ADAS has been attempted, and in fact with great success, as the final AWAKE HMI has been rated as adequate and useful by over 90% of its users.

Finally, within AIDE (IST-1-507674), a new driver model is being developed, attempting to model concurrently the driver, the vehicle and the environment (Panou et al., 2005). The basic assumption made for the development of the model of the driver is that the driver is essentially performing a set of actions that are familiar according to his/her experience. As the driving process is very dynamic, these actions are continuously selected from a vast repository of knowledge (knowledge base) by a diagnostic process. Consequently, the processes of diagnosis and interpretation of acquired information become crucial for the dynamic sequencing of driver's activity. The model of the driver adopted is based on a very simple approach that assumes that behaviour derives from a cyclical sequence of four cognitive functions: perception, interpretation, planning and execution (PIPE). This model is not sequential as the execution function, i.e., the manifested form of behaviour, may result from several iterations (cyclical) of the other functions. Moreover, in agreement with the initial hypothesis, the planning function, is usually bypassed by the 'automatic' selection of familiar frames of knowledge that are associated with procedures or sets of several actions aiming at the fulfilment of the goal of a frame. This function is important as it becomes effective in unknown situations or in the case of novice drivers, when 'simpler' frames, based on single actions or on a limited sequence of very simple/familiar actions, are called into play to deal with the situation. These four cognitive functions can be associated to either sensorial or cognitive processes and are activated according to certain rules or conditions (Table 1.6). This model will be utilised in personalising the multi-ADAS system HMI, in accordance to a particular driver's needs and preferences, and will also be used in the traffic environment.

1.5 Conclusions

Driving task modelling has started as simple task-layers representation for taxonomic use in driver training and has gradually evolved to dynamic models, which consider driver behaviour adaptation as well as the impact of the traffic environment and the driving context. The initial list of driver training and assessment projects that used driver models as their theoretical basis (GADGET, DAN, TRAINER, AGILE, CONSENSUS, etc.) have been followed by a new generation of projects that use driver models to assess the impacts of driver support systems (i.e., ADVISORS, TRAVELGUIDE) and, more recently, by those that attempt to use the model parameters for optimal HMI design (AWAKE, COMUNICAR, AIDE, etc.). Preliminary results have proven that such a correlation is feasible and beneficiary, but it is far from obvious. The model output has to be evaluated and even modified by empirical results. Thus, currently the model is being applied and tested in AIDE, SENSATION and PREVENT Integrated Projects through short- and long-term testing of drivers. Furthermore, the model can only be at the starting basis of the design and development process and only influence the actual ADAS HMI within predefined design boundaries. Nevertheless, we seem to be at the infancy of a new design principle for driver support training and assessment systems – the model-based modular and personalised design.

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