Driver support systems and traffic safety

Theoretical considerations

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Summary

The report provides an overview of possible approaches when considering driver support and traffic safety. One of the main problems when attempting to understand traffic safety is the interaction between a large number of factors. A considerable number of models of driver behaviour and traffic safety have been developed, based in different theories of human behaviour, and focusing on different aspects of the driving task.

The assessment of driver support systems should address potential problems in relation to the environment, the driver and the task. Assessment procedures should focus on potential errors in relation to each of the above mentioned components.

The report summarizes different theories of task performance and human error and recommends areas for research. For instance, it is recommended that research to assess the impact of driver support systems on traffic safety should encompass: (1) the effects of driver support on the amount and quality of the information that motorists obtain while driving; (2) the effects of the timing and modality of additional information or support; (3) the influence of driver's (differing) skills, motives, abilities and knowledge; (4) the effects of driver support on specific aspects of task performance and the occurrence of particular types of errors; and (5) behavioural adaptations or other side effects of using the support system.

However, the selected evaluation strategy will also be influenced by other factors, i.e. the type of support system under investigation, the context of evaluation. In the recent years, several general methodologies have been developed that may assist us in selecting the appropriate approaches and methods for the evaluation of different types of systems.

Contents

1. Introduction

The increasing traffic volume and the quantity of roadside information is putting a lot of pressure on the skills of individual drivers. The last twenty years travel patterns have changed considerably. There have been significant increases in travel distances from 1965 to 1985 (an increase of 41 per cent). This growth of mobility has been made possible by a growth in car ownership. It is predicted that over the next twenty years there will be further increases in car drivers and the number of cars in many European countries. At the same time technological developments will increasingly allow the implementation of advanced electronic information and communication systems on the road and in the vehicle. One class of such systems, usually called driver support systems, aims to facilitate the task performance of drivers. The functionalities of these support systems may vary greatly. The systems may *transfer* information (e.g. about the traffic, weather and road condition), *enhance* information (e.g. vision enhancement technologies), or *manage* information (e.g. adaptive dialogue management). They may also be designed to facilitate the task performance of drivers by providing *real-time advice, instruction and warnings*. The latter type of systems are usually described by the term 'co-driver systems'. Co-driver systems may operate in advisory, semi-automatic or automatic mode (e.g. Rosengren, 1995). They concern, for instance, collision avoidance, speed regulation, but may also include monitoring of the driver state, and instructional support.

The underlying assumption behind presenting drivers with information about the environment or supporting them in performing certain aspects of their tasks, is that their behaviour will change for the better. For example, if you warn a driver that his following distance to a lead vehicle is too short, he will increase the distance. Thus far, little is known about the effects of driver information and support systems on traffic safety. Because of the complexity of the task domain, it has been recommended to develop, at this stage, guidelines that will allow a systematical assessment of current and future in-vehicle support systems. Technical feasibility does not suffice as a reason to actually implement the device. In assessment procedures it is necessary that the human driver is considered in relation to the traffic environment, in terms of their capacities and limitations, terms of the tasks that need to be performed, and in terms of the errors they might make.

2. An overview of approaches when considering driver support and traffic safety

One of the main problems when attempting to understand traffic safety is the interaction between a large number of factors, or to cite Evans (1991, p. 60): "Every aspect of the traffic system is in some way connected to every other aspect. If drivers know that their vehicles are in poor safety condition, they may exercise increased caution. If a hazardous section of roadway is rebuilt to higher safety standards, it is likely that drivers will travel this section faster than before the improvement, or with reduced care."

A considerable number of models of driver behaviour and traffic safety have been developed, based in different theories of human behaviour, and focusing on different aspects of the driving task. In recent years, research has benefited by drawing on cognitive models developed from mainstream psychology and artificial intelligence. Within the information processing framework man is viewed as an intentional being that interacts with the external world. Task performance is described in terms of information processing. Within this framework driving can be generally described as consisting of the following tasks: drivers must perceive relevant elements in the traffic environment; they must assess the task requirements and decide on a suitable response; and they must implement these responses as actual behaviour, monitor the consequences of their actions, and, if needed, adjust their behaviour. An adequate performance of these tasks depends, on the one hand, on the traffic environment (and vehicle) (for instance by making it possible to perceive the most important environmental features), and, on the other, on characteristics of the driver, e.g. their perceptual, decisional and motor skills.

Michon (1985, 1989) has provided an overview of current theories and models of driver behaviour. He distinguished between input-output models and internal models. Input-out models describe driver behaviour without reference to the internal or psychological state of the driver, but describe the relation between the external conditions (the traffic environment and vehicle) and driver behaviour. Driver centred models, on the other hand, describe how variables and conditions with regard to the driver influence driver behaviour. So, whereas the first class of models focus on the role of the task environment in determining driver behaviour, the latter class of models and theories focus on the role of drivers' skills and states in determining behaviour. Sections 2.1 and 2.2 will describe models that emphasize respectively the role of the environment, and the role of the driver. In section 2.3 descriptions will be given of the driving task.

2.1. The traffic environment

Based on control theory models have been developed that explain control behaviour of drivers. Control theory differentiates between 'closed loop' and 'open loop' control. In closed-loop control feedback information from the environment is used continuously, and driving basically consists of continuous adjustments to a changing environment. The output, i.e a certain speed or position on the road, can be predicted on the basis of the input, i.e. feedback from the environment. The feedback from the environment serves to inform the driver when an error has been made, i.e. when his performance deviates from a standard or correct performance. If follows that the driver acts basically as an error-correction mechanism with continuous attention allocated to the task of controlling the vehicle. The model predicts that effective performance in continuous tasks will depend heavily on the type and appropriateness of feedback during task performance. These rather mechanistic models have mainly addressed driver's task performance at operational level, i.e. the regulation of speed and lateral position through the use of steering wheel, accelerator and brakes (e.g. steering models developed by McRuer and Weir, 1969). Although the primary source of feedback concerns visual cues from the traffic environment and from devices inside the vehicle, also other sources of feedback (e.g. auditory and proprioceptive cues) may be used by the driver. Research has shown that many features of the car and the road, influence task performance. For instance, Hale (1990) identified the following factors with regard to the selection of the vehicle speed: the resistance of the accelerator pedal, noise levels from the car and the road surface, road surface features, road lay-out features, signs and warnings or speed restrictions an so on. From these models it is predicted that where sources of information are poor or inadequate, additional information would most certainly enhance performance and increase safety.

However, it has become clear that the driving task, even at operational level, is too complex to be considered purely a closed-loop task (Godthelp, Milgram and Blaauw 1984; Godthelp 1986, 1988, Verwey, 1994). Vehicle control does not always require, or allow, immediate path-error corrections. Owing to the complexity of the task, drivers may be forced to pay attention to other aspects of the driving task and may decide to undertake or not undertake certain actions. Task performance may also take place in open control mode, i.e. without a continuous monitoring of feedback. This control mode is executed with special motor programmes which operate on the perceived position of the car and the driver's internal model of the dynamic characteristics of the car, the environment and other road users respectively. This allows the driver to predict the immediate future in order to decide upon suitable responses. For instance, Godthelp (1986) proposed a model for positioning behaviour of drivers that recognizes influences from both external variables, i.e. features of road lay-out and so on, as well as internal variables, i.e. cognitive skills and characteristics of the learner. Also, Riemersma (1991) who focused on vision control, performed a series of experiments to relate curve characteristics, i.e. curve radius and curve angle, to drivers' skills in perceiving and assessing the curves. He found that drivers' judgements of curves were complex but consistent and could be related to the objective curve characteristics.

The adaptive control models generally indicate that the main task of the driver consists of observing the flow of information from the environment. This requires that they develop the ability to respond appropriately to the demands of the situation. Inaccurate predictions of the driver about the task requirements may lead to inappropriate responses in a particular situation. Drivers may fail to accurately predict their immediate future because of the limitations and inadequacies in the design of the traffic system (e.g. the infrastructure, traffic signs and regulations, supply of information).

The models highlight that increasing traffic safety requires changing aspects of the environment, for instance by changing characteristics of the road, of road furniture, the presence or absence of other (types of) road users, by changing external speed limits, and so on. Advanced telematics systems are considered to be particularly useful in compensating limitations of the traffic environment. According to this view it is crucial that they are designed such that they will generate feedback from the 'environment' that "guides the driver towards a correct response", by either limiting their options of behaviour or enhancing the selection of a desirable strategy.

In conclusion, the attempts to improve safety will primarily address identification and improvement of 'unsafe situations'. Recommended areas for research encompass accident studies, and particularly in-depth analyses of accident situations ('black spots'), and will focus on ways to increase the quality and quantity of the information to the driver. The overall goal of such information would be to assist the driver in correctly predicting the task requirements at any moment in time. The provision of additional information from advanced telematics systems may play an important role towards this end.

2.1.1. *Investigation of accident situations*

The official police accident registration report of 1992 in the Netherlands (CBS, 1993) provides us a general account of the distribution of accident situations. Of all car-accidents, nearly 30% occurred when driving ahead on a straight road, having a rear-end collision (10%), or due to an obstacle on the road (20%). Another 45% of all accidents occurred at intersections and junctions, e.g. crossing (19%), turning left (18%) and turning right (8%). Some 25% occurred in other situations, e.g. overtaking (8%), negotiating curves (5%), and other situations 12%.
However, this tells us little about how specific features of the accident situation influenced the outcome.
To understand the complex nature of an accident, new techniques in accident investigations were developed (Grayson and Hakkert, 1987), e.g. on-the-spot in-depth accident investigations. The in-depth analyses of accidents required that a multidisciplinary team, close to the occurrence of the accident, inquired about the circumstances of the accident.
The philosophy behind the in-depth studies was to obtain knowledge about the multiple causes of the accidents, the interactive factors and mechanisms (vehicle, road user, road and environment). Later, the in-depth studies became more focused on certain problem areas, e.g. 'black spots' locations and also used other techniques, e.g. video equipment, installed at problem locations (e.g. Oude Egberink, Stoop and Poppe, 1988). Grayson and Hakkert (1987) summarized advantages and limitations of the multi-disciplinary on-the-spot investigation technique. One of the most important limitations in the context of our studies is that in spite of an enormous amount of information collected in this type of study, the conclusions reached on the accident process are very limited (p. 42 op. cit.). The authors concluded that: "The in-depth study is a valuable tool to gain experience in the understanding of the accident process, but it is extremely difficult to quantify and translate findings to policy recommendations on counter-measures".
The disadvantages of this approach include the high cost involved, and owing to the predominance of details within the traffic context and the limited number of cases, the difficulty in generalizing the findings to other sites.

Several *theories* of accident causation have been proposed and experimental or observational studies performed within the frame of reference of such theories. For instance, Wagenaar and Reason (1990) proposed a theory of accident causation and remedial action that is based on the findings that certain failure types are the result of decisions made long before the actual accident. Certain conditions of the traffic system (including the driver) allow the execution of so called unsafe acts. The causal sequence runs from decision makers, failure types, precursor, unsafe acts and incorrect defence to accidents. Although remedies can be proposed at each stage of the causal sequence, the authors hypothesize that they are most effective at the earlier stages. The authors recommend to perform in-depth investigations in order to draw valid conclusions about the failure types and the conditions that cause accidents (see also section 3 on errors of driving).

Accident reporting is a practical way of identifying factors which may be contributing to accident causation. However, it has proven to be very difficult to identify the influence of specific road or environmental factors because of large confounding influences from road-user factors. It is recommended that analysis of accident data are firmly based on theories of human task performance and human error.

2.2. The driver

From cognitive theories, models are proposed that focus on the different features of the driver that mediate external variables and drivers' responses. A broad distinction can be made here between driver models that emphasize the influence of skill-based factors and motivational models that emphasize the role of motivational or attitudinal factors of drivers in accident causation.

Skilled-performance models assume that, through training and their participation in traffic, drivers acquire knowledge and skills, (i.e. vehicle control skills, skills in decision taking and judgment), and they develop mental representations of traffic situations and the road. Not the external variables but these specific skills and representations of traffic situations, road and rules are the major determinants of behaviour.
In other words, driving requires domain specific knowledge, motor skills, and a set of higher perceptual and cognitive skills. There is an adherence to the view that driving is a complex task, that requires a high degree of skill of the driver. Such skills may include for instance the perception of hazards, the estimation of speed and distances, drivers' self assessments (McKenna, 1988; Brown and Groeger, 1988), or may concern the balance between the perception of hazards and the assessment of one's own skills (e.g. Brown, 1989). Furthermore it is argued that some of these skills may be insufficiently well developed. For example, research has shown that misperceiving or misjudging traffic hazards is a relatively serious problem for road safety (Sabey and Taylor, 1980, Brown and Groeger, 1988). Hazard perception, described as the ability to identify potentially dangerous situations, not only involves the detection of relevant cues in the environment, also it involves the ability to understand the (potential) consequences of behaviour in terms of safety. This requires the integration of information from many sources. Another skill worth mentioning here concerns drivers' ability to project the present state of the vehicle into the near future and to

predict behaviour of other road users. This requires that they have a basic knowledge about different traffic situations, which makes it possible to predict what to look for in different categories of traffic situations, where to look, and when to look for it (e.g. Rothengatter et al, 1993).
Also the ability to assess one's own abilities to deal with a certain traffic situation has been identified as a potential problem.
Research in these driver centred models is generally not limited to accident studies. Brown, for instance, points out that it appears to be extremely difficult to identify the specific behaviours associated with drivers' accidents and the reasons for those behaviours (Brown, 1989). The author recommends that research needs to be more specific, for instance, by focusing on accidents that have been caused by failures of visual attention. However, road accidents are too infrequent to permit this detailed break-down of data. Instead, empirical studies should concentrate on specific skill deficiencies (e.g. perceptual and judgmental skills) and their contribution to driving errors and accidents. Recommended areas for research should include visual scanning techniques of drivers, the perception of objects in motion, and the ability to estimate the time-to-collision (see also Brown, 1989). Drivers' capacity to judge speed and spacing, may play an important role here. Another area of research may concern driver's 'personal style' of perceiving the traffic world, or the degree of attention required to perform the task. For instance, research has shown with regard to judgment of speed that besides visual feedback, auditory information is very important in judging speed. If the auditory information is masked by other sounds (e.g. auditory messages from driver support systems) judgments may become less accurate. Several authors indicates that in those conditions there is a danger that speeds are systematically underestimated.
While driver performance models primarily refer to driver's perceptual, and motor skills, another class of models assume that certain psychological characteristics may play an important role in driver behaviour. It is argued that driving is a self-paced task, and that drivers choose to some degree their own levels of task difficulty. Pleasure and thrill seeking motives, but also competitiveness, and the sense of power and control may impinge upon driving (e.g. Evans, 1991). Most importantly, in applying utility theory to driving, the following assumptions were embraced: the driver has a goal that can be written as a utility function, desired quantities have positive signs and unwanted consequences have negative signs. The model indicates that the driver will strive to maximize this utility function (e.g. Evans, 1991). Central to utility maximizing models is the need for drivers to estimate risk. A number of motivational models focus on driver's risk handling and threat avoidance, for example Wilde's (1982) risk homeostasis theory, risk threshold theories by Klebelsberg (1971), Naatanen en Summala (1974, 1976), Fuller's (1984) threat avoidance model, and Van der Molen and Botticher's risk model (1988). While support may be given with the aim to improve safety, it may actually reduce safety. For instance, improved braking may lead to increased speeds and closer following.

In conclusion, recommended areas for research encompass studies that investigate the relationship between driver support and individual characteristics of the driver. A range of skill-based, psychological and motivational factors may play a role in driver's behaviour on the road.

The driving task is performed in an often unpredictable and very dynamical environment. While control theory tends to overemphasize the role of the traffic environment and has little room for learning and individual differences, cognitive models tend to be vague about the specific effect of the characteristics of the environment and the task on performance. Generally, the factors that have contributed to traffic accidents will consists of a combination of situational factors and person-dependent factors. It is recommended that in order to assess safety effects of in-vehicle support systems, we also need to develop ways to formalize the driving task, in order to be able to pinpoint driver's errors.

2.3. The driving task

2.3.1. *A taxonomic description*

One approach in describing the driving task is to perform a task analysis. Task analyses have been used in a wide variety of domains in order to promote understanding performance in a particular domain. An ideal task analysis provides an extensive description of the task itself, the normative or ideal task performance, and the required abilities (i.e. skills and knowledge) of the performer. It focuses usually on the description of observable performance, i.e. the operations involved in performing a task. A very detailed analysis of the driving task has been performed by McKnight and Adams. This analysis, which provided an overview of the driving task in more than 1700 elementary subtasks, had primarily educational purposes. It allowed the identification of a complete set of educational objectives. However, it is very doubtful whether such analyses are useful for the purpose of assessing effects of in-vehicle driver support systems.

One of the problems of this type of task analysis is that it provides a summary of all actions that the driver should undertake. However, for driving, it is not always the right sequencing of actions that makes driving safe. Ultimately the safety of the driver depends on the adequate selection of the lateral position and speed in any particular traffic situation. The task analysis does not specify normative behaviour at that level of performance. Other shortcomings of a task analysis which describes observable actions are that it does not describe how the task is performed by the driver, and does not consider the processes which underlie performance.

For our purposes there is a need for a more generic description of the task.

2.3.2. *The hierarchical structure of the driving task*

An influential theory, proposed by Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977), concerned the distinction between controlled and automatic processes of skilled performance. Controlled processes are of limited capacity, require attention and can be used flexibly in changing circumstances. Automatic processes suffer no capacity limitations, do not require attention, and are very difficult to modify once they have been learned. It assumes that aspects of a task can be acquired to such a degree, by extensive practice, that they will be automatized. This theory gave rise to the conception that performance is hierarchically structured. In many domains it is claimed that there are three different levels of functioning: an

automatic level, a semi-automatic/controlled level and a controlled level. Rasmussen described these levels as: skill-based (indicating highly practised routines), rule-based (the choice of the appropriate course of action), and knowledge-based (development of new ways of coping with problems).
From this framework Michon (1971, 1989) and Janssen (1979) proposed a model for the driving task. This model has close parallels to the S-R-K framework. It divides the driving task generally into three major task levels: the strategical (planning), tactical (manoeuvring), and operational (control) level. At strategical level drivers prepare their journey; they are preoccupied with finding their way from origin to destination. They also may decide on a general driving strategy for a particular trip. Decisions are influenced, on the one hand, by their goals and attitudes with respect to traffic and transport, and on the other by the amount of information they have about general traffic conditions and their own state. At the tactical level drivers exercise manoeuvring control, allowing them to respond to directly prevailing circumstances. Here drivers are primarily concerned with interacting with other traffic and the road system. At operational level drivers implement manoeuvring plans and avoid collisions (Brown, 1989). They control the vehicle by using car controls and pedals, the steering wheel etc. Drivers support systems can focus on adjustments of behaviour at all levels, e.g. adjustments of safety margins when car-following during conditions of poor visibility (manoeuvring level), momentary adjustments of steering and acceleration in response to slippery roads (control level), and changes in trip plans to avoid driving under certain conditions (strategical level) (e.g. Ranney, 1994).

In conclusion, for the assessment of driver support systems, it is recommended to investigate the effects of the information provided by such systems, on three separate task levels, i.e. with regard to navigational tasks, manoeuvring tasks and control tasks.
The general conclusion which we might draw from the approaches described above (sections 2.1 to 2.3) is that assessment of driver support systems should focus on problems associated with the environment, the driver and the task and that assessment procedures focus on potential errors in relation to each of the above mentioned components. These components should not be studied in complete isolation from each other.

3. Errors in driving

It is important from the standpoint of traffic safety to consider human error and to try to identify ways to reduce the error impact and/or error frequency. In the recent years, a field of knowledge has developed, i.e. the Human Reliability Assessment (HRA), that attempts to construct a framework for the assessment of human error. HRA has at core three goals, namely: (1) identification of errors (what can go wrong?), (2) the quantification of errors (how often will the error occur?), and (3) the reduction of error (how can the error be prevented from occurring or its impact on the system reduced?) (e.g. Kirwan, 1990).
However, thus far the HRA has mainly concerned itself with the high risk, high technology industry sector, including nuclear power plants and chemical plants. In this situation the high risk is caused by a very small probability of an accident with many and serious consequences. In traffic, on the other hand, the high risk incurs via a large number of 'small' accidents. Also the analysis of cognitive errors is a difficult problem for HRA that has not yet been resolved. Finally, in traffic the occurrence of errors may be strongly influenced by individual, organizational and socio-technical factors (e.g. social pressures). These factors and the errors they cause are rarely assessed in HRAs (e.g. Kirwan, 1990), yet clearly can influence risks. It is recommended here to describe a range of relevant components affecting human performance in traffic and the occurrence of driving errors.

One can argue that the allocation of causes of errors to people or technical parts of the system (e.g. infrastructure, skills, abilities) is a pragmatic question (e.g. Rasmussen, 1987). Rasmussen proposed a multifaceted taxonomy of human error. Firstly, it describes human malfunctioning in terms of factors affecting performance. Secondly it describes the causes and possible mechanisms of human malfunctioning and actual errors. Based on this taxonomy of human error, we made a distinction between three categories for description and analysis of events involving human error (see *Table 1*), namely: (1) conditions that may influence task performance, i.e. characteristics of the traffic environment, the task, and the individual driver (see a and b); (2) A task description at functional level (see c); and (3) a task description at behavioural level (see d).

Conditions affecting performance level	Functional level	Behavioural level
- Characteristics of the environment & the task (complexity) - Characteristics of the individual driver (age /experience/motives)	- Observing the environment (detection, perception) - Decision making (judgment) - Actions (implementation of responses) - Monitoring of consequences of actions and adjustment of actions	- Navigational tasks - Manoeuvring tasks - Control tasks
Causes of errors with regard to conditions	Causes of errors with regard to mental resources	Behavioural errors
- Sit.-/task- induced errors . too little information . too much information . ambiguous information - Person-induced errors, e.g.: (Individual error tendencies) . inexperienced drivers . elderly drivers . risk-seekers and risk-avoiders	- Lack of discrimination - Inattention . distraction . underload . boredom - Mental overload	- Omission of acts - Inaccurate acts - Wrong timing - Making of errors - Adaptive behaviours

Table 1. *Description of components affecting driving behaviour and causes of driving errors.*

3.1. Situation and task dependent variables that affect performance and errors

The information processing framework also allows us to categorize a number of situation-induced problems in task performance: Firstly, the situation provides too little information. Secondly, there is a surplus of information. Some traffic situations may supply too much information, which may lead to an information overload. Thirdly, the information provided by the environment is ambiguous, leading to conflicting actions.

Recommendation: research to assess the impact of driver support systems on traffic safety can usefully encompass the following areas:

- *area 1: The effect of driver support on the amount and quality of the information/feedback that motorists obtain while driving.*
  The support should be designed such that it improves the quality and/or quantity of information from the traffic environment with the aim to facilitate task performance (for instance by reducing the complexity of the situation).
- *area 2: the effects of timing and modality of the additional information or support need to be considered.*

3.2. Person-dependent variables that affect performance and errors

Furthermore, we should consider the interaction between the provision of driver support and person-dependent variables. In-vehicle information or support will not have the same effect on all drivers. Performance is influenced by individual differences in age, gender, driving experience, motivation and impairment. Also drivers' individual goals and expectation may play an important role. What may be enhancing for one driver, may impede the performance of another. The support system should recognize that different drivers will bring to the task different capacities and different a priori knowledge.
For instance, the presentation of information should be sensitive to other characteristics of the driver (e.g. limitations of elderly drivers), and to the influence of certain traits and motives (e.g. risk takers versus risk avoiders).

Recommendation: research to assess the impact of driver support systems on traffic safety can usefully encompass the following areas:

- *area 3: The effects of in-vehicle information or support in relation to drivers' (differing) skills, motives, abilities, knowledge etc.*
  It is expected that effects of driver support may be influenced by characteristics of individual drivers: e.g. driving experience, age, certain traits. While the support may be beneficial for one group of drivers, it may be ineffective or even dangerous for other groups of drivers.
- *Area 4: The effects of driver support systems on (loss of) skills, and dependency of support*

3.3. The driving task at functional level: the information processing framework

A central issue when investigating the performance of complex tasks from an information processing approach concerns the workload of the performer. In information processing theories it is assumed that cognitive processes take time, and that the mind is a limited-capacity processor. Relevant assumptions from an information processing framework are that (1) the quality of task performance is determined by limitations in the information processing capacity (resource limited), and by limitations in the information that is provided (data limited), and (2) tasks require 'resources', but task aspects can draw on different resources, in order to prevent interference (the multiple resource hypothesis).

Recommendation: research in order to assess the impact of driver support systems can usefully encompass the following area:

- *area 5: The effects of driver support on task performance, (i.e. observing the traffic environment, decision making, undertaking actions, and monitoring the consequences of actions), and the occurrence of particular types of errors:*

. distraction, lack of attention; poor discrimination;
. high workload
. underload

3.4. Behavioural errors

Human error can also be classified in terms of the behaviours of the driver. This will require a detailed task analysis. Actual performance can then be contrasted with the task analysis in order to reveal mismatches. This seems particularly useful when there exists a highly structured task description. One of the consequences of the identification of the three task levels is that it offers a means to measure effects of driver support systems by observing the occurrence of behavioural errors of drivers at each of these levels. For instance, at strategic level support to the driver may consist of navigational information. In consequent evaluation trials the number of navigational errors can be observed. The same is true for support on manoeuvring and control level. If the driver makes less errors this may be interpreted as a positive effect of the support. The success of this approach depends on our ability to describe and measure behaviour with regard to these aspects of the driving task.

Recommendation: research to assess the impact of driver support systems on traffic safety can usefully encompass the following areas:

- *area 6: Driving errors at navigational, manoeuvring and control level. In well structured tasks or specific traffic situations it may be possible to directly investigate the behavioural errors that drivers make. For these tasks or in these situations the impact of driver support can be assessed by studying possible reductions in the occurrence of these behavioural errors.*
- *area 7: Behavioural adaptations, compensatory behaviours; other side-effects (e.g. testing of the limits of the system.*

4. Conclusions

It is essential that we assess the impact that driver support systems have on traffic safety. However there are many ways of doing so. *Table 1* provided a means to structure some of the current approaches in this domain of research. The components, summarized in this table, draw on different theories of task performance and human error (see also section 2) and each may dictate a different line of research.

Firstly, the table mentions 'conditions that affect task performance', referring to characteristics of the task, the situation and the individual driver that may influence task performance. Causes of human errors may be related to these conditions of driving.
Secondly, it indicates that the driving task can be described in terms of the different functions. It distinguishes between four types of functions that drivers need to perform, i.e.: observing the environment, decision making, undertaking actions and monitoring the consequences of actions. Causes of error are related to the mental resources of the driver, and generally focus on issues such as: inattention, distraction, mental overload and underload.
Thirdly, the table indicates that the driving task can be described in terms of three main task aspects, i.e. navigation, manoeuvring and control. If the tasks or subtasks are sufficiently well defined, safety assessment can encompass studies that focus directly on the occurrence of specific behavioural errors with regard to these three task aspects.

4.1. Developing a standard evaluation strategy

The selected evaluation strategy will, however, also be influenced by other factors, i.e. the type of support system under investigation, the context of evaluation. Supported by the European Community, some attempts have been made to develop ways to systematically assess how the provision of driver support affects the performance of the driver. One of those projects (i.e. the GEM project) has identified an evaluation method for (integrated) driver support applications (the EPM). The EPM identifies a number of different stages (see *Figure 1*) (e.g. Risk, 1995; Melchior et al, 1995).

4.1.1. *GEM*

In short, the project proposes that definition of the *evaluation project* is the most important stage of the evaluation process. In this stage one should clearly define the objectives and constraints of the evaluation project. Knowledge about constraints of the evaluation project is of crucial importance because time limits, cost, personnel resources, and other constraints may reduce the set of applicable evaluation methods. Definition of the *evaluation scenario* requires that we specify the type of evaluation scenario and the object of evaluation in as much detail as possible.

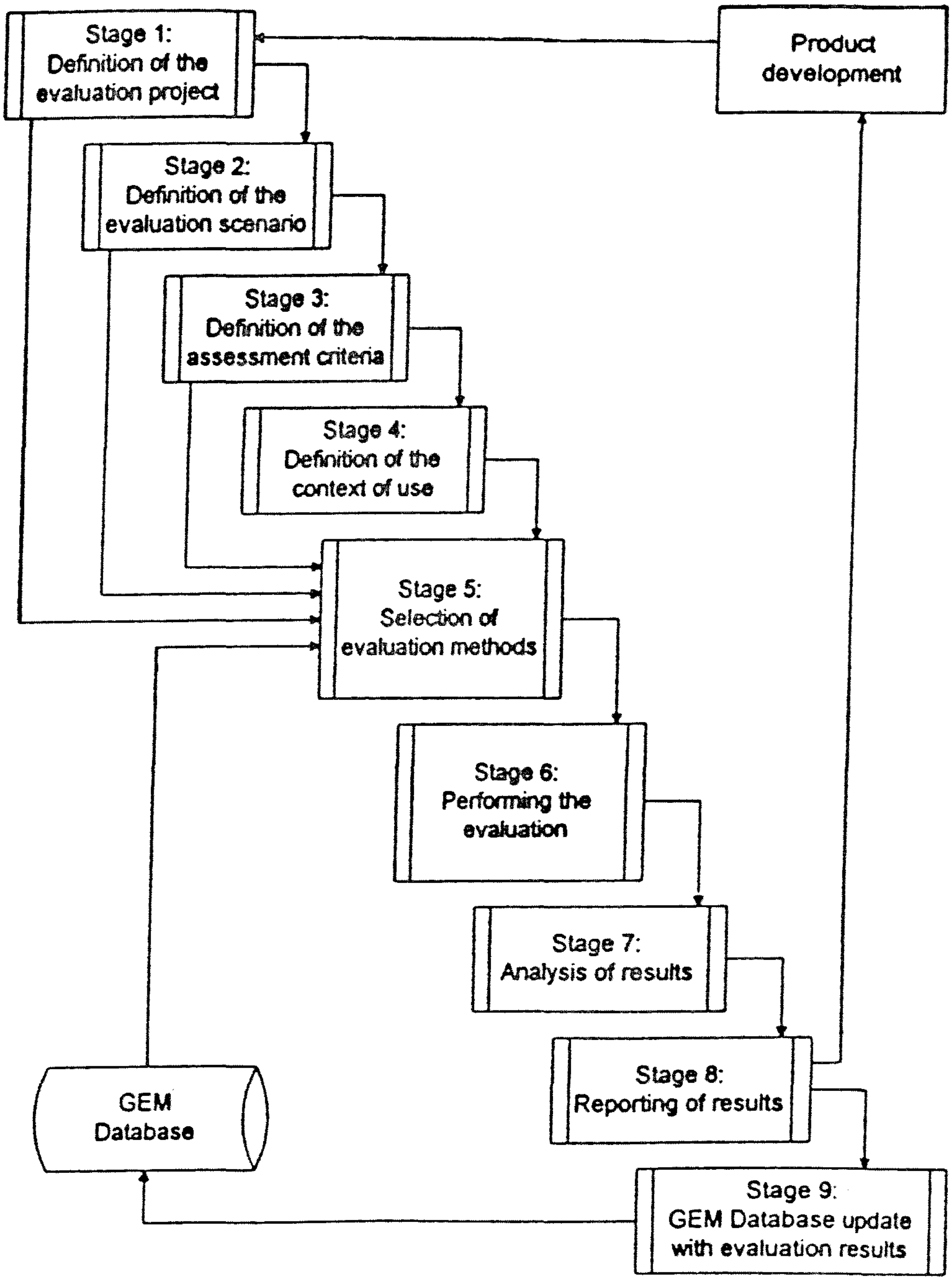

Figure 1. *The stages of the Evaluation process Model (Melchior et al., 1995).*

The next step involves a precise description of the *assessment criteria*. Assessment criteria are the values for relevant measures, which are used for the assessment of the system. Based on existing knowledge and a number of experiments, the GEM project constructed a preliminary knowledge base of assessment criteria that may prove to be useful in a wider context.
Definition of the *context of use* should describe the target group (i.e. drivers who will use the system), the tasks which the drivers intend to perform with the system, the environment, the traffic conditions, and properties of the car in which the system is implemented. Once stages 1 to 4 are sufficiently precise and complete the appropriate *evaluation methods* are selected.

In the GEM project it is proposed that the selection process makes use of a specific database (GEM methods database). *Evaluations* can then be performed. The evaluation results are *analysed* on the basis of the assessment criteria described in stage 3, and results are *reported.*

It is expected that a general methodology like the EPM can assist us in structuring the evaluation process, and in selecting the appropriate approaches and methods for the evaluation of different types of systems. This, however, will require some further study.

4.1.2. *HOPES*

Another project supported by the European Community, i.e. the HOPES project (Horizontal Project for the Evaluation of Safety), investigated the feasibility of evaluation work of advanced transport telematics. The project begins with indicating that: "A potentially difficult area to assess is how safe an RTI is likely to be in the real environment. There are three reasons for this: (1) accidents, the direct measure of safety, are relative infrequent occurrences in terms of vehicle kilometres, (2) large samples would be required to identify with reasonable confidence a modest worsening of safety, (3) it is often difficult to attribute the cause of an accident to a particular factor. This means that the safety aspects of RTI systems must be investigated by other means...".

The project proposes the following four main steps of an evaluation procedure. Firstly, hypothesis generation concerning possible safety effects of the system in question. As it is seldom possible to use the primary indicator of safety, i.e. an accident, it is of primary importance to formulate hypotheses on the mechanisms of the possible safety impact so that the right intermediate indicator can be chosen for the evaluation. Usually an ATT system has a number of possible positive and negative effects on safety. Effects may also differ in relation to road user group, road environment, weather condition etc. The final total impact will thus be the sum of various effects.

Secondly, designing methodology to test hypotheses. Methodology is defined as the formulation of systematic procedures for the testing of hypotheses. A distinction is made between four main tasks, namely: types of evaluation (interview, field studies, laboratory studies), study design, methods and tools for analysis, and planning of data collection. Thirdly, implementation/ use of methods, and fourthly, analysis and interpretation of results.

Furthermore, the project identifies areas of possible safety impact. For instance, studies should investigate direct effects of an in-car system on the user (modification of the driving task); indirect, behaviour modifying effects of the system on the user and on the non-user; modification of interaction between users and non-users (including vulnerable road-users); and modifying exposure (frequency or length of travel) or modal choice. The general conclusion is, however, that safety evaluations are feasible and highly relevant (Rothengatter et al, 1993; HOPES, 1995).

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