11. WHAT CAN WE LEARN FROM DRIVER BEHAVIOR AND ACCIDENTS IN ORDER TO DISCUSS THE RELEVANCE OF NEW TECHNOLOGIES

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SUMMARY

DRIVE and *PROMETHEUS*, two current European projects, are focussed essentially on problems relating to the design and integration of driving aids. This paper will firstly provide an overall outline for the analysis of driving situations and driver activity. The conclusions of three studies intended to evaluate driving aids and which reveal several aid-related difficulties will then be examined. Finally, using the results of accident analysis in the specific situation of controlled intersections, we will discuss the difficulties and questions raised when designing new driving aid devices.

11.1. INTRODUCTION

Drive and Prometheus, two current European projects, are focussed on problems relating to the design and integration of driving aids. In our opinion, the first stage of aid design is to obtain information on the essential features of the task and its malfunctions. This design must then be based on a detailed definition of aid requirements, using an analysis of driving situations and driver activity. We will first present a general framework with which to analyse the driving task and driver activity, together with a preliminary definition of driving aids. The conclusions of driving aid evaluations will then be briefly examined, so as to pinpoint certain aid-related difficulties. We will then develop, for purposes of example, the main results of accident analysis in a specific road situation, controlled intersections. This will then be used as a basis of discussion in dealing with the problems raised when designing new driving aid devices.

11.2 DRIVING TASK AND DRIVER ASSISTANCE : A GENERAL FRAMEWORK

11.2.1 Aspects of the driving task

Research in this field has led to the identification of certain characteristics associated with the driving task that may serve as a general framework to analyse activity and examine the problems raised by the designing of new driver assistance modes.

Driving is generally defined as a complex task of a dynamic nature, which is subject to temporal constraints, requires the driver to adapt continuously to the different and changing road situations he encounters, and involves the coordination and execution of various sub-tasks

[Allen et al., 1971; Neboit, 1982; Van der Molen and Bötticher, 1988]. Furthermore, it is relatively unstructured [Saad, 1975] in the sense that the formal task (such as it is shaped by the rules of the highway code) only partially defines the conditions and procedures for carrying out that process of adaptation. It is also unstructured in that all the road situations that can be encountered by the driver are extremely varied (in view of the many possible combinations of infrastructure, traffic and atmospheric conditions). The information required for journey management is essentially informal information [Neboit, op.cit.]. Finally, in view of present day driving instruction, it can be said that drivers learn to drive "by experience" [Groeger and Grande, 1991].

11.2.2. A driver activity analysis framework

The way drivers adapt through experience demonstrates their capacity to find heuristic solutions to the dynamic problems they are faced with in managing their journeys. Errors, incidents and accidents demonstrate the limits of that adaptation, the determining factors of which need to be analysed. Driver activity models have been widely developed and used in the field of road safety to analyse these adaptation mechanisms as well as human failure in accident occurrence [Schlensinger, 1972; Fell, 1976, Neboit, 1977, Michon, 1985; Malaterre, 1990; Van Elslande et Luber, 1991]. These are functional models, which formalise the different psychological activities brought into play when driving, the mechanisms by which the driver adapts to his environment and manages the various tasks to be performed when driving.

These models usually consider:

- Information acquisition and processing leading to a diagnosis of the situation.
- On the basis of this diagnosis, alternative action is suggested and, depending on the driver's own criteria, a procedure is chosen to control the situation.
- Implementation, which consists of putting into effect the actions defined according to the selected procedure.

Cognitive models stress the fact that all these briefly listed processes interact closely and are functionally linked to the knowledge acquired through experience and stored in the memory (the sum of organised knowledge of the system, its structure, road situation dynamics together with strategies for processing the information and rules of action). They emphasise the active nature of the driver environment interaction and the important role that representations may play when adapting to dynamic driving situations. In the field of cognitive psychology, the notion of representation refers to the idea of an internal model developed by the subject to deal with complex situations [Norman, 1983]. The symbolic structures that enable the subject to deal with such situations result from a construction based on an analysis of the situational data and the retrieval of stored knowledge, as well as on inferential mechanisms [Senach and Falzon, 1985, Falzon, 1989]. These representations serve as a guide for the planning and control of the activity. They thus play an important "functional" role [Leplat, 1985], in particular by enabling the subject to anticipate the result of his own actions, and to make predictions about the evolution of the situations in which he finds himself. The effectiveness of these representations depends on their homomorphisms with "reality".

In that respect, the driver's behaviour in a particular situation is regarded as a function of the information available at a given moment (both information actually present in the road environment and information stored in the driver's memory, acquired with experience), of its

processing and of the decision-making criteria underlying the regulating action he takes [Saad. 1991].
In view of this, ergonomic research for road environment planning and/or driving aid design calls for a joint analysis of the characteristics of road situations and of the driver activity mechanisms.

11.2.3 Driver assistance

In the framework defined above, this assistance can be generally described as an activity structuration aid or, more precisely, as a reliable way of directing the driver (both in space and in time) towards the relevant aspects of road situations that he must consider, if safety and driving are to be effective.

The activity can be assisted by adapting the road network characteristics, and developing building and planning standards so as to improve road "legibility" for the user [Fleury, 1990].

It may also be assisted by designing new driving aid systems. This line of action serves, in some ways, to mediate the interaction between the driver and his environment (infrastructure, traffic, vehicle, other users) by formalising a new source of information, aid devices. One can consider, with Bisseret et al [1980], this device as an interface between the designer and the user. Design problems then stem from the compatibility or not between the choice of the designer (filtering and coding information pertaining to the activity), and what the driver needs to achieve his objectives.

11.2. 4 Driving aid devices

The development of Drive and Prometheus, emphasises an increased need for an integrated approach when analysing these problems. This approach is indispensable, given the number of different aids considered in these projects. The purpose of these aids is to improve the performance of several sub-tasks such as speed control, controlling inter-vehicle distances, overtaking, crossing intersections, identifying and following a route, etc... [for further information on this refer to Fontaine et al, 1989; Lassarre, 1989; Fleury, 1990; Malaterre and Fontaine, 1992].

The concept of an "intelligent co-pilot" which helps the driver to manage all these varied sub-tasks raises the all-important theoretical and methodological problems encountered when analysing the task and formalising driver activity. It also emphasises the need for empirical data on which these formalisations can be based. To assign an "intelligent" function [Michon et al 1990] to these devices, implies that they are adaptable, i.e. they take the specific aspects of the different road situations into account as well as the driver activity characteristics.

11.3. EVALUATING DRIVING AID DEVICES IN ACTUAL DRIVING SITUATIONS

We will now give a short description of the results of three driving aid evaluation studies: two speed control devices and an anti-collision radar device [Malaterre and Saad, 1984; 1986]. These devices are already out-dated, as they appeared in the early 80s. As a result of the technical progress made over the past few years, it is clear that a number of defects that were noted at that time could easily be remedied. Other aspects, however, concern, on a more basic

level, the essential dimensions of driver activity that should always be taken into consideration. These are the points that will be dealt with in this paper.
These evaluations carried out in actual driving situations and involving experienced drivers (within the complex interactions that are to be found on the road) showed the difficulties and limitations of an a priori or unduly normative definition of aid requirements. In particular, they revealed significant discrepancies between designer and user objectives, that actually restricted the integration of "aids" in their activity and their acceptance. These discrepancies extend to both the priorities given by the devices to certain controls and the parameters of the situation being considered. Each of the devices studied favoured one of the "formal demands" of the driving task (respecting speed limits, maintaining "safe" inter-vehicle headways), prioritising them and fixing a threshold regardless of the diversity of situations and tasks that appeared to have a determining effect on driver controls. The problem encountered is the filtering and validation of the information provided by the devices in relation to driver objectives, the task being performed, all the information he acquires directly concerning the situation and the processing thereof. A greater number of parameters are taken into account by the drivers when characterising a given situation and assessing its "critical" nature, than are selected by the aid systems. Furthermore, drivers are more likely to base their decisions on whether or not to undertake a control action on a diagnostic of the possible evolution of the situation in hand, than on its instantaneous characteristics.

The problems encountered can therefore be seen in terms of compatibility between the choices made by the designers, and the needs of the user to reach his objectives, and are a reflection of the discrepancies that are often noted between the "prescribed task" and the "actual task", as differentiated by Leplat and Hoc [1983].

These briefly summarised results raise the question of the psychological relevance of the choices made with regard to driver aids. They emphasise how difficult it is for the driver to integrate and co-ordinate the different items of information when driving (information taken directly from the "situation", usually informal, and "formal" information provided by the devices). This is an indication of the major problems encountered when defining a function able to provide assistance, viz the circumstantial and temporal management of the information to be supplied to the driver in the dynamic driving process [Saad and Malaterre, 1989].

11.4. ANALYSIS OF DRIVER ERRORS IN ACCIDENTS AT CONTROLLED TRAFFIC JUNCTIONS

Accident analysis (and in particular driver "error" analysis) provides a useful indication when identifying aid problems. It is a way of revealing the underlying accident occurrence mechanisms and can be used to identify driving situations that, from a safety standpoint, are particularly critical [e.g. Malaterre and Fontaine, 1992; Van Elslande and Nachtergaele, 1992].

This section of the paper will present an example of an accident analysis at controlled traffic junctions. The situation being studied is relatively complex: it takes place in an urban context and involves essentially multiple interactions between different user and space categories (pedestrians, two-wheelers, light vehicles,...). Traffic control at junctions manages the interactions between road users in space and in time. The formal rule, set up by this regulation, relies on a simple and univocal principle. In practice, driver activities appear to be more complex than expected according to formal regulations [Hauer et al, 1988; Joergensen, 1988; Prashker and Mahalel, 1989; Robertson, 1991].

To obtain a better understanding of the processes involved in accident occurrence at controlled traffic junction, the results of four safety studies were re-examined. These studies came from different sources : Municipal Engineering Departments, The Ministry of Transport or studies carried out by INRETS [Ferrandez et al, 1981; Ferrandez et al, 1982; Fleury, 1983; Fleury et al, 1989]. They had different operational objectives: designing safe infrastructure, setting up information campaigns, in-depth accident analysis and overall safety diagnosis. We will try to categorize types of driver errors according to the mechanisms involved (perceptual or decisional) and to the spatio-temporal conditions of their production.

Before presenting the results of this analysis, we will indicate how the road situation being studied was characterised and describe the analysis schema on which this was based.

11.4.1. Intersection characterisation

The intersection is a place where traffic flows meet, and is, for the driver, an area of potential interaction with one or several other users [Saad et al., 1990]. Junction control defines the conditions in which this interaction takes place, by controlling the movements of the different users in time. For intersections controlled by traffic signals, this is done by phasing lights, thus regulating the timing and duration of the traffic flow. In movement dynamics, the intersection therefore represents a *change in the driving situation*, requiring the driver to adapt to regulatory and/or functional demands that differ from the preceding driving situation. An intersection approach area will be defined as a *transitional zone* in which this adjustment must be made. In this area, the available cues enable the driver to infer the type of control, the type of possible interaction and the regulating action to be carried out. Thus, before reaching a signal-controlled junction, it is possible, in the absence of advance signposting, to define this zone as the area in which the traffic signals and their colour are visible.

11.4.2 A scheme for accident analysis

Different research work carried out in the field of road safety does indeed indicate that the detection and processing of changes in situation is a particularly critical aspect of driving and should be analysed in greater detail [Rumar, 1991; Saad, 1989].

These changes in situation may, for the driver, be more or less predictable or expected, depending on whether or not he has available, as he progresses, the information needed to detect and identify them. The processing of these changes depends on a variety of factors such as the type of change (functional or statutory), the range, duration, temporal constraints and the specific driver criteria which direct his choice of regulating action to be applied to the different cases.

The following scheme is suggested as a guideline for accident analysis [Fleury et Saad, 1992].

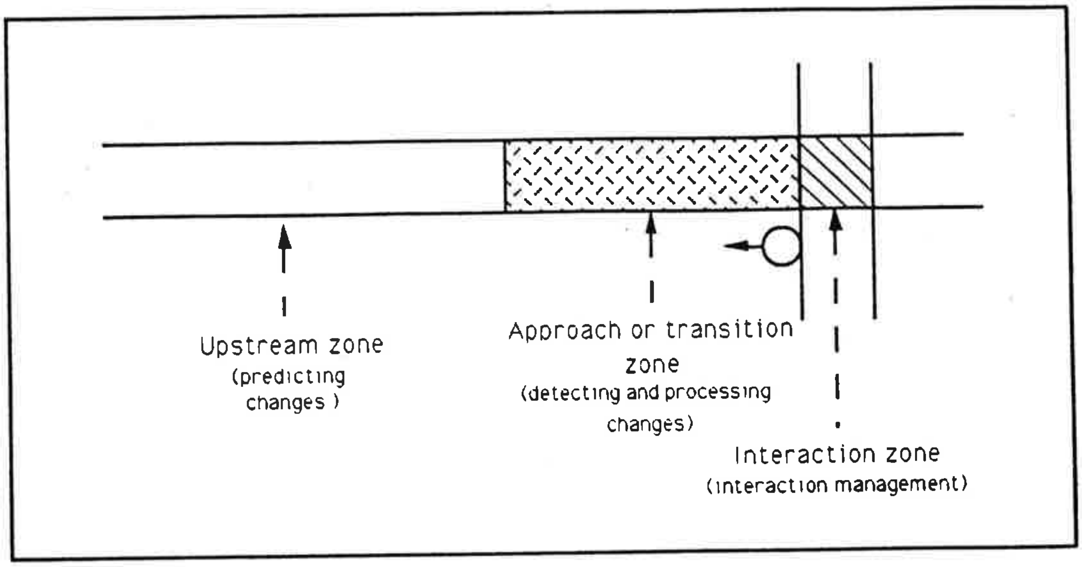

Figure 1: Interaction, approach and upstream zones

In this scheme, certain cognitive mechanisms were deliberately emphasized, as we think they represent the key stages when driving in this type of situation. It tries to take into account the dynamic nature of driving, and the temporal constraints which may influence driver activity. When analysing accidents, we were thus led to consider not only factors linked to the junction itself, but also those found before and on approaching the junction. This scheme formalises the questions that have directed our analysis:

- Could the driver predict the change in situation that the junction is supposed to represent ?
- Has the driver detected this change and how has he processed it ?
- How has interaction with other users at the junction been managed ?

11.5 MAIN RESULTS

On the basis of the schema described above, we have classified the malfunctions in three main categories depending on whether the problem encountered by the driver is related to situation change prediction, to the detection and the processing of this change when approaching the junction, or finally, to interaction management (actual or potential) at the junction itself.

11.5.1 Predicting a change in situation

The cases encountered involve coherency problems between certain types of roads and traffic signals, which is thus relatively unpredictable. For the driver, this results in either failure to detect, or delayed detection of a change in the driving situation.

Driving involves moving along different types of road. For the driver, this is a two-fold problem while driving: he must first recognise the next section, then predict that this section will be equipped with traffic signals. The recognition of a type of road depends on the type of area (open country, urban or semi-urban), the characteristics of the road and the immediate environment, together with the level and type of traffic and road usage. The network structuration is generally such that a certain type of road can only lead on to a limited number of other types of road. The characteristics of the road being used is therefore relevant when predicting equipment - in this case traffic signals - on the following road section. Traffic signals are installed essentially on urban through-roads. It is rare to find traffic signals in the open country, or on motorway type roads, where users expect to have right of way..

Some problems of prediction are to be found, particularly when the section linkage is not predictable during the drive.

Examples :

- There is often a safety problem when pedestrians leave a pedestrian precinct and move directly onto highly-trafficked roads.

- When entering a built-up area there are problems when changing from one type of prediction to another, and the first traffic signal is often difficult to negotiate.

- Another type of problem arises depending on the type of control, on a main road, eg "green waves". The user recognises a sequence of controlled junctions that enable traffic to flow freely. However, a green wave does not necessarily ensure that the driver will be able to continue without stopping, but he may not expect the signal to change to red (or may possibly refuse to stop) which modifies his strategy on this axis. This situation is more likely to be encountered when the traffic signals are close together. A good example of this is when lights are installed at junctions located at both ends of the same bridge.

11.5.2. Detection and processing of changes in situation

There is no problem of coherency between traffic signal control and the section of road the driver is travelling along or is approaching, but the user may not detect the junction or not see the signal. Several types of malfunction can be identified:

- *Detection of a junction*

A junction may not be perceived, as the relevant cues are not sufficiently obvious. In towns, a junction can be identified by a break in the alignment of the facades, indicating a side road and pavements running along it. It is also shown by markings on the road surface, perpendicular to the direction in which users are travelling. This applies particularly to two pedestrian crossings, one on entering and another on leaving a junction. Other cues may become relevant when travelling along a street. Thus, in a well-equipped area (systematic installation of posts equipped with traffic signals at junctions), a junction may not be detected if it is not as well equipped as the junctions through which the driver has previously driven.

- Detection of the signals

Some accidents occur when the signal is not sufficiently visible. This is just as likely to be due to masking (sign, vegetation, parked vehicle), as to insufficient light, a signal barely visible in the urban environment...

- Driver information search strategy

The information search strategy may not be adapted to detecting traffic signals. This is the case when the driving task is concentrated on interaction with other users on a link road. Two types of accidents fall into this category :

- Suddenly stopping some distance before the signal, in a line of traffic on a link road.
- A moped overtaking a line of stationary traffic is surprised by a user turning at a junction.

This lack of search for information also occurs in certain specific cases; when the street is familiar and when a traffic signal controls vehicles moving onto the public highway (fire station, hospital...). As the signal has always been a flashing amber light, the driver will no longer search for specific information, as this usually has no influence on the driving task.

11.5.3 Processing information at the junction itself and managing interactions with other users

The malfunctions dealt with in this context are not related to detection problems when approaching a junction. These have been clearly identified as such, and the signalling status on the branch road in already known. These problems arise more from the processing of information at the junction itself, and more specifically the management of interactions (actual or potential) with other users.

These malfunctions can be grouped under two main headings:

- The problems encountered by users stem from poor focalisation when acquiring information as they cross the junction, or incorrect positioning in the centre of the junction when performing turning manoeuvres, in the face of oncoming traffic. These problems are found particularly at main junctions with a large non-equipped central area. Other problems are linked to evaluating the speed of an oncoming vehicle (particularly motorcycles) ; once again when performing turning manoeuvres.

- The second heading groups together the problems that arise when users do not take into account the formal rule which is intended to manage interactions between different users by controlling the order in which they cross the junction. This often applies to pedestrians or 2-wheelers that take advantage of their small size and relative mobility to adapt to this specific situation. These users seem to consider that traffic signals apply more to motorists than to themselves, and so frequently fail to take the formal rule into account. The strategies they use are based on traffic rather than on signal status. This also applies to drivers of light vehicles who allow themselves to deviate somewhat from the rule and, using their knowledge of the signal sequence, continue to cross or anticipate moving off, taking a chance on the way others will behave. This applies particularly when lights are just changing. It is worth noting that in interviews carried out as part of the In-depth Accident Study [Ferrandez et al. 1986], there was a clear difference in driver attitudes towards crossing on a red light, depending on whether this occurred at the beginning or at the end of the sequence. In the latter situation, although they are anticipating the green light, users do not feel they are breaking the rules, and justify their behaviour on the basis that the signal for oncoming drivers is red. It can therefore be seen that under certain conditions, drivers show a certain laxity with regard to the prescribed task, by loosely interpreting the formal rule and taking into account cues other than those intended to help them carry out this task, such as signal status and/or vehicles stopping on side roads. This laxity is based on a knowledge of the signal sequence (full red light), as drivers think they can cross the junction before users on the side roads move off and, paradoxically, expect that other users will respect the formal rule.

11.6. DISCUSSION

The road situation under consideration was deliberately selected as being one of the most complex. It has been presented here as an example, to illustrate the difficulties encountered when designing relevant aid devices, in view of the questions raised in analysing a specific situation and driver activity in this same situation.

This complexity is seen in the diversity of the malfunctions identified, which affect user information processing when driving and which differ in several ways (non exhaustive). To take them into account may raise several different types of assistance problems:

- depending on the spatio-temporal dimensions in which they occur: some information would have been required well before the intersection, other information is lacking at the intersection itself or at its immediate approach.

- depending on the type of "human failure" identified: in certain cases these failures are linked to a lack of information (present or not, looked for or not,...) or processing difficulties, others are linked to an unexpected or inconsistent usage (in terms of the prescribed task) of available information. In other words, some may be classified as "errors" (or unintentional behaviour) and others as "violations" (deliberate behaviour), as differentiated by Reason et al (1990).

- depending on the type of interaction involved: interaction with the road infrastructure (whether detecting an intersection, its layout or yet again a specific situational factor, traffic light status), interaction with other users (whether evaluating their movement dynamics or predictions, or expectations as to their intentions and behaviour).

- depending on whether these malfunctions concern the performance of a specific sub-task or the management of different sub-tasks during the driving task.

It is obviously not possible, within the scope of this paper, to discuss these different driver assistance dimensions and implications in greater depth. It should, however, be noted that, when dealing with aid design, the dimensions dealt with in this paper lead to the following questions:

- When should assistance be provided for it to be relevant to temporal constraints ?
- What should the role of this assistance be: preventing errors and/or preventing violations ?
- At what level should assistance be provided: a road "reading" aid, an aid for inter-user interaction management, and how to link together these different levels which, during driving, are often closely interconnected ?
- Should it encourage the performance of specific sub-tasks and/or assist the organisation and management of all tasks when driving?

These questions are all-important, not only in terms of technical feasibility but also seen from what one might call an assistance "philosophy", which is expressed in the choice and weighting of criteria such as safety, mobility, the extent of freedom given to the driver, etc... Some of these questions have already been considered and discussed [e.g. Malaterre, 1990; Malaterre and Fontaine, 1992; Van Elslande and Nachtergaele, 1992]. Here, we will indicate only some of the methodological aspects used to identify assistance requirements based on accident analysis studies, and discuss a significant problem which arose when evaluating driving aids, i.e. the circumstantial management of the information to be transmitted to the user.

It should firstly be emphasised that the assistance needs that could be deduced from this analysis obviously reflect the model that was chosen, which helped when classifying the malfunctions. The model selected stressed certain cognitive mechanisms that we assume play a determining role when driving. This led us to consider, when examining the situation, not only intersection characteristics and the events that occurred there, but also prior characteristics and events (1) .

Only to list the step by step correspondance between the malfunctions identified in the accidents, and "aid requirements" would be, in our opinion, an overly simplistic approach. To be able to identify malfunctions when predicting or detecting a change of situation does not necessarily mean that all changes in situation require internal assistance.

As an example, Mazet [1991] has shown that drivers structure examples of intersections into categories, according to "family likeness", and that examples of these categories are not all the same, but are distributed according to a typicality continuum. In other words, certain intersections are more easily "recognisable", and therefore more quickly detected insomuch as they show perceptive and functional characteristics "typical" of their category, that cannot be found at other intersections. Driver "information needs" to detect a given intersection will not, of course, be the same for every intersection. They will vary according to the specific characteristics of each intersection and its approaches. This is where the main difficultiy lies in designing driving aids: that of the selectivity of the information to be transmitted to the users [Mazet and Saad,1990], if undue redundancy is to be avoided (in relation to the actual information to be found in the environment and user knowledge).

Evaluating aids in actual driving situations has shown that drivers filter and validate the information provided by the devices being considered, in relation to their objectives, the on-going or projected tasks and all the information that they have acquired directly about the situation. It would seem at present difficult to design aids which take into account driver objectives or intentions and the procedures they use to organise tasks when driving. Similarly, it should be assumed that direct information about the environment will continue (it will be a long time, perhaps never, before a vehicle will be piloted automatically). The question of the information to be transmitted through aids can, therefore, appear to be justified in terms of its complementarity to the information already available, the way this information is processed by the driver and the difficulties observed in this respect. This assistance could therefore be the taking over of specific processing, known to be difficult to perform in certain conditions (e.g. evaluating certain dynamic parameters).

It could also help to extend the spatio-temporal field of driver control [Leplat,1985] by providing him with access to information he does not have at the present time, as it is outside his "possible field of control" (distance, masking, visibility) or, yet again, by providing information on certain events with which he is unable to deal, because of their somewhat unpredictable, infrequent or "atypical" nature.

This assumes selectivity, flexibility and a choice of priority in the information to be transmitted to users and involves close links with road network "design logic" and planning [Fleury and Dubois,1991], together with knowledge of user information processing procedures or, more generally, "user logic" (whether mental representations used for control purposes or control strategies applied when managing different driving situations, [Mazet op.cit., Saad et al op.cit., Mazet and Saad op.cit., Saad,1992]**(2)**

11.7. CONCLUSION

The questions raised with regard to the potential development of new technologies are complex. Their processing demands a mobilisation and a more detailed knowledge of driver activity as it is performed at the present time with a view to identifying possible "needs". It also involves predicting the effects these devices will have on this activity, once they become part of the driving task. This prediction is all the most difficult because, at the present, the specifications of these devices are far from being clearly defined.

Using a categorization of the malfunctions identified by the analysis of accidents in a given road situation, traffic light controlled intersections, our aim was to illustrate the difficulties found when designing appropriate aids with regard to the questions raised, and provide suggestions as to ways in which this work could evolve.

To be effective aid design cannot dispense with a prior analysis of the mechanisms applied by drivers when managing their journey. This is, for the most part, the analysis of the different driving situations and the activities used by drivers to control them which will, in our opinion, make it possible to reach an optimal balance between means and needs **(3)** .

The psychological analysis of human error, the focal point of driver assistance philosophy, assumes that knowledge of the activity mechanisms which governs their production is available. In view of this, it would seem essential to consider accident and driver activity analyses as complementary approaches, which should be closely associated [Leplat,1985]. The in-depth analysis of road situation characteristics which, as already indicated, are extremely diverse should help to prepare the study and evaluation of incorporating these new devices into the complexity of the interactions involved in actual driving situations.

(2) - This is no way prejudges the use the driver will make of it and the consequences in terms of safety. It has already been seen that, in certain cases, the problems encountered were linked not to a lack of information about the situation, but incorrect use of the available information (either remembered or in the environment). There may therefore be a contradiction between the aid system objectives and safety imperatives.

(3) - It is obvious that no matter what degree of precision is used to study the present situation, it is extremely difficult to predict both qualitatively and quantatively the modifications in activity that these devices will produce. Only the follow-up and iterative evaluation of the effects of incorporating these aids into the driving task will make the detection and possible consideration of any adverse effects possible.

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