# Multiple Driver Support Systems and Traffic Safety

R-96-52
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Leidschendam, 1996
SWOV Institute for Road Safety Research, The Netherlands

# Report documentation

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| Number: | R-96-52 |
| Title: | Multiple Driver Support Systems and Traffic Safety |
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| Research manager: | S. Oppe |
| Project number SWOV: | 54.510 |
| Project code client: | VL 96.501.50 |
| Client: | Minstry of Transport and Public Works, The Transport Research Centre (AVV) |
| Keywords: | Driver information, traffic, safety, driving (veh), error, behaviour, driver, specifications. |
| Contents of the project: | This project is aimed at investigating the effects on road safety of various applications of Advanced Traffic Telematics (ATT systems) intended to support the driver in different aspects of the driving task. Such ATT systems are being developed (or are already on the market) e.g. to provide up to date route information, to maintain a constant speed and headway, to adapt the maximum speed to the local limit or to prevent collisions etc. Although many of those support systems are intended to make driving easier or safer, they can also change or extend the driver's tasks in such a way that safety is impaired. This project aims to develop a checklist and a test-bed for structured field testing in order to assess these adverse safety effects. |
| Number of pages: | 18 pp. |
| Price: | Dfl. 15,- |
| Published by: | SWOV, Leidschendam, 1996 |

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# Contents

# 1. Introduction

This report is part of a project instigated by the Transport Research Centre of the Dutch Ministry of Transport and Public Works. The project is aimed at investigating the effects on road safety of various applications of Advanced Traffic Telematics (ATT systems) intended to support the driver in different aspects of the driving task. Such ATT systems are being developed (or are already on the market) e.g. to provide up to date route information, to maintain a constant speed and headway, to adapt the maximum speed to the local limit or to prevent collisions etc.
Although many of those support systems are intended to make driving easier or safer, they can also change or extend the driver's tasks in such a way that safety is impaired. This project aims to develop a checklist and a test-bed for structured field testing in order to assess these adverse safety effects.

The project extends over a period of three years and is divided in three stages:
- the first stage is an inventory of existing knowledge on the subject and the preparation of a first round of experiments; this stage has been executed during the course of 1995;
- the second stage comprises execution of the first experiments, a theoretical study of simultaneously operating systems (the current report), an integration of all results so far and the preparation of a second round of experiments;
- the third stage contains execution of the second round of experiments and a synthesising report on the overall results.

The overall aim of this research is to provide policy makers with a well-based tool to assess the safety-effects of existing and new telematic systems in road vehicles. The project must result in a set of guidelines and methods to identify potential safety hazards that single or multiple applications of these ATT systems may produce.

The current report concerns stage 2 of this project and considers the possible safety effects of *simultaneously* operating support systems. It is expected that the addition of more, but independent, ATT systems in a single vehicle may not only have safety effects originating from each of the separate systems but can also have additional (mostly detrimental) effects due to interference of the systems or the resulting tasks.
This report was originally foreseen to be predominantly a literature review. However, relevant findings in the field of road traffic were very few. Therefore this report has turned into a brief theoretical study into these problems and an inventory of possible mechanisms that may cause these problems. The general ideas for this study were mainly derived from experiences with automation in other fields like aeronautics and reactor safety.
It is intended as a basis for further discussion and possible subsequent preparation of practical experiments.

# 2. Literature findings

For this report, in the first place a short literature survey has been conducted in the standard resources of SWOV: the IRRD and SWOV libraries which yielded mainly references to DRIVE and PROMETHEUS projects.
Although there is a vast body of publications on ATT systems in general, all allegedly dealing with the topics 'traffic safety' and 'electronic driver support', practically none address the problems generated by simultaneously operating but functionally different systems directly. Only few references in a total of over 100 somehow approach this problem. These papers mostly stress the need for an integrated and harmonised system (Horn, 1986) to channel the information provided by all available sources. Most often, the reports propagate the sharing of a user-interface between various ATT functions for reasons of economy and efficiency and a few mention scheduling of interrupts as a desired characteristic of the interface (Hancock & Stackhouse, 1992; Parkes & Franzen, 1993). The ICE Code of practice and Design Guidelines for Driver Information Systems (Southall & Robertson, 1994) contains no direct recommendations for simultaneous systems. There is a reference to the HARDIE project of DRIVE : in a progress report (Collins, 1993) the question is put up how to deal with combinations of systems, in particular since it is suspected that combinations may lead to overload of the driver, but this question is referred to later research.
Two sources have been found to deal directly with possible problems that may be induced by multiple information devices and possible solutions: is the GIDS project (Michon a.o., 1993) and the GEM project (Generic Evaluation Methodology for integrated driver support applications).
In short, the setup of GIDS implies, that messages from various sources should be tightly controlled by a sophisticated system: the dialogue controller. One of the functions of this controller is to constantly assess the current workload generated by the driving task and decide on the basis of this assessment what sorts of interrupts are allowed if at all. So all messages (interrupts) are prioritised and scheduled, making it impossible for any single application to go around this scheduler.
The GEM project (McMurran, 1995) also recognises the problem of system interference and approaches the problem from a slightly different angle: it tries to formulate a research methodology and criteria to establish which types of driver support systems can be integrated and which can not.

These projects indicate the concern for possible task load problems, specifically overload, induced by simultaneously operating systems. Also prioritising the messages is clearly seen as a problem. Furthermore, it is recognised that some combinations may have a detrimental overall effect and should be avoided.
Also, the GIDS systems implies very advanced technology in the dialogue controller to acquire all information needed about the current driving task. It is realistic to assume that such technology will not be commonly available for some time to come. The realisation of GEM integration of systems and display technology seems marginally closer in time but still will require considerable time to become available.
Yet in the meantime, development of all sorts of ATT systems will continue and they will be marketed as well, mostly separately. We assume here that

these developments will be largely independent, that is, that the ATT systems and their interface will not be developed according to an integrated approach. This causes a sort of random hierarchy in signals, depending on the individual 'mix' of support systems and within the field of road transportation there is no reference of how to handle such a situation. Some parallels could be found in aeronautics, where large scale application of automated support- and control systems has become a standard since the beginning of the 80's. Two important trends started at that time: the replacement of numerous analog instruments by a single CRT display (the 'glass cockpit') and allocating more and more detailed operational tasks to computers. The single display is supposed to handle all important information functions but it unable to present those all at one time: the pilot can choose between different groups of parameters. Summarising a review of a number of accidents and incidents related to the glass cockpit (Hughes & Dornheim, 1995a, 1995b; Phillips, 1995) the following general conclusions can be drawn:

- The sophistication of the automated systems is such, that pilots often misinterpret the current state and inherent assumptions of the automatic controllers, even if the relevant parameters are displayed on the CRT; this is probably caused by the difficulty that human users experience with accommodating all possible states in a valid internal model thereby making the support systems only partly predictable.
- Even if all information is divided in separate 'screens', the CRT picture is often crowded and it is hard for the pilot to extract all information that is needed at any moment.
- The concentrated display causes a general increase in task load, leading to a variety of symptoms including errors.
- Flight management and map displays have been found 'addictive and compelling' causing distraction which contributes to a general lack of awareness of important parameters.
- The multitude of possible alarms and the relative high frequency of alarms often causes reduced awareness or even total neglect of the phenomena they warn about.

The problem with multiple alarms is also evident in some industrial disasters like the Three mile island nuclear disaster. In an analysis used in a post-academic course (Hale, 1996) it is shown that halfway during the prolonged series of mistakes and misinterpretations that led to the disaster, a great number of alarms came on. The fact that these alarms indiscriminately concerned both minor and major aspects of the nuclear installation made it practically impossible for the operators to assess the correct consequences and the alarms merely contributed to the general confusion.

It is of course not possible to translate these findings directly into consequences for the problems of support systems in road traffic. They do support, however, the concern expressed by GIDS about increased taskload and the necessity to prioritise alarms. Also questions of dependency on complicated automatic functions, functional confusion about the operational status of automatic systems and the general possibility of distraction from more important tasks may be relevant to our problem.
Finally, dependency on automatic systems may produce dangerous underload; automatic systems that function correctly most of the time may induce a lack of attention or even a degradation of skills because the human

operator will rely on their actions, whether this be autonomous control or timely warning. Then, in the event that a situation occurs that lays outside the operational range of the automatic systems, the human operator may be too late or even altogether unable to cope with the situation.

On the basis of these considerations this report tries to provide an analysis of those combinations of systems or system properties that are most likely to provide difficulties.

# 3. Characteristics of support systems

In this chapter the way in which single support systems can operate is analysed in terms of a set of main characteristics and their influence on the taskload of the user. Taskload here will be interpreted along the well known model of Rasmussen in which specifically the cognitive demands on tactical and strategic levels will be regarded as a the prime sources of task load. However, the possible link between elevated taskload and reduced safety is not the only relevant mechanism. Sustained low levels of task load, that may well be induced by increasing the number of automated systems, must also be regarded as dangerous due to lack of attention, sleepiness or even (in the long term) loss of certain skills.

Furthermore, it is possible that support systems cause a distraction from the primary task which is in effect a substitution of the primary task by another one; this needs not result in increased workload but may very well be dangerous. Therefore some important characteristics will be analysed in terms of task load and distraction and these findings will be used in the next chapter to structure possible conflicts induced by two simultaneously operating systems.

## 3.1. Modality of the interface

The physical channel to convey information between the support system and the user may have three different forms:

- visual displays;
- auditory output;
- haptic information.

Each of these channels addresses a different input mode in the human operator. There are several problems that the human operator may experience due to the modality of interface alone:

- The visual channel is the channel that is predominantly used in traffic and additional use of this channel can lead to overload or distraction, which may manifest itself in a number of ways. However, due to this predominance the human operator is usually very skilled in processing visual information in all levels of the driving task, which may, in some cases, compensate the adverse effects somewhat.
  An additional aspect for visual displays is also the location of the display with respect to the visual scanning range of the normal driving task; a location well outside this range induces a greater distraction that a closer location.
- The auditory channel is much less used to convey meaningful traffic information (alarm signals and engine sounds mostly) and it therefore seems to have capacity for additional information. We can surmise that because the auditory channel plays a minor role and possibly only at the operational level of the driving may result in a longer learning period when providing extra information; however no reference to this effect was found. Furthermore it is known from experimental psychology that messages through one channel delay messages through other channels. Auditory stimuli e.g. may suppress visual information shortly and enlarge reaction times. Furthermore, auditory signals will soon be perceived as machine paced; even if the user can repeat the message at

will, the whole message must always be repeated whereas it is possible to sample parts of visual messages.

- The haptic channel is a complicated one because actually it involves a number of senses e.g. tactile, proprioceptive and balancing senses (acceleration sensors). These senses are all involved in the execution of different aspects of the driving task, especially on the operational level. How much 'room' there is to use this channel for additional information, and more specific: for information that involves processing on higher levels, is not clear.

## 3.2. Complexity and context of the messages or autonomous operations

The interpretation of messages and alarms, but often also the assessment of the consequences of the action of an autonomous system, nearly always demands some activity at the tactical level. How much activity will be needed depends for an important part on what may conveniently be called the complexity of the message. This 'complexity' itself is rather complex. There are several ways in which a message may be complicated which are related to the length of the message, the symbols used to convey the message, the familiarity of the message and consistency with the context of the current driving task.
Generally speaking we may suppose that long messages require more processing time and are a greater distraction than short one's. Also that the processing time of concise symbols (e.g. arrows) may be shorter than with written instructions with the same purpose. Moreover, some subjects will inherently (have to) attract more attention than others. Since this can either help to get a contextually correct message across or do the opposite: distract from more important duties (contextually incorrect) this subject deserves some attention.

To add to the problems of complexity, we find that it is not a stationary quality: experience with often occurring messages, however complex, may cause pattern recognition to replace semantic analysis and this will reduce the processing time considerably. Also a consistent relation between certain messages and certain traffic situations (contextual consistency) will have much the same effect.
Conversely, the occurrence of a well known message out of context or a superfluous message will probably lead to an increase in processing time (and hence distraction).
An other aspect is, whether the message is self-paced or externally paced: self paced messages enable the driver to postpone processing to a more convenient time (prioritising) whereas externally paced messages (as actions by autonomous systems always are) must be dealt with immediately, regardless of the current driving task.
In the latter case the message can also be completely or partly missed which can have negative consequences ( if this regards an auditory message, the question is raised if there is an optimal repeating frequency and how much repetitions are needed).

A special case in this respect is a false alarm or inappropriate action: these are potentially the most disturbing because of the extra time required to analyse the situation and judge the event faulty. The problem than can further be compounded in case unforeseen corrective actions are necessary.

## 3.3. Urgency of the message

ATT systems may operate on all sorts of parameters like external parameters (traffic conditions, infrastructural conditions, weather conditions etc.), internal parameters of the vehicle (speed, engine conditions etc.) and even parameters internal to the driver (medical condition).
Generally speaking, every message or alarm is associated with a specific timespan within which some action of the driver will be required (this timespan can be very long). Short timespans suggest higher urgency but this is only true if the consequences of exceeding the timespan or omitting the required action are unacceptable. Therefore urgency of the messages is here defined as being inversely proportional to the maximum allowed timespan, under the condition that omission of action or late action has unacceptable consequences.

## 3.4. Level of autonomy

An important characteristic to describe functional differences between support systems is the level of autonomy.
This level ranges from completely autonomous systems, like ABS or traction control, to systems that only provide information to the user, e.g. the indicators for water temperature.
Autonomous systems that exist so far operate only at the operational level of the driving task. New concepts of autonomous systems like AICC involve actions that also may interfere with the tactical level. As an example: a human driver may, during the execution of an overtaking manoeuvre, temporarily accept a very close distance to a preceding vehicle: a collision avoidance system, which does not accept this short distance, may interfere and make the overtaking manoeuvre impossible.
This will lead to adaptations by the driver at the tactical level of the driving task.

The type of system that to some extent relies on actions that the user must take when prompted by the system will presumably make out the majority of user support systems (at least on the short- and intermediate term) .
This action of the user may be completely optional, like following the instructions of a route guidance system, to more or less mandatory e.g. a collision warning or the warning of a major engine failure. This kind of system may interfere with all levels of the driving task.

## 3.5. Reliability of messages or actions

Reliability of support systems is a logical requirement but one that is not always easy to realise. An obvious demand is the correctness of the information or action provided. When the systems provides information, a more difficult condition is the timeliness of the information: the messages must be provided early enough for the driver to process the information and act on it. Timeliness however, is not only related to the event or situation that causes the message but also to the momentary taskload of the driver, which must be low enough to accommodate the processing and also high enough to be suitably prepared. Creating support systems that are unconditionally correct and timely, especially if we have to take into account possible interference, seems very difficult if not impossible.

# 4. Possible interference of two support systems

## 4.1. General considerations

In this chapter we will try to analyse the possible consequences of *two* simultaneous messages or actions by different systems on the basis of the four characteristics defined in the previous chapter. Interaction between more support systems than two can be analysed stepwise by comparing the third system with the two previous one's and so on. The possibilities of conflicts evoked by a simultaneous messages will be considered starting from a consideration of modality and than introducing the effects of possible combinations of other characteristics.
The reasoning in these considerations is based on the following assumptions and considerations:

- Safety can be impaired by any of a number of mechanisms:
  - by distraction from the driving task
  - by causing overload, resulting in all sorts of driver errors
  - by causing underload, resulting in too low levels of attention and even (in the long run) degradation of skills. This is specifically important if automatic systems are implemented to replace essential driver tasks e.g. maintaining/correcting the course.
  - by driver dependency on correctly operating systems; this makes it more difficult for the driver to recognise and counteract undesired effects of interference. This difficulty for the driver may be caused by the unexpected complexity of the interference, like sudden limitation of control options, which poses problems to even an experienced driver.
  - by failing to act appropriately on information with elevated urgency: this can be provoked by short available processing time or too much information (overload) causing the driver to misinterpret or even completely miss a message (there are several examples in civil aeronautics where accidents have been caused by the crew missing one of multiple high-priority alarms).

  These factors are also part of the factors considered in the effects of single ATT systems in the first phase of this project (Verwey, Brookhuis & Jansen, 1996; Kuiken & Heijer, 1995). The safety effects of two interfering systems can be seen as: the effect of each of the separate systems plus effects of the specific interference (these can be positive as well as negative with respect to safety!)

- Two simultaneous messages will have extended processing time (probably even more than the combined time for each system separately), thus increasing the distraction from the driving task

- The length of the distraction depends furthermore on the expectedness of the messages or actions

- Task load will always increase with simultaneous messages because there is always the cognitive problem of deciding which message to process first (prioritising); the extent of the increase depends (amongst others) on the complexity of the messages and on the urgency of both messages.

If elevated task loads occur regularly, this may also increase the general dependency on support systems

- Finally, there is the possibility that both messages are correctly assimilated by the driver and correctly interpreted, but a conflict exists between (parts of) the ensuing actions. For instance general routing instructions and local traffic control information may lead to conflicting directional information.

## 4.2. Systems using the same modality

In this type of interference, a single channel is shared between data sources. This does not automatically imply however that these sources also address the same *cognitive* resources (Verwey, 1991), in which case data processing need not be an extra problem. In general we may say that problems in this case may arise from three sources:
- confusion of data in the input channel which leads to misinterpretation, loss of data and may also require extra data-acquisition time ;
- problems in data processing if both sources address the same cognitive resources, in which case extended processing time will likely interfere with the scanning of the normal driving task;
- conflicts between the ensuing tasks.

These considerations form the background reasoning for the following paragraphs in this chapter.

### 4.2.1. *Auditory mode*

Auditory messages that occur simultaneously very probably lead to confusion which renders both messages unintelligible. Whatever the other characteristics of both messages are, the user cannot be expected to act according to either of them. The distraction caused can be considerable however, so the conclusion must be that *this type of simultaneity must always be avoided and is unacceptable*. If the messages are made to be self paced, care must be taken that simultaneous presentation is always avoided.

### 4.2.2. *Visual mode*

The possible effects of two simultaneous visual messages are less simple to discard because visual messages always are, to some extent, self paced (of course these messages are also temporary, but they can easily be made to persist for an acceptable period of time). Several types of interference can occur and even combination of some types:

a. Both messages are semantically simple and quickly assimilated: regardless of the urgency of either message there is a high probability that the driver will not experience an unacceptable increase in taskload due to the messages themselves.
   This means that there probably is sufficient capacity left for prioritising the messages by the driver. A problem with taskload now can only occur if the consequent actions or decisions of either (or both) of the messages involve considerable cognitive elaboration.

b. One of the messages or both are semantically complex or otherwise time-consuming. This implies a heightened taskload already generated by the messages themselves. Prioritising the messages will also add to the taskload which, in total, may lead to unacceptably long distraction from the driving task. Even if only one of the messages is complex, chances are that one of the two will be disregarded or insufficiently responded to, which is particularly unacceptable if the neglected message has a high urgency.
*High complexity in simultaneous messages should therefore be counted as unacceptable, especially if the urgency of (one of) the messages is high and regardless of whether the ensuing actions are simple or not.*

c. Both messages have high urgency: in this case it is relevant to distinguish between urgency related to the driving task or to the driver (medical condition) and urgency related to the technical state of the vehicle (e.g. impending engine failure due to loss of lubricant).
In most cases an urgency considering the driving task should prevail over the technical emergency and it can be expected that most drivers will prioritise the messages accordingly.
A problem with prioritising the messages may occur when both pertain to the driving task. *It should be regard as unacceptable if as a consequence the driver insufficiently responds to either of the urgent messages.*

d. Both messages are semantically simple, but one of them (or both) is false or unrelated to the driving situation: this will certainly create an elevated task load. It seems trivial to conclude that false or incomprehensible messages should always be avoided, but designing systems with such a specification is no trivial task.

### 4.2.3. *Haptic mode*

Although e.g. tactile messages may convey semantically complex messages, like in the use of Braille, this requires much training and far from a common application. In the existing concepts of haptic signals, this channel is used to convey only simple messages with a singular meaning. Following the reasoning from § 4.2.2 sub a, the use of two simultaneous haptic messages should not pose severe problems, provided the channels are physically separate (e.g. via hands and feet) and the messages are always kinked to the same type of response. Using the same channel however will soon result in confusion and unacceptable consequences.

## 4.3. **Messages with different modality**

Since the input channels in this case are separated there is no physical reason for confusion of input signals. But where visual messages and haptic messages can be made persistent so that they may be assimilated at a suitable moment, auditory messages are by nature transient. When these auditory messages occur during the processing of messages of other modalities the probability increases that particularly that message will be (partly) missed unless they can be repeated at will.

Then there are of course the problems already described in the previous paragraph which are also valid in this case: the problems caused by resource sharing, complexity and high urgency.

## 4.4. Interference with autonomous systems

Autonomous systems like ABS, traction control or AICC are usually intended to facilitate the driver's tasks or compensate for human limitations. Such autonomous systems may thus facilitate the use of other, non-autonomous, ATT systems by creating more room for the driver to deal with messages, which may rated a positive interference effect.

However, also negative effects of interference of autonomous systems must be considered.
In the first place there is the possible effect of two interfering autonomous systems. This concerns possible contradictive actions by the systems themselves e.g. simultaneous braking and accelerating or simultaneous steering and hard braking. Because the user cannot influence these systems directly but has to cope with the effects indirectly such actions are very confusing to the driver and this severely limits possible human corrective actions.
*For these reasons, this type of functional interference of two autonomous systems is unacceptable and should be ruled out by the manufacturers.*

In the second place autonomous systems, especially those that *facilitate* existing driver skills, may also evoke *dependency or degradation of skill* which may cause a special type of interference: the driver simply expects the system to operate in a certain way under all conditions and therefore also expects to have more time for other tasks.
Then, when autonomous systems fail or execute unexpected, unforeseen or undesired manoeuvres while the driver is processing a message from another device this may either disturb the processing of the message or the driver's response to the manoeuvres. Therefore the possibility of degradation of essential skills should be checked.

## 4.5. Other possibilities of interference

A single system may use more than one channel to convey its messages. Route guidance for instance, may make use of both visual displays (maps) for overall orientation and auditory instructions to follow a distinct route. Another possibility is e.g. auditory prompting to indicate a new visual message. It is clear that such systems are even more likely to interfere with other ATT systems present.

## 4.6. An interference check list

Most of the previous considerations can be summarised by the following flow chart. The flowchart is deceptively simple because it implies that *all* possible or relevant scenario's per pair of systems should be considered before deciding Yes or No in each step.

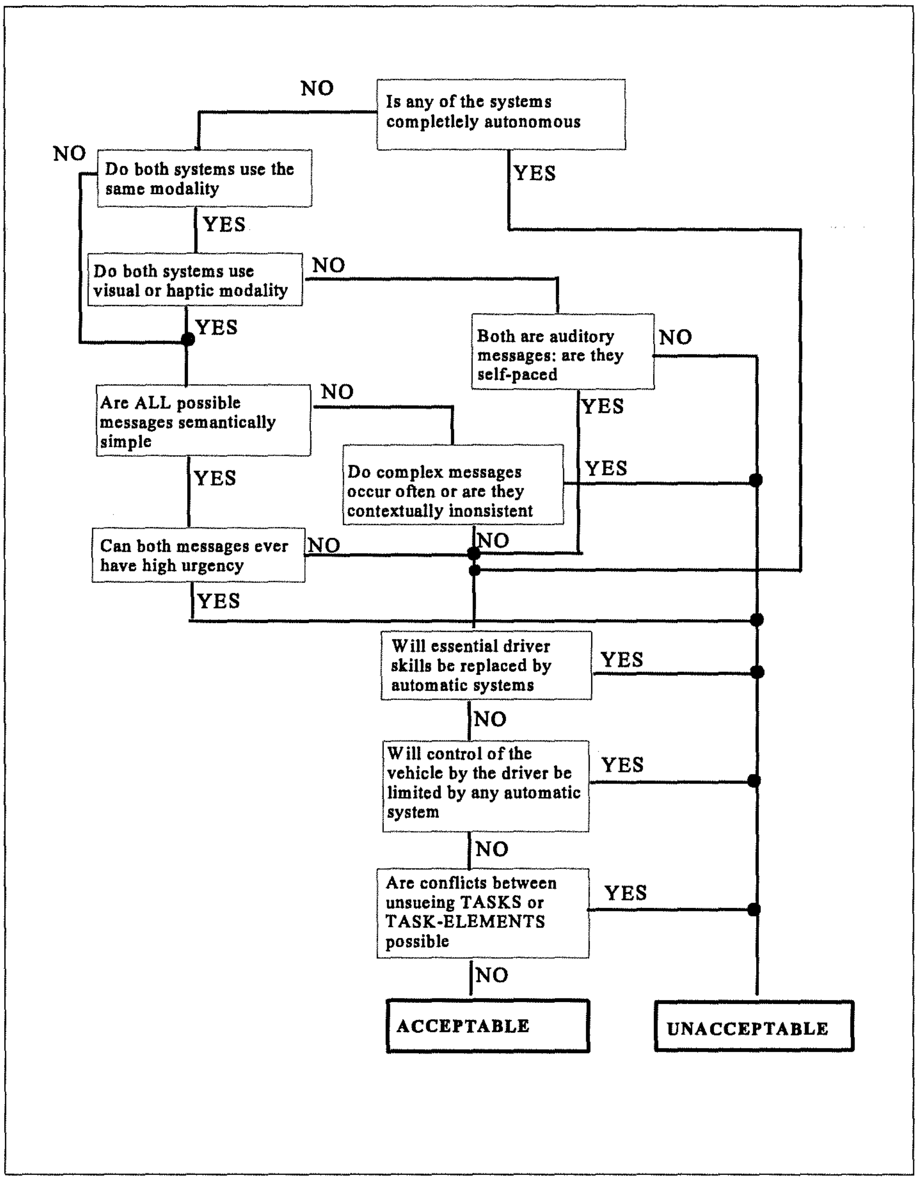


Figure 1. *Checklist for the assessment of system interference.*

# 5. Summary and conclusions

Electronic driver support in various forms is rapidly becoming a reality. It is widely recognised that these systems will change the driving environment in an number ways and that, apart from the intended benefits to the driver, unwanted detrimental side effects are possible or even likely. The current project, of which this report is a part, addresses these side effects in a broad manner; in the first phase of this study the possible deterioration of road safety due to single systems was investigated, in this second phase the possible detrimental effects of simultaneously operating systems are considered.

Although in the course of the DRIVE project the safety effects of simultaneous systems was mentioned as a potential problem by several authors, only the GIDS and GEM projects have developed a philosophy of how to deal with this problem. Their solution, an integrated scheduling and prioritising system, is rigorous and demands highly sophisticated equipment, which is not likely to be on the market very soon. It is more than likely that various support systems will be introduced far before an effective system will be available to organise the support.

Therefore this report tries to trace the consequences of simultaneously operating but otherwise unconnected support systems on a theoretical basis. To this end a number of possible detrimental effects on driver behaviour are postulated:

- task overload due to: time consumption by processing of messages, prioritising messages etc.;
- distraction from the primary driving task;
- too much dependency on support systems leading to underload and possible loss of skills;
- neglecting messages or actions;
- conflicting tasks;
- limitation of driver control.

*The general conclusion must be that there are many possible combinations of properties of commonly conceived ATT systems that lead to potentially unacceptable interference with the driving task and only few conditions where combined actions may be considered acceptable.*

The considerations lead to the conclusion that either completely integrated systems or a type of GIDS-like 'interrupt handler' will be required to avoid unacceptable interference. Where a full blown GIDS system, that prioritises messages according to momentary task load of the driver, will not be available for a considerable time, a practical recommendation is to develop a system that may accommodate separately marketed applications. This will require a standardised 'interrupt BUS system' to which separate applications submit their messages or actions, that will be transferred to the driver according to interrupt priorities fixed in advance.

This is analogous to the interrupt handling in computers, to which all support systems submit there message requests which are then processed according to a predetermined (by the user or manufacturer) priority; thus the processor itself never handles more than one message at a time.

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