ANALYSIS AND MODELLING METHODS FOR THE DESIGN AND EVALUATION OF AN ECO-DRIVING SYSTEM

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ABSTRACT: The modification of driving behaviour can generate fuel consumption reduction. From this point of view, our solution was to design a new automotive onboard system to modify the driving activity. This paper presents the framework adopted to analyse the domain of driver activity in order to define the preliminary specifications of the system design and evaluation.

1 Introduction

The driving task has become more difficult because the driver has to manage increasing traffic complexity on the road and various onboard systems integrated in modern vehicles. The designer of new systems has to take into account the variability and the multiplicity of parameters concerned in order to design systems where the cooperation with the driver and the distribution between these various tasks will respect the context of use. It is important to consider the interaction between the human and the machine in a dynamic environment such as the automotive domain in order to reduce human and system errors during the design process. Cacciabue and Hollnagel [1] make a review of main existing driver models. For these authors the most useful models for the analysis and the design are the models correlated with the paradigms of the vehicle and the environment (Driver-Vehicle-Environment: DVE). However, the authors specify that to use and select the adequate model, a preliminary analysis needs to be carried out to define the various objectives in terms of system design and evaluation. Consequently, designers need an analytical framework that enables understanding interaction problems with respect to domain specific parameters. Generally, models are too precise or are too targeted on the description of specific interactions or particular driving behaviours. These models do not provide a general analysis framework and an overall picture of the problem but give a specific answer to a clearly defined objective.

During the **G**lobal **E**ne**R**gy management and driver **I**nterface for a **C**itizen **O**ptimal driving behaviour (GERICO) project a preliminary analysis was done using a specific framework to understand correctly the domain activity in order to specify the design and the evaluation of a new eco-driving system. The goal of this project was to contribute to the reduction of fuel consumption and CO2 production by optimising on-board energy and designing an appropriate interface that enables the driver to adopt the best driving behaviour, smooth speed and appropriate gear management. A framework adapted from the AUTOS pyramid [2] was used to perform the preliminary analysis. This framework called “DRIVENTS” includes some existing models to explain some behaviours or specific interactions in the automotive domain. Using this framework, the designer can see the interactions between the agents of the domain studied and especially the links between these agents in order to understand and define the relevance of each one in the design and the evaluation of the human-machine interaction.

In this paper we present the DRIVENTS framework adopted to analyse the automotive domain. According to this analysis, we defined the objectives in terms of human-machine cooperation in order to select the adequate requirements for system design and evaluation. Analysing the domain activity (e.g. automotive domain) allows to take into account dynamic and contextual parameters and associated concepts. This approach considers that the analysis of the domain activity was used as a base to define the design model of the system in order to improve driving performance, comfort and safety of the driver.

2 Automotive domain analysis : DRIVENT framework

The DRIVENT framework (Fig.1) enables four main agents to connect in the automotive domain: the DRIver, the Vehicle and onboard systems, the ENvironment and the driving Task/activity. Each agent was defined by some characteristics. Drivers, and more generally humans, are characterized by the variability of their behaviour (inter-individual and intra-individual variance). In this sense, several factors can influence driver behaviour and are variable for each driver. Personal factors play a fundamental role in the driving activity: age, sex, driving experience, social attitudes, cognitive capacities or handicap. Situational factors depend on the driver’s psychological state at a given time. These factors are fatigue, motivation, stress, vigilance and emotions for example. The road environment is variable and complex and can be characterised by three principal components to define the road context: traffic conditions, climatic conditions and road infrastructure. The tasks and the activity represent the primary driving task and the secondary tasks associated (e.g. radio, phone…). Lastly, the vehicle can be characterised according to its type (4x4, compact…), its onboard systems and more generally by all its characteristics (weight, engine…). The analysis of the various relations between these four agents during the design process is multidirectional in the sense that each entity influences the other or involves specific relations that the designer has to consider in the automotive domain before the system specification.

Fig.1. DRIVENT Framework

- **Driver ↔ Tasks:** There are three interconnected levels proposed by Michon to define the driving task [3]: operational, tactical and strategical. The operational level is related to vehicle control and concerns very short-term actions (this level can be defined as skill-based according to the Rasmussen terminology). The tactical level is related to vehicle guidance and concerns short-term actions (rule-based). The strategical level is related to itinerary-following and concerns long-term actions (knowledge-based). Moreover, two other tasks were carried out by the driver during the driving activity. The tasks of driving indicators management (speedometer, engine, oil…) and the secondary tasks that correspond to manage different instruments like the radio, the onboard computer, the navigation system, but also instruments added in the vehicle cockpit such as the mobile phone for example. These systems are not essential for the driving task and provide information which should not disturb it. These different tasks involve the mobilisation of drivers' cognitive resources. Humans have limited capacities or limited attention resources. Driver attention corresponds to cognitive processes: as perception, access in memory, reasoning, control, decision-making, and actions [4]. The driver must share his/her attention and mobilize resources between these various tasks. The process of time-sharing represents the driver's capacity to maintain this attention between the various processes necessary to make the decisions and provide the adequate actions. Applied to the previous driving task analysis the driver must share these cognitive processes between five tasks, resulting in the limitation of available resources. These concepts are important for the designer because the addition of new onboard systems can increase the mobilisation of the drivers' cognitive resources.

- **Tasks ↔ Vehicle:** The driver interacts with the vehicle via the controls and with the various onboard systems that form an integral part of the vehicle. The driver is responsible for the management of these various systems. In some situations, this can result in a possible overload according to the contexts of use. The workload generated by the accumulation of tasks can have an impact on driver performance. Thus, it is important that the designer of new systems makes sure that operator workload is maintained on an acceptable level. Independent systems integrated in the vehicle can generate interferences with the driving tasks and can be an important source of distraction. Indeed, in double task situations, interference or competition for the resources between concurrent tasks need to be taken into account by the designer. According to Wickens [5], two tasks that share the same requirements of resources will be carried out in time-sharing with less effectiveness than two tasks that do not overlap. Thus, the designer has to select appropriate inputs/outputs and manage the role and priority of the different tasks to avoid possible coverings.

- **Driver ↔ Environment:** Situation awareness is defined by Endsley [6] as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future". Endsley defines three dependent hierarchical levels preceding decision-making and the action in dynamic situations: perception, comprehension and projection. Endsley's model is influenced by the external factors of the task such as systems which can influence situation awareness from their interface, interaction level, complexity, and by individual factors specific to each person, such as experience or training. The designer has to develop the system to reduce or to improve the impact on driver situation awareness. The driver is responsible for his/her mobility and his/her environmental impact on pollution, traffic or on the other road users. According to this point of view, the social interaction in the automotive domain is also a factor where the good citizenship of the driver plays an important role. For this reason, the interactions between the drivers are an integral part of the driving activity and can explain some driving behaviour. Onboard systems can have an impact on the improvement or the deterioration of the relation between the various agents of the environment. For example, the use of mobile phones or navigation systems can modify the driver performance (deceleration, approximate trajectory) and consequently impact on the other road users.

➢ **Driver ↔ Vehicle:** The link between the driver and the vehicle can be seen in two ways: the first is the direct interaction with vehicle controls and onboard systems and the second is the relation between the driver and his/her vehicle, for example paying more attention in town to avoid small collisions or on regular maintenance to reduce the risk of breakdowns. These types of behaviour can be considered safer while the opposite can contribute to increasing unsafe driving behaviour. The vehicle gives sensory feedback indications to the driver on acceleration, deceleration or the aspect of the road for example. This information is necessary to provide the driver with driving sensation. The concept of driving sensation can also be considered according to the vehicle type. The driving behaviour will be different if the driver has a sports or a city vehicle. Thus, it is necessary to take into account the driver/vehicle couple and the relation that exists between them to study and to understand some driving behaviour.

➢ **Environment ↔ Tasks:** The driver analyses environmental situations and takes adequate actions according to a given context. The environment can generate specific interactions and modify the task and the activity of the driver. The driver will react consequently while adapting to the external conditions such as climatic or traffic condition for example. This type of interaction is more a direct perception-action cycle and can correspond to the driver’s automated responses. We can take the example of an emergency action in a very short time like emergency braking or obstacle avoidance.

➢ **Environment ↔ Vehicle:** The relation between the vehicle and the environment can be seen by physical interactions (tires for example) but also by some onboard systems which communicate with the environment (electronic pricing or GPS). In the near future, it will be important for the designer to consider the possibilities of communication between the environment and the vehicle, generally called “Car to Infrastructure Communication” and communication between vehicles called “Car to Car communication”.

3 System design analysis : DRIVENTS framework

At the first stage of the analysis, four agents and their main relations were defined by the DRIVENT framework for the automotive domain. In the second stage, the DRIVENTS framework purposed to show the relations and the concepts linked to the integration of a new system in the vehicle in order to define the requirements for the system design and evaluation (Fig.2). The designer has to take into account the different agents to have a clear understanding of different parameters and variables involved in these relations.

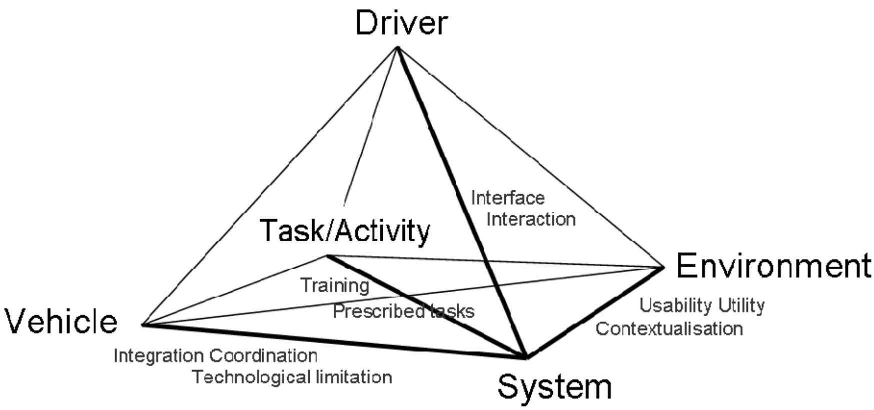

Fig.2. DRIVENTS Framework

The DRIVENTS framework (Table.1) resumes the different concepts coming from the DRIVENT analysis and the concepts used to design a new system to cooperate with the driver, the driving activity, the vehicle and the environment.

Table 1. DRIVENTS matrix (Top-down lecture)

	Driver	Vehicle	Environment	Task/activity	System
Driver	Dri	Driving sensation	Situation awareness	Cognitive resources mobilisation	Interface Ergonomic
Vehicle	Relational aspects	V	Communication Infrastructure	Vehicle & on board systems management	Integration
Environment	Social aspects	Mechanical interactions	En	Situated actions	Interaction & communication
Task/activity	Task & activity analysis	Role & priority	Reaction	T	Prescribed tasks Procedure
System	Interaction	Coordination	Contextualisation	Training	S

The DRIVENTS matrix shows the different parameters involved to design a new system such as integration, coordination, contextualisation, training, prescribed tasks, interface and interaction that the designer has to consider to improve the human-machine integration according to the concepts defined in the DRIVENT preliminary analysis, e.g. with respect to the agents of the automotive domain. In this chapter, we give an overview of different parameters that we took in consideration for the design of an eco-driving system in relation with the different concepts defined in the DRIVENTS framework.

➢ **Eco driving system principle:** The goal of the eco-driving system was to change the driving task to reduce fuel consumption. The GERICO system interacts with the other agents defined in the DRIVENT framework. The relation existing between them was modelled to describe agent interactions (Fig.3). The system developed was based on a partial analysis of the environment and did not determine and anticipate all road situations. Indeed, the automation of some system functions was not an optimal solution to aid the driver in his/her driving task. The system only provides information and warning to assist the driver that keeps the control of the vehicle. The principal problem in the interaction was the choice between intrusiveness/severity of the system to keep an optimal driving performance and a good acceptability for the comfort and safety of the driver.

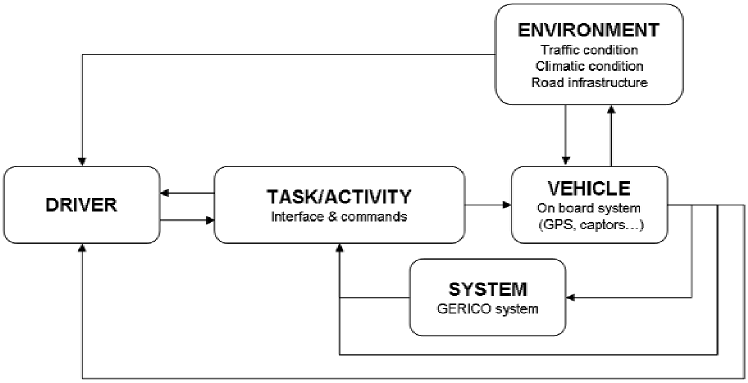

Fig.3. Agents interactions

The system provides prescribed tasks via an HMI to reduce fuel consumption with respect to contextual and dynamic constraints of the automotive domain. A global optimisation algorithm takes into account the environmental data via the navigation system (road type, topography, traffic), and internal data from on-board computers (fuel injection, engine speed). This algorithm processes these data to provide the driver with an economic driving pattern (prescribed tasks) for a given trip (Fig.4).

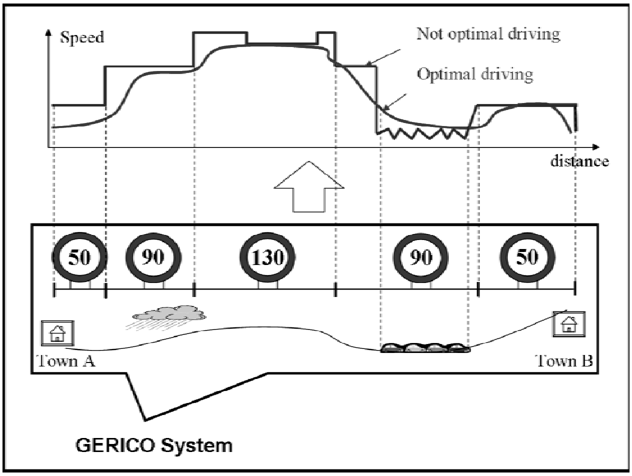

Fig.4. GERICO principle

- **System ↔ Tasks:** In the analysis of the eco-driving principles, the speed and gear management were two main factors to be considered for the reduction of fuel consumption. Consequently, the Eco-driving system provides prescribed tasks, e.g. optimal speed and gear advices, to the driver. Some information concerning eco-driving activity will not be provided by the system (for example optimal acceleration or deceleration). The system will aid the driver for some driving tasks but other tasks will be entirely performed by the driver to adapt his/her driving activity in some situations. In this sense, it is human-machine cooperation with an allocation of the cognitive functions between the system and the driver. However, the driver remains the person in charge of the human-machine couple to adopt the best eco-driving activity with respect to the road context. We can consider that the first impact of the system was on the operational level because the system provides information influencing directly the control of the vehicle (speed and gear advice) and consequently influences the other levels. These changes were considered during the design process and observed during evaluations. The social impact of this system was also important to consider. This system acts on the "driving style" and tries to change driver habits. From this perspective, the driver's motivation to use the system is crucial. Consequently, system usefulness needs to be demonstrated in terms of fuel consumption reduction, as well as usability and acceptability.

- **System ↔ Driver:** The driver interacts with the system via a specific interface. The ergonomic questions concerning the interface are important to facilitate the human-machine interaction. For Norman [7, p61] "*User-centred design emphasizes that the purpose of the system is to serve the user ... The needs of the users should dominate the design of the interface, and the needs of the interface should dominate the design of the rest of the system*". Thus, the interface of the system was developed using many guidelines such as ISO (International Standards Organisation), AAM (Alliance of Automobile Manufacturers) guidelines and so on, a user-centred and participatory design approach during the design process to improve perceived complexity and affordance of the system with respect to driver needs in order to avoid human errors and dysfunction of the "Human-Machine coupling".

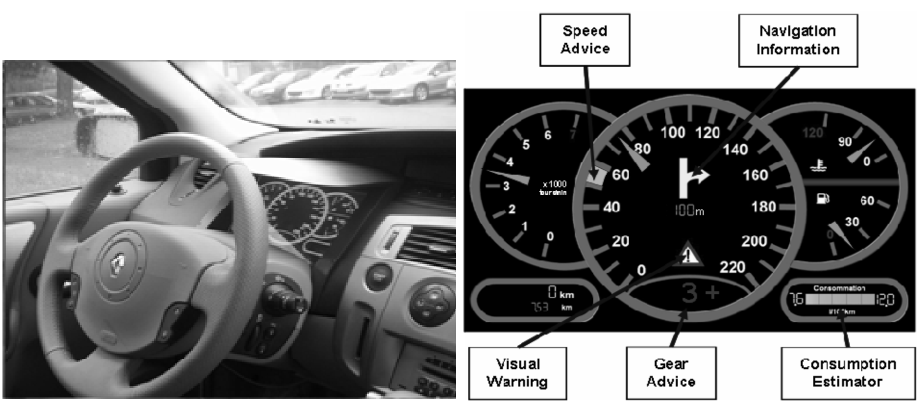

Fig.5. GERICO instrument cluster view

A multimodal interface [8] was developed based on the analysis of the possible interferences with the driving task. Four types of information were provided by the system with two modalities: Navigation (visual and auditory), Assistance (auditory), Advice (visual and auditory) and Warning (visual and auditory). All visual information was proposed via an instrument cluster design (Fig.5). The auditory information was implemented in addition to the visual modality to provide information to the driver. This modality enables better information management to avoid excessive workload in visual perception that can generate disturbances at the level of the main driving task.

- **System ↔ Environment:** Dey [9, p4] gives the following definition of the context: “context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application including the user and applications themselves”. This author defines that “a system is context-aware if it uses the context to provide relevant information and/or services to the user, where relevancy depends on the user’s task” [9, p5]. Thus the designer has to take into account as well as possible the situational parameters of the road context during the driving activity such as climatic conditions, traffic conditions, infrastructure and specific events that can occur on the road. Consequently, optimal advices, warning and assistances information are contextualised with respect to the road context. The system developed diagnoses some driving activities and determines the mode of interaction and the most adequate type of information in the situational context. Even if we send the right information, the way it is delivered is as important as the information itself. Information sent to the driver has to be useful and well synchronised with the car’s position and driving context (essentially road topography and infrastructure). For example, the system provides limited information in town due to driver workload and cognitive resources mobilisation. Moreover, anticipation of situations can improve driving performance to reduce pollution as well as safety. Thus, the system provides assistance information to anticipate some elements of the road infrastructure such as right of way, dangerous curves and zones limited to 30 km/h for example.

The Interaction Control System (ICS) was developed to provide the driver with visual information (optimal speed and gear advices) and vocal messages with respect to road context in order to reduce cognitive interferences, risk and human errors. A multi-agent model was used [10], based on cognitive function analysis, to define the structure of the ICS (Fig. 6). The ICS includes several specific agents that take into account internal and external parameters involved in the driving task. Agents are involved in Driving Activity Assessment (DAAs), in Driving Activity Analysis (DAAn), in Environment Assessment (EA) and in Multimodal Management (MM). DAAs agents control the driving activity (speed, gear and pedals), DAAn agents compare the global driving activity with the optimal driving pattern, EA agents analyse the road context and MM agents manage visual and auditory information provided to the driver.

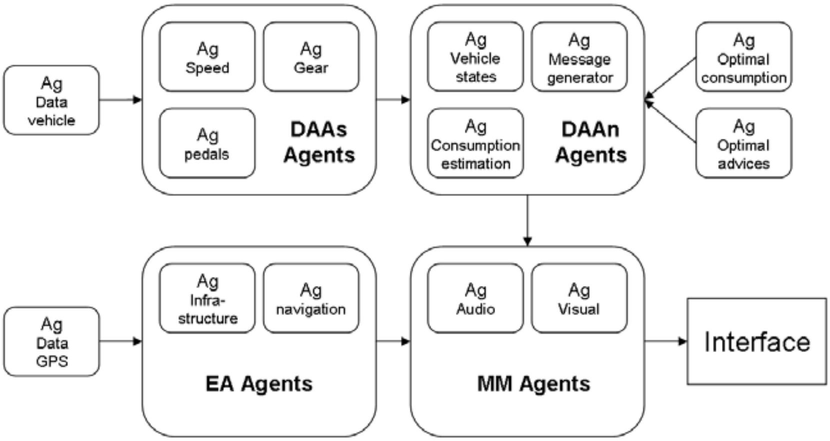

Fig.6. Interaction Control System architecture

➢ **System ↔ Vehicle:** The system integration was controlled in function of the technological limits of the vehicle and onboard systems integrated. The system developed needs resources from other systems (vehicle and GPS data). It was necessary to set up communication and reliable coordination in order to manage the roles and the priorities with the other systems. Information was provided to the driver via the LCD (liquid crystal display) instrument cluster (fig.5) and vocal messages via the vehicle radio.

4 Conclusion

This paper presented the "DRIVENTS" framework used to analyse the driving activity context during the design process of a new eco-driving system. This framework enables the specification of the design of the system with respect to the agents involved in the automotive domain. This framework can associate a systemic approach to the problem and an anthropocentric approach. It can be used for a simple system or a complex system in order to improve comfort, performance and safety. Moreover this framework was used to identify and define variables for the system evaluation [11]. The framework showed that different driver's factors can be influenced by the addition of new systems in the vehicle such as workload, situation awareness, time-sharing, cognitive interference and mobilisation. The questions concerning ergonomic, communication, interaction or interface aspects need to be resolved with respect to the driver's needs in order to reduce the influence of the new system on the agents in the automotive domain defined in the DRIVENT framework. Finally, during the design process, the designer has to verify as well as possible that all points were considered and evaluated to improve the system design in order to obtain the best human-machine cooperation with respect to the context of use.

5 References

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