DEVELOPMENT OF INNOVATIVE METHODOLOGIES TO EVALUATE ITS SAFETY AND USABILITY: HUMANIST TF E

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ABSTRACT: During the HUMANIST project Task the aim of Task Force E (TF E) was to develop innovative methodologies to evaluate ITS safety and usability. A matrix of methods for the assessment of ADAS and IVIS was developed and subsequently a proposed model for integration of these methodologies was proposed. A number of methods for the assessment of driver appropriation of ITS over time were also established and another model was proposed for the integration of these methods into one integrated methodology.

1 Introduction

In-vehicle information and communication systems (IVIS) are increasingly the standard equipment of modern cars. Advanced Driver Assistance Systems (ADAS) are also increasing, but the boundaries between the definition of IVIS and ADAS systems are blurred. Despite the obvious benefits of IVIS and ADAS there are also concerns that their use while driving may cause safety problems due to distraction and increased workload. Thereby it is assumed that it depends mainly on the user-friendly design of the Human-Machine-Interface (HMI) if the use of IVIS is compatible with the primary task of driving. In Europe recent efforts to develop and evaluate a catalogue of design goals for the in-vehicle HMI of IVIS, the so called “European Statement of Principles” (ESoP), reflect this approach. Nevertheless, the character of the ESoP is generic, i.e. defining no criteria to assess if the design goals have been achieved by a certain HMI solution. From all this it follows that there is an urgent need for methods to evaluate the effects of IVIS on driver workload and behaviour in order to assess potential problems for traffic safety and to improve HMI design [1]. It is also vital that researchers start to understand how drivers learn to use IVIS and ADAS and how this affects their driving performance over time as they become more familiar with particular systems.

One of the main objectives of HUMANIST Task Force E (TF E) was to exchange through the network, the knowledge and experience of projects which have applied or developed methodologies for the evaluation of on-board and off-board ITS; assessing systems both in terms of safety and usability. The Task force was required to consider the integration of various methods into comprehensive methodologies and then to consider the investigation of driver appropriation processes overtime.

2 Innovative methodologies to evaluate its safety and usability

The TF took a decision early in the project that the development of a matrix of methods would assist in the conception and confrontation of methods and procedures for usability and safety evaluations of ITS. The purpose of the matrix was to identify and categorise existing and proposed methods for usability and safety evaluation of ITS. When assessing usability and safety, different metrics (or measures) are used. These metrics are collected using specific techniques and often require specific tools, such as cameras or questionnaires. The metrics are collected in one or more physical environments. The following measures were collated for each method identified:

- Metric: Measure used to assess safety and usability of ITS e.g. brake response time.
- Technique: Details how the metric is determined e.g. deviation in distance between the vehicle centre and the road centre line
- Tool: Equipment needed to use the metric e.g. video camera, adjusted speedometer
- Environment: Environment in which the test is carried out. e.g. Instrumented vehicle
- Aspect of the system/human investigated: Describes how the metric assesses ITS safety and/or usability
- Type of data: Objective, subjective or observed (expert opinion)
- Effectiveness: How useful the measure is
- Practical issues: Issues to consider when using metric e.g. time, expense
- Organisation: Organisation which submitted or had experience of the metric

The combination of metric/technique/tool/ environment is what is referred to as a method. The Task force held two workshops to discuss different metrics and the formation of a matrix. A summary of some presentations can be seen in HUMANIST Deliverable D.2/E.2 [2]. To populate the matrix information was collated through these workshops as well as through scientific literature and experience of the HUMANIST partners. The measures were categories into nine groups; lateral control measures; longitudinal control measures (speed, vehicle following); steering wheel movement measures; eye tracking measures; physiological measures; situation awareness measures; task orientated measures; subjective mental workload measures; incident analysis measures. Initially only IVIS were considered then later in the task force a final category of ADAS measures was included in the matrix.

That matrix contains 130 methods. Partners were asked to indicate their ‘favourite’ method. Favourite meaning those most frequently used or most useful to the HUMAIST network partners. There are 22 favourites identified and the range of favourites is very broad, demonstrating the variety of methods available and that the methods used depend heavily on the objectives of a study. The ‘favourites’ were categorised at 3 levels according to the number of partners selecting the method (level 1 being the most popular favourites and level 3 being the least popular favourite). There were two ‘level 1’ favourites: lane standard deviation and minimum following distance (closest longitudinal approach). The ‘Level 2’ favourites were: occlusion, glance frequency, glance duration, brake response time, time headway and time to line crossing. The full matrix can be found in the HUMANIST deliverable E.4 [3].

The matrix summarises important information and experience about each method based on scientific literature and experience of the HUMANIST partners. This information includes the type of data obtained (e.g. objective, subjective, observational or expert opinion); the effectiveness of the method expressed in terms of the validity, reliability and sensitivity; and practical issues of application including time, cost and training requirements. Where possible, the matrix provides scientific references and lists the HUMANIST partners with experience or knowledge of the methods. From developing the matrix it is clear that partners are doing substantial research into the impact of IVIS on driver workload and behaviour and that a large variety of ITS assessment methods are used.

3 ADAS and IVIS

An ‘In Vehicle Information **System**’ (IVIS) and an ‘Advanced Driver Assistance **System**’ ADAS are both obviously defined as systems. All systems perform **functions**, such as obtaining an address from the driver, warning of a collision or adjusting headway. Additionally some systems may include information functions, warning functions and assistance functions (and also in-built stability functions such as ABS). IVIS focuses on informing while ADAS focuses on warning and assisting. The table below demonstrates the issues associated with each of the four functions, hence distinguishing the difference between each of the functions. A detailed explanation and definition can be found in HUMANIST Deliverable E.4 [3]. An integrated methodology needs to address all of the safety issues listed in the diagram.

FUNCTION / ISSUE	In-built	Informing	Warning	Assisting
Example	ABS ASC Collision mitigation	Route guidance Mobile phone	LDWS ISA Advisory	ACC
Focus	Vehicle stability	Information to the driver	Warning the driver	Aspects of longitudinal and lateral control
Driver’s locus of control	None	Full	Depends	Overrideable
System supplier	OEM	OEM aftermarket Nomadic	OEM aftermarket	OEM
Safety issue	Technical	Distraction	Understandability	Controllability
Typical human interface	None (or via existing controls)	Screen + Audio	Buzzer, Symbol	Button Small display Existing controls

Fig.1. IVIS and ADAS function matrix

4 Integration of Methods

Humanist partners had several meetings and an internal workshop to discuss the process of developing an integrated methodology. The main objective of the workshop was to collate and review existing knowledge concerning the integration of individual methods into a more holistic approach to assessing safety and usability. A detailed report is in HUMANIST Deliverable E.3 [4]. An Integrated methodology was defined by HUMANIST TF E as:

> *"Structured human factors evaluation (of a system or function) that combines evidence from multiple assessments of different aspects of driver-vehicle interaction within a conceptual framework"*

Developing an integrated methodology is a complex task and TF E have made some significant advances. From the first workshop it was clear that there remains a research gap concerning how to combine individual methods into an overall integrated methodology. The partners had a general common understanding of safety and risk, but there was a need to identify and use a common conceptual framework of driver information processing and risk. The next challenge was to find a conceptual model.

An integrated methodology should help to:

1. Understand the system being studied
2. Identify behaviours and communication aspects that could have influence on traffic safety
3. Formulate hypotheses concerning how (in what direction, in what aspects) behaviour and communication might be influenced
4. Decide how the effects can be measured in principle
5. Design and undertake appropriate assessments & analysis
6. Combine and present results

There are several reasons why a conceptual framework is needed in context of Integrated Methodologies. First, as a "theoretical backbone" it should offer some "guidance" through the process of HMI assessment. Second, it should represent relevant aspects of driver-vehicle interaction (with IVIS/ADAS), and third, it should make meaningful predictions for user tests. From this point of view it was obvious to clarify in a first step if some ideas could be derived from the work on driver models performed by HUMANIST (Task Force C) at the "International Workshop On Modelling Driver Behaviour In Automotive Environments". The model proposed by Oliver Carsten [5] was considered worth further examination.

The group formed a view that the application of this model for the development of an Integrated Methodology can be described as a top down approach. On the other hand the question was raised in the discussion if such an approach would be really viable in practice and it was suggested that a bottom up approach which is driven by the actual demands of the system(s) under investigation might be more appropriate. This is, of course, a strong point in particular because the "Carsten-Model" is purely descriptive and does not specify how the relationships described are moderated by IVIS and ADAS. As a result an agreement on a conceptual model as specified in the definition of Integrated

Methodologies could not be achieved within HUMANIST, however work continued on integrated methodology.

The International Standards Organisation (ISO) have developed a suitability standard. Additionally the RESPONSE [6] and ADVISORS [7] projects have suggested methodologies which the HUMANIST group considered as a framework for integration.

The aim of this part of the HUMANIST work was to merge all the methods described in “The Matrix” towards one “Integrated Methodology” as a guide to the assessment process.

A proposal of how an integrated methodology could be developed into a model is shown below where available tools have been related to the different phases of the process. The HUMANIST Group then applied their knowledge of what is possible from current research, to establish where we are in the process of developing an integrated methodology. The diagram below shows the model that the HUMIST partners have generated.

As can be seen from the figure there are three phases in the process (IVIS/ADAS description, selection of measurement methods, measurement and analysis) where it is possible to refer to available inventories of methods as e.g. the “HUMANIST Matrix”. The most critical item seems to be the Multi-Criteria-Analysis or other combination/analysis tool at the end of the process where it has to be concluded that suitable tools do not exist. Of course, some related work has been done within the European projects ADVISORS and RESPONSE but these were developed for different purposes. This does not mean to say that an Integrated Methodology following this definition is incompatible with these developments. Rather, the approach followed here aims at a stronger microscopic or scientific level bridging the knowledge gaps between system functions, driving behaviour and accident risk.

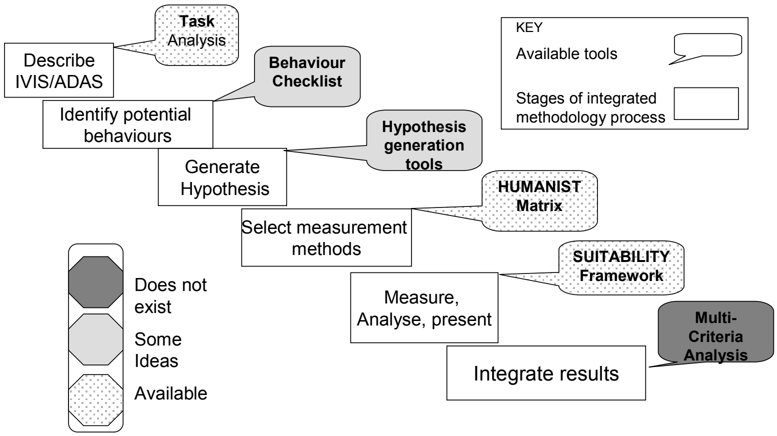

Fig.2. HUMANIST TFE model of the stages and tools required for an integrated methodology

As can be further concluded from the figure above, there are two phases in the process (identification of potential behaviours, generation of hypotheses) where at least some ideas on necessary tools exist but the state-of-the-art is far from satisfying. The discussions within TF E on conceptual models and frameworks [3] open research issues and reflect the need for a specific, meaningful, empirically validated but also parsimonious conceptual model. The continued review of models of driving behaviour might provide further input. However, it also became very clear during the discussions that these are too general to have more than a heuristic value. This means that we might now be at a stage where as well as practical tests assessments, deliberate theorising and careful experimentation are necessary in order to convert the orange and red fields in the Figure above into green ones.

A joint AIDE/HUMANIST workshop took place in March 2006. The Humanist integrated methodology model was presented to AIDE and it received positive approval.

Overall the work on Integrated Methodology has been useful at two levels. At the more immediate practical level the work has provided support for assessment by summarising the features of specific approaches. In addition the conceptual work has allowed a dis-aggregation of the complex issue of integrated methodology into a number of separate components that appear to be amendable to further research.

5 Driver appropriation of its over time

TF E was required to investigate methodologies to evaluate the safety and usability of ITS systems. One group of such methodologies includes methods to assess driver appropriation of IVIS and ADAS systems. Therefore the next aim of the HUMANIST work was to consider methods for the investigation of driver appropriation processes over time. In this paper ‘appropriation’ is considered as a specific case for integration into the general topic of methodologies (as depicted in Figure 2). The entirety of behavioural changes in response to a safety measure is generally referred to as ‘behavioural adaptation’ [8] [9]. An Organisation for Economic Co-operation and Development (OECD) report states that “Behavioural adaptations are those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change. Behavioural adaptations occur as road users respond to changes in the road transport system such that their personal needs are achieved as a result. The adaptations create a continuum of effects ranging from positive increase in safety to a decrease in safety” [10]. TF E contributors agreed that appropriation does not only include observable behavioural changes, but also changes in cognitive, regulatory and motivational processes that underlie those observable behaviours. TF E contributors agreed therefore to adopt a wider view regarding the nature of the adaptation processes.

A workshop was held and several presentations from partners were given providing different methods. A review of the workshop presentations and discussions can be found in HUMANIST Deliverable E.5 [11]. In addition the next deliverable, E.6, [12] provides a detailed description of 12 methods that can be used to assess driver appropriation of ITS over time. Additionally brief descriptions of a further 10 methods are provided with advantages, disadvantages and comments on how the method is linked to driver appropriation. The TF has developed a main body of the deliverable that provides an overview of driver appropriation processes and a discussion of scope for an integrated methodology for appropriation measurement informed by an underlying model of driver appropriation processes.

Starting from a number of presentations explaining possible methods to measure driver appropriation, the TF built a better understanding of different aspects of appropriation. This led to a deeper understanding and a better definition of appropriation. Task Force E aimed to develop an 'integration model' to conceptualise integrated driver appropriation methods. The HUMANIST task force agreed on the following definition of driver appropriation:

> *"Acquisition of knowledge, skills and attitudes underlying short term and long term changes in behaviour"*

As stated in this definition, driver appropriation in response to ADAS may occur directly after introducing a new system into the vehicle (e.g. short-term changes in workload), as well as after a certain period of time of driving with the system. Furthermore, the definition emphasises the different nature of causes underlying driver appropriation, which are knowledge (e.g. of how a system works in different conditions), skills (e.g. in using /driving with the system), and attitudes (e.g. trust in the system).

In order to conceptualise driver appropriation it was regarded as useful to view different aspects of appropriation in relation to the three levels of the driving task as proposed by hierarchical control models of driving (Michon, 1985).

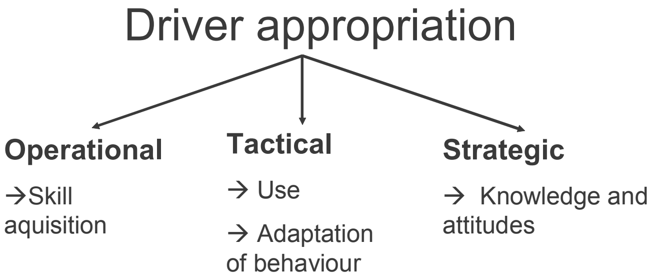

Fig.3. A diagram to show the different levels of driver appropriation

Appropriation on the **'operational level'** of the driving task is mainly concerned with skill acquisition in how to operate a system. Decisions and skill in how to use or to apply a system in particular situations and driving manoeuvres (overtaking, lane changing) primarily affect driving on the **'tactical level'**. Overall, behavioural adaptation in response to ITS is observable on the tactical level of the driving task. Changes in drivers' knowledge, attitudes and motives (e.g. overall risk taking, trust in a system) will mostly affect the **'strategic level'** of the driving task, and thereby influence control on the lower levels. As the three hierarchical levels do interact with each other, adaptation at one level of driver control has influence on the other levels as well.

A number of factors influence drivers' response to ITS. HUMANIST TF E focused on appropriation processes in response to IVIS and ADAS that are influenced by three interacting factors: system characteristics, situation characteristics and driver characteristics.

A conceptual model of driver appropriation has been developed (By Anke Mogilka of CUT forming part of the PhD studies). The model together with a detailed description can be found in HUMANIST Deliverable E.6 [10]. The model aims to draw attention to relevant variables and their interdependences in influencing driver appropriation. The model includes several processes, including behavioural adaptation, risk compensation, and changes in information processing in response to the introduction of ADAS.

According to this model, driver appropriation develops in response to changes in the driving task due to driver assistance systems. The systems' characteristics have a direct impact on driver's information processing. The degree of assistance offered by the system, i.e. the level of automation and the systems feedback mediated by the HMI are believed to have an impact on driver's situational awareness and mental workload. Feedback from the system about its current state and behaviour is necessary to build up a comprehensive situation model that governs behaviour in unforeseen situations. Driver's workload is thought to have an influence on alertness and vigilance in such a way that vigilance decreases to a greater extent over time when workload is below or above a medium optimal level.

6 Integration of appropriation methods

Within the work of TF E, a concept was developed concerning possible integration of methods based on the theoretical background and processes of appropriation. In order to develop the concept/model the integrated methodology model presented in a previous deliverable [3] was used as a 'baseline' approach. There were several issues raised and discussed. It should be noted that previous work of TF E has been more concerned with methods that relate to skill acquisition and driver behaviour measurement.

The new and wider perspective requires methods that have not hitherto received as much attention including: elicitation of attitudes and knowledge by "soft" means; extended field trials and naturalistic measurements; measurement of system use/ non-use and measurement of changes in use of vehicles. A very important issue is the need to be able to identify loss of 'manual driving' skills caused by new technical system and the potential impacts of this skill loss e.g. during system malfunction or failure.

The HUMANIST TF E proposed integration of driver appropriation model is shown below. It is considered a working model that requires further research and validation:

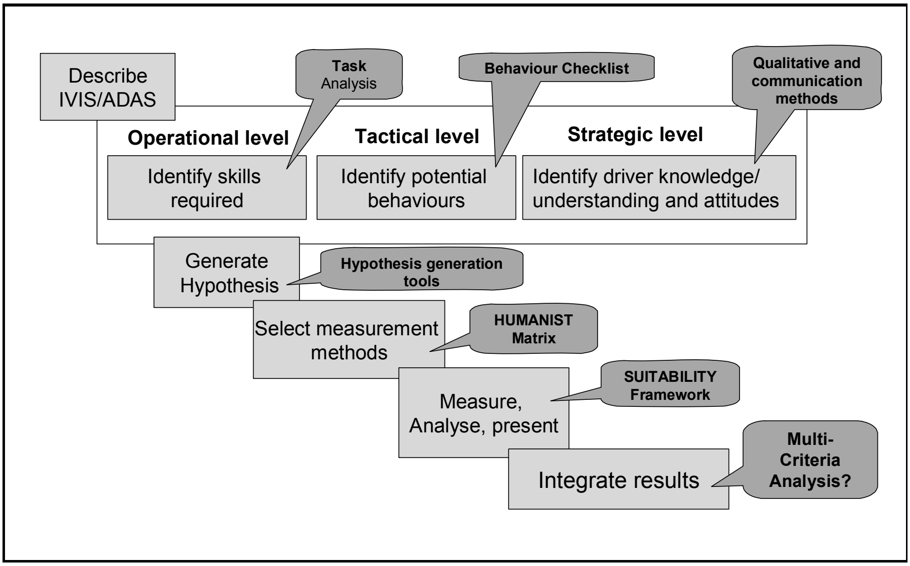

Fig.4. Diagram to summarise HUMANIST TFE proposed model of the integration of driver appropriation methods

7 Conclusions and future work

HUMANIST TFE has made a significant research contribution through the development of a matrix of methods and advances towards an integrated methodology. The work on Integrated Methodology has been useful at two levels. At the more immediate practical level the work has provided support for assessment by summarising the features of specific approaches. In addition the conceptual work has allowed a dis-aggregation of the complex issue of integrated methodology into a number of separate components that appear to be amendable to further research. It is therefore a challenge for future projects to make progress in these target areas.

Discussion within TF E on driver appropriation has helped to understand the requirement for future work in the research area. Starting from a “flat” list of possible methods to measure driver appropriation, a better understanding of different aspects of appropriation was built and a three-level characterisation developed. This led to a deeper understanding and a better definition of appropriation based on common understanding. Because driver appropriation and the integration of appropriation methods is such a new work area more questions have been raised than answers provided. The next phase of work in this area should focus on further developing the conceptual model of driver appropriation and the appropriation integrated methods model. In developing these models further it will be important to resolve detailed issues. For example:

- How can we measure transfer of learning from other environments?
- How do differences in intelligence or educational background affect appropriation?

- What intervals should be measured to detect important adaptive changes?
- How can we quantify driver distraction (internal and external) and its impacts?
- What are the driver appropriation processes for IVIS and ADAS and their impact on safety?

The work of TF E has been very productive with some thought-provoking contributions in this relatively new scientific area. These considerations led to a better understanding of the development of innovative methodologies to evaluate ITS safety and usability.

8 Acknowledgement

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