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Original citation:
Birrell, Stewart A., Young, Mark S., Jenkins, Daniel P. and Stanton, Neville A.. (2012) Cognitive work analysis for safe and efficient driving. Theoretical Issues in Ergonomics Science, Vol.13 (No.4). pp. 430-449**.**

Cognitive Work Analysis for safe and efficient driving

Stewart A. Birrell[a *], Mark S. Young[a], Daniel P. Jenkins[b] and Neville A. Stanton[c]

[a] *Human-Centered Design Institute, School of Engineering and Design, Brunel University, Uxbridge, Middlesex, UB8 3PH, UK*

[b] *Sociotechnic Solutions Ltd, 2 Mitchell Close, St Albans, AL1 2LW, UK*

[c] *Transportation Research Group, School of Civil Engineering & the Environment, University of Southampton, Highfield, Southampton, SO17 1BJ, UK*

Abstract

Both the environmental and safety costs of road transport are considered to be unacceptably high. The 'Foot-LITE' project aims to encourage drivers to adopt greener and safer driving practices, with real-time feedback being given in-vehicle (during driving) and retrospective feedback off-line (pre- and post-driving). This paper focuses on the early concept development of the Foot-LITE system, for which a Cognitive Work Analysis (CWA) methodology was adopted. Presented are results from a Work Domain Analysis (WDA) conducted to scope the relevant driving domain and to identify the constraints on the system. As well as establishing a common framework and language for the project, the process will ultimately contribute to the design of the in-vehicle interface. The paper also suggests an extension to the WDA framework to include novel methods for assessing the priority of lower level nodes and contributions of these nodes to the high level objectives of the system.

Keywords

Cognitive Work Analysis (CWA); Work Domain Analysis (WDA); Driving; Eco-driving; Road Safety.

* Corresponding Author: Stewart.Birrell@Brunel.ac.uk

1. Introduction

1.1 Cognitive Work Analysis

Cognitive work analysis (CWA) was first developed by Jens Rasmussen in 1986, at the Risø National Laboratory in Denmark. It was established for use within the nuclear power industry where a new approach was needed to design systems for emerging situations. CWA (Rasmussen et al, 1994; Vicente, 1999) is a structured framework for considering the development and analysis of complex socio-technical systems. Vicente (1999) further developed the CWA methodology, offering a more definitive description with an increased number of tools for analysis. According to Naikar & Lintern (2002), the framework supports *revolutionary rather than evolutionary design*. This is reinforced by Vicente (1999) who recommends CWA for systems that need to support performance in the face of unanticipated variability and systems which have no precedent. The framework leads the analyst to consider the environment within which the task takes place, and the effects of constraints imposed on the system's ability to perform its purpose.

The CWA methodology has been developed for a variety of applications, including system modeling (Hajdukiewicz, 1998), system design (Bisantz et al., 2003), interface design and evaluation (Vicente, 1999), and information requirements specification (Ahlstrom, 2005). In addition, it has been used in a range of complex safety critical domains including air traffic control (Ahlstrom, 2005), aviation (Naikar & Sanderson, 2001) hydropower (Memisevic et al., 2005), nuclear power (Olsson & Lee, 1994), naval (Bisantz et al., 2003), manufacturing (Higgins, 1998), military command and control (Jenkins et al, 2008), and rail (Jansson et al, 2006). More specifically within the scientific literature a small number of studies have used CWA and its design corollary, ecological interface design (EID; cf. Burns & Hajdukiewicz, 2004), for automotive vehicle design. These studies have largely used the Work Domain Analysis (WDA) phase of CWA to identify variables and guide design for a lateral collision warning system (Jenkins et al, 2007a), lane change maneuvers (Stoner et al., 2003), the road transport system (Salmon et al, 2007), adaptive cruise control (Seppelt and Lee, 2007) and rapid prototyping and design of an in-vehicle interface (Young and Birrell, 2010).

1.2 Work Domain Analysis

CWA can be broken down into five phases (Vicente, 1999), each of which models different constraints on the system: Work Domain Analysis; Control Task Analysis; Strategies Analysis; Social Organization and Cooperation Analysis; and Worker Competencies Analysis. Whilst the details on all these phases can be found elsewhere (e.g., Vicente, 1999), for the purposes of this paper the main focus will be the Work Domain Analysis (WDA) – more specifically, the Abstraction Hierarchy.

The WDA is used to represent the constraints implicit on the domain in which the activity of a system is conducted. The key benefit of a WDA for the design process is that it offers a framework for the systematic organization of information to assist design. The WDA can be structured using an Abstraction Decomposition Space or an Abstraction Hierarchy (AH; Rasmussen, 1985); these enable the systems to be considered at different 'levels' of abstraction while the AH also considers how these levels are connected, by the use of means-end links. In our study, the labels used for each level of the hierarchy are adopted from Naikar's 'new labels' as described in Reising (2000). It is believed that these labels are more appropriate for describing intentional domains, describing the levels and the relationship between them. These levels are (adapted from Naikar et al, 2005):

Functional purpose – the highest level objectives of the system, or why the system exists. These objectives do not change with time or as a result of different events, but remain fixed. The success of the system is defined by whether these functional purposes are achieved.

Values and priority measures – define the criteria used to determine whether or not the functional purposes are being achieved. Within this level more specific measures are outlined to determine what makes for the successful attainment of the overall aims of the system.

Purpose related functions – characterized by what functions the system is performing in relation to the overall purpose. In simple terms this is how the values and priority measures will be achieved.

Object-related processes – what the physical objects in the system can do, or a further detailed breakdown of functions.

Physical objects – the bottom level of the hierarchy lists all of the physical objects or resources in the system, which can be either man-made or natural.

1.3 Safe and efficient driving

Environmental issues are high on the political agenda, with one of the main focal points being the transport industry. In particular, private car use is often targeted as an area where significant reductions in environmental impact can be made (EEA, 2007) – which can be achieved either through the way cars are driven, or through more appropriate modal choices. Meanwhile, safety concerns have not gone away, with many developed countries now seeing their road traffic accident statistics having reached a plateau, despite the European Commission's target of a 50% reduction in road fatalities by 2010 (EC, 2001). Within the European Community, road transport accounts for approximately one quarter of greenhouse gas emissions (EEA, 2007), and results in over 40,000 deaths (ERSO, 2007). New initiatives are therefore clearly needed in order to make breakthroughs in eco-friendly driving and road safety improvement.

A new project is underway which aims to encourage drivers to adopt safer and greener driving behaviours. 'Foot-LITE'[†] represents a UK consortium of six commercial companies, three governmental/charity organisations, and three universities, funded jointly by the Technology Strategy Board, UK Department for Transport and the Engineering and Physical Sciences Research Council. The objective of the project is to develop a system for providing feedback and advice on driving style. The system ostensibly comprises two aspects: an on-line (i.e., in-car) interface providing real time feedback and advice on driving style, coupled with an off-line (post-drive) data logging system which can help to inform transport choices. Whilst there already exist some in-car monitoring systems which can provide information on fuel consumption in the vehicle, or post event data recorders (see Arroyo et al, 2006; McGehee et al, 2007; Tomer and Lotan, 2006; van der Voort et al, 2001), none of these as yet provide detailed feedback to the driver in real-time with tailored driving advice thus enabling them to refine their behaviour to actually improve driving efficiency.

[†] See www.foot-lite.net

In order to achieve its goals of changing driving style while avoiding negative effects of distraction or workload, the in-car interface in particular needs to be designed with the driver's information requirements in mind. The research presented in this paper is part of a wider workpackage specifically focused on the ergonomics of the product – determining the driver behaviour parameters by conducting a cognitive work analysis, and designing an interface to optimise performance. There is already much research in ergonomics regarding driving safety, with a lot of attention on advanced driver assistance systems (ADAS). Many authors have commented on the potential positive (Carsten & Tate, 2005; Shinar et al, 1998) and negative (Dominez et al, 2007; Young and Stanton, 2007) effects of such devices on driver performance, and models of human interaction with technology are abundant. However, to date there has been relatively little ergonomics research dedicated to improving performance factors specifically related to environmental impact. Moreover, these factors need to be traded off against their impact on safety. In driving, there may be specific behaviours which are both safe and 'green'; likewise, there may be occasions when these goals are in conflict. Enabling drivers to develop the skills for managing these conflicts is a challenge for ergonomics. Before decisions on any particular technology solution can be made, the project needs to assess the system's purposes, values, priorities and functions by undertaking a systems-led approach where both technical and human system components are equally as important.

1.4 CWA for the Foot-LITE Project

CWA was proposed as a potential method for developing the Foot-LITE concept as well as for informing the potential design of the in-car interface. Naikar and Lintern (2002) offer CWA as a formative (as opposed to normative) design methodology, while Vicente (1999) makes the argument that the AH is particularly useful for systems that have no precedent. Foot-LITE, as a first-of-a-kind vehicle system, warrants a formative approach, and so the project is an excellent opportunity to apply CWA from idea conception to interface design.

Within the Foot-LITE project all five phases of the CWA will ultimately be completed; however in this paper we detail the results of the first phase – Work Domain Analysis (WDA). We do not go into detail on the literature or process regarding CWA; more detailed reviews of the methodology and its applications are available elsewhere (e.g., Vicente, 1999; Naikar and Lintern, 2002; Burns and Hajdukiewicz, 2002; Naikar et al, 2005; Mazaeva and Bisantz, 2007; Jenkins et al, 2008; Morineau et al, 2009). Instead, this paper presents the findings of the WDA for a smart driving aid, which adds to the available literature regarding CWA. In addition this paper also proposes a novel method for the prioritization of user requirements for product design and development. The importance for this lies in the fact that most design projects are faced with the problem of limited resources, which means that the implementation of all possible user requirements is generally infeasible, the effective prioritization of user requirements on a design project is certainly critical. To address this problem, the authors propose a heuristic method for the prioritization of user requirements on a design project using an abstraction hierarchy. This extension to the accepted CWA methodology was created specifically for the Foot-LITE project, enabling the authors to determine the priority of driving related information to be presented on the in-vehicle display.

2. Methodology

Input for the WDA, and more specifically the AH, was gathered during three focus group sessions conducted over four days, involving representatives from all members of the Foot-LITE consortium. On the whole, the first two days of meetings covered the upper levels of the abstraction hierarchy, while the final two days focused on development of the bottom two levels of the hierarchy. The middle level (purpose-related functions), which is considered to be more challenging to complete (c.f. Vicente, 1999), was produced independently by the authors using the input from the focus groups.

In terms of procedure, whole group discussions helped to define the overall boundaries of the analysis, but for more detailed consideration of the functional purposes it was more practical to break into sub-groups. Notes were recorded by the authors (as facilitators) on flip charts throughout the discussions. The output from these meetings was organized and assembled into the structured WDA framework off-line following these meetings using a CWA software tool developed in-house

(Jenkins et al, 2007b). Draft results were then circulated to partners electronically for review and ratification.

3. Results and Discussion

3.1 Foot-LITE Abstraction Hierarchy

The AH presented in this paper is domain specific and focuses on constraints relevant only to the Foot-LITE system and not the vehicle or roadway environments in their entirety. Before the Foot-LITE AH was constructed the focus group discussed a 'global' AH which did attempt to review all factors which could affect the safety and efficiency of road transport. Ideas such as 'Land use planning' and 'Vehicle design', which have obvious impacts on road and vehicle safety and efficiency, were included in this global AH. The focus of this paper, and of our continued CWA work, is the Foot-LITE AH, as this is more directly relevant and specific to the goals of the project.

3.1.1 Functional Purposes

The first objective of the analysis was to define the functional purposes of the system, the top level of the AH. Two such purposes were identified immediately as safe and eco-friendly road use, these being the principal objectives of the Foot-LITE system. Following detailed discussions a third was added that focused on efficiency. Efficiency was deemed important as it has a direct link to cost savings for the user, either by lower fuel consumption, maintenance or repair costs. In addition an efficient road network is also inherently related to both a safer and greener transport system, due to a reduction of road accidents and traffic jams. The functional purposes of the Foot-LITE system are thus:

1. Eco-friendly road transport use
2. Safe road transport use
3. Efficient road transport use

3.1.2 Values and Priority Measures

After the functional purposes were established the group then set about defining the 'Values and priority measures'. These are the criteria used to judge whether the system is achieving its purposes. Detailed discussions, as set out in the methodology, generated the following measures:

1. Reduce carbon footprint
2. Reduce polluting emissions
3. Reduce local environmental impacts
4. Reduce risk, number and severity of road traffic accidents and incidents
5. Reduce inappropriate driver behavior
6. Reinforce good driver behavior
7. Satisfy personal mobility requirements
8. Increase predictability of journey times
9. Reduce cost of use
10. Increase availability of capacity

For the first three values and priority measures, focusing on eco-friendly driving, it was felt important to not over-emphasize global carbon output or carbon footprint. Local effects of polluting emissions (such as nitrous oxide and particulate matter), as well as other local environmental impacts (e.g., noise or vibrations) were also deemed important for consideration.

The next three measures related to safe road transport use, with the primary measure of this being reduced number and severity of accidents. In general, reducing inappropriate driver behavior and reinforcing good driver behavior were considered to be the methods by which short and long term behavior changes, respectively, would be achieved. The final four measures refer to efficiency and relate to both time and cost savings for the individual user, as well as increasing the efficiency of the road network as a whole.

3.1.3 Purpose-Related Functions

The purpose-related functions identify how the Foot-LITE system will actually achieve its aims of more eco-friendly, safe and efficient road transport usage. By reviewing these aims it was established that the most likely way that Foot-LITE will achieve them is by informing and influencing user transport choices and driving behavior. As detailed previously the purpose-related functions were defined after the initial focus groups by the authors, with later ratification by the group, and emerged as follows:

1. Influencing transport choices
2. Awareness of impact of transport choice
3. Improve communication between vehicle and driver
4. Reduce vehicle energy losses
5. Improve driver information provision
6. Improve driving styles and technique
7. Improve route management
8. Awareness of cost of transport choice

Influencing transport choices was considered to be an important objective of the Foot-LITE system. By informing the user of the actual environmental and economic costs of their personal transport, informed decisions regarding the use of public transport might then be achieved. In addition, providing the driver with optimal fuel use or cost figures for a certain journey may also encourage efficiency.

Making the driver aware of the environmental impact of their transport choice is an essential part of the project. It is hoped that armed with this knowledge the user will make more informed decisions regarding modal choice before a journey, and during a journey (if traveling by car) they will be able to see the impact their driving style has on the environment.

Improving communication between the driver and their vehicle was envisaged to inform the driver when the vehicle was pushed to its limits, e.g., when ABS, electronic stability or traction control have been activated. These have clear safety implications, yet at the present time a driver has limited or no feedback as to when these systems are employed - and hence the driver does not know that they may be driving inappropriately.

Reducing vehicle energy losses encompasses both pre-, during and post-driving. Removing excessive weight from the car (such as a roof rack) when not needed, will have the obvious impact of reducing the weight and aerodynamic drag of the car, thereby increasing fuel economy. Energy losses can also be reduced through routine maintenance (e.g., regular checking of tire pressures), or through the appropriate use of air conditioning during driving.

Improving driver information provision is in essence the core of Foot-LITE; this is both in-vehicle as well as pre- and post-journey. The Foot-LITE system will receive information from many different sources (vehicle inputs, satellite navigation, route planning etc.); the challenge is to filter this information and present pertinent, timely and usable advice to the driver.

Improving driver styles and techniques is realistically the area where the majority of savings can be made. The principal benefits to efficiency will come from encouraging the driver to maintain a constant speed profile by 'smoothing out' excessive acceleration and braking events, as well as making appropriate gear selections. Whilst the majority of discussions so far have focused on fuel efficiency or cost savings rather than safety, improving drivers' style or technique can contribute to both. Driving parameters which have been shown to increase safety include increased headway times (Brackstone and McDonald, 2007), more appropriate speeds (Haworth & Symmons, 2001; Taylor et al., 2002), and reduction of excessive accelerations (af Wahlberg, 2006).

Improving route management could include the planning of a route for maximum fuel efficiency or avoiding traffic black-spots. Finally, improved driver information provision is the method by which information (emissions, fuel use, alternative routes etc.) or advice (current driving tips, future information etc.) will be delivered. As detailed in the physical objects to follow, such information could be delivered either in-vehicle (via auditory, visual or haptic feedback) or offline (via electronic or paper feedback).

The final, but by no means least important function was awareness of cost of transport choice. Again this information will enable the user to make more informed decisions regarding transport options. Estimating the cost of a specific journey will have a large bearing on transport mode. Also considered an important feature will be the fiscal benefits to the user of adopting a safer and greener driving style compared to their current driving style, as this may encourage longer term adaptations in behavior.

3.1.4 Object-Related Processes and Physical Objects

As shown in table 1, the object-related processes represent actions or parameters which influence eco, efficient and/or safe driving. Some of these are driver related actions (that is, they can be directly controlled by the driver), such as anticipation and observation, acceleration patterns, and gear selection. Other parameters are those which may facilitate changes in behavior, decision making or driving technique, such as on- and off-line feedback, driver mental workload and route planning. These parameters are to some degree out of the drivers' direct control but can be assisted by the Foot-LITE system. Numerous physical objects have been included in table 1; many of these will be integral to the proposed system whilst some will be outside of the project scope.

Insert Table 1 Here

3.1.5 Means-Ends Links

Means-ends links connect nodes at adjoining levels of the AH; they show 'how' a particular node is being achieved, or 'why' a particular function is present. Figure 1 shows a section of the Foot-LITE AH; by way of illustration the means-ends links which relate to 'Vehicle powertrain information' have been highlighted. Following through the example in figure 1 shows that vehicle powertrain information is linked to the level above via in-vehicle and off-line feedback. In turn, feedback is then linked to numerous other functions and measures, and ultimately affects all three of the functional purposes (safety, eco-friendliness and efficiency).

Insert Figure 1 Here

3.1.6 WDA Discussion

The WDA is the most recognized and widely used phase of the CWA process. The principal benefits are that it creates an explicit link, through different levels of abstraction, between the low level affordances of individual components and the overall purposes of the system. This is considered to be particularly useful at the beginning of a project. One limitation is that value or importance of these means-ends links which interconnect the levels are the AH are not weighted, as each link is considered as important as any other. Additional benefits are that the analysis has provided a universal language for the project, and acted as a very effective springboard for numerous discussions about the concept. The AH defined the aims of the system, and started to outline methods of how this may be realized. As well as highlighting performance measures, the AH also sets criteria to judge the relative success of the system. The tangible benefit of conducting the WDA is that the physical objects and purpose-related functions established via this process can be used as direct input for the user requirements identification.

A clear message reiterated throughout the CWA process was the need to establish criteria at the physical objects level such as fuel consumption and emissions. If these data cannot be obtained from the vehicle powertrain then they must be measured or inferred using other means. The WDA identified many aftermarket sensors at a physical objects level (such as hands on wheel sensors, eye trackers, and weight sensors) that have the potential to assist the driver in positively changing their driving behavior and in turn influence the higher order functional purposes of the system. These are in addition to pre-installed devices such as proximity and headway sensors, tire pressure sensors and ambient temperature, which could also provide input to the Foot-LITE system.

In order to assess driving style, variables such as acceleration, braking, gear selection and steering also need to be measured. Again, whether these are actual or inferred data is for future consideration. For more detailed analysis of driving style and more specific driver feedback the focus groups identified some essential functionality with GPS (such as satellite navigation). Feedback such as speed alerts, traffic violation information and geo-fencing will assist the user to drive in a safer manner. The analysis also revealed that to influence the functional purposes the Foot-LITE system may wish to draw on other sources of information such as route planning and traffic information. These sources may inform the driver and assist in better transport and route choices. Finally, off-line information in the form of after journey reviews will be extremely beneficial – for instance in informing the user of their cost of use or carbon footprint. The off-line feedback is envisaged to be the principal method to induce longer term behavioral changes.

3.2 Priority of Individual Nodes

The upper levels of the AH are considered to be 'technologically agnostic', with an emphasis on what can be done, not what is currently or typically done. Whilst it is acknowledged that the abstraction hierarchy model has been developed to support unexpected and unanticipated events, and is therefore independent of specific contexts, there is perceived benefit for the purposes of design in creating an understanding of the relative importance of nodes in the hierarchy. The aim of this paper is to present this heuristic method, which the authors acknowledge as having potential limitations of over-simplification, but may also have potential benefits in other domains. In order to support functional specification in the wider design process for the Foot-LITE project, the authors developed a method to rank the individual nodes in the AH in terms of importance. This prioritization heuristic is intended to facilitate the functional and user requirements specification process, as well as to categorize driving information in order of importance which will assist with the design of the in-vehicle interface. The causal nature of the domain, and the linear relationships between action and effect mean that the approach is applicable. It is acknowledged that this approach may be less appropriate for more intentional domains. All nodes in the Foot-LITE AH were classified according to three levels of priority – high, medium or low.

3.2.1 Calculation of Priorities

The method used to calculate the priority of individual nodes, as described below, was created specifically for the Foot-LITE project. The method adopted was loosely based on the Failure Modes and Effects Analysis (FMEA) method. FMEA is a risk assessment technique for systematically identifying potential failures in a system or a process. For the present analysis the top three levels of the AH were assigned arbitrary priorities by the authors. Their conclusions were based on a detailed review of the discussions and minutes from the focus groups as well as expert judgment. As a result, all of the highest level functional purposes were considered as high priority, while the nodes in the next two levels were assigned either high or medium priority.

For example, 'reducing carbon footprint' and 'polluting emissions' were considered by the majority of the focus group to be of higher priority in reducing local environmental impacts (such as noise, vibrations and local emissions). In addition, reinforcing good driver behavior was considered to be of great importance to the project's safety objectives. Of the efficiency related measures, 'Reduce cost of use' was considered of primary importance as saving money is probably one of the main reasons why people will be motivated to actually purchase the Foot-LITE system. Hence this was given a high priority rating with other efficiency measures rated of medium importance.

To calculate the priority of the bottom two levels of the AH (the object-related processes and physical objects), a combination of the number of means-ends links, and priority of linked nodes (from top-down) was used. The priority of the object-related processes was calculated first; in turn, these priorities were used to evaluate the physical objects. A consistent heuristic was used to weight priorities. A link to a designated high priority node was worth 9 points, to a medium priority node 3 points, and to a low priority node 1 point. This ensured that the high value links were considered and not just absolute number of links. The specific priority of a particular node was therefore dependent on the score it attained. Table 2 shows how the priority groups were categorized. These categories were derived by considering the results from the priorities analysis, and were not established beforehand. Although this method of designating priority is somewhat arbitrary and analysis dependent, which will inevitably differ between projects, this is relatively consistent within the subjective nature of the CWA approach as a whole.

Insert Table 2 Here

The following worked example will help to illustrate how the scores were calculated. 'Driver incentives / rewards schemes' is connected to the level above via 'Efficiency, reliability, convenience, cost of transport', 'Incentive and motivation' and 'Feedback off-line'. These nodes have been given priorities of low, medium and high, respectively. Thus the links are worth 1, 3 and 9 points for a total of 13 points and, using the grading system in table 2, the node is therefore assigned a priority of medium.

3.2.2 Priority Results and Discussion

Table 3 shows the object-related processes (as defined in the WDA, see section 3.1.4 and table 1) and priorities assigned using the method described above. Not surprisingly the highest ranked process was ‘Feedback in-vehicle’, due to the integral nature of this method for delivering information on all three functional purposes to the driver.

Insert Table 3 Here

Using the WDA output to prioritize the physical objects was considered to be the principal benefit of this analysis to the Foot-LITE project. The physical objects listed in table 4 were mostly defined from the CWA focus groups, off-line analysis, and user requirements analyses. Just over half of the physical objects were rated as being of medium priority; such nodes ranging from ‘Engine temperature’ to ‘Training organizations’. Low priority nodes are dominated by different types of sensors or parameters outside of Foot-LITE control, such as league tables and insurance. High priority nodes consist of those which are key to the Foot-LITE system such as fuel consumption, journey information and driver coaching aids. However, some nodes were designated as high priority which may not have been expected to be so, such as other road users and vehicle safety systems.

Insert Table 4 Here

The main benefit of conducting these priority calculations is that they provide a high-level summary highlighting which nodes are highly connected, and may be more important for future consideration in the functional specification and design decisions for the Foot-LITE system. For example, if only one external sensor can be included in the Foot-LITE system then table 4 shows that ‘headway sensors’ is of higher priority than a tire pressure sensor. Both sensors are connected to two higher level nodes each, but the headway sensor is linked to two high priority nodes of ‘Vehicle position on road’ and ‘Spatial and situational awareness’, compared to the two low priority nodes of ‘Additional weight in car’ and ‘Drag coefficient’ for the tire pressure sensor. The AH also indicates that headway sensors will affect all three functional purposes of the Foot-LITE system, compared to the tire pressure sensors which only affect eco-friendly road transport.

3.2.3 ‘Priorities’ Summary

The method outlined in this paper has introduced an approach based upon the output of the WDA, the abstraction hierarchy, which provides a structured way to group the nodes in terms of their priority. Within the CWA discussions conducted by the group (outlined in section 3.1), the intended priority of nodes within the lower levels of the hierarchy were informally discussed, but the minting and evaluation of these conversations would have proved very difficult. The process outlined here can confirm an otherwise unstructured view within the project, and importantly with the WDA phase of CWA. This method, however, can suggest which nodes are of greater importance based solely on their connectivity. It can also quantitatively inform cost-benefit decisions in design relating to which system parameters are of importance, or which could reasonably be forsaken. Whilst the method has undoubtedly provided useful insights for the Foot-LITE project, this has very much been an exploratory study. It is therefore recommended at this stage that the method be used in conjunction with additional validation or further weighting from other analysts or subject matter experts.

3.3 Contributions to Functional Purposes

As well as calculating the priorities of individual nodes, we can use a similar process to highlight the relative contributions of each of the purpose-related functions and object-related processes (3rd and 4th levels of the AH detailed in 3.1) to the three functional purposes of Eco-friendly, Safe and Efficient road transport use. Relative contributions have been calculated in terms of percentages, and it is important to note that these percentages are in relation to the potential benefits of the Foot-LITE system to the user. The perceived benefit of this extension to the conventional CWA methodology is that it offers the chance to prioritize information on an adaptive in-vehicle or off-line interface. Namely, this will enable the analyst to focus on functions and processes which most contribute to the desired functional purpose.

3.3.1 Calculation of Contributions

This section of the paper will discuss the heuristic method used to calculate the contributions of the lower levels of the Foot-LITE AH to the functional purposes. The contributions are expressed as percentages and were derived for both the purpose-related functions and object-related processes by assessing the number of ‘Values and priority measures' nodes (2nd level of AH) that each individual node was connected to via means-ends links, according to the AH. As explained in section 3.1.2 of this paper, the ten value and priority measures generated generally fitted into one or other of the functional purposes, with the exception of driver behavior which would affect all three. In addition to this, these nodes were weighted for importance according to the high, medium or low priority derived in the previous section. Table 5 shows the values and priority measures (as defined in the WDA, see section 3.1.2) and their allocated contributions to the functional purposes (these were given a contribution by the analyst based on expert judgment, and not calculated unlike the lower levels). The weighting system adopted for this process took account of the priorities calculated in section 3.2, by halving the relative contributions if the value and priority measure was classified as of medium importance as opposed to high importance. This arbitrary rating ensured that greater emphasis was placed on important nodes.

Taking 'Reduce local environmental impacts' as an example, in section 3.2 this was rated of being of medium importance, therefore its contribution to eco-friendly road transport use was reduced to 50% (table 5). At this point it is worth indicating that this approach is a significant departure from the accepted formative description of the WDA. However, for this project in particular (and it is envisaged for many others) the determination of the object-related processes and purpose-related functions contribution to the three functional purposes was deemed of significant importance.

Insert Table 5 Here

The first three measures (reduce carbon footprint, polluting emissions and local environmental impacts) are only linked to the eco-friendliness of road transport. Consequently they do not contribute to either safety or efficiency. The next three measures in table 5 (reduce RTAs, reduce inappropriate driver behavior and reinforce good driver behavior) contribute to all three functional purposes. However, this contribution is not equal for all three. The 'Reduce risk, number, severity of RTA' measure was rated as high priority and deemed to affect safe road transport (80%) considerably more than the eco or efficient purposes (10% each). In the context of the Foot-LITE system 'Reduce inappropriate driver behavior' and 'Reinforce good driver behavior' were considered to have the primary influence on eco and safe road transport (40%), but still play a smaller role in increasing efficiency of road transport by decreasing cost of fuel and routine maintenance. The contribution of reinforcing good driver behavior was halved as it was considered a medium priority measure (table 5). The final four measures relate solely to efficient road transport use, with only 'Reduce cost of use' being rated a high priority measure.

From here, and having calculated the priorities of all nodes in section 3.2, the relative contributions of the purpose-related functions and object-related processes to the three functional purposes can be evaluated. The contributions of these lower level nodes were assessed by the number and relative priority of values and priority measures they were connected to. A worked example will better illustrate the method.

Taking 'Improve driving styles and technique' as an example, the AH shows that 'Improve driving styles and technique' is linked to all of the values and priority measures in the level above, with the exception of 'Satisfy personal mobility requirements' and 'Increase availability of capacity' (i.e., measures numbered 1-6 and 8-9 in table 5). To calculate the percentage contribution to each functional purpose, the following equation is used:

- (Total % of functional purpose related measures ÷ Total % of selected measures) x 100%

Total % of selected measures refers to the combined percentages of measures for all three functional purposes connected to the selected node. Using our 'Improve driving style and technique' example, this was connected via means-ends links to values and priority measures numbers 1-6 and 8-9 (table 5). Therefore, the total % of selected measures was 650% (e.g. measure number 1 – 'Reduce carbon footprint' = 100%, 2 = 100%, 3 = 50%, 4 = 100%, 5 = 100%, 6 = 50%, 8 = 50%, 9 = 100%; total = 650%).

Total % of functional purpose related measures refers to the combined percentages of either the eco, safe or efficient measures. Again using 'Improve driving style and technique', for eco-driving this equates to 320% (1 = 100%, 2 = 100%, 3 = 50%, 4 = 10%, 5 = 40%, 6 = 20%, 8 = 0%, 9 = 0%; total = 320%). Using the equation above the percentage contribution of 'Improve driving styles and technique' to the eco functional purpose is: (320 ÷ 650) x 100% = 49.2%. Similar calculations for safe and efficient road use lead to the figures in table 6, which show that ‘Improve driving styles and techniques’ predominately affects eco-friendly road transport use at almost 50%, and has relative contributions to safe and efficient road use of approximately 20% and 30% respectively.

3.3.2 ‘Contributions’ Results and Discussion

Tables 6 and 7 show all the results from the calculations of relative contributions to functional purposes. It is again worth pointing out that these contributions are related to the perceived and planned benefits of the Foot-LITE system. For this reason the results are slightly weighted towards a change in eco-friendliness of road transport, as this is where Foot-LITE is ostensibly intended to make the greater calculable positive difference in user behavior. This is shown in the preceding tables where the relative contributions were consistently higher than their safe and efficient counterparts. For ease of interpretation the percentages calculated for the contributions have been reinterpreted into categories of high, medium and low. This reflects the contribution of a particular node to the three functional purposes. If the node’s contribution to one of the functional purposes was 50% or greater then this was deemed as having a high contribution to that particular purpose. Between 0 and 24% was deemed as low, and between 25 to 49% as medium. As with the priorities detailed above, these parameters are to some degree arbitrary and can be reset for any individual analysis, these however suited the specific Foot-LITE related analysis.

Insert Tables 6 and 7 Here

Evaluating the results has highlighted some issues which may be seen as potential limitations of the method, or even with the Foot-LITE system itself. The object-related process of ‘Driver mental workload’, according to table 7, contributes around 40% to both eco and efficient road use, and 20% to safe road use. The mental workload of a driver is of considerable ergonomic importance, and is heavily related to safe driving performance (Ranney, 1994; Young and Stanton, 2007), suggesting that the AH means-ends links need revision. Another observation is that the contribution of safety rarely increases above 20%. This may be due to constraints within the project on how safety improvements can actually be achieved, apart from by reducing inappropriate driver behavior. However, devices such as lane positioning cameras and headway sensors should assist the driver to drive in a safer manner. Foot-LITE is primarily aimed at improving eco aspects of road transport, whilst not negating safety improvements which can also be made; therefore, the high level objectives of the system are clearly reflected in this method of analysis.

3.3.4 'Contributions' Summary

This paper has proposed a method, extending the use of the abstraction hierarchy, which calculates the relative contributions of lower level nodes to achieving the functional purposes of a system. This extension adds extra context-specific information to the WDA and increases the quantifiable measures resulting from the analysis. The results of this process identified a key issue with the Foot-LITE system, in that as it stands it is predominately focused around an increase in eco-friendly road use, and limited safety applications have been identified as yet.

4. Conclusions

In this paper, we have presented the results and findings from the first phases of CWA, the Work Domain Analysis, as it relates to a project to improve safe and eco-friendly driving. This has proved extremely beneficial in ensuring a common language for the project, generating discussion and debate regarding the Foot-LITE system. Furthermore, the process has helped determine how the success of the system will be measured and suggested how and what information should be presented to the user. The findings can now be taken forward to the next phases of the project, informing the user requirements specification, and testing the assumptions during simulator and road trials.

Building upon the CWA model, this paper has introduced a new approach, reusing the WDA outputs to calculate relative importance of the nodes within the hierarchy, using two novel methods for calculating the priority of individual nodes and the contributions of each individual node to the functional purposes of the system. These add quantifiable evidence based on the abstraction hierarchy, assisting user requirements identification and ultimately helping to improve product design. These heuristic methods also served to assist in the bridging of the gap between CWA and interface design, by helping to derive the functional specification and detailing the priority of driving related information to be shown in the vehicle. The causal nature of the domain lends itself well to this type of analysis. Its mechanistic properties made it possible to clearly establish which objects impacted which purposes; moreover, it was also possible to add a fairly accurate approximation of the magnitude of impact. These heuristic processes were proposed to solve specific, context dependent issues within the Foot-LITE project. The results were of practical importance to the project in determining what is deemed essential and desirable information to be presented on an in-vehicle coaching aid; of which the methods were ultimately successful. This paper intends to put these methods out into the CWA community for debate, and hopefully to add some degree of substantive analysis to the existing CWA methodology.

As WDA was developed to be independent of context, there is no recognized scientific method used in WDA to calculate the contributions of lower level nodes to the high level functional purposes. The relative importance of different nodes in different contexts is likely to change; other relevant methodologies that can cope with this flexibility (such as Social Network Analysis (SNA)) do exist but these were considered inappropriate for use with CWA. SNA solely considers the connectivity of nodes and not the importance of the links between them. In addition the structure of the Abstraction Hierarchy only allows links to the levels above and below on the hierarchy to be assessed, whereas this kind of analysis is infrequently conducted with SNA.

The approach here represents a context dependent, post-analysis method using the accepted definition of the WDA outputs. It is an amalgamation of methods developed purely for the needs of the current project, and this will inevitably cause debate. However, it is a more structured effort to assist the project, aid the functional specification and guide the design process.

The approach is considered transferable to other causal domains, in which it is possible to identify not only the relationships between objects and functions, but also predict their influence. In more intentional domains, which are exposed to a wider, more diverse, range of situations, it is predicted that the approach will be less applicable. Thus, like all analysis techniques, the use of this approach needs to be closely matched to the domain in question and the aims of the analysis.

5. Acknowledgements

Foot-LITE is sponsored by the TSB, DfT and EPSRC under the Future Intelligent Transport Systems initiative. The Foot-LITE consortium is comprised of: MIRA, TRW Conket, Auto_txt, HW Communications, Ricardo, Zettlex, Hampshire County Council, Institute of Advanced Motorists, Transport for London, Southampton University, Newcastle University and Brunel University. All partners were represented and contributed at the CWA focus group meetings, for which the authors extend our particular thanks. Also many thanks to the anonymous reviewers whose valuable comments have improved the paper.

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