Inception, ideation and implementation: developing interfaces to improve drivers' fuel efficiency

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ABSTRACT

Cognitive Work Analysis has become a staple methodology for human factors and ergonomics researchers and practitioners. Despite this popularity, limited guidance is available to take the insights of the methodology forward into the development of newer systems and interfaces. This paper describes the use of the established design toolkit 'Design with Intent' as a suitable approach to help progress the insights of Cognitive Work Analysis towards the development of novel interfaces. An abridged account of developing a Cognitive Work Analysis for fuel efficient driving is presented, alongside the application of the Design with Intent toolkit to progress the insights from the Cognitive Work Analysis to generate novel design ideas which can be incorporated into future interfaces. Finally, early development work, compiling the ideas generated using the Design with Intent toolkit, is presented, demonstrating the potential for this combination of methods to produce interfaces for future testing and validation.

KEYWORDS

Interface design, cognitive work analysis, design with intent

Introduction

Pervasive technology and constant access to information has become a defining feature of the 21st century, with the automotive industry beginning to adapt to the potential of these new information systems. Fogg (2003) defined pervasive technologies as *"any interactive computing system designed to change peoples attitudes or behaviours"*. Within the automotive industry, pervasive technology has focused on the provision of safety critical information to the driver, primarily designed to reduce the likeliness of accidents and improve drivers' situation awareness and safety (Rakotonirainy & Steinhardt, 2009). One area of increasing importance to drivers is fuel economy (Turrentine & Kurani, 2007). Although vehicle drive trains (Chan, 2007) and vehicle mechanical systems (Vining, 2009) are large contributors to fuel economy, the way in which a vehicle is driven can also significantly impact its fuel use (Barkenbus, 2010).

Eco-driving is a style of driving that is typified by behaviours such as modest acceleration, early gear changes, limiting the engine to approximately 2500 revolutions per minute (RPM), anticipating traffic flow to minimise braking, driving below the speed limit, and limiting unnecessary idling (Barkenbus, 2010). By engaging in eco-driving behaviours, drivers can save a significant quantity of fuel with no significant increase to their journey time (Birrell, Young & Weldon, 2013). Advocating eco-driving behaviours is advantageous in that all drivers can employ these techniques, and the savings are not reliant on significant financial investment, such as would be necessary to purchase a newer, and more fuel-efficient vehicle. Consequently, encouraging eco-driving is an appropriate technique for owners of older cars and for those with limited disposable income (Saboohi & Farzaneh, 2009) to reduce the economic and environmental impact of their driving behaviours.

Despite the environmental and economic benefits of eco-driving, encouraging the permanent adoption of these behaviours is a great challenge. Drivers typically fail to maintain eco-driving long term. Geiler and Kerwien (2008, cited in Heyes, Daun, Zimmermann, & Lienkamp, 2015) explored the impact of an eco-driving training course and found that despite an initial fuel saving of 7% compared to before attending the course, in a follow up examination 10 months later, this saving had dropped to only 4% when compared to original fuel expenditure. Wahlberg (2007) reported a similar deterioration, specifically examining bus drivers. Wahlberg found that despite a 6% drop in fuel use following drivers attending an eco-driving course, a follow up investigation 12 months later identified that the fuel saving had been reduced to just 2%. Zarkadoula, Zoidis and Tritopoulou (2007), also investigating bus drivers, found that following an eco-driving training course, overall fuel usage dropped by 10.2%. Zarkadoula et al. notes however that this figure had dropped to a 4.35% saving compared to initial fuel use only two months after the course. Developing interventions to maintain the benefits of eco-driving training long term is therefore needed.

Previous research has considered the driving task in general, and eco-driving specifically (Young & Stanton, 2007; Young, Birrell & Stanton, 2011; Birrell, Young, Jenkins & Stanton, 2012), using system thinking methods, including Cognitive Work Analysis (CWA) (Rasmussen, 1986; Naikar & Lintern, 2002; Stanton, Salmon, Walker & Jenkins, 2018). CWA seeks to map the constraints that govern the system, understanding fundamental system requirements as well as understanding the possibilities that exist within the confines of the system operations (Vicente, 1999). CWA offers a technology agnostic approach to consider a system, allowing for consideration of both technology and human agents in the same analysis. The complete CWA process compromises of five key phases (Vicente, 1999), Work Domain Analysis (WDA), Control Task Analysis (ConTA), Strategies Analysis (StrA), Social Organisation and Cooperation Analysis (SOCA) and Worker Competencies Analysis (WCA). Although all stages of the CWA process were completed as part of the current analysis, focus within this paper will be given to the WDA component. WDA, and specifically the Abstraction Hierarchy element aims to map the proposed system on five conceptual levels:

- Functional purpose, the systems' raison d'etre.
- The values and priorities level maps metrics for measuring the systems success.
- Purpose-related functions are functions linking the systems functions to the roles offered by each of its components.
- Objects related processes are the things that each object system contributes to the wider system.
- The physical object level maps the tangible objects that the system is comprised of.

The generated abstraction hierarchy can be validated using an exhaustive means end analysis, following the why-what-how triad approach (McIlroy & Stanton, 2011). It is possible to nominate any item within the hierarchy and ask the question "what does this do?". By examining all connections in the layer immediately above the node, it is possible to answer the question "why does it do this?". When considering all connections in the layer immediately below, it must be possible to answer the question "how does it achieve this?". This validation ensured that all connections are suitable. Once completed, the abstraction hierarchy actively maps out the system for designers. This stage is considered essential for development as it can be seen as laying the foundation for the system under investigation.

One criticism that can be levelled at CWA as a means for informing development however is that despite claims that it can act as a key tool when designing innovative systems (Rasmussen et al., 1990), taking the ideas forward to developing these systems is a significant challenge, with limited guidance available. The current work sought to bridge this gap by the use of a design toolkit 'Design with Intent' (DWI) (Lockton, Harrison & Stanton, 2010). DWI is based upon a set of 101 design cards, organised across eight key themes or lenses, which seek to inspire designers to make novel and creative design decisions. The DWI approach is founded on the view that behaviour can be directed by design (Buchanan, 1985). Applied to the development of in-vehicle interfaces, the DWI approach advocates that desirable behaviours should be promoted and made easier whilst the potential for undesirable behaviours to occur should be constrained and reduced. DWI can be considered a *'Suggestion tool'* (Lockton, Harrison & Stanton, 2010, *p383*), which seeks to inspire designers to develop novel solutions, promoting creative thinking.

The aim of the current paper is to provide an overview of work undertaken to develop novel interfaces targeting reduced fuel use, from the mapping of constraints using CWA, the conception of ideas using DWI and how these ideas will be implemented for testing within the Southampton University Driving Simulator (SUDS) for initial user testing.

Methodology

Two separate one-day workshop sessions were run as part of this research program. The first workshop centred on the development of the CWA, with a focus on the WDA and specifically the development of the Abstraction Hierarchy. Nine participants, aged 27 – 57 years old (M = 36.33, $S.D.$ = 10.84) attended the session. The workshop drew together individuals with an extensive knowledge of car mechanics and operations, traffic operations, eco-driving, human factors and fuel usage. During this workshop, participants were guided through the theoretical underpinnings of the CWA process, and completed a WDA for the task of fuel-efficient driving. Following the workshop, the research team continued to develop the complete CWA process, seeking validation from the session's attendees once each of the five phases had completed. Feedback was used to refine the developed CWA to ensure that it accurately reflected participants' opinions. Where disagreements arose, the group was required to make a collective decision in order to ensure that the completed CWA accurately represented the groups' knowledge.

The second workshop focused on using the outputs of the completed CWA to constrain the development of novel interfaces, using the DWI cards. An example of which is presented in Figure 1. Eight participants, aged 26 - 57 years (M = 35.25, $S.D.$ = 11.06) attended this session. Participants were from a variety of academic backgrounds including Psychology, Human Factors, Control Engineering, Automotive Engineering and Electronic Engineering. Following a detailed walk through of the completed CWA, with all stages being illustrated and explained, each participant was given a random selection of unique DWI cards, so that all 101 DWI cards were distributed. Each participant was then asked to sequentially lead a group discussion on each of the DWI cards they had been assigned, generating ideas relating to the development of new in-vehicle interfaces to support fuel-efficient driving. In this way, every DWI card had the potential to inspire multiple design ideas. Once an idea was generated, it was categorised as suitable for either visual (Heads Ups Display, HUD), visual (Heads Down Display, HDD), Auditory, Haptic (Pedals) Haptic (Seat) or Other implementation. These modalities were chosen as they represent the primary sources of sensory feedback possible within the confines of an automobile, and have all been utilised within previous work to present information to drivers (McIlroy, Stanton, Godwin & Wood, 2017).

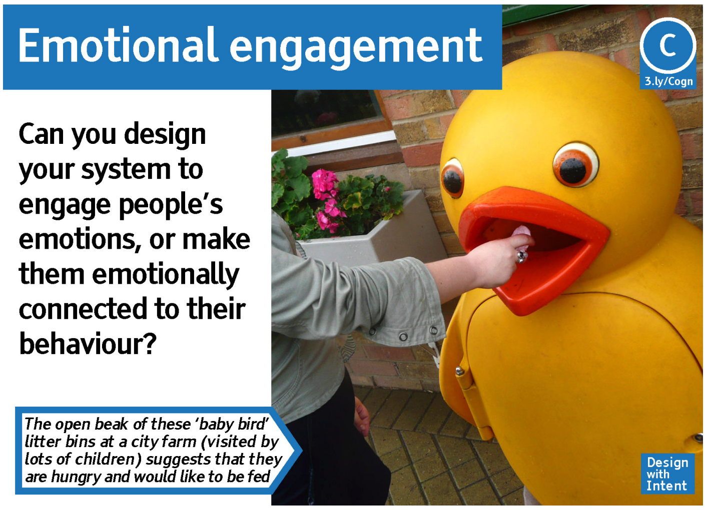

Figure 1: Example DWI card 'Emotional Engagement' from the Cognitive lens. Each card presents the designer with a question to ask of their design/ system/ idea and an example of the lens in action. Taken from Lockton, Harrison and Stanton (2010).

Following the second workshop, the research team collated the generated ideas and used them to develop a series of in-vehicle displays for further testing.

Results and Discussion

Inception - development of the cognitive work analysis and the abstraction hierarchy

The completed abstraction hierarchy comprised of 84 items distributed across the five levels of analysis. Three Functional Purposes were identified. These were 'Save Energy', 'Reduce Emissions (CO_2 and NOx)', and 'Getting From A to B'. To support these Functional Purposes, eight Values and Priorities were identified, 'Optimise Vehicle Range', 'Reduce Fuel Usage', 'Minimise Traffic Delay', 'Minimise Congestion', 'Optimise Driver Satisfaction', 'Optimise Travel Time', 'Reduce CO_2' and 'Reduce NOx'.

Five Purpose-Related Functions emerged as part of the analysis, which were largely focused on identifying the difference between the environment as identified by 'Road Attributes' 'Objects in the World', controlling the vehicle, 'Control Vehicle Motion' and ensuring 'Driver Comfort' and 'Passenger Comfort'. When considering the Object Related Processes level, 39 items were identified. This level focused around in vehicle displays, such as 'Display Vehicle Speed', 'Display vehicle RPM', knowledge of other vehicles and the external environment, including 'Detecting Traffic Jams' and 'Provide Information on Other Vehicle Behaviours'. Route based guidance including 'Shortest Path', 'Fastest Path' and 'Most Fuel Efficient Path' and functional controls for vehicular systems and ancillary systems were also included such as 'Control Vehicle Lane Position', 'Control Vehicle Headway', 'Control Cabin Humidity' and 'Control Lighting'.

The Physical Objects layer comprised of 29 items. Items in this layer can be seen as the essential physical components that relate to the specific task of fuel efficient driving, including an 'Internal Combustion Engine', 'Battery' and 'Fuel'. This level also included essential vehicle components that are reliant on energy, be it chemical or electrical to function including 'Vehicle Heating' and 'Vehicle Lights'. Finally, items related to infrastructure changes and vehicle communication were included to allow for the potential for technological developments and basic automation, including 'V2X Communication', 'Radar' and 'Lidar'.

Following the completion of the WDA within the workshop, the remaining CWA stages (ConTA, StrA, SOCA and WCA) were completed by the research team and subsequently validated. The complete CWA identified the prescribed nature of the driving task, with set operations being needed to control the vehicle. Despite this, fuel saving and a shift towards greater eco-driving should be possible if the driver was made aware of upcoming road events through greater information provision, which could be provided through in-vehicle interfaces.

Ideation - design with intent Idea generation workshop

A total of 138 ideas were generated from the DWI cards during the second workshop. Following discussion of each idea, it was classified as being suitable for one of the six interface modalities Visual (HUD), Visual (HDD), Auditory, Haptic (Pedals) Haptic (Seat) and Other. The relative distribution of these ideas is presented in Figure 2.

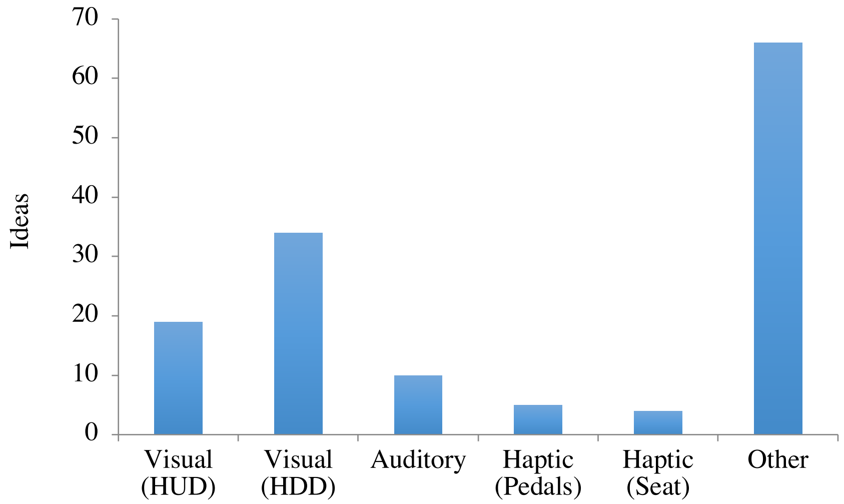

Figure 2: Summary of the ideas generated within the workshop.

Of the five established feedback modalities, the ‘Visual (HDD)’ was the most commonly chosen. The largest category however was ‘Other’, with a considerable number of ideas being generated that were not suitable for immediate implementation within any of the identified feedback modalities. These ideas however, which included ‘Encourage greater awareness and use of alternative and public transport options, for example Park and Ride schemes when planning routes’ could be pursued within future research and were therefore encouraged throughout the session.

A summary of the ideas generated when considering the Visual (HUD) is presented in Table 1. For completeness, the DWI lens and specific card that inspired the idea is presented for each idea, however focus should be given to the ideas generated. As can be seen from this table, the main themes centred on greater information provision, encouraging greater engagement with eco-driving and fuel-efficient driving as well as attempting to constrain the driver so that they are less likely to engage in fuel inefficient behaviours.

Table 1: Summary of ideas generated for the Visual (HUD) during the workshop.

Lens	Card	Description/ Reasoning
Interaction	Realtime Feedback	Clear MPG display presented to the driver at all times
Interaction	Realtime Feedback	Tailored eco-driving suggestions based on current location, informed by GPS position
Interaction	Kairos	Gear change indicator, guidance regarding when to change up or down gear
Interaction	Kairos	Guidance regarding the best moments to coast to a stop

Perceptual	Mood	HUD displays changes colour from red (bad) to green (good) based on current level of eco-driving
Errorproofing	Conditional Warning	Notification regarding when heating or cooling system is not required
Errorproofing	Choice Editing	Suggest route/ journey modification based on most eco-friendly
Errorproofing	Choice Editing	Suggest best eco-friendly options for achieving journey
Machiavellian	Serving Suggestion	Example "Ghost Car" for the driver to mimic, displaying the most environmentally friendly actions a driver can take
Machiavellian	Anchoring	Provide eco-information at the start and end of the route
Security	Where you are	Display informative eco-driving tips, based on their recent behaviour, when stopped to provide drivers with more information
Cognitive	Do As You're Told	Personal choice of instructor/ authority figure to offer guidance
Cognitive	Personality	Apply consistent avatar for different interactions and interface displays
Cognitive	Commitment and Consistency	Eco-driving/ environmentally tailored start up notification
Cognitive	Framing	Positive messages regarding eco-driving
Ludic	Playfulness	Polar bear on a small iceberg – shrinking & growing based on driving style and amount driven
Ludic	Playfulness	Smiling/ crying emoji to rate recent driving behaviours
Ludic	Playfulness	Emoji display to indicate current eco-driving behaviours
Ludic	Playfulness	Challenge goal of keeping item within a set margin based on level of acceleration/ braking lateral force (Olive in a Martini analogy)

Implementation – digitising the developed Ideas

Taking the ideas from the DWI workshop, a series of potential interfaces were developed for testing within the SUDS laboratory. Paper based prototypes of the interface displays were originally developed and subsequently digitised. Following the initial prototyping, each interface was validated by comparing the separate elements against the completed CWA. This ensured that all required functions were met and that the interface operated within the identified constraints. Figure 3. presents an initial HDD interface design. The HDD interface was programmed on a Microsoft Surface tablet computer that can be recessed directly over the SUDS dashboard to provide an artificial dashboard. For the digitisation of the interface elements, the C# programming language was used to allow for the desired information to be presented. This display would be available to drivers during the general drive and additional elements can become available when the driver would be required to complete further eco-driving action.

Within Figure 3, the key interface element is the addition of a dynamic eco-band on the speedometer to guide drivers to travel at the most fuel-efficient speed, appropriate for their current road environment. Should it be likely that the driver would encounter a body of traffic, the band would move to encourage a slower speed than if the road was clear. It is envisioned that this band would encourage drivers to travel at an appropriate speed, whereby the likelihood of stopping would be significantly reduced. This interface element was primarily inspired by the DWI card 'Contrast', but also incorporated ideas that emerged from the cards 'Colour Associations', 'Simulation and Feedforward' and 'Kairos'. Future research is planned to test whether access to this display, alongside additional interface elements, which were developed following the interface workshop, can reduce participants' fuel use in a series of simulator trials.

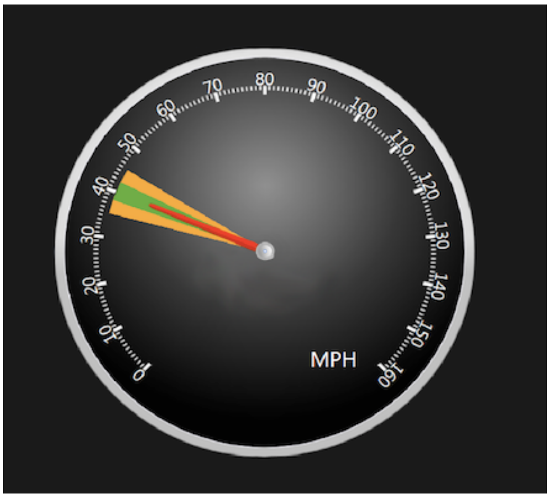

Figure 3: Initial interface mock-up based upon ideas emerging from the DWI workshop.

Conclusions

This paper has presented an overview of work completed in order to develop in-vehicle interfaces to encourage the uptake of eco-driving behaviours and reduce the fuel use associated with everyday driving. The first stage in this analysis was the development of a complete CWA for eco-driving, including the Work Domain Analysis that was summarised within the current paper. The CWA helped to illustrate the fundamental requirements of future interfaces designed to improve fuel-efficiency and illustrated the constraints that would operate around the use of such systems. This knowledge was then taken forwarded and used to ground initial design ideas that were generated following the use of the DWI toolkit. It is proposed that the DWI approach allowed creative ideas to be developed that could be used to produce novel interfaces for future testing.

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