Enabling Multitasking by Designing for Situation Awareness within the Vehicle Environment

Journal: Theoretical Issues in Ergonomics Science

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Abstract

In the driving environment, competition exists between Driving Related Activities (DRAs) and Non-Driving Related Activities (NDRAs). This is a source of inattention and human error. Continual proliferation of in-vehicle information systems (IVIS) presents drivers with opportunities for distraction. Drivers simultaneously manage DRAs alongside unrelated but cognitively demanding NDRAs. Vehicle designers need ways of understanding human capability in such situations to provide solutions that accommodate these conflicting demands. This paper proposes a framework intended to address such challenges, rooted in the widely accepted construct of Situation Awareness (SA). However, SA theory does not presently accommodate disparate unrelated goal-driven tasks performed in parallel. This framework reconciles the present reality of drivers simultaneously devoting cognitive resources to attain SA for multiple activities by proposing a separate body of knowledge for each active goal. Additionally, the process of achieving SA is expanded to incorporate this concurrent development of separate bodies of goal-directed knowledge. The advantage of reconceptualising SA for driving allows consideration of interface design which minimises the impact of competing activities. The aim is a framework facilitating creation of IVIS that help drivers succeed in multi-goal multitasking situations. Implications of the proposed framework for theory, design, and industry-driven automotive safety efforts are discussed.

Keywords

Automotive, Human Machine Interface, Situation Awareness, Multitasking

Word Count: 9999

Relevance to human factors / ergonomics theory – The present work is relevant for this journal because it directly addresses issues associated with characterisations of awareness in relation to the vehicle environment, this is a topic central to human factors and ergonomic theory. It also proposes an approach to human centred design that could allow for operators to better multitask in the vehicle. This covers a number of core topics oat the heart of this particular journal.

1. Introduction

1.1 The Motivation

Human error is cited as a leading cause of incidents on the road (Singh, 2015). Vehicle manufacturers therefore aim to reduce the likelihood of human error by addressing its primary causes. Inattention, a major source of human error (Dingus et al., 2006; Ranney, 1994), is the subject of a rich body of literature documenting how driving whilst engaging in alternative tasks challenge drivers' ability to multitask, often resulting in poor driving performance (Rogers et al., 2011; Strayer and Drews, 2006). Innovations in both mobile electronics and In Vehicle Information Systems (IVIS) have resulted in more alternative activities available in the vehicle than at any previous time in automotive history. As such, IVIS require a long design process (Clark et al., 1987) and are expected to meet implementation guidelines to minimize their impact on driving (EU, 2005; JAMA, 2000; NHTSA, 2014). Such guidelines often constrain what is possible in tandem with driving. This challenges designers to ensure guidelines focussed on driving safety are met, while delivering useable IVIS that create high customer satisfaction.

1.2 The Makeup and Relevancy of The Vehicle Environment

The driver must engage with an environment made up of both external and internal components (see Figure 1). Externally, increases in complexity impact driving performance. These include roadway-related factors such as an increasing number of cars on the road (Sperling and Gordon, 2008) as well as changes in driving conditions such as extreme weather (Leard and Roth, 2015). The internal environment is similarly divided. Some in-vehicle activities directly support the driver in carrying out roadway-related goals of vehicle use (i.e. getting from A to B). This includes interactions with the primary driving controls and can be thought of as Driving Related Activities (DRAs) (Pfleging and Schmidt, 2015). The second group concerns activities unrelated to driving. This includes IVIS tasks but also anything the driver may decide to bring into the vehicle such as a passenger(s) or a mobile device. This variety increases the potential for multitasking, especially if the vehicle itself does not possess identical functionality in an easily accessible manner. These interactions are known as Non-Driving Related Activities (NDRAs) (Pfleging and Schmidt, 2015). To successfully carry out DRAs and NDRAs, cognitive resources and knowledge of the relevant aspects of both the external and internal environment are required. When DRAs and NDRAs are performed in tandem, the resultant competition may impact the driver in carrying out either activity. The outcome being degraded performance on at least one if not both activities.

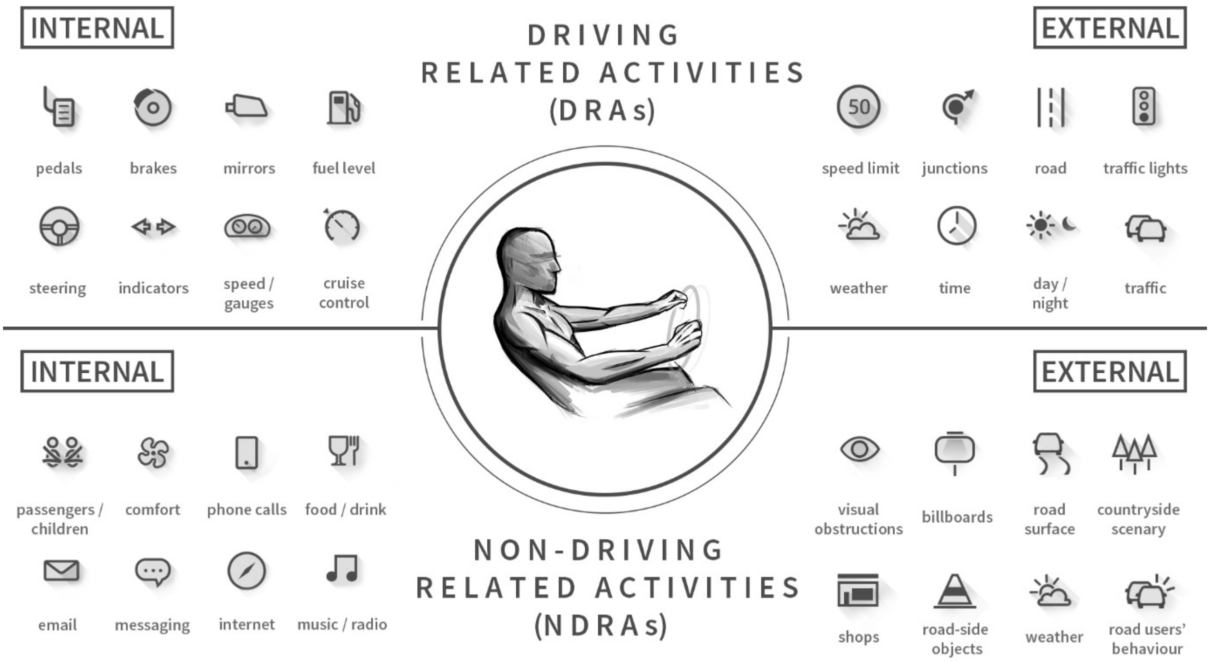

Figure 1 – The Main Constituents of the Vehicle Environment

1.3 The Importance of the Role of the Designer

Today, many design approaches specific to automotive focus on ergonomics (Bhise, 2011). These do not extend well to complex interactions, focussing more on physical impact. There are examples that focus on individual interaction technologies such as voice (Hua and Ng, 2010) or gesture (Alpern and Minardo, 2003) but do not take a system level approach. User-centred approaches are also adopted but these do not take into account cognitive aspects

(Thomke and Reinertsen, 1998). Other generic methods look at the cognitive aspects, such as Cognitive Task Analysis (Militello and Hutton, 1998), but do not focus on the combination of tasks present within the vehicle environment. Therefore, a holistic design approach considering all of the challenges presented is currently absent from the literature.

Figure 1 shows how the vehicle interior has evolved to be as dynamic as the exterior. Increasing amounts of information compete for the driver attention, yet human ability to multitask remains unchanged. This creates a challenge for the designer who needs to balance the needs of the system with those of the individual driver. Furthermore, there appears to be no direct support to assist the designer other than the promise of automation and the stated guideline constraint. It is the design team that ultimately defines how successful multitasking will be in the vehicle and it is vital that they follow approaches that address potential conflicts that might happen. This paper proposes a framework that takes into account many aspects of the holistic vehicle environment important to the driver and discusses how this can be used to design appropriate IVIS.

2 Situation Awareness

2.1 Basic Principles

Situation Awareness (SA) describes how operators build detailed knowledge of their immediate environment. In terms of DRAs and NDRAs, such knowledge is required to interact successfully. Both therefore adhere to the most common definition of SA (Endsley, 1995b), *"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"* (*p. 36*). That said, many believe there is a lack of a universally accepted definition of SA. In a review on the topic Stanton et al., (2010) discusses three viewpoints and categorises them as psychological, engineering and systems based.

The psychological approach treats SA as a cognitive construct best characterised by Endsley's three-level model (Endsley, 1995) which describes the psychological influences behind SA. It uses three main components, task and system factors, the perception to action loop which incorporates the three levels of SA and finally individual factors. It follows logic described by the human information processing system which implicates memory and attention as core characteristics.

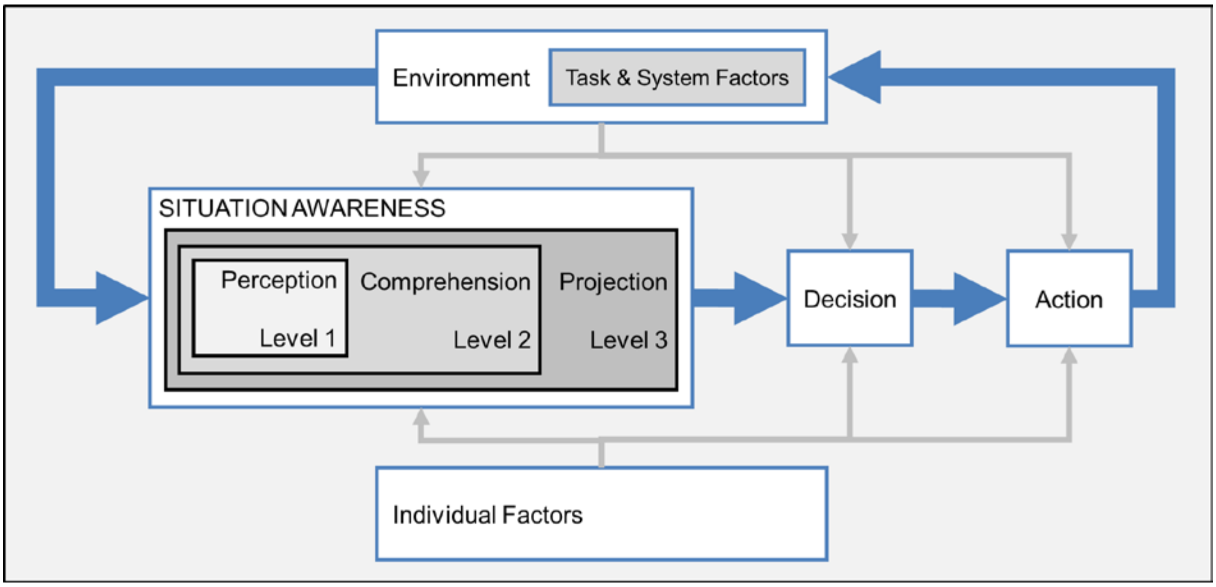

Figure 2 - A simplified version of Endsley's Model of SA, taken from (Endsley, 1995b)

Figure 2 illustrates a simplified version of Endsley's three-level SA model. Human senses gather information about the immediate environment leading to goal-directed perception (L1), which influences the selection of appropriate Long-Term Memory (LTM) such as mental models, schema and scripts. These direct attention and ongoing perception aiming to collect goal relevant information such as aspects required for safe operation (Endsley, 2013).

Comprehension (L2) is a synthesis of these perceived elements creating an output known as the Situation Model (SM), which is continually updated by a process called Situation Assessment (SAS). The SM represents an up to date body of knowledge for the current situation containing what the operator is aware of. Endsley, (1995) uses the term interchangeably with the term SA in subsequent literature. Comprehension requires domain knowledge, otherwise inaccuracies can exist which can lead to poor decision making (Endsley *et al.*, 2003b). Projection (L3) is where the SM is used to predict future events. These predictions influence decision making and action and are common amongst skilled or highly trained operators (Endsley and Garland, 2008).

The psychological approach takes the view that SA exists primarily in the mind of the user but does recognise the importance of other factors such as the task, system and the individual properties of the operator. Stanton et al. (2010) describe the three-level approach as the simplest to understand and measure but that this simplicity belies the complexity being explained. Being heavily influenced by human information processing makes it easier to understand the mechanisms by which SA occurs, Endsley uses perception, working and long-term memory to explain what elements of the human mind are implicated.

The engineering viewpoint takes the approach that information is placed within the environment to generate SA. For example, a display that takes the form of the three-levels discussed can remove the need for the operator to hold that information within memory. This view is common in military settings and has the advantage of helping an operator manage what they need to be aware of but can suffer from being too technologically focussed. This approach does not always lead to the operator making better decisions because of the potential for information overload or poor interpretation.

The final approach is systems-based and proposes that the system and the human interact either together or in distributed fashion around the operational environment. This view evolved from the distributed cognition research (Hutchins, 1995). This view describes the bond created by the flow of information between operator and system and allows for an understanding of the efficiency of a system. Stanton et al. (2010), define Distributed Situation Awareness (DSA) as "*activated knowledge for a specific task within a system at a specific* *time by specific agents*" (*p.34*). It combines the previous views (psychological and engineering) together using the Perceptual Cycle (PC) as the basic for operation (Neisser, 1976). The PC, shown in Figure 3 is a cyclic process that generates knowledge in the form of schema. The cycle shows how the operator samples the active environment, perceived information then modifies the schema of the present environment, this cognitive map of the world then directs attention to the next stage of perceptual exploration after which the cycle repeats. Active schema relate to the active goals of the operator and are equivalent to the SM.

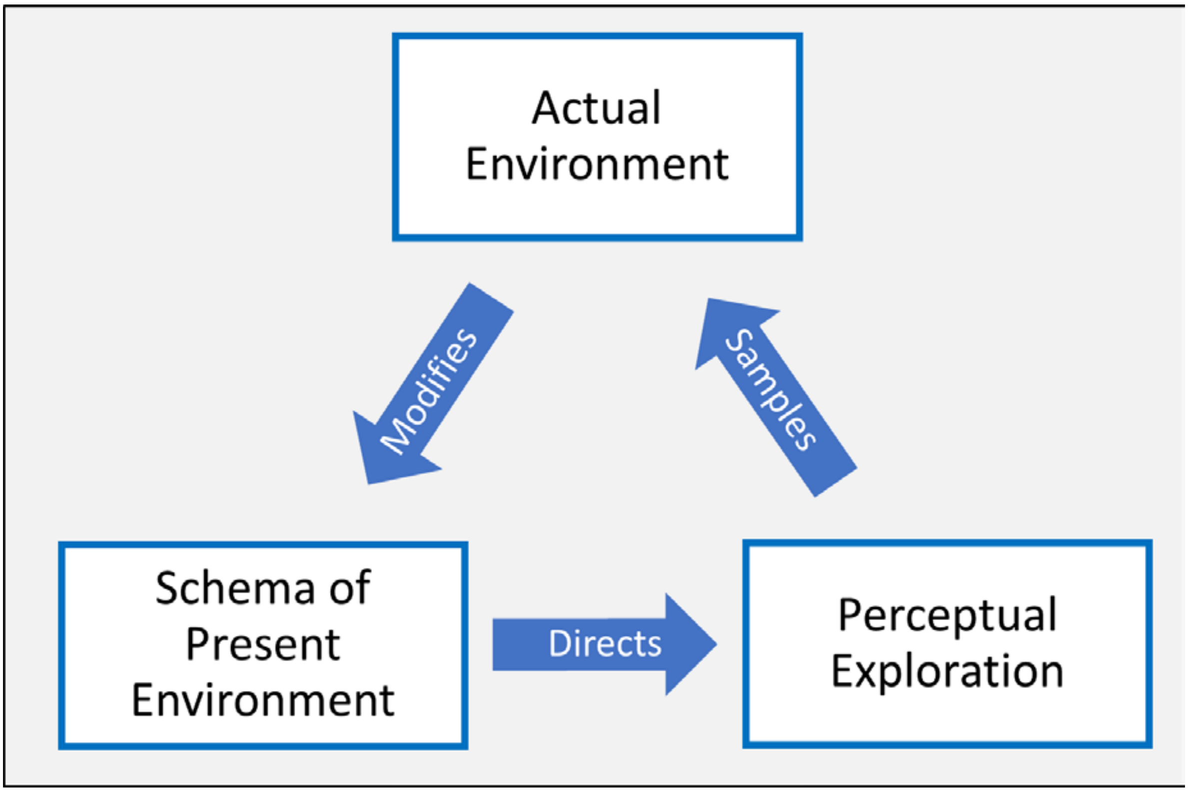

Figure 3 - Simplified version of the Perceptual Cycle Model, taken from Adams et al., (1995)

One recent, complimentary approach to the systems-based view is proposed in Chiappe, Strybel and Vu (2015). This approach takes a broader view of SA than Endsley's three level model and attempts to move it towards a systems-based view. They define the term Situated SA and explain that SA is both in the mind of the user and in elements within the environment. This approach describes that users will often remember that they can retrieve information from technology in the environment and therefore remember the location of it and check it when required rather than keep a continuous check on the information itself. Despite Chiappe et al, (2015) attempting to distance their view from the three-level model, in a recent rebuttal, Endsley suggests situated SA may not be as different to the three-level model as is suggested by Chiappe et al, (2015), Endsley then offers a number of criticisms toward the approach (Endsley, 2015). Whilst the systems view considers both the operator and the system, it can be complex to use and doesn't necessarily take in to account the specific properties of the different operators and how they might behave in a particular situation. That said it does consider the flow of information and how an operator needs to interact to achieve a specified goal.

One common debate is whether SA is a product; a specific knowledge structure held by the operator (Tenney et al., 1992), or a process (Stanton et al., 2001), "*the perceptual and cognitive activities involved in revising the state of situational awareness*" (*p. 9*). Endsley (1995b) proposes that SA is part process (SAS), part product (SM) as both are required for successful prediction or Level 3 SA. A cyclic process, used to refresh the SM, is common to most views on SA (Smith and Hancock, 1995; Walker et al., 2009). The systems viewpoint offers the PC as the process and active schema as the knowledge relevant to each situation, therefore both develop common ground here.

All views hold validity in the context of the design of IVIS for the driving environment. Those that concern the properties of the user (the psychological approach) are particularly relevant, especially considering driving skill and prior experience as well as individual motivation and the decision-making process. That said, the systems-based approach is also useful. Considering the information flow between the user and the system can help to identify efficiencies and when information overload or poor comprehension and prediction may occur.

All approaches take the view that SA focuses on the changing elements of an environment (including systems and information technology), how these develop over time and how this forms a user's interpretation of a situation (Durso et al., 2007). This makes SA relevant and potentially useful in an automotive design context. There is however a lack of detail about how SA should be applied where multiple competing goals are active. The size of the design challenge is possibly summed up by Adams et al., (1995) who conclude that humans are not suited to simultaneous disjointed tasks. Whilst all approaches discuss multiple competing tasks supporting the same goal none discuss in depth multiple competing goals. This paper will explore this topic in more detail.

2.2 Memory and Attention

SA is thought to exist as a combination of reportable knowledge (explicit short-term memory) and unreportable knowledge (implicit long-term memory) (Gugerty, 1997). All SA viewpoints allow for the operator to achieve high SA through linkage to LTM (Adams et al., 1995). The more experienced an operator the more they are able to call upon Long Term Memory (LTM) to support SA and is largely driven implicitly, gained through learning or prior experience. A reliance on Working Memory (WM) to carry out and complete an activity leads to greater workload and increased cognitive demand to both maintain SA as well as carry out the activity. This happens when engaging with novel or unfamiliar situations, which occurs explicitly. The interaction between WM and LTM has been described as existing in a special type of memory called Long Term Working Memory (LTWM) (Ericsson and Kintsch, 1995). LTWM is reported to help operators maintain access to large amounts of information therefore aiding comprehension.

Attention, or knowing where and when to focus attention from moment to moment will significantly aid SA. Poorly designed systems or unexpected events can lead to attention tunnelling which can disrupt the cyclic process potentially compromising performance

(Endsley et al., 2003b). One driving related example is when a NDRA is being attempted and the display being used is poorly designed or complex to read with lots of information contained within it, this can cause long glance times required to establish what to do next.

2.3 Application Areas for SA

The concept of SA was developed in safety critical domains, such as aviation, but has been described as being ubiquitous. Many domains share similar properties to aviation including dynamism, high information load, variable workload and risk; themes consistent with driving. Other domains to explore SA include team or crew based situations (Ellis, 2014), air traffic control (Durso et al., 1999), military command and control (Riley et al., 2006), submarine operators (Loft et al., 2014), military aviation (Endsley, 1987; Sulistyawati et al., 2011), battlefield operations (Kim and Hoffmann, 2003; Strater et al., 2004), team situations (Kaber and Endsley, 1998), medical disciplines such as education of health practitioners (Patterson et al., 2017; Wright et al., 2004), nursing (Sitterding et al., 2012), emergency services (Busby and Witucki-Brown, 2011) and anaesthesiology (Gaba et al., 1995), mobile computing (Dancu and Marshall, 2015; Streefkerk et al., 2006), fleet management (D'Aniello et al., 2017), seafaring (Cordon et al., 2017), train controllers (Lo et al., 2016) control room operations (Collier and Folleso, 1995; Connors et al., 2007), offshore oil drilling crews (Sneddon et al., 2006), computing based environments (Wang, 2010), cyber operations (Mancuso et al., 2015) and executive decision making forums (Resnick, 2003).

2.4 Driving SA Research

Early research focussed on SA in the context of accident safety (Egberink et al., 1986; Macdonald and Hoffmann, 1991). Over time this moved toward understanding the effects of IVIS on driving SA with many reporting increased errors, increased glance times and age based effects as indicators of poor SA (Graham and Mitchell, 1994; Labiale, 1991). In much of this early research, the construct of SA is implicit, but the methods used are consistent with those used to assess SA. One of the first examples of SA being used explicitly focussed on individual driver differences (Gugerty, 1997). Driving SA was assessed by asking participants to carry out a driving-like activity with probe methods used to establish the different elements of SA. This was similar to the commonly used Situation Awareness Global Assessment Technique (Endsley, 1988).

Examples of using novice and experienced drivers to assess driving SA is common (Kass et al., 2007; Walker et al., 2009). Experienced drivers build up high levels of awareness through extensive practice (Charlton and Starkey, 2011). Many experiments have looked at the impact of mobile phone conversations on driving SA, reporting greater speed variation, greater pedal variation and higher subjective workload (Parkes and Hooijmeijer, 2001; Rakauskas et al., 2004). Schömig *et al.*, (2011), investigated how drivers use SA to decide whether to interact with an NDRA. The key findings point to drivers making conscious decisions not to attempt NDRAs if there is uncertainty within the DRA.

More recent theoretical approaches have associated different DRAs to SA (Matthews et al., 2001; Ward, 2000), whilst others have confirmed links to established theory through experimentation such as strategic, tactical and operational control (Matthews et al., 2001) and the skill, rule and knowledge taxonomy (Wickens et al., 2013). Baumann and Krems, (2007) take a psychological viewpoint and propose a framework for driving SA describing how information is integrated into the SM. They explain that highly demanding sub-tasks do not lead to DRA SA degradation if the driving situation is not dynamic enough. This emphasises the importance of understanding what constitutes SA under divided attention.

2.5 SA Design Approaches to date

SA design approaches are evident in the literature. Endsley and Jones, (2016) defines fifty principles of design ranging from organisation of information presentation to complexity and automation. These offer high level direction for system design to support SA. Whilst useful as starting point they offer no specific direction regarding complex situations, such as the vehicle, where many competing goals exist.

One approach considers interruption recovery as a core element (St. John and Smallman, 2008). An example is offered where military officers are interrupted by messages aimed at providing supplementary information to the goal. This example discusses specific activities over long, relatively inactive periods of time. They break interruption down into four stages; Change detection, Pre-interrupt preparation, Post interrupt reorientation and Post hoc change detection. A display was developed to help with SA recovery post interruption. More specifically any changes that happened during an interruption were explicitly displayed to allow for recovery. In an experiment, participants were much faster at spotting the changes with this new display. They conclude 4 key principles for SA design all focussed around the topic of interruption and conclude that highlighting key changes within the environment as being important in facilitating change detection. Whilst this is useful in a driving context, it only considers a very small part of what constitutes DRAs, it also considers the primary activity as the focus and not the implications of the interruption and how both streams of information could be supported.

Matthews et al. (2001), suggest a series of guidelines for SA design. They propose that IVIS design should aim to minimise the errors and so design should be consistent with what SA errors are likely to happen during the DRA. The guidelines are all relative to the levels of SA defined in the three-level model. Again, there is no consideration for how NDRAs are considered in this approach.

There is evidence of SA based design (Foyle et al., 2005; Zacharias and Gonsalves, 1992) and a number of non SA based examples considering the vehicle environment (Howard et al., 2013; Seppelt, 2009; Wang et al., 2002) which generally take an ecological approach towards supporting DRA awareness. Whilst many of these designs and design rules have evidence supporting their use in publication, there is less evidence of others taking these approaches and applying them in the wild and less evidence of these being used to good effect in the automotive industry and even less in a competitive multitasking situation. There is no evidence of research into design that aims to support the competing nature of DRAs and NDRAs lacking consideration of aspects of competing activities in the design approach such that support is given for all active goals.

3. Theoretical Approach

3.1 Considering SA as a Framework for the Vehicle Environment

There are many aspects of SA which make it relevant for the vehicle environment particularly as internal or external to the car, dynamic elements exist. What is clear from much of the automotive literature to date is that DRAs are considered the extent of the environment associated with SA. Any alternative goal is considered separate from it. This is most commonly seen when DRA SA is disrupted by the presence of a NDRA, itself considered to be outside of the boundary of SA. To understand driver’s overall or global SA within the vehicle environment the NDRA must be considered alongside the DRA. The boundary of SA should encompass all activities to facilitate a complete understanding of the entire environment. When considering IVIS design for the vehicle this is a significant gap in SA research as NDRAs are integral to the modern-day vehicle. In many other domains, such as aviation, the focus of SA has been the primary goal of the operator to help with specific goals of operation. Competing goals, or distractions are not considered part of the model which appears to be the approach taken in automotive so far. Considering this difference, what other key aspects standout in an SA context for automotive?

3.2 The Competing Goals of the Modern Driver

The goal of DRAs (such as vehicle status, navigation knowledge, local scene comprehension and spatial orientation) are to control the vehicle safely from one place to another (Gugerty and Tirre, 2000). These generally remain consistent between journeys. The goal of NDRAs are less well defined and could be one of a multitude of alternatives. These two groups of competing activities make the vehicle stand apart from other SA domains. The driver can be thought of as having multiple roles within the vehicle where the currently active goal will dictate which role they will play (Hancock et al., 2008). Many existing SA domains are characteristic of a professional employed to complete an activity where multitasking happens, but is almost certainly related to the primary goal, especially in critical situations.

3.3 Understanding the Vehicle Environment Requires Consideration of both DRAs and NDRAs

In the vehicle, DRA knowledge is built primarily from the real world. Gibson and Crooks, (1938) spoke of how a driver scans the environment to develop the "*field of safe travel"* (p. 454) by observing natural boundaries, obstacles, road limits, corners and dynamic objects such as other road users. Viewing the road scene gives the operator a clear, uninterrupted view of the environment but has the disadvantage of being highly variable, uncontrolled and unfiltered. The ecological approach describes how highlighting parameters associated with these natural boundaries can inform the driver without them needing to directly observe the environment directly. DRA awareness can take up significant visual resource, thus parallel activities requiring visual resource can create conflict. Ecological approaches aim to reinforce information such that when the direct visual resource is compromised the state of the environment still remains salient. In driving, natural scanning provides a challenge of its own, various sub goals require resources to be focussed in specific ways. Drivers decide, based upon the situation and the goal what aspects of the environment are relevant. Experience makes this process more efficient. That said, a complex situation can sometimes disadvantage the pursuit of other DRA sub goals. For example, overtaking places more of an emphasis on awareness behind the vehicle. As a result there is an increased risk if the car in front decides to brake sharply. There are also times when there are too many invariants to take in with just scanning alone. Information provided through alternative forms of display can replace the visual resource as long as it follows certain cognitive conventions such as Multiple Resources Theory (Wickens, 2008).

In the context of this paper, and the vehicle environment, this is only half the story. The NDRA can be considered a barrier to the driver being able to maintain understanding of the DRA in the same way certain aspects of the driving environment inhibit SAS. The key difference being that the environment in focus, information types, context of use and the fundamental goal are different to that of the DRA. NDRA based information is generally found in-vehicle, meaning the driver has to scan differently to establish the key information required to be able to achieve SA. Ecologically, natural boundaries (display and control layout), obstacles (gear stick, steering wheel, cabin layout), limits (button boundaries and size), dynamic objects (inertia of vehicle, daylight) also exist. In the NDRA context, the exact situation (combination of DRA and NDRA) will invariably differ from previous attempts, unless the vehicle is stationary, making it difficult to retain the exact experiential conditions. The number of unique situations are therefore almost infinite. NDRAs vary in complexity containing different interactions based upon the goal. From eating to drinking, changing music to making a phone call and personalising the environment, the variety makes it very disruptive to the natural state of the DRA.

Taking context from Figure 1 and the discussion above, there is clearly a divide in the information provided by the on-board systems. DRA information is generally supplementary, linked to legalities; such as speed, or to aid the driver in areas where they are disadvantaged, such as blind spots. Onboard NDRAs have their own dynamic needs. These can range from rotating a dial to typing on a touchscreen or dealing with children in the backseat. There are aspects common to both groups of activities albeit with different consequences. For example, the driver may steer the vehicle sharply, placing inertial effects on any attempt to simultaneously operate a switch. Alternatively, sunlight can provide visibility for DRAs (externally) but can inhibit the NDRAs by washing out displays (internally). There are very few application areas where these varying demands are equalled.

3.4 Operator Differences with the Automotive Domain

One of the most significant differences in an automotive context is age range. Figures in the USA put the number of drivers over 85 with driving licences at 3.5 million (US DOT, 2014). This creates a number of challenges such as the effects of prior experience, attitude to new technology, likelihood to engage in NDRAs and age related performance (Ponds et al., 1988). Drivers largely operate private vehicles. This is different to the majority of other SA domains where paid professionals operate. A vocational environment brings with it more responsibility but also a well-regulated performance spectrum. Operators are highly trained, taking years, and are focussed on a single, albeit complex, system such as an aircraft cockpit. Pilots are only allowed to fly the model of aircraft they are trained for and require further training to fly an alternative. Measures are also put in place to maintain performance, such as shift work, and many operators will be replaced when they reach retirement. This is because risks associated with flying a plane are much higher than those associated with driving.

Airline pilots have intense periods of concentration (i.e. take-off) followed by long periods of monitoring (auto-pilot control). Processes and training ensure that pilots are less likely to be involved in activities that conflict with or affect their primary goal during the intense periods, especially as this is often monitored by the airline or co-pilot. For driving, the situation is very different. The operator is trained with basic vehicle controls, taking months, and tested to a nationally agreed level. The DRA can vary significantly from one moment to the next and whilst driving has more frequent intense periods these are much less consistent than in flying. Drivers are free to choose the vehicle they drive and largely drive alone. In many cases DRA controls have similarities from vehicle to vehicle, NDRA controls, however, vary vehicle to vehicle and are rarely trained for within the driving context. There are very few constraints, other than the driver's decision process on the nature and number of NDRAs active at any point in time.

3.5 Can Classical SA Address the Vehicle Environment?

SA can, and has been applied successfully in the automotive context (Endsley, 2017; Kass et al., 2007; Parkes and Hooijmeijer, 2001). This review, however, points toward a closer look at the construct of SA for the vehicle environment in the context of multitasking. Differences in highly complex dynamic domains mean generic models can be too vague to apply universally without sufficient appraisal. In the context of this paper there appears to be promise in using SA, but also some gaps in how it has been applied. As already discussed, one conclusion that can be drawn is that focussing only on the DRA as being the extent of the boundary of SA is not going to help focus on interface design to address all potential activities that may be active to the driver. As the aim is to establish how IVIS can be designed to support both DRAs and NDRAs concurrently, it would seem worthwhile to consider how to incorporate both explicitly within the SA construct. With this in mind, the question can then be posed; How can an interface designer consider SA when designing IVIS for the challenge of the automotive environment?

4. Situational Awareness for the Automotive Domain

4.1 Reconceptualising SA for the Automotive Environment

Baumann and Krems (2009) explain that performing NDRAs that require the same cognitive resources as those required for DRAs, will affect driver awareness of the DRA. Equally, if the same resources are shared, the same construct (SA) must also be true for NDRAs. When a driver continually refreshes his knowledge of the changing environment, what must happen when a driver is focussed on an NDRA is a build-up of situational knowledge relating to that specific NDRA, just as situational knowledge builds for the DRA. Due to known limitations within WM, whilst one activity is in focus, knowledge of the other activity will decay and vice-versa. If cognitive resources are therefore split between the activities then SA should also be split (Johannsdottir and Herdman, 2010). So, to consider how SA is formed during multitasking, it therefore follows that NDRAs conceptually create their own separate knowledge base accessing completely different mental models, schema and schemata than the DRA. Therefore, the driver must build up and balance at least two simultaneous SMs or schemata when competing goals are present. Such complexities require an appropriate modification to the existing SA framework expanding beyond previous approaches.

4.2 Modelling Competition Between DRA And NDRA

Figure 4 presents a framework reconceptualising Endsley's three-level model of SA for the vehicle environment. Whilst integrated here into the three-level model, it is equally applicable to the engineering or systems-based approaches. The top half of Figure 4 shows the original three-level model where SA contains a single SM to represent the active goal. The bottom half of Figure 4 proposes how SA is visualised when multiple goals are active. A number of SMs are active, relative to the competing activities within the vehicle. The extent to which an individual contends with this competition is dependent upon the complexity of the different goals that exist in a specific situation. As the driver refreshes their knowledge of the environment according to the active goal, the specific SM or schemata in focus develops. This knowledge is used for interacting with the relevant task and system factors.

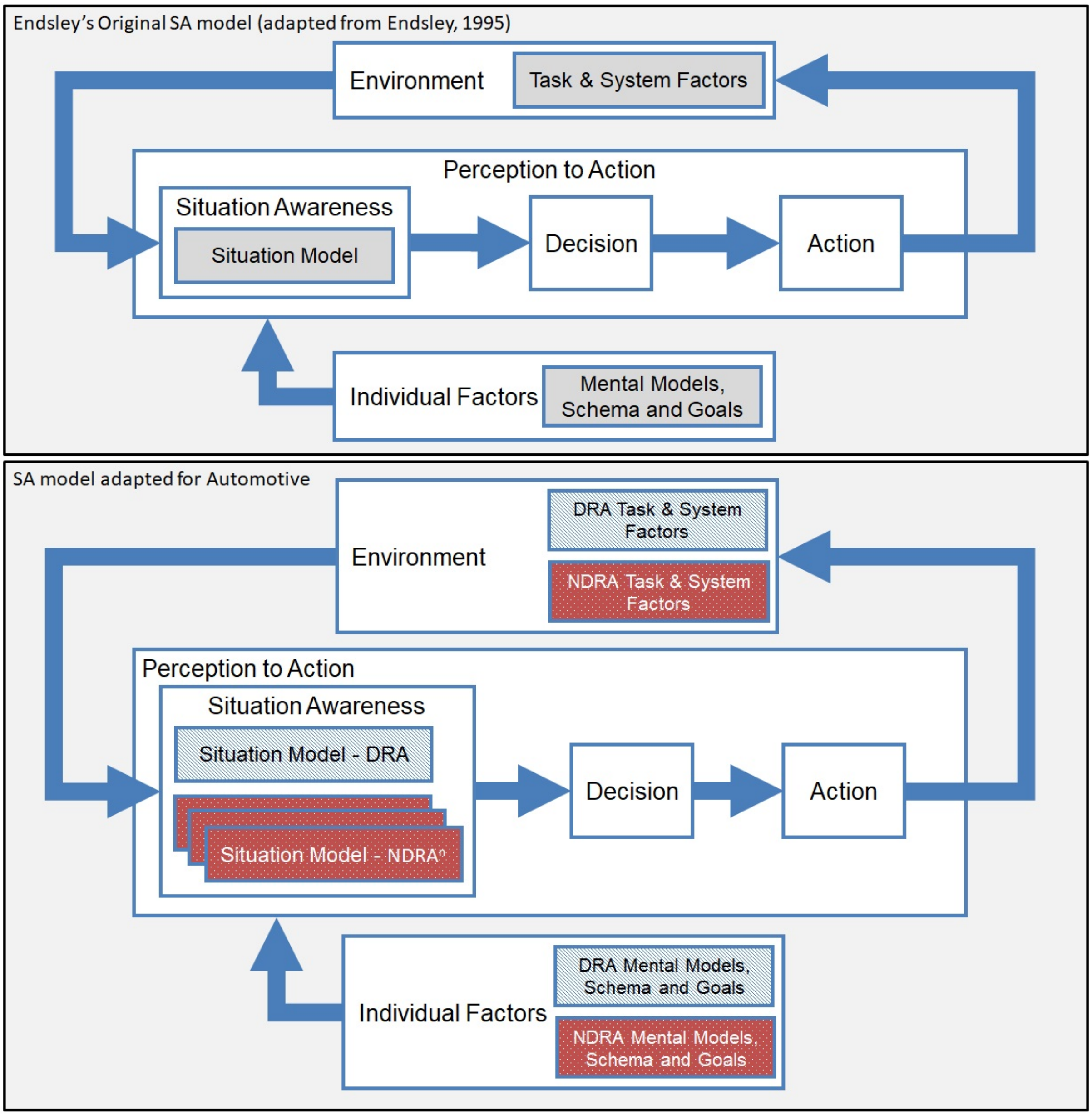

Figure 4 - A Simplified version of Endsley's three-level model of SA for Automotive

The key modification proposed is the explicit consideration of DRAs and NDRAs as separate aspects of a driver's SA. This change helps to conceptualise the impact on memory of switching between multiple unrelated activities. DRAs are continuous and always active, which means a driver continuously scans for factors associated with DRAs. This builds DRA awareness to become an accurate reflection of the environment over time. DRA task switching will occur naturally based upon the demands of driving, therefore drivers will work to keep their DRA awareness accurate and relevant. This means frequent glances to the roadway, mirrors, blind spots and instrument cluster or head up display. Experienced drivers with appropriate LTM will likely use the knowledge implicitly and react accordingly with little or no demand on WM. Novel or rapidly changing situations require explicit means placing heavy demands upon WM (Chiappe et al., 2015).

For NDRAs to become active, the driver will either be drawn to something on the interior of the vehicle (i.e. an incoming phone call) or develop an internal goal (i.e. change the cabin temperature). This, combined with mechanisms like intrinsic motivation (Ryan and Deci, 2000), meta-cognition (Finley et al., 2014) or risk homeostasis (Wilde, 1998) will trigger a switch to an alternative goal and may be influenced by the current state of the DRA. Once an NDRA is active, specific NDRA knowledge will grow. The focus of attention towards NDRAs do not positively impact DRAs unless the interface system is specifically designed to do so. Therefore, any time spent building NDRA awareness will mean that knowledge relating to DRA will decay (Altmann, 2002). The more time the user spends attending to NDRAs, the more depleted and less accurate DRA knowledge will become. This is proven by research that confirms that inattention can lead to a driver leaving a lane, when seconds before they were able to safely progress (Senders et al., 1967). The presence of NDRAs inhibit rehearsal and information gathering for DRAs, due to limitations within WM (Baddeley, 2007; Wickens, 2002). Once the NDRA is complete the driver will return focus to the DRA and the NDRA knowledge will decay to a residual level.

Different types of NDRA have their own specific properties. They can be ongoing requiring very low, almost none-existent levels of demand (listening to music) or periodic requiring very high levels of demand for short periods (typing a destination or finding a music track in a long list). Some NDRAs require constant monitoring such as a phone conversation, radio news program or sports commentary. Others require focus for short periods then disappear into the background (i.e. changing volume). NDRAs can occur at any point but are more likely to occur towards the start of a journey. There will be periods where very few NDRAs will be active. Equally many could be active simultaneously (radio listening, talking to a passenger, eating an apple). This constitutes dynamism within NDRAs. The instances of driving with no music playing whilst thinking only of driving will be the exception rather than the rule.

To imagine a specific scenario, suppose a driver wants to change the audio volume whilst driving. They immediately start gathering relevant information towards this goal. This includes retrieval of LTM relevant to this specific NDRA. For example, the location of, and the amount they need to turn the control required to hit the target volume. The more experienced the individual the more they will be able to call on LTM and execute the action with very little effort, constantly updating their active knowledge of the situation based upon feedback of the changing volume of the audio system. Those lacking experience or a complete novice will attempt to gather equivalent information, searching for cues in the environment. If they are interacting with an unfamiliar system or attempt a task for the first time, ambiguity will cause difficulty in comprehension leading to false predictions about what they need to do next and may lead to error, which may in turn also have impact on the DRA. An example would be multiple knobs that have similar size and location creating doubt in the mind of the driver as to which changes volume. The driver will then engage in the NDRA whilst periodically switching back to DRAs to maintain performance on both. Constant switching between activities is required to maintain DRA awareness because of the short time scales and speed at which difficult driving scenarios can develop. Different user strategies incorporating short switches in attention (i.e. glances) between the two activities is common (Brumby et al., 2007). Whilst this is a fairly simple example where only a little amount of knowledge is required to complete the activity, it gives an idea of the mechanisms at play and suggests how this could be extended to much more complex interactions such as entering a destination, finding a music track or reading a text message. Equally, the extent to which complexity exists in the DRA will also implicate how easy it is to build awareness to the NDRA.

So far, this is a relatively straight forward automotive engineering story, however, this mechanism may also describe processes and representations used by the mind in general cognition (i.e. everyday life). For example, the relationship between bottom-up and top-down processing and their interaction with WM and current schema is not currently understood. There may be a number of other processes involved such as episodic memory, meta-cognition and reinforcement learning that lead to individual variability or may provide a more complete account of behaviour in the vehicle. The goal of the present approach is to consider how to develop better interfaces by understanding how these competing goals affect knowledge structures in the brain, and not to understand how individuals generate or prioritise activities.

4.3 What are the Implications of this Approach?

From a design perspective, current NDRA interfaces are not designed in harmony with the DRA. They present information arbitrarily and do not consider the nature of the DRA-NDRA combination. It is the authors' belief that this is because of a lack of understanding in the design process of the specific cognitive and situational demands within the vehicle environment that NDRAs can create high levels of demand within the vehicle. Therefore, a shift is required towards interfaces that support the driver in a multitasking situation. This can have a two-fold effect, one, to reduce the levels of demand associated with multitasking and two, to increase performance on both activities by reducing the likelihood of error.

Why is this approach worth consideration? The first reason is that all active goals are recognised, helping to ensure that all information requirements are considered. The way information is structured and presented will determine how accessible it is when driving. The easier information is to perceive, comprehend and predict will mean lower operator demand leading to better overall performance. For example, an over-reliance on displaying large amounts of status information may lead to increased visual search times and possibly reduce SA overall.

Taking a goal-directed approach has always been at the core of SA. However, it takes on extra emphasis in the automotive context because of the differences highlighted within this paper. The integration of non-driving factors as part of any task analysis, especially those embedded within the vehicle, will allow for these to be considered alongside driving during the design process. It is highly likely that drivers will at some point be thinking about these goals in parallel within the vehicle. Secondly, it recognises the potential for concurrent activities within the vehicle. Multiple NDRAs could be active all requiring attention to maintain SA. Considering these conflicts can only increase the likelihood of a design that addresses these competing aspects by looking at how different activities combine; the result would allow for a more structured interface design process. This will increase the potential for designing IVIS that produce elevated levels of awareness across the two tasks, potentially reducing the cognitive burden that multitasking can place upon a driver. Finally, as autonomous driving increases, the reliance on the driver to carry out DRAs reduces. This novel approach will enable thought towards how NDRAs will affect SA when driving becomes a less active task. This will be essential in understanding how aware drivers are of DRAs and how to bring them back into the loop as and when they have to take over from the autonomous system. Instead of thinking about the DRA as an independent goal, the designer can think about the DRA and the NDRA together and consider issues related to the two being attempted in parallel.

4.4 What does this mean for IVIS Design?

Considering that this research is focussed on how IVIS influence driver performance, what does this approach mean for the future of in-vehicle interface design? The answer may be derived from the way that SA has previously been used to design interfaces. By understanding how an operator performs in a continually changing multitasking environment it may be possible to design in-vehicle interfaces that provide for both DRAs and NDRAs simultaneously. For DRAs, this could mean a greater emphasis on providing information that is suppressed during periods of multitasking. For example, the ecological approach of indicating hazards in the roadway environment. When drivers take their eyes off the road, they switch their visual attention toward gathering information about the NDRA. Any DRA-related information presented when an NDRA is active could help to assist DRA awareness. Equally, continuous presentation of artefacts of NDRAs whilst driving could help prepare a driver for NDRA operation. This could be as simple as presenting button layout in the driver's field of view helping them to achieve level 3 SA (projection) for a specific NDRA step and reducing the time needed for visual search when they do look away from the road.

To support design for SA, a number of design rules exist (Endsley et al., 2003c). There is no concrete evidence of these being put to use in automotive context, as such they may need revising to consider the competing goal aspect. For example, one of the rules advises spatial separation of unrelated information as an approach to enhance SA. Applying this in the vehicle could result in difficulties due to the extra time required to divide attention between two spatially separate competing information streams especially when driving demands are high. This approach will also promote thought by the designer about how

NDRAs impact the demands of different driving scenarios, helping to elicit specific information required for successful operation. This may mean subtly different approaches dependent upon the state of DRAs, leading the designer to think about how one may affect the other and vice versa. One concept of interest is augmented reality. In particular, the integration of NDRA information over the driving scene in a way that both DRA and NDRA information could be perceived simultaneously. Future mechanisms of information presentation may allow for this simultaneous SA development to take place.

Future research will look at designing IVIS using this approach to establish whether it is possible to enhance awareness. Current experimental work is looking at the effects of how task performance changes during varying levels of SA and will be the subject of a forthcoming experimental paper. Future experiments will focus on testing interfaces that are designed to exhibit features which will reduce the effect of decaying levels of awareness to competing simultaneous tasks. The output of these studies will focus on proving the concept and theory behind the approach proposed.

5. Conclusion

This paper proposes and discusses a new approach to understanding SA in the context of the multitasking in vehicle environment. This is framed as a way to design vehicle interfaces using SA as a theoretical basis. The main contribution is the adaptation of SA towards the multitasking nature of the vehicle, something not considered within driving research to date. It takes a system-level approach, focussing on information content for competing activities. The key consideration is how to knit the competing information streams together into interface systems that make drivers more capable when multitasking. By designing with SA in mind, it is proposed that the driver will be able to interact with DRAs and NDRAs simultaneously whilst being fully aware of threats in each, such that they are able to act accordingly. Fully autonomous vehicles are on the horizon but during the transition through partial autonomy the driver still will need to be DRA aware for some time to come. In an autonomous scenario DRAs will either become secondary to NDRAs or allow the user to become more aware of certain DRAs because of the reduction in sub goals they are directly responsible for. Also focus on NDRAs will be more pronounced, as what constitutes the DRA is less obvious.

It is expected that this approach will expose novel interface and interaction systems and techniques by allowing a designer to understand the information requirements to make a driver situationally aware of all relevant aspects of the environment required to help them achieve their goals. This could assist in the development of interfaces that enable drivers within autonomous or manually driven vehicles to achieve high performance with various NDRAs without inhibiting or constraining performance for DRAs. The overall aim is to create high awareness toward simultaneous activities and deliver high performance regardless of the situation. Current design approaches aim to reduce complexity and inhibit NDRAs. With the increase in available NDRAs this is likely to frustrate drivers. This alternative approach could potentially lead to increased satisfaction as well as improvements in multitasking performance through smart interface design.

Acknowledgements

This research is funded by Jaguar Land Rover Research Department in collaboration with the Centre for Advanced Photonics and Electronics (CAPE) and the Engineering Design Centre at Cambridge University.

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