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LITERATURE SURVEY ON SMART SIGNS FOR BETTER ROAD SAFETY

The impact of road advertising signs on driver behavior andimplications for road safety: A critical systematic review

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A R T I C L E I N F O

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A B S T R A C T

Driver inattention and distraction are recognised as two of the most critical factors for road safety worldwide. While roadside advertising is often identified as a potential source of distraction, it has received less attention compared to other types of distractions such as texting or calling while driving. Therefore, this study focused on the impact of roadside advertising signs on driver behaviour and road safety. To examine this, a theory-driven systematic literature review was undertaken. In total, 90 unique documents were identified and reviewed using the Task-Capability Interface (TCI) Model to explain the potential safety impact of roadside advertising. The findings confirmed that theTCI model is a useful tool for describing the relationship between roadside advertising and driver behaviour. From this perspective, roadside advertising signs can be considered environmental clutter,which adds additional demands to the driving task. In particular, roadside advertising signs impairedeye movement patterns of drivers. Additionally, it was demonstrated that the impact of roadside advertising on driving behaviour is greatly moderated by individual differences among drivers. Of great importance was that young drivers invest more attentional resources in interacting with roadside advertising, which suggests a lower capacity to discriminate between relevant and irrele- vant driving information. Based on the available evidence, however, it is not possible to definitively conclude that there is a direct relationship between the driving behaviour changes attributed to roadside advertising and road crashes. Nonetheless, while most studies remain inconclusive, there isan emerging trend in the literature suggesting that roadside advertising can increase crash risk, particularly for those signs that have the capacity to frequently change (often referred to as digital billboards). Lastly, it is important to mention that most of the empirical studies undertaken to datefeature strong methodological limitations. Consequently, there is an urgent need for more research inthis area, given that roadside technology and the transport system are changing rapidly.

1. Introduction

Driving as a transport behaviour delivers important social and economic benefits, but also poses significant risks to quality of life, including injury and death. Worldwide, over 1.2 million people die each year as a result of injuries sustained from road crashes (WHO, 2015). Economically, injuries and death that result from road crashes cost governments on average 3% of their gross domestic product (WHO, 2015). Notable improvements in technologies such as cooperative intelligent transport systems and driving automation are

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expected to benefit road safety in the future. However, recent estimates suggest that large benefits are only likely to be observed in the long term—25 to 30 years—(Dia, 2015) due to numerous challenges related to infrastructure investment (Clark et al., 2016), public perception (Kyriakidis et al., 2015), and vehicle design policies (Smith, 2016). Until active safety technologies are completely accessible to all drivers, it will remain necessary to develop and implement effective road safety countermeasures to prevent road trauma.

Inappropriate or inadequate interactions between drivers and vehicles play a significant role in vehicle collisions. Driver per- formance is influenced by a wide range of factors, including fatigue (Filtness et al., 2012), distraction (Regan et al., 2011), mood (Rhodes et al., 2015), etc. Among these, distraction is recognised as one of the most critical factors for road safety worldwide (WHO, 2011). Conservative estimates suggest that distracted drivers are heavily overrepresented in road traffic crashes (Beanland et al., 2013). Distracted driving involves sharing attention between the primary task (driving) and a non-driving related secondary task. The non-driving related secondary task can be in-vehicle (e.g., mobile phones conversations, in-vehicle infotainment interactions, etc.) or external (e.g., reading roadside advertising signs, looking at non-related landscape elements, etc.).

Roadside advertising signs (often referred to in the literature as billboards) have become a common form of advertising around the world. As such, the impact of these signs on road safety is an area that needs a strong research focus to support policy decisions. Technology is evolving exponentially, and this extends to the technology utilised by road advertising companies. For example, an advertising company has recently created a sign that tailors its advertisements based on how heavy the traffic is (Adweek, 2018). This roadside advertising technology has been used to advertise restaurants, where simple images of food items are presented in fast- flowing traffic with the purpose of stimulating drivers' appetite. Meanwhile in heavy traffic, the advertisement changes to the words 'stuck in a jam? There's light at the end of the tunnel' with a picture of the restaurant logo. In addition, some advertising companies are considering creating personalised messages on roadside advertising signs for specific individuals via number plate recognition (Global Marketing Alliance, 2018) or new delivery modes such as turning other vehicles' windows into video billboards (Kumparak, 2018). These emerging technologies highlight the necessity of an up-to-date review of the literature in this area.

1.1. The interaction between driving and roadside advertising signs

Driving is a complex task that involves extensive interactions between road users and the other components of the transport system such as the driver, the vehicle, and the road traffic environment. Additionally, each component of the transport system includes various elements which can have an impact on driving performance (Rothengatter, 1997). For example, a person with 10 years' driving experience travelling at the speed limit on a clear highway is likely going to demonstrate a different level of perfor- mance than someone who has less experience and is driving on the same highway with multiple noisy passengers. Drivers' individual differences and the wide range of elements in the road traffic environment necessitate the implementation of systemic frameworks to analyse driving and manage safety risks (Scott-Parker et al., 2015; Oviedo-Trespalacios et al., 2018).

Various theoretical frameworks have been developed to conceptualise the driving task and explain safety risks. A notable fra- mework that has the ultimate goal of explaining crash risk is the Task-Capability Interface (TCI) model developed by Fuller (2000). Using a driver-centred approach, the TCI model focuses on two key elements relating to the driving task: (i) the task demands experienced by drivers, and (ii) the driver's capability. The driving task requires the driver to successfully travel from one locationand arrive at another while also avoiding safety-threatening events (Oviedo-Trespalacios et al., 2016). The difficulty of completingthis task is affected by a number of factors including the environment, control characteristics of the vehicle such as speed or tra- jectory, the driving behaviour of others, and the communication between drivers on the road. The resulting difficulty of the task is what is referred to as task demands (Fuller, 2000). The ability to successfully meet these task demands and complete a successful tripis dependent on the driver's capability. Within the TCI model, a driver's level of competence (skills and knowledge) interacts with human factors (fatigue, emotions, substances, distraction, etc.) to determine the driver's capability. The model explains how human factors can influence a driver's capability but do not influence the task demands. Using these definitions, the TCI model provides a simple conceptualisation of how task demands and driver capability can explain the interactions between the driver, the vehicle, andthe environment, which will lead to either positive or negative driving outcomes. Roadside advertising signs are part of the road traffic environment and, therefore, serve to modify the driving task demands (see Fig. 1). This could be problematic because drivers' attentional resources (drivers' capability) might not be sufficient to both safely drive and interact with the roadside advertising sign. More specifically, the balance of capability and task demands impacts on the perceived difficulty of the task and the task outcome. In other words, in any given situation a matrix of competence and task demands will exist such that if the task demands are low, then the task is perceived as not difficult for drivers with low and high capability. However, if the task demands are high, then those with low capability willfind the task more difficult than those with high capability. Similarly, if a driver's capability is impaired, a task can quickly become moredifficult than it was previously perceived. In the same way that the balance of capability and task demands impacts perception, it also relates directly to the driving outcomes. As shown in Fig. 1, when the capability is higher than task demands, the driver can maintain control.However, if the task demands exceed the driver's current capabilities, the driver would potentially lose control. This loss of control will likelylead to a crash unless action is taken to ensure safety. Applications of the TCI model have demonstrated its usefulness in explaining speed selection (Fuller, 2011), mobile phone use while driving (Oviedo-Trespalacios et al., 2017a,b), and other driving behaviours.

1.2. Current study

Despite the relatively widespread use of roadside advertising, scientific understanding about its impact on task demands is limited. Firstly, the available literature is disorganised and limited compared to other road safety concerns such as mobile phone distracted driving, fatigue, speeding, etc. Secondly, roadside advertising signs are continuing to evolve technologically, creating the

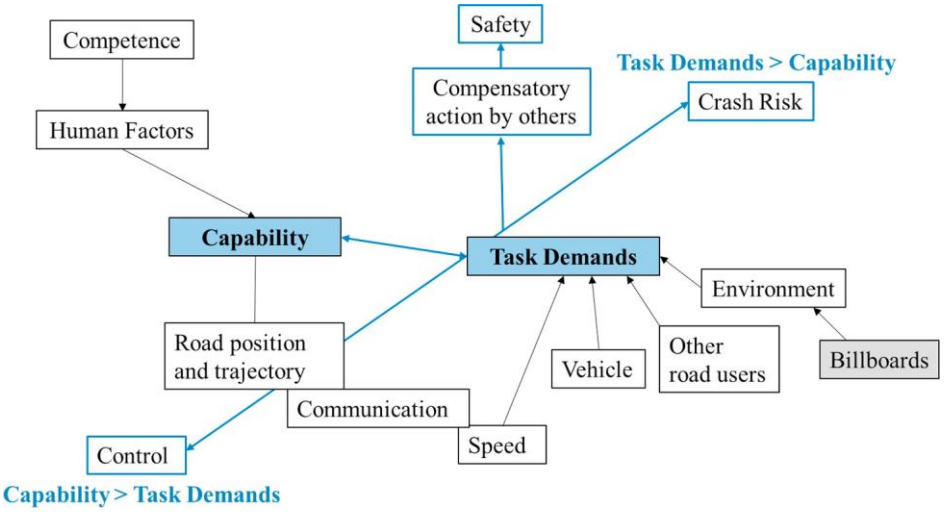

Fig. 1. Modification of the task capability interface model.

need for ongoing research to address recent technological advancements. For example, over the last 50 years, roadside advertising signs have evolved from static images to incorporate digital displays and changing pictures/videos designed to capture drivers' attention. Therefore, these technological differences are likely to influence driving task demands in different ways. To close this gap, we conducted a comprehensive systematic literature review informed by the TCI model.

2. Method

A literature review was selected as the most appropriate method of research to address the question of whether roadside ad- vertising signs impact on driver behaviour and crash risk. Given the number of components and causal mechanisms theoretically described in the TCI model, a systematic classification scheme (SCS) was developed to guide and assist in synthesising the available literature. As described in the introduction, the TCI model proposes that crashes are a result of impaired driver behaviour (i.e., longitudinal and lateral vehicle control including eye movements) which is a function of driving demands exceeding driver cap- ability. The SCS adopted in this study consists of the following four questions:

- What was the study design (e.g., simulator studies, naturalistic studies)?
- What variations in driving demands were considered (e.g., presence of roadside advertising, vehicle type, road traffic environment, etc.)?
- What variations in the driver's capability (e.g., driver demographics, driving experience, etc.) were included?
- What safety performance metrics (e.g., crashes, near-misses, etc.) were investigated?

The retrieved documents were also analysed based on the type of publication (e.g., journal article, conference paper, report etc.).

2.1. Search strategy

All searches included the words "driving" as mandatory, followed by the terms "advertising" or "billboard" and were conducted in February 2018. These terms were sought in the full text of the references. The search of academic references and grey literature was conducted in Google scholar and academic databases, i.e., PROQUEST, SCOPUS, TRID, EBSCO, and Web of Science. No time frame was specified in the searches. Besides, a request was sent to the Department of Transport and Main Roads (Queensland, Australia) to obtain access to the literature utilised in their policymaking. With regards to exclusion criteria, studies explaining roadside char- acteristics without considering road users' behaviour were excluded as well as road authorities communicating driving-related in- formation (e.g., directions or work zones) to drivers.

3. Results

A total of 90 unique documents were identified and reviewed using the SCS. The process to identify the articles followed a PRISMA methodology (Moher et al., 2009) as described in Fig. 2. These studies were divided in two groups: (i) documents including original research data (n = 60) and (ii) documents including reviews or position papers (n = 31). The number of references in this list is 91 because the conference paper by Herrstedt et al. (2013) was counted twice as it included original research and a literature review. The final studies included in the synthesis consisted of 28 journal articles, 24 literature reviews (published in the form of journal articles, reports, conference papers, and book chapters), 15 conference papers, 12 reports, 4 theses, 1 handbook chapter, 2 letters to the editor, 3 opinion/position papers and 2 paper critiques. The literature review findings are presented in the Appendix.

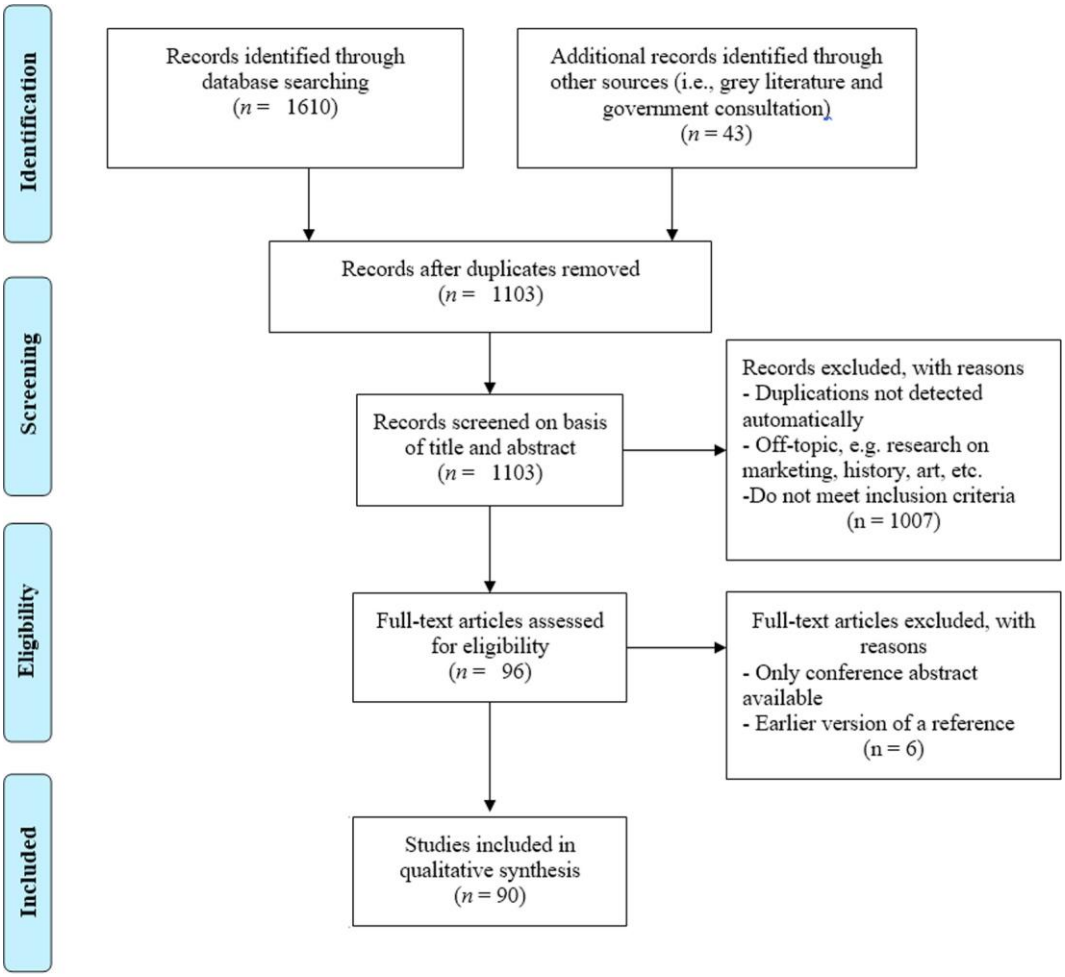

Fig. 2. PRISMA flow diagram.

4. Discussion

The discussion section is divided into four sections, corresponding to the questions identified in the SCS.

4.1. Methodological approaches and issues

The main approaches utilised in the available literature to study the effects of roadside advertising on driver behaviour and safety included: crash data analyses; on-road studies; laboratory observations; and self-report studies. Crash data analysis involves studying patterns in police or medical records to identify the potential effects of roadside advertising on crash involvement at particular places and times. On-road observations comprise naturalistic and quasi-naturalistic studies that involve observing the driver's behaviour, in uncontrolled or controlled environments. Laboratory observations, which include high-fidelity and desktop driving simulators, have been utilised extensively in road safety research, as they are a low risk and low cost option for studying driving behaviours while controlling for different factors. Self-report studies include questionnaires regarding drivers' perception of the impact that roadside advertising signs have on driving behaviour.

In the context of distracted driving, crash data is acknowledged as the key performance measure for safety (Oviedo-Trespalacios et al., 2016). However, only 15% of the references with new data (i.e., excluding reviews and opinion pieces) use crash data to study the effects of roadside advertising. Some examples of roadside advertising safety research using crash data include Yannis et al. (2013) and Izadpanah et al. (2014). The provision of ongoing and reliable crash data is a critical component of evidence-based road safety practice and research. Crash data is usually provided by government-related entities; with the most common source being crash reports (e.g. police or health-care providers). However, there are several limitations associated with crash data from police or hospital sources. These include the under-reporting of low severity crashes, low occurrence of crashes linked to distraction, and lack of detail about the behaviour preceding the crash. Therefore, it is reasonable to argue that crash data, albeit a critical indicator, should not serve as a unique and standalone tool for informing evidence-led initiatives in roadside advertising safety.

Various authors have developed important safety evaluation methods based on naturalistic and simulated driving behaviour observations. These result in the predominant forms of evidence relating to the safety effects of roadside advertising. With new technological developments in in-vehicle driving monitoring, naturalistic studies have become more common in the distracted driving literature. Examples of roadside advertising research that used naturalistic or simulated driving methods include Perez et al.(2012), Rasdorf et al. (2017) and Zalesinska (2018). Traditionally, driving simulators are considered the principal tool for road safety laboratory research. Driving simulators have been developed using advances in computer technology and are nowadays cheaper andsafer than in-vehicle or on-road testing. Generally, in simulator studies, it is possible to observe driving behaviour, near-misses, and crashes. Although intuitively, the best option for studying crashes would be in a controlled environment such as a simulator, diffi- culties arise because crashes are rare events (Svensson and Hydén, 2006). The lack of crashes limits the identification of patterns, the generalizability of results, and subsequent external validity of the finding. To overcome these limitations, the use of surrogate safety measurements as a way of studying driving performance has been a frequent practice in the distracted driving literature. These surrogate measures include: acceleration, headway distance, lane position, speed, among others. Yan et al. (2008) validated a set of surrogate measures for evaluating safety in signalised intersections through a comparison of crash reports and simulator data. As a result, risky driving parameters such as levels of speed, acceleration, and headway are accepted as surrogate measures of safety. Nonetheless, driving simulators are often questioned concerning their resemblance to real-world driving and vehicle motion. Even the most sophisticated driving simulators do not provide all of the visual, vestibular, and proprioceptive changes that occur when driving. Validation studies of high-fidelity simulators conducted by Meuleners and Fraser (2015) and Larue et al. (2018) have demonstrated the relative validity of driving simulators compared to real-world driving. Therefore, simulators could potentially be utilised to study driving behaviour in the presence of roadside advertising while ensuring external validity.

The number of studies using self-reported data was relatively low (less than 10%). Examples of roadside advertising studies that used self-reported data include Hasan (2015) and Olejniczak-Serowiec et al. (2017). Self-reported data, including questionnaires or interviews, could explain crash circumstances and conflicts with roadside advertising. Although self-reported data suffers from several drawbacks related to human factors such as memory or social desirability bias, it could help to triangulate findings and inform potential risks. Qualitative or mixed research methods can provide valuable insight into road users conflicts with roadside adver- tising, which are not detected in controlled studies.

4.2. Impacts on driving task demands

Driving task demands are a function of the elements within the traffic system external to the driver, including the road traffic environment, road furniture, vehicle, weather, etc. The task-capability interface model (Fuller, 2000) suggests that an understanding of the determinants of road demands would help to support safe driving. The main driving task demands variables considered in thereviewed literature are discussed below.

4.2.1. Demands of the road traffic environment

The road traffic environment moderates the impact that roadside advertising has on driving. A consistent finding in the literature is that the presence of roadside advertising seems to be correlated with road crashes (Sisiopiku et al., 2015; Wallace, 2003). Authors such as Molino et al. (2009) advise that commercial signs should be completely avoided at intersections (or nearby). Notwithstanding this finding, there is very little information in the literature on the impact that roadside advertising signs have on secondary roads orrural areas.

Studies involving the impact of speed limits on drivers' roadside advertising interactions (e.g. reading, thinking about or avoiding the sign) have been limited. Misokefalou et al. (2016) reported a non-significant difference in the duration of engagements with roadside advertising signs and other non-related roadside objects between speeds over and under 80 km/h. Additionally, most of the empirical and observational studies have been undertaken during the day. An exception is an on-road study conducted by Dukic et al. (2013) which included night and day driving. The results showed that there are no significant differences between day time and night time attention to electronic roadside advertising signs. There is a need to undertake more systematic evaluations examining the impact of these signs in a broader range of traffic environments.

4.2.2. Roadside advertising sign type

The references reviewed confirmed that there is a wide range of roadside advertising sign types. The two types most frequently cited in the literature are static and changeable (also known as digital, electronic or roller bar). Additionally, some studies have specialised in emergent or currently less common road advertising technologies such as video-based signs, business logo signs, LED signs, tri-vision signs etc. Roadside advertising technologies are continuously evolving. Emergent roadside advertising technology includes advertisements which target specific individuals via number plate recognition (Global Marketing Alliance, 2018), as well as advertisements which change based on the traffic conditions (Adweek, 2018). As these are new technologies, they have not been studied or included in any study. Given that road advertising technologies are constantly changing, there is a need for ongoing monitoring of the risks associated with emergent technologies.

At this point, the broad diversity of technologies limits our capacity to generalise findings about the impact of advertising on roadsafety. On the one hand, there is insufficient evidence regarding the impact of each type of roadside advertising on road safety. A clear example of this is that less than 5% of reviewed references included video-based advertising. On the other hand, the available evidence needs to be evaluated with consideration of the socio-technical factors that may have varied from one location to another. For example, the impact of a roadside advertisement located in Southeast Europe may well be different to the road safety outcomes of

the same roadside advertisement in Australia, given the inherent differences across the regions concerning road standards, driver behaviour, road traffic composition, weather, etc.

Notwithstanding the limitations of the current literature, the degree of changeability in the information conveyed by the roadside advertising signs appears to have a persistent adverse effect on driver behaviour. The degree of changeability refers to the amount of information displayed by the roadside advertisement and can vary considerably from static signs to those that can display video or multiple images successively. Static roadside advertisements are passive in nature, since they convey a single image. In contrast, changeable signs are more active since they convey a collection of images that change at predetermined times. The most active form of changeable signs is video advertising signs, which can show multiple images at high speed. It is important to consider that changeable signs (including digital, electronic or roller bar signs) are simplified versions of video advertising signs as they present a limited number of images that change at specified times (remaining in passive mode the majority of the time).

When comparing the effect of different types of roadside advertising signs on driver task demands, it has been demonstrated that changeable (i.e., digital with multiple advertising signs) roadside advertising signs represent a greater distraction to drivers than static (i.e., single advertising sign) roadside advertising signs (Beijer et al., 2004; Decker et al., 2015; Herrstedt et al., 2013; Missokefalou and Eliou, 2012). Indeed, a recent study demonstrated that static roadside advertising does not affect situation awareness of drivers (Young et al., 2017). This has been primarily attributed to the movement involved in changeable roadside advertising signs, which is more likely to capture the attention of the driver (Missokefalou and Eliou, 2012). A recent study using on-road testing suggested that rapid light onsets of changeable roadside advertising signs could result in a sudden shift of visual attention (Belyusar et al., 2016). Additionally, it has been found that a driver's gaze duration is longer and occurs more often when looking at changeable signs compared to static signs (Chattington et al., 2009; Dukic et al., 2013; Belyusar et al., 2016; Decker et al., 2015). A potential explanation for this is that drivers might anticipate the change. When drivers' opinions of this distraction have been investigated, it has also been found that drivers perceive videos, special effects and animation on roadside advertising, to be more distracting (Yellappan et al., 2016; Smiley et al., 2005). Therefore, changeable roadside advertising (i.e., active) has been shown to have a stronger effect on driver distraction compared to static roadside advertising (i.e., passive).

The location and physical attributes of the roadside advertising are associated with the level of attention given by drivers. As described by Wilson and Casper (2016), the proximity to the driver's window of attention and location of the roadside advertising are the most important variables for predicting attention, i.e., roadside advertising signs are more likely to be noticed if they are closer to the road, have a centre approach, have a longer amount of time in which it is visible to those who pass by it, and are larger in size. The impact of business logo signs on motorways has been an emergent topic in the scientific literature. Generally, supplementary signs do not seem to reduce safety (Metz and Krüger, 2014). A simulator study conducted by Rasdorf et al. (2017) confirmed that six-and nine-panel signs did not result in glances larger than 2 s. Typically, off-road glances longer than 2 s have been found to increase near-crash and crash risks by at least two times that of normal baseline driving (Klauer et al., 2006). However, using the two-second guideline is problematic because drivers might not instantly recover their performance on safety-critical driving tasks such as hazard perception (Borowsky et al., 2016). On the other hand, Zahabi et al. (2017) reported that a nine-panel roadside advertisement resulted in a larger reduction in driving speed in comparison to six panels. Although visual allocation of attention does not seem impaired, there could be a risk of traffic conflicts due to the reduced speed. More research is necessary to confirm this.

4.2.3. Roadside advertising sign level of illumination

The literature reviewed supports the conclusion that the level of brightness and illumination of roadside advertising has an important effect on driver behaviour. Changing luminance within a visual field will reflexively attract a driver's gaze (CTC, 2012; Roberts et al., 2013). As such, many researchers have claimed that digital roadside advertising signs present a higher safety risk for the general public as the changes in luminance are more likely to catch a driver's attention than traditional static signs (CTC, 2012; Herrstedt et al., 2017; Roberts, 2013). Furthermore, digital roadside advertising signs also hold a driver's attention for longer than standard floodlit signs (Birdsall, 2008; CTC, 2012). Herrstedt et al. (2017) conducted a simulation experiment investigating how LED- advertising signs impacted the driver's attention. The researchers found that average glance duration at LED signs was longer when compared to other types of objects (i.e. anything the driver looked at for more than one second, including static, non-LED adver- tisements, spectacular objects, and driving relating objects such as road signs, road users, mirror/speedometer etc.).

While research demonstrates that changing luminance is more likely to attract and hold a driver's attention, limited experimental research is available to show that this distraction will lead to a greater risk of safety-threatening events. Indeed, some correlational studies investigating how the introduction of a digital advertising sign impacts crash rates have failed to find a significant effect (Hawkins et al., 2012; Izadpanah et al., 2014; Yannis et al., 2013). Despite limited research connecting luminance to crash risk, Zhang et al. (2017) have reported that over-bright highway roadside advertising signs can cause visual discomfort, further increasing associated risks.

A number of recommendations and regulations are set in place to minimise risk for drivers. Australia currently regulates lumi- nance changes for digital roadside advertising signs, and within the states of Queensland and New South Wales, moving images are not permitted (OMA, 2013). Roberts (2013) argues that luminance levels of digital roadside advertising signs should be equal to the brightness of static signs in the same ambient lighting condition. Other sources recommend that luminance should be within 10 to 40 times the brightness of objects (e.g. headlights) within the driving environment to allow for transient adaptation effects (CTC, 2012). Zalesinska's (2018) recent study indicated that areas with a size of over 0.58 m × 0.38 m and luminance of more than 400 cd/m^2 were associated with deteriorations in visual performance of the observers. Finally, the recommended change in luminance between day and night also varies from 20 to 50% (Jenkins, 2016).

4.2.4. Roadside advertising sign content

The content of roadside advertising signs has been found to have features that influence driver behaviour. The features that have been more thoroughly investigated include the number of words, emotional valence, human representation, and design character- istics. Studies have shown decreased lane keeping and longer gaze durations when participants are presented with roadside ad- vertising signs that have a larger number of words to read (Schieber et al., 2014). Schieber et al. (2014) proposed that processing overload emerged when participants were presented with eight or more words on a digital roadside advertising sign.

Drivers' responses are also influenced by the emotional or arousal content of the roadside advertising signs. A driver's sensitivity to sexualised or attractive static images has been found to increase their level of gaze distraction (Targosiński, 2017). Additionally, the presence of negative emotional content on roadside advertising signs is associated with an increase in drivers' reaction time and steering variations (Rodd, 2017). Chan and Singhal (2013) found that negative and positive valence words impaired driving speed. Likewise, it was also reported that taboo words (taboo-related arousal) seem to enhance attentional focus (Chan et al., 2016). The interactions between drivers and textual content need to be considered in future risk assessments.

Human representation on roadside advertising signs also appears to influence drivers' behaviour. Tarnowski et al. (2017) found that drivers were more distracted by roadside advertising signs where humans were represented than by signs where humans were not present.

The design characteristics of the roadside advertising have also been found to affect driving performance. Based on an analysis of drivers' perceptions using data mining techniques, Marciano and Setter (2017) proposed that roadside advertising signs can be classified into at least three groups:

- Loaded roadside advertising signs are characterised as colourful, containing proportionately small quantities of graphic elements and large quantities of text. The text itself consists of many letters of all sizes. Also, these roadside advertising signs contain many logos and many information items.
- Graphical roadside advertising signs are characterised as colourful, containing large quantities of graphic elements and small quantities of text.
- Minimal roadside advertising signs are characterised by few or no graphic elements, few colours, and a small amount of text with mainly large letters.

Marciano and Setter (2017) found that loaded roadside advertising signs seem to interfere more with drivers' tracking perfor- mance and continuous motor performance than graphical and minimal signs. Indeed, minimal roadside advertising signs do not seem to interfere with any of the experimental tasks explored in their study.

4.2.5. Vehicle type

Vehicle type of the driver is one of the variables that has had limited consideration. Cars are the most frequent vehicles analysed in most studies. There is, however, one study (see Megías et al., 2011) that involved a motorcycle simulator. The results showed that motorcycle riders also experience impaired reaction time in the presence of static roadside advertising signs with negative valence.

4.3. Impacts on driver capability

A driver's capability is a function of a plethora of human factor variables, including personal characteristics, physiological characteristics, personal experiences, psychological resources, etc. Although accounting for all these variables would be ideal, the large number of these human factors makes it difficult to study them systematically. Nonetheless, key human factor variables have been explored in relation to roadside advertising signs, as outlined below.

4.3.1. Age and driving experience

Age and driver experience are associated with the different outcomes in the interactions between drivers and roadside advertising signs. Research has consistently found that older drivers (generally aged 65 years or older) are negatively impacted by the presence of roadside advertising signs. Edquist et al. (2011) found that older drivers made more lane change errors, particularly in the presence of static roadside advertising signs, than drivers in other age groups (18–25 or 26–55). This is not surprising since research has sug- gested that age-related medical conditions and declining of functional/cognitive abilities often contribute to higher crash risk among senior drivers (Asbridge et al., 2017). Research in traffic psychology has consistently reported that older drivers engaging in sec- ondary tasks while driving are typically more affected than young drivers (Fofanova and Vollrath, 2011).

Teens and young drivers seem to give significantly more attention to roadside advertising. A study conducted by Stavrinos et al. (2016) found that drivers aged 16–19 years give longer glances to roadside advertising signs (digital or static) compared to drivers aged 35+ years. Roadside advertising signs appear to have an effect on the driving performance of young adults, as the age group (16–24) shows a slower reaction time to hazards (Farbry et al., 2001); greater levels of distraction to both digital and static signs (Stavrinos et al., 2016); and self-reported agreement that both static and digital signs create distraction when driving (Sisiopiku et al.,2015). In contrast, other studies have shown no age differences in the detection of static roadside advertisements (Topolšek et al., 2016) or eye glance behaviour in response to static and digital roadside advertising signs (Lee et al., 2004). More research is needed to fully determine the effect of roadside advertising on young drivers.

4.3.2. Gender

Research also suggests that gender can have an impact on responses to static roadside advertising sign content, with women showing greater distraction in response to advertisements evoking negative emotions, and men showing greater distraction to ad- vertisements with sexual content (Olejniczak-Serowiec et al., 2017). Overall, men appear to be more likely to read digital roadside advertising signs than women (Islam, 2015); however, women appear to have longer gaze duration than men, meaning that they were distracted for a longer time period (Lee et al., 2004). It is important to emphasise that research into gender differences is limited, and the significant results only displayed small effect sizes. As such, these findings should be treated with caution.

4.3.3. Other personal characteristics

The level of distraction an individual may experience when driving past a roadside advertising sign may also differ according to transient factors such as fatigue and motivations (Horberry and Edquist, 2008). Also, it has been suggested that a driver's level of distraction might increase depending on whether the content of the sign is appealing to an individual or not (Chattington et al., 2009). While these factors have been identified as important, their effect on a driver's level of distraction when driving past roadside advertising signs has not yet been examined. It is also possible that more permanent personal characteristics such as beliefs towards safety or personality could influence this distraction; however, research is yet to explore this.

4.4. Safety implications of roadside advertising signs

Analysis of crash data has suggested a link between roadside advertising signs and safety (Cairney and Gunatillake, 2000; Sisiopiku et al., 2015). Research suggests that crash risk increases by approximately 25–29% in the presence of digital roadside advertising signs compared to control areas (Islam, 2015; Sisiopiku et al., 2015). On the other hand, static roadside advertising signshave not been linked with differences in the crash count (Yannis et al., 2013). However, this finding is contrary to previous research that suggests differences in crash counts exist in the presence of static roadside advertising, see Staffeld (1953) and Ady (1967). The quantity and quality of available evidence limit our conclusion.

Fixed object, side swipe and rear end crashes are the most common types of crashes in the presence of roadside advertising signs (Islam, 2015; Sisiopiku et al., 2015). In addition, drivers showed increased eye fixations and increased drifting between lanes on the road (Sisiopiku et al., 2015; Young and Mahfoud, 2007). In their meta-analysis of existing studies investigating digital roadside advertising signs; Sisiopiku et al. (2015) found an increased crash risk as a result of digital signs, however, the effect was exclusive tosections of road with intersections.

Studies into the before-and-after effects of the installation or removal of roadside advertising signs did not find a significant difference in crash prevalence when the sign was present on the road compared to when the sign was not present (Hawkins et al., 2012; Izadpanah et al., 2014; Yannis et al., 2013). These findings may demonstrate that drivers can self-regulate their interactions with roadside advertising (as they do with other distractions, see Oviedo-Trespalacios (2018)) and, therefore, it could be problematic if the roadside advertising design prevents self-regulation among drivers. For example, a roadside advertising sign can capture drivers' attention in moments of high driving demands such as heavy traffic or potential road hazards. As such, drivers would not beable to safely manage the additional workload.

5. Conclusion

5.1. Key findings

The evidence regarding roadside advertising safety has been widely scattered with little attempt to explore systemic patterns. This has hindered effective risk characterisation and an understanding of the mechanisms through which certain roadside advertising characteristics contribute to road crashes. To address this gap in the literature, the current study revised literature using a systematicapproach informed by the Task-Capability Interface (TCI) model (Fuller, 2000). The TCI model is a seminal theoretical framework that explains determinants of driving behaviour and crash risk. To ensure a structured and efficient approach, the PRISMA framework (Preferred Reporting Items for Systematic Reviews and Meta-analysis) was used to guide this process (Moher et al., 2009).

A total of 90 unique documents were identified and reviewed using the Task-Capability Interface (TCI) Model. Overall, the findings show that the TCI model is useful in explaining the relationship between roadside advertising and driver behaviour. Roadside advertising signs were considered to be environmental clutter, which adds additional demands to the driving task. For example, some features of roadside advertising such as the changeability level have been consistently linked with changes in eye scanning behaviour of drivers (Beijer et al., 2004). Additionally, it seems that the impact that roadside advertising has on driving behaviour is greatly moderated by individual differences among drivers. Of great importance was that young drivers seem to invest more resources interacting with roadside advertising, suggesting a lower capacity to discriminate between relevant and irrelevant driving information (Stavrinos et al., 2016).

Based on the available evidence, it is not possible to conclude that there is a direct relationship between the driving behaviour changes that can be attributed to roadside advertising and subsequent road crashes. Most of the results in this respect remain inconclusive. However, there is an emerging trend in the literature suggesting that roadside advertising, particularly those signs with changeable messages, can increase crash risk (Cairney and Gunatillake, 2000; Sisiopiku et al., 2015). It is important to bear in mind that most of the empirical studies undertaken to date feature strong methodological limitations. Finally, roadside advertising tech- nology is continually evolving, so there is a need for further research to ensure the recent technological advancements are addressed.

5.2. Policy implications

Advertising signs directed at road users are designed to communicate messages to the driving public. For the advertising industry, roadsides are sought-after, well established and increasingly profitable locations for advertising signs. Although the industry ac- knowledges the importance of safety, advertisers are not accountable for road safety and efficiency or the prevention of road trauma. Notably, government road agencies work to minimise driver distraction potential while advertisers seek to optimise it (Horberry et al., 2013). In this review, it is suggested that roadside advertising signs are associated with changes in crash risk. Unfortunately, findings from this review also revealed that research is not always conclusive regarding the mechanisms of these changes in crash risk. The lack of conclusive evidence limits the ability of policy-makers to apply risk-minimisation strategies. Nonetheless, roadside advertising is a legitimate business and public policy needs to manage the risks, not prohibit the activity. Commercial and community interest in roadside advertising is growing. Government road agencies also use roadside advertising signs for road safety campaigns and to communicate information about severe weather events and critical safety alerts (for example, child abductions). Given this demand trajectory, comprehensive empirical research will enable road regulators to develop robust technical standards that can be reliably and consistently applied across road agencies.

When setting public policy and technical standards, road agencies are reluctant to adopt subjective and qualitative guidelines, preferring to rely on defensible criteria drawn from independent evidence-based research. Without unequivocal evidence, some government road agencies develop technical criteria based on risk management and engineering principles substantiated by human factors, safety-in-design or driver-centred design approaches (Horberry et al., 2013). While these methods are reasonable, businesses and industries are challenging the legitimacy of road agencies' technical criteria citing the absence of systematic and supporting empirical data. Private sector practitioners are engaged to produce reports and make submissions outlining the rationale for why an advertising sign should be approved, despite its non-compliance with regulators' requirements or sufficient regard for human factors or ergonomic principles. In some instances, when applications for advertising signs are rejected on road safety grounds, applicants pursue their cases through the courts (Dulebenets et al., 2018; Sharpe, 2011).

As roadside advertising technologies are continually changing, there is a need for ongoing monitoring of the risks associated with emergent technologies. Therefore, continued monitoring of roadside advertising technologies and generation of safety data is ne- cessary. Legislation in some jurisdictions such as the US has not progressed as fast as the roadside advertising technology (Sharpe, 2011). Likewise, although roadside advertising should naturally be driven by road safety concerns, some other policy considerations should be weighted as well e.g., scenic beauty (Sharpe, 2011) and clutter (Beijer et al., 2004). Sharpe (2011) explains that if left effectively unregulated, current technologies of roadside advertising would destroy the scenic vistas and put drivers (and other road users) at risk.

5.3. Practical recommendations

Some considerations also need to be made for the types of roadside advertising allowed and roadside advertising management. Concerning dwell time and transition, the following recommendations were defined based on current evidence:

- The message dwell time should be designed to expose drivers to only one image per interaction with a roadside advertising sign. Evidence from on-road studies has confirmed that dwell times of 7 sec in a motorway (more than 100 kph) (Dukic et al., 2013) or 7–10 sec in a 104 kph road (Belyusar et al., 2016) attract more glances. At the moment, there is insufficient information on the right dwell time duration, but a reduction in the number of drivers seeing changes would suggest that a number larger than 10 secwould be a conservative approach.
- Stavrinos et al. (2016) documented that when a changeable roadside advertising sign transitioned to another image, there was an increase in glances longer than two seconds. Transitions that occur less than 154 m distance could result in fewer glances that last longer than two seconds.
- Transition duration is particularly problematic. Belyusar et al. (2016) explained that drivers are neurophysiologically predisposed to orient to motion and sudden change in the periphery. We recommend increasing the transition duration to avoid sudden motion or change. Design features and illumination guidelines could be utilised to mitigate these risks.

About location, the following recommendations were defined based on current evidence:

- Roadside advertising should not be located in complex driving locations where the traffic conditions are likely to change rapidly, or in the centre of drivers' field of view (i.e., viewable from the centre of the windshield at any point during viewing) (Wilson and Casper, 2016).
- Drivers seem to display performance decrements even after their interaction with the roadside advertising sign is finished. A "recovery zone" (road segment with low driving demands and lack of unexpected risks) of at least 8 sec should be considered afterdigital roadside advertising signs (Schieber et al., 2014).

Two key findings about illumination should be considered:

- The illumination of roadside advertising is an important issue that needs to be regulated. Road advertisements should not be over- bright, with the luminance of digital signs not exceeding that of static signs (Roberts, 2013).

- Additionally, luminance should be within 10–40 times the brightness of objects (e.g. headlights) within the driving environment to allow for transient adaptation effects (CTC, 2012).

It is important to note that the practice recommendations are likely only to apply to passenger car drivers, given the limited amount of research conducted using other road users. Evidence from the literature review suggests that motorcycle riders directly modify their vision towards billboards (their average fixation duration when viewing billboards was 339.33 ms), as well as their reaction time, with motorcyclists showing a significantly faster reaction time after viewing negative roadside advertisements than after viewing positive and neutral advertisements (Megías et al., 2011). Likewise, other studies have found that bicycle riders report that billboards can result in distraction from the driving task (Useche et al., 2018). There is a need to investigate the full impact of billboards on road safety, and this research needs to consider the wide range of road users and their interactions.

Finally, one of the issues that emerged from this review is the need for a better understanding of the role of the roadside advertising content. The results showed that both the appearance of billboards (graphics vs. text, text size, colours, etc.) and the content itself (taboos, negative vs positive/neutral contents, etc.) interact with driving behaviour.

5.4. Future research

As roadside advertising technology and the transport system is constantly changing, continued monitoring of roadside technol- ogies and generation of safety data is necessary. Additionally, regulators should consider a general human-factors metric (e.g., the amount of attention required to process the roadside advertising sign using eye movements or driving performance) to regulate permitted technologies and road traffic design recommendations. Furthermore, the concept of the 'recovery zone', in which it was concluded that roadside advertising sign effects could migrate to the 8 sec of travel beyond the sign (Schieber et al., 2014) is an important concern that needs further study. There is also a need to empirically assess the most appropriate dwell time for changeable roadside advertising signs. Importantly, the full impact of roadside advertising signs on road safety requires further investigation, and this research needs to consider the wide range of road users, including motorcycle riders and pedestrians, and their interactions.

Future studies also need to consider including a wider range of participants, as most studies have involved healthy participants with perfect vision and considerable driving experience. As studies in the U.S. have found young and senior drivers are more likely to be affected by roadside advertising, focusing on these age groups is also an important area to consider for future research. Finally, qualitative research approaches also need to be considered, as this type of research can be beneficial in defining optimal research questions and identifying emergent issues.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tra.2019.01.012.

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