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The impact of the luminance, size and location of LED billboards on drivers' visual performance—Laboratory tests

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ABSTRACT

A proper visual performance by drivers can be ensured by, among else, a correct distribution of luminance in their field of view. At night, when the driver's sight is adapted to low luminance levels, high luminance level objects located near the road may be a source of glare, which is not only a nuisance, but it may also blind the driver. For many years, LED billboards (light-emitting diode billboards) have been installed near roads. Such billboards are usually large, have high luminance and show dynamically changing images. These parameters have a significant impact on the drivers' visual performance and, in turn, on road traffic safety.

The study on the impact of the luminance, size and location of LED billboards on the drivers' visual performance was conducted on a volunteer group. Testing the impact of LED billboards on the visual performance of drivers in real-life conditions is very difficult. Therefore, the tests have been conducted in laboratory conditions, using a car driving simulator. The paper describes the testing procedure and tests results. The permissible luminance and areas of LED screens in two locations near the road, which significantly reduce the drivers' visual performance in municipal traffic at night, were determined by conducting an analysis of the results. Recommendations on the permissible luminance and areas of LED billboards were formulated.

1. Introduction

The application of light emitting diodes (LED) in outdoor advertising opened new possibilities in presenting all sorts of advertising content. Such advertising devices could be used to display text, graphic images, animations and video. A dozen of advertisements, arranged in a sequence and clearly visible, both during the day and at night, could be presented on just one LED screen. However, everything that makes this advertising medium highly attractive may be, on many occasions, a potential danger to road traffic safety. LED billboards have large areas and are very bright - much brighter than traditional billboards. The maximal luminance values specified by LED screen manufactures (white) are around 7000 cd/m^2. Tests conducted in the laboratory showed that the maximal value of an actual, real LED module was 8.300 cd/m^2 (Zalesinska and Wandachowicz, 2012)

The research conducted by Domke et al. (2010) shows that the average value of maximum luminance measured for 18 screens operating at night in real conditions was 1980 cd/m^2 for advertising content using various colours. Given such high luminance levels in comparison to the low luminance in the billboard's vicinity (several or a dozen cd/m^2 - e.g. the measured values for the background were 108 cd/m^2 – 0.9 cd/m^2, sky – 6.3 cd/m^2 0.2 cd/m^2, road 4.6 cd/m^2 –1.1 cd/m^2) and a much lower luminance of traditional billboards (e.g. measured value for billboards illuminated externally was 7 cd/m^2 – 67 cd/m^2 and billboards illuminated from the inside - 106 cd/m^2 – 360 cd/m^2 (Zalesinska and Wandachowicz, 2013)), such objects are a potential source of blinding glare, making it impossible to see and, in the best case, limiting the ability to see – disability glare. Additionally, involuntarily directing sight at very bright objects diverts it from the road ("the moth effect" Green, 2006). Tests carried out by Klauer et al. (2006) showed that distracting a driver's attention from the road for over 2 s is a potential threat to road traffic safety.

Moreover, LED billboards displaying animations, video images and quickly alternating advertisements can potentially distract drivers, and by displaying content that resembles traffic signs or colours used in traffic lights, they may mislead drivers, potentially leading to dangerous situations in road traffic (Roberts et al., 2013; Wachtel, 2009).

2. Current knowledge

2.1. Review of the research on the impact of LED billboards on road traffic safety

Tests aiming to determine the relation between the increase of car accidents and the possible presence of LED billboards near such places have been carried out for many years. Due to the complexity of this

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phenomenon, it is very difficult to determine such a relation. Oftentimes, drivers themselves are not aware of all the factors that played a role in the accident or, fearing a fine or having to pay increased insurance premiums, fail to admit, on purpose, that the accident was caused because they were distracted by a billboard (Speirs et al., 2008). The published research results are also not unanimous. Tests carried out by Tantala and Tantala (2009, 2010) showed that the number of accidents dropped by several or even a dozen percent after a billboard was installed in the vicinity of the road. However, tests carried at the order of the Wisconsin Department of Transportation (WisDOT, 1994) for ads with a variable message sign showed that, after the installation of billboards in the drivers' field of view, the number of accidents spiked by a few dozen percent. Similar tests carried out for ads displaying video images showed an increase in the number of accidents in 2 out of 3 examined intersections (Smiley et al., 2005). Despite the lack of documentation explicitly proving the influence of LED billboards on the higher number of road accidents, numerous tests confirm that electronic billboards negatively affect the drivers' visual conditions. Attracting the drivers' attention and distracting them are usually considered as the major factors (Belyusar et al. 2016, Dukic et al., 2013; Molino et al., 2009, Speirs et al., 2008, Dudek, 2008;Crudall et al., 2006,Farbry et al., 2001). Nonetheless, some references report test results showing a negative impact of the colour and content of the displayed ads (Speirs et al., 2008).

The negative impact of LED billboards on the drivers' visual conditions was confirmed by surveys carried out by Domke et al. (2013). One hundred and twelve drivers of different ages participated in the study. The participants of the survey were asked about their attention being drawn to LED billboards. Ninety respondents, i.e. 80%, answered affirmatively to the question. Another question was: Do LED billboards distract you, as a driver, when you are driving? Most of the respondents, namely 69 people (62%), confirmed the negative impact of LED billboards on the visual conditions. The most commonly cited factor was the excessive brightness of the areas of billboards, followed by excessively bright colours and rapidly changing images.

2.2. Review of the requirements with regard to LED billboards

In some countries where problems with very bright LED billboards have emerged, e.g. USA, Australia, South Africa, Holland and Poland, attempts have been made to limit the negative impact of LED billboards on the safety of road traffic by issuing relevant legal regulations. These regulations often differ from each other significantly and only apply to factors affecting distraction, such as displaying moving images, minimum dwell times, visual effects and the interval between consecutive images. Parameters, such as the luminance of the displayed images, their size and location in relation to the road, which may have an additional impact on the glare of drivers, are rarely taken into account. The requirements in force in selected countries, related to the permissible luminance, size and locations of advertising devices, are presented below.

2.2.1. Permissible luminance of large billboards

Usually, limiting the luminance of billboards during the day is not necessary, but such a limitation should be unquestionably introduced at night. Unfortunately, legal regulations rarely provide for such requirements. If, however, the maximal luminance values are taken into account, the applied values vary a lot. For example:

In the New York State in America (NYSDOT, 2008), the maximal luminance is specified at 5000 cd/m^2 for daytime and 280 cd/m^2 for the night. In San Antonio, Texas, a luminance of 7000 cd/m^2 is permitted during daytime and 2.500 cd/m^2 at night (Ord. No. 2017-05-04-0297, 2017) The regulations, however, fail to specify the required lighting conditions in the billboard's vicinity. In Queensland and New South Wales, Australia, a limitation of billboard luminance was introduced in relation to the surrounding level of lighting. Still, the permissible values of luminance differ significantly for those two states. Three zones were introduced in Queensland (Roberts et al., 2013): high level of lighting, e.g. town centres - max. 500 cd/m^2; average level of lighting, e.g. suburban industrial zones, parking lots – max. 350 cd/m^2; and low level of lighting, e.g. residential areas – max. 300 cd/m^2. Four zones were introduced in New South Wales (Roberts et al., 2013): high level of lighting, e.g. town centres - unlimited; average level of lighting, e.g. suburban industrial zones, parking lots – max. 1.200 cd/m^2; low level of lighting, e.g. small, isolated shopping centres – max. 300 cd/m^2; and areas lacking external lighting, e.g. rural areas 400 cd/m^2. In South Africa (SANRAL, 2000), the permissible luminance depends on the billboard's size. The following permissible luminance values were used: 1000 cd/m^2 for billboards whose area is below 0.5 m^2; 800 cd/m^2 for 0.5–2.0 m^2; 600 cd/m^2 for 2.0–10.0 m^2; 350 cd/m^2 - above 10.0 m^2 (within the road lane); and 400 cd/m^2 above 10.0 m^2 (outside the road lane). In Poland, there are also plans to limit the luminance of advertising billboards in developed areas to 4000 cd/m^2 in the daytime and 400 cd/m^2 at night, and in undeveloped areas to 4000 cd/m^2 in the daytime and to 300 cd/m^2 at night (Draft Regulation, 2016)

2.2.2. Permissible area and location of billboards

The maximal permissible advertising areas usually depend on the state (or local) legal regulations and range from a few to several tens of square meters. For example, in Tasmania (Roberts et al., 2013), the maximal advertising surface is 3 m^2; in New Zealand (Roberts et al., 2013), the maximal size is 3 m high and 6 m wide; in Queensland (Roberts et al., 2013), Australia – 43 m^2; in San Antonio, Texas – 62 m^2 (Ord. No. 2017-05-04-0297, 2017). With regard to the permissible location requirements, it is often stipulated that a billboard may not limit visibility and endanger road traffic. Billboards should not be installed in places where drivers are required to pay special attention (e.g. near pedestrian crossings). Still, some regulations precisely specify permissible location zones for billboards. For example, in South Africa (SANRAL, 2000), billboards should be installed over 50 m away from intersections where the speed limit is below 60 km/h, 100 m where the speed is limited to 60 km/h, and 200 m where the speed limit is over 100 km/h. In New South Wales (Roberts et al., 2013), Australia, the minimal distance from a billboard to the zone where traffic changes direction, to traffic signs or exits should be 10 m in cities, 15 m outside cities and 15 m on highways. In Holland (Daluge et al., 2011), billboards must not be placed closer than 13 m from the road and 200 m from the place where the road begins to curve; moreover, billboards cannot be placed in front of or behind road traffic signs or other traffic control devices. In Poland (Arc of 21 March 1985), placing billboards near roads is subject to the road category and the land it crosses. In developed areas, the minimal distance is 6 m for local roads, 8 m for district and regional roads, and 10 m for national roads. Outside developed areas, the distances are 15 m, 20 m and 25 m, respectively.

3. Objective of research

The problem of unpleasant and distracting glare has been known for a long time. As new technologies are being developed, e.g. CCD matrix (Charge-Coupled Device matrix), eye trackers or driving simulators, numerous research projects are under way, aiming to create newer methods of measuring and evaluating the impact of glare on visual performance (Porsch et al., 2014, Blaszczyk, 2013; Van den Berg et al., 2009; Rob, 2007). Although recommendations and methods of evaluating glare caused by luminaires are known, there are no specific requirements and recommendations for large LED billboards, especially with regard to their photometric and geometric properties. Therefore, a research project has been commenced to determine the impact of LED billboards on the drivers' visual performance. In several studies, a luminance was recommended, which does not reduce the drivers' visual performance in urban traffic. However, the cumulative impact of the luminance, size and the location of the billboard on the drivers' visual