Considerations for assessing the road safety impact of digital and projected advertising displays in Canada

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Abstract

Recent advancements in digital advertising technologies combined with the reduction in costs of these technologies have led to increasing pressure on governments to approve their installation adjacent to roads. These signs typically use light-emitting diode (LED) technologies with the capability of displaying dynamic messages with high luminance levels. They are specifically designed to attract maximum driver attention and subsequently create maximum driver distraction. Although the effect of roadside advertisements on driver distraction and road safety has been researched since the 1930s, digital advertising is relatively new and its effect on road safety is still inadequately understood. However, jurisdictions must be prepared to evaluate requests for these advertisements and develop policies and regulations for their control with an understanding about their potential impact on road safety.

This paper summarizes the findings from a literature review on the road safety impacts of digital and projected advertising displays (DPADs). Specifically, it identifies challenges for regulating DPADs and assessing their impact on road safety, discusses issues concerning DPAD policy and regulation, and reveals considerations for DPAD policy and regulation. Current research is unable to conclusively determine the road safety impact of DPADs; consequently road authorities have difficulty accepting or rejecting DPAD applications on the basis of safety and advertisers have difficulty demonstrating that DPADs do not negatively impact safety. Despite the lack of conclusive evidence, the literature provides sufficient information to guide policy and regulatory direction concerning DPADs.

INTRODUCTION

Recent advancements in digital advertising technologies combined with the reduction in costs of these technologies have led to increasing pressure on governments to approve their installation adjacent to roads. These signs typically use light-emitting diode (LED) technologies with the capability of displaying dynamic messages with high luminance levels. They are specifically designed to attract maximum driver attention and subsequently create maximum driver distraction. Although the effect of roadside advertisements on driver distraction and road safety has been researched since the 1930s, digital advertising is relatively new and its effect on road safety is still inadequately understood. However, jurisdictions must be prepared to evaluate requests for these advertisements and develop policies and regulations for their control with an understanding about their potential impact on road safety.

The definition of digital and projected advertising displays (DPADs) used in this paper is as follows:

"Any type of stationary advertising display that is located outside of a building, visible from the road, and capable of displaying dynamic content or automatically changing content.

DPADs can be located on private property or within public right-of-way with content that includes text and/or images. This content can be displayed statically with multiple advertising messages presented in sequence, dynamically using full motion video, or using scrolling text. These displays can be stand-alone billboards, signs affixed to or advertising projected onto buildings, sidewalks, or other structures, or message centres incorporated into ground signs. DPADs are privately owned and operated for the primary purpose of displaying commercial advertising and occasionally for displaying public service announcements.

DPADs exclude portable variable message signs governed by the Manual of Uniform Traffic Control Devices of Canada in Section D3.8, mobile displays such as those affixed to vehicles, and indoor displays."

The objective of this paper is to identify key considerations for assessing the road safety impact of DPADs for the purposes of evaluating permit applications for these signs and developing regulations. Considerations described in this paper are identified through an extensive literature review.

The scope of this paper is limited to research results that have been published (i.e., no new research was conducted for this study) primarily since 2001 which is about the time when DPADs began emerging. The paper is specific to road safety considerations only and does not include other factors that may impact the decision to permit DPADs such as political reasons, aesthetics, or economic development opportunities. The views expressed in this paper do not necessarily reflect or represent those of the Transportation Association of Canada (TAC) or the DPAD guidelines that are currently being developed under TAC.

BACKGROUND

Outdoor advertising is an innovative, fast-paced, and technically advanced industry. Rapid changes to DPAD technologies have occurred primarily due to the widespread use of digital light emitting diodes (LED) arrays and the implementation of new programmable formats and messages. Advertising agencies are exploiting the increased light intensity, resolution, animation functions, and size of these displays to maximize driver attention to these signs with the negative consequence of maximizing driver distraction. Furthermore, the reduced costs of these displays have resulted in increased requests for approval to install these signs near roadways. This is occurring at the same time as transportation professionals and government agencies are seeking ways to minimize driver distraction for safety purposes (e.g., requiring hands-free cellphone technologies in vehicles).

Digital advertisements are often displayed for six to eight seconds (although this bound varies between jurisdictions) before a new static or dynamic image appears. The amount of time an image is displayed is known as the message duration and the time between successive static images is called the transition time. Images can fade or dissolve during the transition time. DPADs allow advertisers to change advertising content in real-time and also display internet feeds such as time, weather, and traffic conditions.

The Highway Beautification Act enacted in the U.S. in 1965 regulates off-premise advertising signs along federal-aid routes (e.g., Interstate highways, National Highway System). Until 1996 this Act considered static billboards only; however, the FHWA has since allowed digital billboards to be included, subject to the discretion of individual states and provided that they do not contain flashing, intermittent, or moving lights. The Act also gives states the authority to regulate the message change interval and spacing between signs. Similar federal legislation does not exist in Canada. Individual Canadian jurisdictions either have their own policies, regulations, and practices for DPAD permit applications or handle DPAD permit requests on an ad-hoc basis without following a consistent or documented method.

Drivers function as information managers and controllers. They are faced with many information sources and must select which sources to attend to and process. It is necessary to sort through these sources in an expeditious manner, separating the necessary from the irrelevant. Many sources of information are irrelevant to the driving task and can lead to driver distraction. One such source is DPADs. A certain, albeit undefined, amount of distraction is generally accepted by roadway agencies as evidenced by the universal permission of advertising along the roadside by jurisdictions. The premise behind this permission is that driver's tend to have spare mental capacity that allows them to direct their attention, to some extent, to stimuli and activities unrelated to the driving task (e.g., looking at scenery, talking to a passenger, reading a billboard). However, directing attention to objects and activities unrelated to driving can distract the driver, reduce situational awareness, and lead to driver error and/or a crash.

Currently there is an inability to quantify an acceptable distraction threshold, develop a method to accurately measure distraction, and objectively determine the distraction levels of DPADs.

METHODOLOGY

The considerations for assessing the road safety impacts of DPADs were obtained from an extensive literature review. Literature published in 2013 and earlier was reviewed. Relevant documents found included 45 academic research papers, 22 studies conducted for or by government agencies, and eight consultant studies conducted for the private advertising industry. Most literature on this subject has been published since the early 2000s. Although this paper is inclusive of all 75 reports and studies reviewed, the following three reports contribute a significant portion of the information and knowledge contained in this paper:

- Impact of Roadside Advertising on Road Safety published by Austroads (1).
- The Effects of Commercial Electronic Variable Message Signs (CEVMS) on Driver Attention and Distraction: An Update published by the U.S. Federal Highway Administration (FHWA) (2).
- Safety Impacts of the Emerging Digital Display Technology for Outdoor Advertising Signs published by the Transportation Research Board (TRB) (3).

The Austroads report is developed for Australia and intended to facilitate the harmonization of agency criteria for the management of roadside advertising devices, promote improved and consistent practice by road agencies, and assist road agencies in understanding and addressing the safety impact of digital display technology for outdoor advertising signs. This report reviews human factors elements related to this issue, conducts a literature review, creates an inventory of guidelines and practices used by other jurisdictions, and develops best-practice guiding principles and guidelines.

The FHWA report identifies research gaps concerning the safety impact of DPADs and develops a strategy to address these gaps. This report conducts a literature review to identify independent and dependent variables associated with DPADs that affect road safety, develops research methods and scientific techniques for evaluating the safety of DPADs, and outlines a high-level potential research program to understand these variables.

The TRB report provides guidance related to the safety aspects of digital display technology for outdoor advertising signs for state and local authorities to adopt; this report also includes an extensive literature review. The report reviews guidelines and/or regulations in the U.S., Australia, South Africa, the Netherlands, and Brazil and prepares a set of recommendations, including identifying location and operational characteristics that seem to exacerbate the risk and/or consequences of distraction.

CHALLENGES FOR REGULATING DPADS AND ASSESSING THEIR IMPACT ON ROAD SAFETY

The FHWA and TRB have published authoritative reports on the subject of digital advertising signs and find that despite years of research there have been no definitive conclusions about the presence or strength of adverse safety impacts of DPADs. Post-hoc collision studies, field investigations, and laboratory tests are common methods used to determine a relationship between DPADs and safety impacts; however, each has their own set of significant limitations as shown in Table 1. A common limitation for each method is the variability that exists between the different types of DPADs and the contexts in which they are placed. The variation in sign characteristics (e.g., size, luminance), message content (text, images, video), placement (e.g., urban, rural, lateral offset from road, height), and driver demographics create thousands of unique environments in which DPADs can be studied and each which can lead to measurable differences in distraction regardless of the study method.

Table 1: Limitations of post-hoc collision studies, field investigations, and laboratory experiments for determining the road safety impacts of DPADs (2) (3)

Study type	Limitations
Post-hoc collision studies	• Underreported collisions • Driver involved may be unwilling or unable to report distracted driving • Requires data collection over extensive time periods
Field investigations	• Artificial nature of implementation • Route contrived for experimental purposes • Participants sometimes drive with experimenter present • Driver may wear a head-mounted eye tracking device
Laboratory experiments	• Artificial nature of implementation • Requires drivers to adapt to simulator

The three study types identified in Table 1 can be categorized further and additional study types can be added for the purposes of assessing literature quality. Specifically, the literature reveals eight types of research and study approaches for determining the road safety impacts of DPADs. Figure 1 shows each type and categorizes them based on the rigorousness applied and if they provide quantitative or qualitative results. This categorization helps inform practitioners about the strength and application of information contained in these reports. Quantitative and rigorous studies are those that describe and apply statistical analysis to post-hoc collision analyses, field tests, or laboratory experiments or that use data from the 100-car naturalistic driving study. Quantitative and non-rigorous studies are naïve post-hoc collisions analyses and field tests and laboratory experiments that do not describe or apply statistical analyses. Meta-analyses and studies that do not adequately describe their methodology are considered qualitative studies; however, some studies are rigorous while others are not. Generally the numerical order of the studies in Figure 1 reflects the quality of the results (i.e., post-hoc collision analysis using empirical-Bayes statistics is the highest quality); however, this is not always necessarily the case.

	Rigorous	**Non Rigorous**
Quantitative	1. Post-hoc collision analysis using empirical-Bayes (statistically significant results) 2. Post-hoc collision analysis using a control group (statistically significant results) 3. Statistically significant results derived from the 100-car naturalistic driving study 4. Field tests or laboratory experiments (statistically significant results)	5. Post-hoc collision analysis using the naive approach 6. Field tests or laboratory experiments (without statistically significant results)
Qualitative	7. Meta-analyses (i.e., results generated based on literature reviews) 8. Any studies that do not adequately describe their methodology or data	7. Meta-analyses (i.e., results generated based on literature reviews) 8. Any studies that do not adequately describe their methodology or data

Figure 1: Categorization of DPAD research and studies

Research limitations and the current state of knowledge about the road safety impacts of DPADs leads to difficulties in providing answers to important questions concerning their implementation and operation. Figure 2 illustrates these questions, comments on the current ability to answer each question, and concludes with the level of confidence in answering each question. In essence this figure demonstrates that (1) driver distraction can cause collisions and that DPADs are a source of distraction, (2) there is an acceptable level of distraction that does not significantly increase the probability of a collision, and (3) DPADs may or may not exceed this acceptable level of distraction.

The inability to precisely determine if DPADs significantly contribute to adverse road safety effects has implications for both public road authorities who typically issue permits for DPADs and for the DPAD industry. For public authorities, there is inconclusive evidence to support their rejection of DPAD permit applications for road safety reasons. For the DPAD industry, there is inconclusive evidence to support their position that DPADs do not have a negative road safety effect. Despite this apparent stalemate, DPADs should not necessarily be prohibited and progress in their development and implementation has already progressed to a point where it is difficult to reverse the precedent that has been set in many jurisdictions. A prudent approach could be a gradual adoption of DPADs along with careful, quantifiable, and rigorous analysis of their road safety impact. It is with this uncertainty and cautiousness that this paper identifies issues to consider when evaluating the road safety impacts of DPADs. This paper does not, however, make recommendations for developing DPAD policies and regulations.

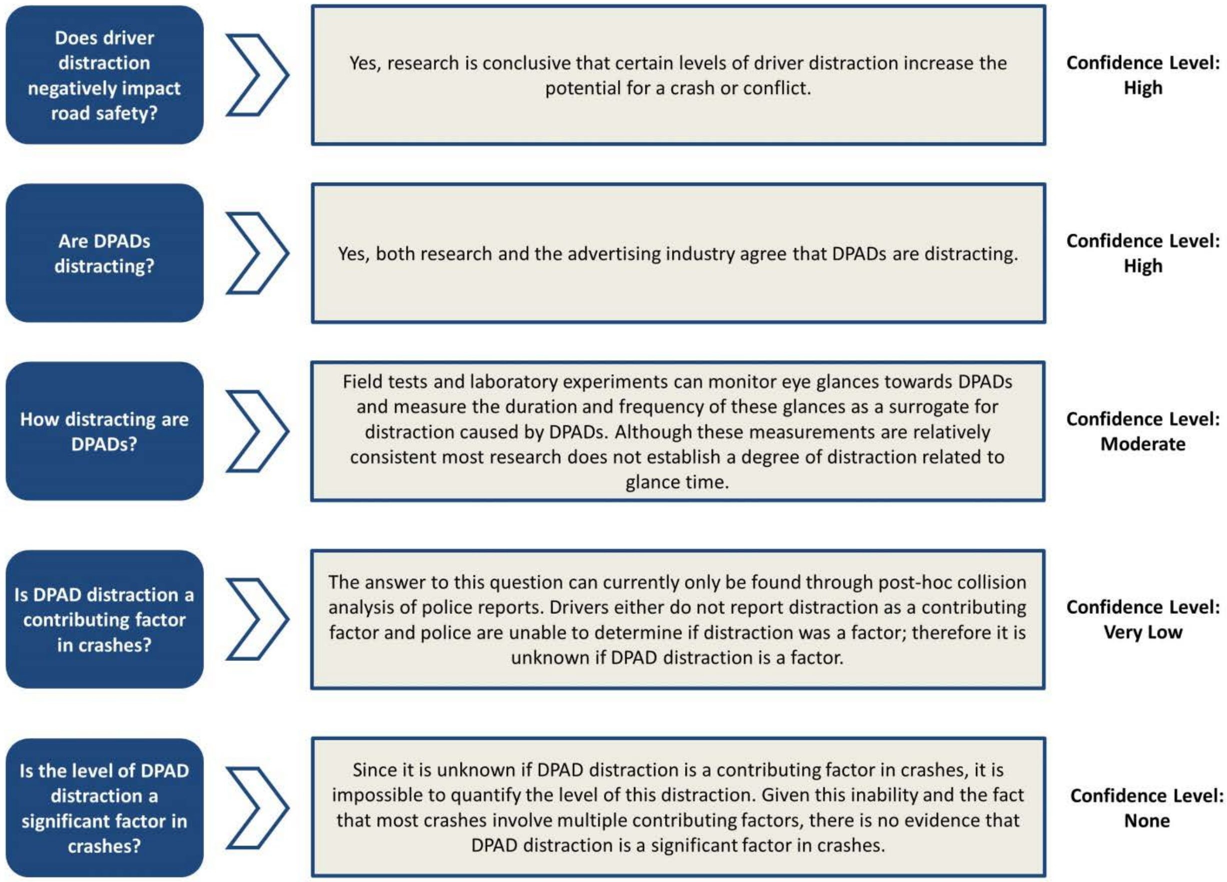

Figure 2: Research uncertainty concerning DPAD impact on road safety

Another challenge in determining the road safety impact of DPADs is the cumulative effect of variables affecting road safety, including sign characteristics, sign placement, and roadway characteristics. There are thousands of combinations of these variables (furthermore, there is variation within each variable) and determining the safety effect of each combination is impossible. While there has been research on the individual effects of some of these variables on road safety, there is no research on how to combine these effects. For example, the literature may state that increasing Variable X decreases road safety and increasing Variable Y improves road safety, but there is no information about the cumulative effect of increasing X and Y simultaneously: will this result in an overall improvement in road safety or not? There are potentially thousands of variable combinations with DPAD characteristics, sign placement, and roadway characteristics that it is impossible to specify the road safety impact of an individual sign for each combination. This issue is analogous to crash modification factors (CMFs) used in the Highway Safety Manual (HSM); however, whereas the HSM multiplies CMFs to arrive at the cumulative effect, there is no such statistical support (or opposition) to do the same with DPAD variables.

ISSUES CONCERNING DPAD POLICY AND REGULATION

Important issues concerning DPAD policies and regulations include the method for measuring the road safety impact of DPADs, the risk tolerance of a jurisdiction, and the impact of DPADs on older drivers.

Methods for Measuring the Road Safety Impact of DPADs

Road safety cannot be measured directly and relies on the use of surrogate measures as an approximation. The road safety impacts of DPADs are no different in this regard. The most common surrogate for approximating road safety is collision frequency (sometimes as a function of traffic volume, i.e., collision rate). Preferably, the road safety impact of DPADs could be approximated by measuring the change in collision frequency before and after the DPAD was installed using empirical-Bayes statistical procedures. Unfortunately these types of analyses are largely unavailable at this time. Therefore, the literature uses the following six surrogate measures to approximate the change in collision frequency due to DPADs: (1) glance frequency, (2) maximum glance duration (MGD), (3) time-eyes-off-road (TEOR), (4) lane position control, (5) travel speed and deceleration, and (6) driver response time. The literature has established a quantitative relationship between the increased risk of a collision and the former three surrogates (i.e., objective surrogates); however, the effect on collision risk of the latter three surrogates is only defined qualitatively (i.e., subjective surrogates) and their significance on road safety is undetermined.

Without statistically significant, empirical-Bayes before-and-after collision analyses, the six surrogates can be used by jurisdictions to inform DPAD policy and regulation. Objective surrogates measure eye glances as a surrogate for distraction; distraction is used as a surrogate for estimating the increased risk of a collision; and the increased risk of a collision is used as a surrogate measure for road safety. Using eye glances as a surrogate measure for distraction has limitations and assumes that the mind concentrates on the same thing that is focused on by the eye. For example, it is possible for the eye to be fixed on the road but for the mind to be distracted. Eye glance measurements typically do not account for peripheral vision capabilities of a driver. Despite these limitations, eye glances remain one of the most commonly used surrogates for measuring distraction. Table 2 shows the increased risk of a collision for each objective surrogate as revealed in the literature. As a simple example, if a jurisdiction decides that they will only permit DPADs which attract less than two glances per driver, they will be accepting a 140 percent increase in the risk of a collision. If the risk of a collision at a location is very low, a 140 percent increase in this risk may not produce a meaningful difference in collision frequency and subsequently would not significantly impact road safety.

Table 2: Objective surrogate measures for the road safety impact of DPADs (4) (5)

Surrogate	Threshold	Risk of a collision
Glance frequency	1 – 2 glances	Increase by 140%
	>2 glances	Increase by 230%
Maximum glance duration	>0.75 s	NA*
	>2 s	Increase by 200%
Time-eyes-off-road	2 s out of 6 s task	Increase by 160%
	3 s out of 15 s task	Increase by 130%

* 0.75s is defined as the reaction time to a braking vehicle directly in front of a driver and therefore the amount of time needed to avoid a rear-end collision.

It is important to note that the expected increase in collision risk shown in Table 2 are based on a limited number of studies and should be used as heuristics only. Further, comparing thresholds and changes in collision risk across surrogates reveals discrepancies. For example, the surrogate time-eyes-off-road of 3 s in a 15 s task suggests an increased collision risk of 130 percent; however, if the 3 s comprises a single glance, this would suggest an increased collision risk of either 140 percent (based on the glance frequency surrogate) or 200 percent (based on the glance duration surrogate). This underscores the heuristic nature of the surrogates. Differences in collision risk can be compared within each surrogate but not across surrogates. However, it is possible to use the collision risk across surrogates to arrive at an expected range of increased collision risk. Using the example in this paragraph, the increase in collision risk is expected to be between 130 percent and 200 percent.

Subjective surrogates can also be used heuristically at certain locations to help make a decision on a case-by-case basis. The literature generally finds that DPADs decrease lane position control, decrease travel speed, and increase driver response time. However, the significance of these relationships on collision frequency is unknown. As a simple example of applying these subjective surrogates, a jurisdiction may reject a DPAD permit application at a location where side-swipe collisions are high since the DPAD has the potential to exacerbate this problem by decreasing the ability of drivers to maintain lane position control.

Risk Tolerance of a Jurisdiction

There have been no documented instances where DPADs have improved road safety (or have been the primary factor in reducing collision frequency). Literature consistently reports that the impact of DPADs on road safety or collision frequency is either neutral or negative. Furthermore, there is general agreement (including from DPAD manufacturers and vendors) that DPADs are distracting. Therefore, by permitting DPADs, jurisdictions are willingly and knowingly accepting an increased risk in collision frequency. In doing so, each jurisdiction is implicitly (or perhaps explicitly) defining an acceptable risk tolerance. This tolerance is unlikely to be published or agreed upon by everyone; however, if the direction of a jurisdiction is to base their DPAD policy on objective surrogate measures, they will be acknowledging and accepting a quantifiable increased risk in collisions (as shown in Table 2). Studies that measure glance duration at DPADs generally find that between 20 and 25 percent of drivers have glances exceeding 0.75 seconds and less than five percent have glances that exceed 2.0 seconds. By knowing the traffic volume at a location, these percentages give an indication about the number of distracted drivers to expect which can be used to estimate the increase in collisions resulting from DPADs. If the estimated increase in collisions is acceptable to a jurisdiction, the DPAD permit may be issued from a safety perspective.

DPADs and Older Drivers

Research consistently shows that DPADs increase older driver response time, increase the difficulty older drivers have in finding official road signs, and contribute to more lane change errors by older drivers (6) (7) (8). This research has not conclusively and quantitatively related an increase in older driver collision frequency and DPADs, but given the empirical observations and research to-date, it is not unreasonable to expect this type of quantitative evidence to arise in the future. The literature has not, however, considered the social issues associated with the potential increase in collisions involving seniors due to the increased installation of DPADs. For example, older drivers may be at a higher risk of losing their license compared to other age demographics due to age-related diminishing capabilities. Permitting DPADs may contribute to increased collisions among older drivers and subsequently have mobility implications for this demographic in terms of licensing.

CONSIDERATIONS FOR DPAD POLICY AND REGULATION

There are four primary considerations for developing digital and projected advertising display (DPAD) policies and regulations: DPAD characteristics, DPAD placement, roadway characteristics, and driver response to DPADs.

DPAD Characteristics

DPAD characteristics can have potential safety impacts depending on the level of distraction, conspicuity of display, and legibility of sign (9). As shown in Table 3, key variables to consider regulating are movement, message duration, transition time, message sequencing, quantity of information, information presentation, colour, information content, and luminance.

Table 3: DPAD characteristic variables to consider regulating

Variable	Description
Movement	Covers the presence of motion in the advertisement, including video and special effects within a single display/message as well as transition, movement, and rotation between successive displays.
Message Duration	Also referred to as dwell time, message on-time, or exposure time.
Transition Time	Interval between successive displays or messages; also referred to as message change time.
Message Sequencing	Covers the use of a sequence of displays and messages as part of a single advertisement.
Quantity of Information	Includes message length, quantity of text, or number of informational elements.
Information Presentation	Covers the format of information including font type, text size and spacing, layout, and arrangement.
Colour	Covers the use of colour in general or in relation to a specific area of a sign.
Information Content	Covers the content and meaning of the information contained within the message including textual and graphical elements.
Luminance	Also known as photometric brightness is the "brightness" of the billboard as seen from a particular angle of view. It is measured in candelas per square metre (cd/m^2), also termed "nits."

Source: Adapted from (1).

The following summarizes findings from the literature review in terms of the potential safety impact of each variable.

Movement

DPADs with dynamic displays increase glance frequency (between two and five times more glances (10)), glance duration, and the number of long glances (i.e., greater than 0.75 seconds) compared to static signs. Drivers operating in the vicinity of DPADs with dynamic displays tend to have less lateral lane control, brake harder (i.e., exhibited slower reaction time), and decrease vehicle speed (11). The negative road safety effects of DPADs with dynamic displays tend to decrease as sight distance to these signs increases. There is a significant body of literature that recommends prohibiting the use of dynamic displays on DPADs.

Message Duration

As the message duration decreases, glance frequency tends to increase and can also increase glance duration in anticipation of the next message. Many jurisdictions have established fixed message duration limits regardless of travel speed. However, literature recommends developing minimum message duration times which are dependent on travel speed and sight distance (3). The objective of variable message duration limits is to ensure that drivers only see one or two messages per DPAD.

Transition Time

The literature recommends minimizing the transition time between successive messages on a DPAD. Preferably the transition time between messages should be as close to instantaneous as possible (3).

Message Sequencing

Although there is no research that quantifies the relationship between message sequencing and road safety, the application of human factors principles, such as the Ziegarnik Effect, suggests that message sequencing should be discouraged. The Ziegarnik Effect refers to the psychological difficulty of abandoning a task which has not been completed. This effect concerns DPADs in that these signs may attract drivers' attention for longer periods if there are changing images or messages.

Quantity of Information

There is insufficient research to make recommendations on the amount of information to display on a DPAD; however, the literature suggests that the amount of information should be a function of the distance where the sign becomes legible, posted speed limit, legibility, text height, lateral placement of the sign, and glance duration (1.5 to 2.0 seconds per glance is suggested). The quantity of information should consider driver characteristics such as vision, reaction time, reading time, and spare capacity available to process the information (12).

Information Presentation

Text size should be chosen to encourage drivers to read the sign at a distance of 500 m in front of the sign (the lateral offset of the sign should be chosen such that the sign is not legible at a distance of 150 m in front of the sign). This is a function of travel speed but the range of text height values generally falls between 0.3 m to 1.0 m (12). According to the literature, if the DPAD includes navigational information to a business, these instructions should contain as few words as possible (less than or equal to six words) in order to be read in a single glance. Further, navigational information should be larger than non-navigational information (13).

Colour

The literature finds that DPADs using similar colours and designs as official traffic signs tends to decrease road safety. Therefore official traffic sign colours should be discouraged on DPADs (14).

Information Content

Messages with both positive and negative emotional content impact vehicle speed, lane position, and driver response time. Emotional content can hold the drivers attention longer than neutral content and can adversely affect driver performance for up to 0.8 s after the sign (15). Negative content decreases speed and increases lateral lane movement. Positive content increases travel speed after the sign and reduces driver response time. (16)

Although DPADs offer the opportunity to mix advertising content with public service announcements, drivers may not notice that a sign's message has changed from irrelevant information to relevant information, particularly drivers familiar with the route (3).

Luminance

The effect of luminance on road safety is dependent on ambient lighting conditions. Many jurisdictions require advertisers to automatically adjust sign luminance using ambient light sensors. Higher sign luminance increases driver distraction and reduces the visibility of official traffic signs. High luminance levels can cause glare and increase visual adaptation times when drivers observe a sign and then return their attention back to the road (especially at night). Maximum luminance levels and ranges of acceptable luminance vary significantly between jurisdictions. Although luminance should be a function of ambient lighting conditions, limiting the maximum luminance of a DPAD to 100 nits is a recommended practice in the literature (17).

DPAD Placement

The location of a DPAD impacts the level of driver distraction in terms of glance duration and overall duration of glances away from the roadway. As shown in Table 4, key variables to consider regulating are the longitudinal, lateral, and vertical placement, and sight distance.

Table 4: DPAD placement variables to consider regulating

Variable	Description
Longitudinal Placement/Spacing	Covers restriction distances in relation to traffic control devices and driver decision and action points, as well as advertising device density constraints.
Lateral Placement	This is the position of the sign typically measured from the centre of the travel lane or edge of pavement.
Vertical Placement	Covers both the maximum height of a sign and the overhead placement.
Sight Distance / Visibility	This is the distance at which a DPAD becomes visible to a driver, but not necessarily legible.

Source: Adapted from (1).

The following summarizes findings from the literature review in terms of the potential safety impact of each variable.

Longitudinal Placement / Sign Spacing

The number of collisions at a location tends to increase in proportion to the number of billboards (although research does not distinguish between static billboards and DPADs) (18). Some research suggests that drivers should not have more than one DPAD in their field of view at any one point time.

Lateral Placement

The lateral placement of a sign directly affects its conspicuity. The angle of eccentricity of a DPAD (i.e., the angle from a driver's line of sight to the sign) has a greater effect on sign conspicuity than the sign's size or reflectivity. A sign's conspicuity increases as the angle of eccentricity decreases, the sign sight distance increases, and when signs are placed along a horizontal curve (19). Increasing sign conspicuity increases glance frequency and total time that a driver's eyes are off the road but does not necessarily increase glance duration. Therefore DPADs should be placed such that conspicuity is decreased.

Lateral placement of a sign should be measured from the driver's field of view and not as a fixed offset from the edge of the roadway (10). Road safety is generally improved by ensuring that official signs are more conspicuous than DPADs and when DPADs are placed outside of the driver's field of view.

Vertical Placement

The literature finds that DPADs installed at the eye-level of drivers tend to cause higher glance frequencies and longer glance durations compared to signs that are raised above eye-level (20). Similar to the lateral placement of signs, the literature recommends placing DPADs outside of the field of view.

Sight Distance / Visibility

Drivers tend to be more distracted by DPADs that are visible for short amounts of time. DPADs which are visible for long amounts of time do not significantly affect glance duration but do increase overall time of eyes off the road (11). Furthermore, consideration should be given about the road safety effects of DPADs which are visible to adjacent roads.

Roadway Characteristics

Distraction levels of DPADs vary as a function of the complexity of the driving task where the adverse effects of distraction increase with greater driving task demands. Complex geometry and operational characteristics of the road environment, high visual clutter, work zone areas, and areas with road signs and signals that require drivers to make complex decisions have higher driver attention demand. The combined effect of the various distraction inducing roadway characteristics is more important that any single characteristic. Table 5 identifies important roadway characteristics that can impact road safety near DPADs, as reported in the literature.

Table 5: Roadway characteristic variables that can impact road safety near DPADs

Variable	Description
Geometry	Refers to the physical dimensions of a road including vertical and horizontal curvature, cross-sectional features, and longitudinal grade.
Complexity	Refers to the complexity of the roadway in terms of the driving demand placed on the driver.
Operations	Refers to the operational characteristics of a roadway including traffic volume, travel speed, and vehicle types using the road.

Source: Adapted from (1).

The following summarizes findings from the literature review in terms of the potential safety impact of each variable.

Roadway Geometry

Glance frequency and glance duration increases when DPADs are placed along roads with long sight distances, an uninterrupted view to the sign, and along a horizontal curve with a low degree of eccentricity (19) (21) . Increasing glance frequency and duration has been shown to increase the risk of a collision.

Roadway Complexity

The distracting effects of DPADs contribute to driver demand loads and can significantly increase roadway complexity. Collision rates tend to increase on roads and at locations with high complexity (e.g., busy intersections, interchanges, weaving areas, work zones) and the presence of DPADs at complex locations can contribute to higher collision rates. As driver demand load conditions increase, the response time to road signs increases which leads to negative impacts on road safety.

Increasing visual clutter and driver workload decreases drivers' detection and response to official signs, decreases travel speed, increases the time to change lanes as directed by official signs, increases driving errors, and decreases time spent looking at the road (6) (8). While visual clutter comprises many elements (e.g., buildings, official road signs, traffic), research shows a strong correlation between the distraction caused by roadside advertising clutter and collision frequency (22). However, there is no quantifiable metric for clutter.

The literature reveals that older drivers have more difficulty locating information on official signs in areas of high visual clutter (6). It also shows that drivers are more sensitive to changes in visual clutter when clutter is low and often do not detect changes in clutter when clutter is high (7).

Operations

The negative effects of DPAD distraction on road safety increases on roads with high traffic volumes or high operating speeds (23); however, a quantifiable relationship between traffic volume and operating speed in the vicinity of DPADs and collision frequency has not been established.

Driver Characteristics and Response to DPADs

The following section generally describes how different types of drivers respond to DPADs. As shown in Table 6, this includes age, gender, and driving experience, attention to the driving task, speed and deceleration, and lane position.

Table 6: Driver characteristics and responses to DPADs

Variable	Description
Age, Gender, and Driving Experience	Refers to the age and gender of a driver and the number of years a driver has driven based on the number of years the driver has held a valid driver's license.
Attention to the Driving Task	Refers to the effect that DPADs have on diverting driver attention away from the primary driving task.
Speed and Deceleration	Refers to the effect of DPADs on driver speed, deceleration, headways, and gaps (i.e., whether drivers increase or decrease their speed due to the presence of a DPAD).
Lane Position	Refers to the impact that DPADs have on the ability of drivers to maintain proper and consistent lane position (i.e., whether DPADs cause drivers to increase lateral vehicle movements within or across lanes).

Age, Gender, and Driving Experience

Age and driving experience do not affect the average glance duration toward DPADs, unsafe glance distribution patterns (i.e., glances longer than 2 seconds) at DPADs, or the ability to anticipate hazards in the presence of DPADs (24) (25). However, the maximum glance durations for inexperienced drivers is higher compared to experienced driver. In addition, older drivers have difficulty finding and responding to official signs and detecting changes in the traffic stream under conditions of high workload and visual clutter (e.g. advertisement signs) (8) (7).

Attention to Driving Task

Drivers tend to look at DPADs more frequently and with longer durations compared to other signs on the road although available research does not find a difference in glance duration between day and night conditions. As the driving task increases, there is conflicting results in the literature about the effect on glance frequency. Despite this, research generally shows that the driving task demand level does not affect the average and maximum glance duration toward DPADs.

Research shows that the chance of crash nearly doubles when glance durations off the roadway (including at DPADs) exceed 2.0 seconds and that there does not appear to be a correlation between crash probability and glance durations less than 2.0 seconds (4).

The literature finds that drivers are often unable to ignore irrelevant stimulation (e.g., DPADs) even under highly demanding driving tasks and even if the driver is intending to concentrate on the driving task. Although drivers intend to direct their attention to perform the critical driving task first and then direct any spare attention to non-driving tasks, the distracting effects of DPADs can inadvertently assume primary importance. This effect is greatest among novice and older drivers.

Some research suggests that DPADs on straight roads in monotonous environments where the driving task is under-stimulating can have a positive effect on road safety by increasing driver attentiveness; however, others suggest that there may not be a safety benefit due to phototaxis which refers to the human tendency to direct attention to bright lights (26).

Speed and Deceleration

There are inconsistent findings in the literature pertaining to the relationship between DPADs and travel speed and headways. However, some studies find drivers are more likely to drive slower and with a shorter following distance in the presence of a distraction, which can cause safety issues due to speed variability (7) (27).

Lane Position

DPADs tend to increase lane deviations along road segments but do not seem to impact lane deviation at intersections. When DPADs are present along a road segment, drivers are more than two times as likely to make a lane changing error (7).

CONCLUSIONS

Recent advancements in digital advertising technologies combined with the reduction in costs of these technologies have led to increasing pressure on governments to approve their installation adjacent to roads. However, digital advertising is relatively new and its effect on road safety is still inadequately understood. This paper summarizes the findings from a literature review and discusses challenges for regulating DPADs and assessing their impact on road safety, issues concerning DPAD policy and regulation, and considerations for DPAD policy and regulation.

Challenges for regulating DPADs and assessing their impact on road safety include inherent limitations in research methodologies that have been used for estimating this impact. Post-hoc collision studies, field investigations, and laboratory experiments are the most common methodologies used and each have critical limitations which undermine the ability to conclusively determine the road safety impact of DPADs. Current research can demonstrate that driver distraction can cause collisions and that DPADs are a source of distraction. It also recognizes that there is an acceptable level of distraction that does not significantly increase the probability of a collision; however, current research cannot determine if DPADs exceed this acceptable level of distraction. Another challenge in determining the road safety impact of DPADs is determining the cumulative effect of variables affecting road safety, including sign characteristics, sign placement, and roadway characteristics. Research is specific to isolating one variable and attempting to determine its impact on road safety; however, there is no method for understanding how these variables interact and affect road safety in different combinations.

Issues concerning DPAD policy and regulation for jurisdictions to consider include the method for measuring the road safety impact of DPADs, risk tolerance of a jurisdiction, and equity. The road safety impacts of DPADs cannot be measured directly and relies on the measurement of surrogate measures as an approximation. The most common surrogate for approximating road safety is collision frequency; however, there is little information about the effect of DPADs on collision frequency. Therefore an intermediate surrogate is necessary to estimate the change in collision frequency which is then used as a surrogate to estimate the road safety impact. The literature suggests using glance frequency and duration as surrogate measures for estimating the change in collision risk resulting from the installation of a DPAD. Most literature states that DPADs have either a neutral or negative effect on road safety. By allowing DPADs, jurisdictions are accepting an increased risk in collisions. This risk tolerance should be determined by a jurisdiction prior to permitting DPADs.

The literature identifies four primary considerations for developing DPAD policies and regulations: DPAD characteristics, DPAD placement, roadway characteristics, and driver response to DPADs. Within each of these considerations are different variables which should be regulated. Generally, the negative road safety impacts of DPADs can be minimized by developing policies and regulations such that DPADs are nearly indistinguishable from static billboards, decrease DPAD conspicuity, and decrease time-eyes-off-road duration. Policies and regulations concerning movement, message duration, luminance, and message sequencing can be used to control DPAD characteristics and make them similar to static billboards. Policies and regulations that stipulate that DPADs must be placed outside of a driver's field of view can decrease conspicuity. Time-eyes-off-road duration can be decreased by decreasing glance frequency at DPADs, glance duration at DPADs, or both.

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