URBAN VMS CONSPICUITY AND MESSAGE COMPREHENSION

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ABSTRACT

The majority of literature and guidelines on variable message signs (VMS) cover applications in either a rural highway or motorway context. The urban driving environments are quite different from a motorway where in the latter case, the guidance and regulating information is presented to the driver in a measured and sequential fashion within a low distraction environment. In contrast, an urban environment has a multitude of guidance, warning and regulatory information that is often presented in very short succession, often in parallel with multiple sources of potential hazards from both on and off-road sources.

The nature of the design and operation of a VMS makes it a highly visible device, but the design and message format requires longer reading times than an equivalent static sign with the same information load. Poorly designed messages consume a disproportionate amount of the driver's attention, and it confuses the driver if the message is too long for the available reading time. Delayed processing occurs when the VMS has to compete with other critical roadside information or traffic conditions, thus leading to low compliance rates, defeating the purpose of the VMS. A need was identified by Auckland Transport to develop suitable guidance on VMS location and message design specifically for urban environments.

This document is based on a review of existing VMS guidelines and peer-reviewed research on various topics relating to VMS, signing, and human factors to develop guidance on evaluating the suitability of the VMS message content based on a particular location's information presentation and workload profile.

BACKGROUND

With the increasing roll-out of ITS related equipment onto our urban arterials and streets to help manage a congested system, New Zealand road authorities have found that the existing guidelines relating to location, message content, and message design of variable message signs (VMS) is not easily applied on local and arterial urban streets. The guidelines are traditionally developed for rural high speed and relatively uncluttered roadside environments, with sufficient space to locate and erect a VMS sign. Urban streets often lack the space for a side ground-mounted sign, requiring the use of smaller signs making them less legible, or erecting them on gantries can be expensive and unsightly.

Sign placement and appropriate letter height for the intended message content are determined by a number of factors. A process for determining these values is presented in resources such as the NZ Transport Agency's ITS specification: Variable message sign supply and installation – notes, Australian VMS Guide, and South African Sign Manuals (ITS-06-02).(RTA, 2008, Bain, 2005, NZTA, 2011), but the NZTA guide is lacking in many respects to merely apply the recommendations within urban environments. These are visually complex and full of environmental distractions. Often when the VMS is in use, the traffic flow conditions are congested and the driver workload already high. Appropriate sign placement is determined by the overall information presentation distance, which is the total distance at which the driver needs information about the choice point (e.g., intersection) as shown in Figure 1. This distance is the sum of the reading distance, the decision distance, and the manoeuvre distance.

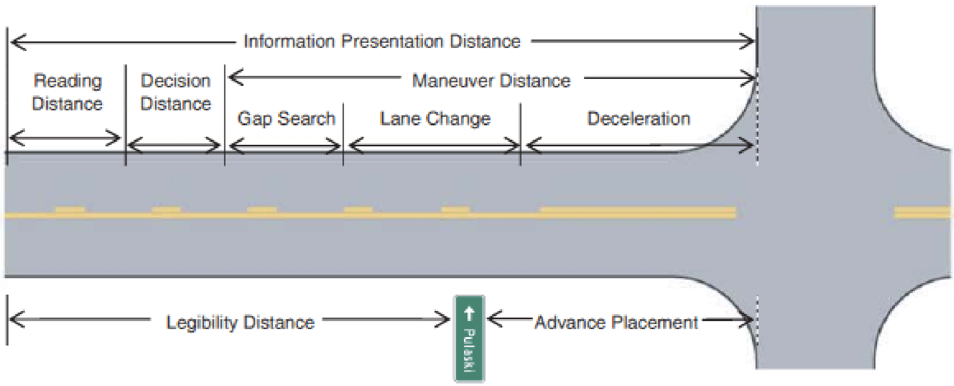

Figure 1: Driver Perception-Reaction Distance Requirements

The reading distance is determined by the amount of time that the driver needs to read the sign's message, depending on the number of words, numbers, and symbols contained in the message. The decision distance is determined by the amount of time needed to make a choice decision and initiate a manoeuvre. However, in the urban environment drivers typically have an information bottleneck at the approach to a signalised intersection. The message design is of vital importance given the unique site constraints.

In addition to a greater frequency of conflicts, intersections generally are more complex and difficult to navigate, compared to a motorway with its dual carriageway and well-spaced grade separated interchanges. In the urban environment the driver workload is often highest at the point when they need to comprehend unique and complex VMS messages compared to those messages found for instance, on a rural road. Figure 2 illustrates the workload drivers typically allocate to various phases of the approach to an intersection to help illustrate information bottlenecks.

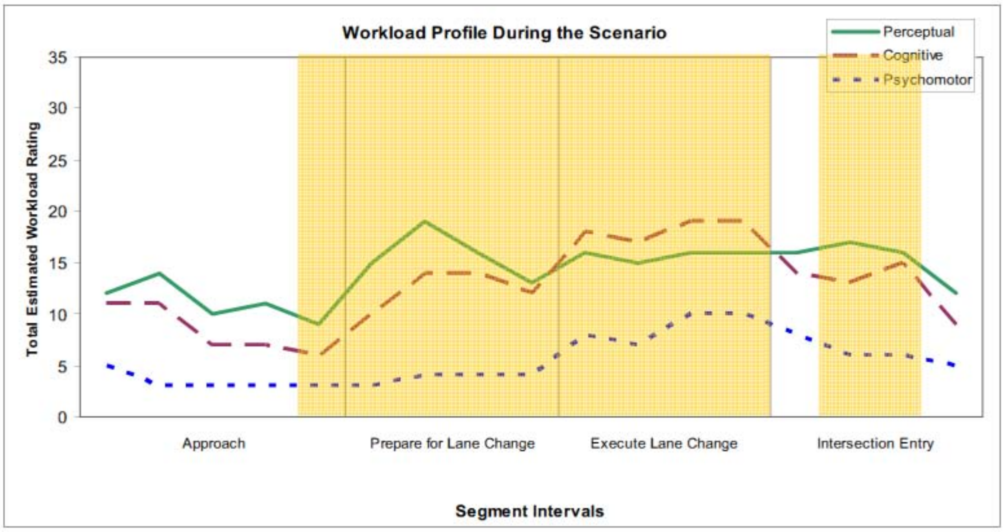

Figure 2: Total Estimated Workload on Signalised Approach

Ideally a VMS should be located in those zones that have the least opportunity for creating a bottleneck. Richard et al. (2006) analysis of information bottlenecks mentions that task pacing (self-paced or forced-paced) can have an effect on the difficulty of a particular subtask by affecting the time available to perform various tasks. Tasks can be perceptual (visually scanning roadway), cognitive (determine decelerating distance), or psychomotor (execute braking) and can be initiated either sequentially or simultaneously, depending on the demand of manoeuvring a vehicle. Individual tasks can be either self-paced, meaning that the driver generally has significant control over the timing and execution of task performance, or forced-paced, whereby performance involves task timing and execution that is mostly determined by factors outside of the operator's control.

An important consideration is to be mindful of how different tasks potentially interfere with each other. Segments that highlight the highest workload are in the preparation for a lane change and lane change manoeuvre. On urban arterial roads where traffic diversions are anticipated and will be frequently recommended, and where complex manoeuvres are required, it is desirable that the VMS be located 300 — 500 m in advance of the diversion point and also at least 200 – 300 m from existing guidance signage. Where complex manoeuvres are not required the following minimum distances between the VMS and other significant road signs (e.g. major directional signposting) should generally be: (RTA, 2008)

- 30 m in business and residential districts
- 50 m for 60 — 70 km/h
- 60 m for 80 — 90 km/h

Drivers tend to search for information in locations where they expect to find it. Generally it takes around 300 ms to search a scene location and 500 ms to notice a particular scene feature. Our available reading time is influenced by a number of factors, the earliest we can read a sign is limited by its conspicuity amongst environmental detractors and ambient lighting, and letter legibility as influenced by the font, letter height and use of upper or mixed case and that VMS take longer to comprehend than static signs as drivers can efficiently scan a static sign to find relevant information whereas they need to read the entire VMS to comprehend the message (Dudek and Ullman, 2004).

The latest we can read a sign is influenced by our sharpness of vision (visual acuity). Our visual acuity extends 18 around the centre of the eye, and the visual span (cone of vision), which excludes our peripheral field, is around 15° horizontal and 7° vertical from the centre.

In-between the maximum and minimum distances we need to account for reduced comprehension based on:

- Workload, which affects memory and reading speed;
- Upper vs. mixed case, the former takes longer to read;
- Available glance durations, an attention grabbing device such as a VMS reduces the driver’s available time to observe other more important hazards.

In the urban context, and due to site constraints, the **reading time required** often **exceeds the reading time available** for many typical messages used on motorways, as well as in less complex rural settings.

Bain (2005) noted that it should be noted that it is generally accepted that drivers' attention should not be diverted from their primary task of safe vehicle control for periods much in excess of 1.50 seconds. To read a sign requiring 3 or more seconds, drivers will normally have to read such a sign with two or more eye movements. In between these sign reading eye movements the driver's eye should return to check the vehicle movement in relation to the roadway and other traffic. The checking eye movements are likely to last at least 1.0 seconds each time. The overall time that a sign should be available for reading (T) therefore needs to be increased over the reading time required (t) based on the amount of information on the sign face. **As a general rule, it could be argued that the reading time required should be increased by up to 1.0 seconds for every 1.5 seconds of reading time required by the message.** A typical message (Figure 3) will take the average person 3.5 s to read based on the number of units of information or words presented. (Table 3 and **Eq. (9)**) However, as a driver they would need to make multiple glances increasing the total read time to 5.5 seconds or 78 m @ 50km/h (156 m @100 km/h).

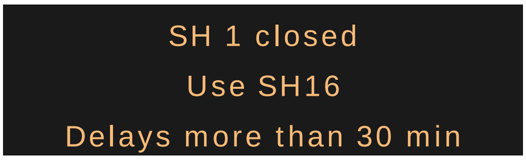

Figure 3: VMS message example

Poor message design or long content can result in confusion, poor driving manoeuvres and increased risk of causing secondary incidents due to driver error that has been exacerbated by the VMS message. No comprehensive guidance exists in the Australasian guides commonly used to evaluate site conditions relative to the critical messages that the site is likely to display.

METHODOLOGY

Auckland Transport Traffic Operations team required a technical guideline to evaluate their new urban VMS locations, as the NZTA VMS guideline (NZTA, 2011) is more suited for rural and urban motorway conditions. Da Vinci’s were appointed to review the available literature and then to expand the existing NZTA guideline with recent research studies, preferably with studies less than 10 years old. The review comprised a literature review of existing guidelines, relevant academic, scientific peer reviewed journal papers dealing with urban-based VMS, human factors, and augmenting this with primary research on eye tracking and environmental driver distraction undertaken by the author. The new guideline was subdivided into the main components that relate to VMS message comprehension so that the relevant technical detail and supporting evidence referenced will guide users to the technical details that underpin the resulting guideline recommendations. The final 66-page guideline is summarised below.

LITERATURE REVIEW

Conspicuity: Many factors influence the visibility of a road sign, the visual complexity of the scene is most important in determining night-time sign luminance requirements. Specifically, the complexity of the area immediately surrounding a sign (e.g., other signs, lights, structures, trees, etc.) greatly influences a driver's ability to perceive and extract information from a sign.

Edquist (2008) also found a lack of any method to measure clutter and determine what level of visual clutter will be a safe range (for most road users, most of the time). A recent analysis of the road system in Victoria, Australia concluded that the system did not provide enough guidance information (Salmon et al., 2005). However, this information must be displayed at such a rate that the driver can absorb and process it in time to make the appropriate decision. Environmental clutter could have an effect on drivers' ability to detect changes such as when a 2-phase VMS changes the message. Previous researchers (McCarley et al., 2004) found that both age, as well as inexperience with the situation depicted, can impair people's ability to detect changes. Edquist's analysis set out to determine whether drivers would be able to detect the changed screen, or not, if they happen to glance away at the moment when the screen changes and proposed a new taxonomy to classify the degree of clutter. .

Changes in traffic density can also affect attention to signs. Bhise and Rockwell cited in Mitchell (2010)found that drivers who were travelling in low-density traffic and followed an unfamiliar route spent an average of ***2.6 seconds*** viewing signs that were useful to their wayfinding. In contrast, drivers who were travelling in high-density traffic and followed an unfamiliar route spent an average ***of 0.9 seconds***. These results indicate that signs need to be designed so that they can be easily read by drivers who need to devote a greater portion of their attention to the surrounding traffic.

Dudek and Ullman (2004) have illustrated from their research the impact heavy vehicles have on driver reading time and comprehension of VMS messages.(Table 1) This ranged from 95% of drivers read and understood a standard message with 500 vph with 5% trucks , to 70% understanding at 1500 vph.

Percent of Motorists Able to Fully Read a VMS Message
with Maximum Base Number of Units with Maximum Base Number of Units (Two-Lane, Two-Way Highway)

	Operating Speed Range								
	0-55 km/h			**55-90 km/h**			**90-112 km/h**		
Percent Trucks	**500 vph**	**1000 vph**	**1500 vph**	**500 vph**	**1000 vph**	**1500 vph**	**500 vph**	**1000 vph**	**1500 vph**
5	95	95	90	100	95	95	100	95	90
10	95	90	85	95	90	85	95	90	80
20	90	80	70	90	85	75	90	85	70
30	90	75	65	90	80	65	90	80	60
50	85	70	55	85	75	60	90	75	50

Table 1: Interference of trucks on readability

Legibility: Several studies have shown that VMS impose higher attention demands on drivers than fixed signs. (Erke et al., 2007). The type of message i.e. regulatory, warning or guidance should be clearly recognisable from a distance of at least 200 m;

- Essential messages, such as speed limit value or other legend must be clearly legible from a distance of at least 150 m;
- The system should be designed so that the sign is visible from a distance as close as 35 m, even when approached from a wide angle of vision.

Critical detail must be legible, and this is called the legibility distance L_d. Using the minimum angle of resolution for the human eye shows a legibility distance for 90% of people with normal vision of 1/0.290 = 3.4 m for every millimetre of detailed dimension.

$$\frac{W}{D} = 0.00029 \qquad \textbf{Eq. (1)}$$

or

$$D \leq 3500W \qquad \textbf{Eq. (2)}$$

or

$$L_d = 3500W \qquad \textbf{Eq. (3)}$$

Where W is the stroke width, D is the observation distance, and consistent units are used.

The associated legibility distance is 1/0.00175 = 600 mm for every millimetre of letter height, H. For capital L_d in metres and H in millimetres for the more common lowercase letters, this becomes:

$$L_d = 0.6H_{opt} \qquad \textbf{Eq. (4)}$$

Many design codes conservatively take $^{2}/_{3}$ of this value, i.e**. 0.4*H*$_{opt}$**. This means that many road users can recognise a word without distinguishing every detail of each letter in the word. This is particular so for familiar messages. The Southern African Road Traffic Signs Manual (Bain, 2005), which is based on research from a number of different countries, has found the a legibility factor of 0.5 m/mm. This means that a driver with a visual acuity of 1.14 (85% of the South African driver population) can read a 100 mm high lowercase letter at a distance of 50 m. The legibility distance at which the sign is deemed to become legible can thus be determined once a letter size is chosen

Detecting whole words: The effective legibility distance is the distance at which the intended message can be read, and this is not always dependent on the details of each individual letter seen because legibility is also a function of the shape of the word or symbol and familiarity to the reader. This legibility distance is much greater than would be predicted from knowledge of the/widths of the letters and a driver's visual acuity. This effect is more pronounced if upper-case (i.e. capital) letters are avoided and lowercase letters are used wherever possible. This is because the lowercase letters give words, a varying contour, whereas uppercase words are all in a rectangular shape. Although common experience and research (Mitchell, 2010) suggests that **MESSAGES SOLELY IN UPPERCASE LETTERS ARE MUCH HARDER TO READ QUICKLY,** it is surprising how alarm and emergency messages on VMS messages use uppercase letters, presumably to highlight the perceived importance of the message. Mitchell (2010), compared the distance from which drivers could read signs containing place names that were printed in uppercase and mixed-case text. In the recognition task, drivers were told what word they were looking for and were asked to indicate the moment when they recognised the word on a sign. In the legibility test, drivers were asked simply to read a word as soon as they were able. In the legibility test, there was no significant difference in reading time between mixed case and uppercase for text of the same size. In the recognition task, however, the 'same-sized mixed-case fonts performed significantly better than the all-uppercase' (p.10). ***It is highly recommended to use capitals only on the main information words with the remainder being lower case.***

Glance Legibility: This relates to reading the sign during brief periods of exposure. The reading time available to the driver will restrict the complexity and the length of the message. In a single glance, the driver can read about one new word, between 6 to 8 characters. The number of words, N that can be read during a longer period, T is given approximately by:

$$T = (0.32N - 0.2)\,s \qquad \textbf{Eq. (5)}$$

This translates to about three words per second, which is consistent with research findings (Castro and Horberry, 2005). However, from a practical perspective familiarity of a message content assumes that two additional words can be read, bringing it to five words per second. Many design codes assume:

$$T = (0.25N)\,s \qquad \textbf{Eq. (6)}$$

Short-term memory can retain about seven words or chunks of information. Therefore, a vehicle travelling a constant speed of *v* km/h over time *T* seconds is *vT/3.6*, the distance travelled, while *N* words are read is *Nv/14.4* m. the glance legibility distance must occur when the reading commences and so the sign placement distance, L_p, ahead of this point and provides the following equation:

$$\boldsymbol{Ld = 0.6\,H_{opt} = \frac{Nv}{14}.4 + Lp} \quad \textbf{Eq. (7)}$$

or

$$\boldsymbol{H = 0.12Nv + 1.7L_p} \quad \textbf{Eq. (8)}$$

This equation appears in many design manuals to determine sign placement. However, other factors such as road geometry, lateral or vertical offset, traffic congestion, environmental clutter, size of the display, complex traffic manoeuvres, etc. will influence this distance.

Eye movement studies indicate that during highway driving, drivers make frequent brief glances – on the order of 3 glances per second (330 ms), within a narrowly constrained area, suggesting that driving is a visually demanding task. Signs are generally glanced at more than once. Long fixations are avoided because drivers are reluctant to go for more than two seconds without checking the road.

Message length: Dudek and Ullman (2004) described message load as the units of information in the total message. A **unit of information (informational unit)** refers to the **answer to a question a motorist might ask**. Stated another way, a unit of information is each data item in a message that a motorist could use to make a decision. Each answer is one unit of information. (Table 2)

Unit of Information		
Question	***Answer***	***Unit of Info***
1. What happened?	**ACCIDENT**	**1 unit**
2. Where?	**SH1 NB**	**1 unit**
3. Who is advisory for?	**FANSHAW**	**1 unit**
4. What is advised?	**USE SH16**	**1 unit**

Table 2: Illustration of a unit of information

A unit of information typically is one to three words, but at times can be up to four words. Since motorists can process a limited amount of information, the amount of information that should be displayed on a VMS is also limited. Research and operational experience indicate that no more than four units of information should be in a message when the traffic operating speeds are 50 km/h or more. No more than five units of information should be displayed when the operating speeds are less than 50 km/h. In addition, no more than three units of information should be displayed in a one message phase.

Determination of the reading time required (t) for a sign and the reading time available (T) has been researched in a number of countries with wide-ranging results. The reading time required (**Eq. (9)**) is based on that derived by Australian researchers, but this was under laboratory conditions, devoid of the normal distractions pertaining when driving on busy roads. Based on South African research and experience the formula has been adapted by **the addition of Distraction Factor D** and which now forms the basis of guidance sign design in the South African Road Traffic Signs Manual since c1997. (Bain, 2005)

A useful tool for considering what a reasonable amount of information for a billboard is provided by the South African National Roads Agency Limited. (Coetzee, 2003) These regulations limit the message length of billboard advertisements as measured in bits of information using the criteria presented in Table 3.

Content	Bits
Words up to 8 letters	1
Words > 8 letters	2
Numbers to 4 digits	0.5
Numbers 5 – 8 digits	1
Symbol/Abbreviation	0.5
Logo/graphics	2

Table 3: Bit values of information on signs (Bain, 2005)

The bit limits were established based on reading time, which SANRAL wanted to keep low so that drivers would have time to react to events ahead of them. SANRAL uses the following formula to determine road sign reading time:

$$\boldsymbol{T = (0.32N - 0.2)D} \quad \textbf{Eq. (9)}$$

T = Reading time
N = Bits on signs
D = Distraction Factor
D = 1.00 straight roads, less than 5000 vpd (vehicles per day)
D = 1.25 straight roads with 5000 – 30,000 vpd
D = 1.50 freeways, roads in urban areas, more than 30,000 vpd

Bain (2005) noted that it was generally accepted that drivers' attention should not be diverted from their primary task of safe vehicle control for periods much in excess of 1.50 seconds. In order therefore to read a sign requiring 3 or more seconds, drivers will normally have to read such a sign with two or more eye movements. In between these sign reading eye movements the driver's eye should return to check the vehicle movement in relation to the roadway and other traffic. The checking eye movements are likely to last at least 1.0 seconds each time. The overall time that a sign should be available for reading (T) therefore needs to be increased over the reading time required (t) based on the amount of information on the sign face. **As a general rule, it could be argued that the reading time required should be increased by up to 1.0 seconds for every 1.5 seconds of reading time required by the message. This factor should particularly be borne in mind when considering signs with over 6 "bits" of information**, and also when sign reading times and/or driver reactions, in order to exit or turn, are under pressure from other factors such as the high risk of signs being obscured by traffic or a difficulty in finding gaps in traffic in order to make lane changing manoeuvres. **Eq. (9)** is modified to become;

$$\boldsymbol{T = \left\{(0.32N - 0.2)D + \frac{(0.32N - 0.2)D}{1.5}\right\}} \quad \textbf{Eq. (10)}$$

CONCLUSIONS

- Urban environments are more complex in nature particularly when congested due to conflicting vehicle movements, the presence of pedestrians, cyclists not found on motorways. There is more clutter from other signage that increases driver workload.
- Road links between intersections are shorter and hence there is less opportunity for placing a VMS in adequate advance positions for drivers to read, comprehend, react and manoeuvre a vehicle particularly if the message is complex.
- Delays at signals due to queues and the presence of heavy vehicles erode the memory of the driver, and hence long and unfamiliar messages will have a lower comprehension rate.

- The design of the VMS font and layout compared to static signs increase comprehension times.
- The use of capital letters requires longer reading times that similar information load static sign.
- The general information unit used to evaluate message lengths and required reading time does not allow for urban complexity when compared to the information bit with distracting factor used in Equation 10.

RECOMMENDATIONS

- For urban sites the degree of environmental clutter and other signage distraction should be analysed and a suitable distraction factor (D) determined.
- The available reading time and distance to manoeuvre should be analysed in terms of messages likely to be displayed.
- Typical longer messages for each site, particularly those that route change decisions are made at, should be should be evaluated using **Eq. (10)** to determine whether the available reading time is adequate for message comprehension requiring an immediate action by drivers.

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