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Application of Light Emitting Variable Messages Signs to Convey Information to Motorists on High Speed Highways

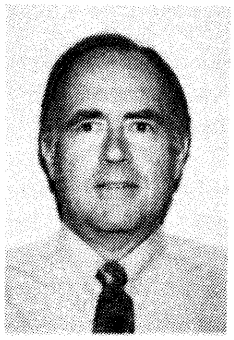
David R. Aylward and Terry J. Valentine

ABSTRACT

This paper has been prepared to show that an appreciation of the factors involved in the correct design and implementation of Variable Message Sign (VMS) technology will enhance the delivery of critical information to the motorist.

The message content and context are critical to the credibility of the information displayed on a sign when presented to a driver in abnormal or emergency situations. For a driver to reliably read and comprehend information presented on a variable message sign in these situations the message content, context, positioning and optical performance of the sign are critical.

Message comprehension as it relates to the use of symbols, sign position, relevance of the information, how the information can be communicated for mandatory and advisory signs are covered. Design considerations such as the half angle, contrast ratio, pixel spacing, multi-stroke characters, irradiance, control of intensity to compliment ambient light levels, colour selection as it relates to atmospheric conditions and visual acuity, road geometry (horizontal and vertical alignment), the relative position of the sun to account for the effects of backlight, washout (veiling glare) along with the effects of background confusion are all discussed.



David Aylward, B.E.(Elect.)(Hons), MIRSE, Dip.CM
Managing Director, Stratford Traffic Pty Ltd

David Aylward formed the Melbourne based Stratford Traffic Pty Ltd in May 1991 to initially supply and distribute traffic survey equipment. David's professional career in telecommunications and railway signalling have facilitated the expansion of Stratford into specialist projects for Intelligent Transport Systems. The company specialises in systems engineering, for traffic data capture, information processing and display systems. Projects to date include the F6 Tollway Fog Warning System and implementing the Sydney M4 Incident Management system. Stratford Traffic undertake feasibility studies, project definition studies and specification preparation, in addition to total turnkey solutions.

David holds a Bachelor of Engineering (with First Class Honours) obtained from Canterbury University (New Zealand). He has spent many years working for multinational companies in senior engineering and marketing management positions in New Zealand, England and Australia prior to establishing Stratford Traffic in 1991.

Terry Valentine, B.E.(Civil), MIEAust., CP Eng., MBA
Marketing Manager, Stratford Traffic Pty Ltd

Terry Valentine joined Stratford Traffic in September 1992 where he became responsible for the marketing of Stratford Traffic's products and services. After extensive customer contact he quickly identified the high level of customer support required for the distribution of traffic data collection equipment. This led to the production of the training video 'Traffic Survey Technology' (1994) now used by many of the universities across Australia.

Terry's undergraduate study in civil engineering was followed by ten years experience in local government and project management within the heavy construction industry. This experience spanned across Australia and internationally. Terry then completed his Masters of Business Administration (majoring in marketing) at Monash University which led him to his present position.

INTRODUCTION

1. This paper addresses the factors to be considered in how to communicate critical information to drivers on high speed roadways in less than ideal driving conditions. In particular it looks at the placement of the sign to display the message, what the message should contain, how it is to be presented and how the driver can safely follow the content of the message. It considers this in the context of high visibility Variable and Changeable Message Signs (VMS and CMS).

2. We will discuss some of the more fundamental technical considerations such as the contrast ratio, colour, effects of irradiation on visibility, layout and the sign positioning with respect to the driver environment.

COMMUNICATION OF INFORMATION TO THE ROAD USER

3. The purpose of a sign is to encourage the motorist to react to a message in a controlled and predictable fashion. VMS are used when the message to be communicated varies, such as in abnormal or emergency situations. For a driver to reliably read, comprehend and predictably act upon information presented in such situations, the message content, context, layout, credibility and location, along with the optical performance of the sign are critical.

MESSAGE COMPREHENSION

4. Messages are often displayed when there is an abnormal or emergency situation either existing or about to happen in the nearby environment. This means that it is critical that the driver not only understands the message, but believes the content of the message, so that a given course of action can and will be carried out safely and effectively. Graphical symbols can often be used to supplement text to convey the necessary information. Where a symbol (or symbols) are used however, they need to be clear and unambiguous.

5. The context in which the message is given is very important. The message has to relate to the location, environment and most importantly to the situation which the driver is experiencing at the time that the message is presented, to be credible.

6. The substance of the message needs to be relevant, to be in a form which the driver can reach the desired conclusion in the reaction time available. The interpretation of a message can be affected by the background and experience of the driver. Hence the text needs to be derived from common words, words which are of low complexity and which provide a short and succinct message.

SYMBOLS

7. The use of internationally accepted symbols alone or in conjunction with variable text signs can enhance the power of the message and hence the way in which it is perceived by the driver. If the symbol is clear and unambiguous for the situation then it will act as positive reinforcement of the text. Complex symbols and those not clearly identifiable with the situation may be ignored or worse still, misinterpreted. International standard (accepted) symbols and formats also assist business travellers, tourists and helps to overcome language barriers where an ethnic mix exists and multiple languages are used.

8. Clarity of a symbol needs to be carefully assessed. Designers need to take into account that VMS displays are made up of a matrix of discrete pixels and not of a relatively continuous form as may be displayed on a computer screen or on a painted sign board.

9. International symbols are normally associated with fixed sign locations where a driver will see the same sign regularly. Unless some form of differentiation is used such as flashing, colour change or movement the symbol image will not necessarily be associated with a degree of urgency.

POSITIONING

10. The sign needs to be located at a position where the message has some relationship to the situation and is therefore perceived by the driver to have relevance. This needs to be balanced against the need for the sign position to be chosen so as to allow the driver to safely obey the directive of the message. Thus the factors affecting the sign location include the cognitive requirement and the contextual requirement in order that the message has the optimum impact.

11. The viewing time that the driver has of the VMS will affect the recognition of the information. Hence the speed with which the driver is travelling and the distance over which the message can be recognised are factors to be considered in the sign placement. Too far from the action point however and the content of the sign will lose immediacy; too close and it may not be possible to obey the instruction safely.

12. The position of the sign is important to ensure that the driver is not only aware of the sign but that it is within the primary area of concentration as opposed to the peripheral vision of the driver. This is particularly important when the driver is under stress as a result of abnormal situations or adverse driving conditions (for example when driving into the sun or especially in heavy traffic).

13. The sign needs to stand out from the surroundings but at the same time it is not to dominate the viewer to the point where the message saturates the viewers attention. If a sign, set with high illumination levels was placed in a country environment on a dark night with no surrounding lights, the intensity would be excessive and the driver may lose contact with the surroundings. Careful setting

of illumination levels is therefore required with maximum contrast with the immediate surrounding of the characters as well as the intensity of the surrounding environment to be considered.

RELEVANCE OF INFORMATION

14. For the sign to have maximum impact it should only have information displayed when there is something for the driver to see and to take note of. This means that the sign should not be used to display "advertising" messages, such as road safety notices, and trivial non-messages. However it is important that the driver retains confidence that the sign is still alive, hence the need to display a small number of pixels to convince the viewer that the sign is capable of displaying a message when the time arises.

15. Signs can show both advisory as well as mandatory messages to the driver. It is important that the driver has the information to distinguish between these two categories of information. Mandatory signs are an instruction that must be obeyed and as a result need to always assume the highest level of importance to the driver. The advisory sign which provides information to allow a driver to make an informed decision, have a lower importance to the driver.

16. Ideally the two types of messages should be on different signs and at locations which emphasise the relative importance to the viewer. It is not advisable to display both types of message on the same sign unless there is a mechanism to create a conspicuous difference between the two messages in the viewers perception.

INFORMATION TO BE COMMUNICATED

17. In order to communicate the desired information to the driver it is necessary to carefully select the information to be presented and to clearly define the format. To make the information assume a level of importance commensurate with the value of the information to the driver it needs to be differentiated from surrounding sources vying for attention. This may be achieved by colour, size, change of appearance (e.g. flashing, alternating) or possibly position on the sign face.

18. The information on the mandatory signs needs to be a positive instruction and to remove or restrict the level of choice available to the driver, i.e.:

TAKE NEXT EXIT
NO ENTRY
LANE CLOSED
USE LEFT LANE
SPEED LIMIT 80 KPH

19. These messages can be modified to include some explanation without significantly degrading the strength of the message, i.e.:

MOTORWAY CLOSED, TAKE NEXT EXIT
NO ENTRY, MOTORWAY CLOSED
ACCIDENT AHEAD, LANE CLOSED
ACCIDENT AHEAD, USE LEFT LANE

20. In multi-lane situations it may be necessary to provide additional, or alternative, symbolic messages to guide the driver to the desired lane. The use of flashing diagonal arrows to point to the open lane is a case in point.

ADAPTIVE SPEED SIGNS

21. Mandatory adaptive (or variable) speed signs are used to change the legal maximum speed over sections of motorway to smooth traffic flow and to reduce approach speeds to congested sections. These signs can be adjacent to the edge of the road when all lanes are to assume a common speed. Spatial interlocking between signs on adjacent lanes and between adjacent sign sites is used to ensure that the speed changes are not unreasonable between successive locations and that they cannot lead to unsafe driving conditions.

22. Where the speed per lane is to be individually set the signs can be installed above each lane. This introduces additional complexity in the spatial interlocking of the signs to ensure that unsafe speed differentials cannot be set up and that the information presented to the driver is clearly unique to that lane. The speed differentials between lanes and between indicators on the particular lane need to be carefully considered to ensure that the driver can understand and has time to react in a safe manner to any changes in set speeds. In particular the driver response during the transition of the display information from one state to the next needs to be understood and taken into account when setting up the sign environment. With the current performance of speed measuring systems it is possible to set up enforcement grade detection systems. This will have an effect on the driver behaviour if they believe that they can be detected if they do not obey the mandatory speed signs.

ADVISORY SIGNS

23. Advisory messages are to inform the motorist about conditions ahead and to allow some judgement on their behalf about possible alternatives. Thus advisory messages are often well in advance of the incident and allow the motorist a choice about continuing the planned journey or taking an alternative route or even abandoning the journey altogether.

24. The advisory messages can be of the form:

CONGESTION AHEAD

ACCIDENT AHEAD
ROAD CLOSED AHEAD
MOTORWAY CLEAR

25. Additional information can be supplied as

CONGESTION NEXT 5 KM
ACCIDENT AT JUNCTION 5
JUNCTION 5 CLOSED
MOTORWAY CLOSED AT CUMBERLAND

26. This additional information allows the motorist to make a choice about where to leave and where to return to the motorway.

27. In the case of the Driver Fog Warning System on the F6 Tollway New South Wales, Australia the individual vehicle speed is measured and a message related to a specific vehicle is generated from the speed of the preceding vehicle, the vehicle to which the message will be directed and the absolute visibility at the site. Although this is an advisory message it is directed at a specific vehicle by the use of flashing lane indicator arrows, and by the timing of when the message is presented to the driver. The intention in this case is to modify driver behaviour to more closely match the current driving environment.

MISINTERPRETATION

28. The misinterpretation of a message can have serious consequences for not only the driver but also for other road users. That is the comprehension capacity of a range of drivers can vary considerably depending upon experience, ethnic background, age, skill level and the environment which can all contribute to the misinterpretation of information.

29. It is therefore important to use only common words or terms as well as standard symbols that are preferably internationally accepted.

RESTORATION OF NORMAL CONDITIONS

30. When the problem, danger, abnormality has cleared or is no longer relevant to the situation the driver must be made aware of the return to normal conditions as soon as possible. This is necessary to maintain the credibility of the messaging system. If the sign displays information about a event which no longer exists, then the driver will accumulate a view that the signs are not to be trusted, and as a result when a real event is present the driver may not react quickly or appropriately. The detection of the abnormal situation then needs to be considered for accuracy and for the level of false alarms that can tolerated by the viewers.

COMMUNICATION OF INFORMATION

31. The information must be within the drivers field of understanding and the conclusions must relate to the context of the drivers experience. Careful selection and vetting of messages for mandatory and advisory signs is very important. The creation of free form messages can therefore be dangerous for critical situations. The designer needs to decide message intent and to understand the consequences of misinterpretation.

SIGN SELECTION PARAMETERS

PURPOSE OF THE SIGN

32. As previously discussed the purpose of a sign is to encourage the motorist to react to a message in a controlled and predictable fashion. We have discussed what may effect the drivers comprehension, the need to consider the position, the need for relevance, the forms in which the information may be communicated, the importance that the driver will place on the information provided, factors which may lead to misinterpretation and the need to ensure the messages are credible.

33. We will now focus our attention on some of the more technical considerations associated with the decision to use CMS or VMS technology, define some of the commonly used terms, layout requirements and how these considerations relate to the effectiveness of VMS's.

34. The choice of signage technology is usually the first thing that is to be decided and *Table 1* below serves as an initial guide

TABLE 1

The choice of signage technology

Driver Impact Messages	Low	Medium	High
1 Message Continual Display	Static Display ← →		
1 Message Occasional Use	Static Display	Mechanical	(High Performance) Light Emitting
2-3 Messages	trivision or (Low performance) Light Emitting		Changeable Message (High Performance) Light Emitting
4 + Messages	Variable (Low performance)	Variable (High performance)	

35. It must be noted that the cost of the signs as shown in the above table rise steeply from the top left hand corner to the bottom right hand corner. It is therefore important to be aware that specification of higher technology solution comes at a cost which invariably has to be justified.

36. In this paper we are focusing on high performance VMS and CMS and will not discuss the other options further. It is important however to note that there are other options available to full VMS technology.

LOCATION

37. While the sign position has been discussed that will facilitate the driver reacting in the desired manner various factors may affect the signs performance at a specified location.

Emitter Half Angle

38. The emitted half angle is frequently used when VMS signage is discussed. As fibre optic signs are highly directional the intensity or brightness created by the emitters drops off quickly at the half angle of the lenses used. The half angle is commonly defined as "the angle at which the intensity of the light is half of that when viewed from directly in line with the emitter". A typical graph of the intensity vs. the viewing angle as it relates to the Half angle is shown in *Figure 1* below.

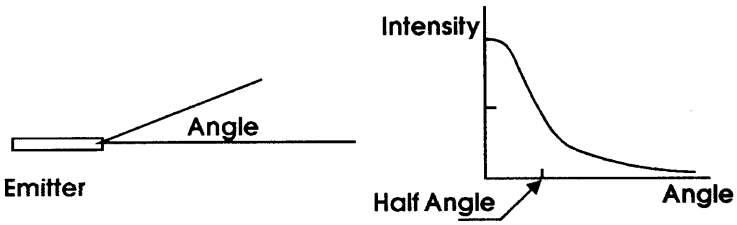


Fig. 1 - Half angle - Intensity vs. Viewing Angle

39. This has important implications with the type of sign that is specified (in so far as its half angle) for a given application.

40. If we consider a sign optimised for a high speed environment (i.e. 6° lens) then at close proximity the motorist will not be able to read the entire sign as the *Figure 2* below illustrates.

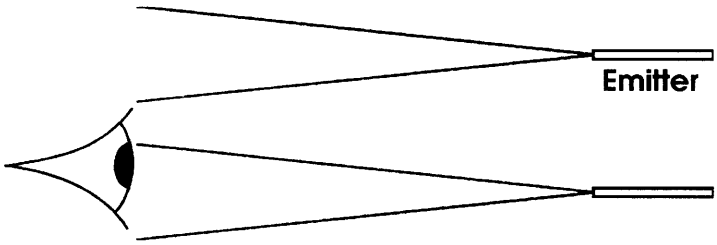


Fig. 2 - View of sign at close proximity

41. Where the driver needs to see the sign in close proximity such as in slow speed city traffic, such as for overhead lane indicators or turn symbols at the side of the road, a 15° angle or greater is used as shown on *Figure 3* below.

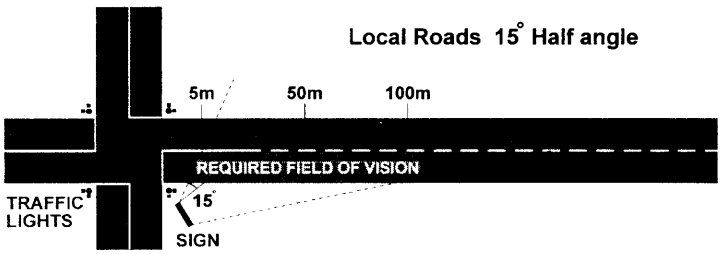


Fig. 3 - 15 Degree half angle application

42. In a high speed environment a narrow lens (using fibre optic technology) is appropriate due to the greater distances involved as shown on *Figure 4* below.

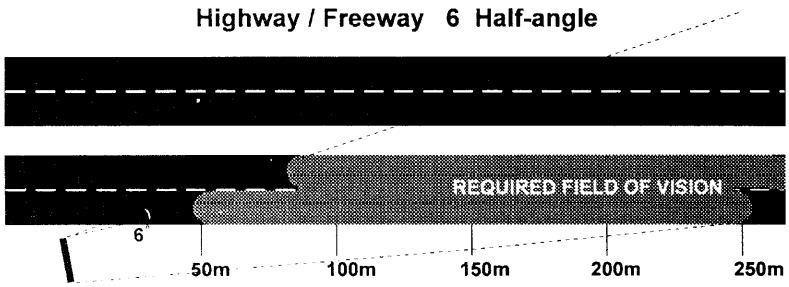


Fig. 4 - 6 Degree half angle application

43. If the light output from either the 15° lens or the 6° lens (of the same diameter) is the same then from a given distance the 15° lens will have a lower intensity as its light is spread over the wider area.

Contrast Ratio (Light Intensity)

44. The contrast ratio is defined as $\Delta L/L$ which in the case of a light emitting sign is $(L_{pixel} - L_{bgrnd})/ L_{bgrnd}$ where L_{pixel} is the luminance of the pixel (the light emitted) and L_{bgrnd} is the luminance (actually the light reflected) of the background. "The 50% correct legibility occurs at a contrast of 3. The legibility continues to improve with contrast until it levels off at a contrast of about 8 - 20" (Jenkins 1991).

45. It should be noted that the contrast ratio can be affected by either reducing the background light (reflected) as well as by increasing the intensity of the pixels. The amount of reflected light can be significant and is discussed in the section below on washout. Increasing the intensity is also an important consideration in several circumstances and is particularly relevant in backlight conditions as discussed below.

Pixel Spacing

46. The amount of light (energy) per unit area (flux) produced by two different emitters may vary. As the pupil of the eye only takes in the light energy that is directed toward it, this intensity of this energy affects the distance at which the light can be comfortably read.

47. A limit exists as to when the eye can distinguish individual pixels or sources of light. This can be determined by a formula which is termed the "Rayleigh Criterion" (Tippler 1982) which can illustrated for the specific application as shown in *figure 5* below.

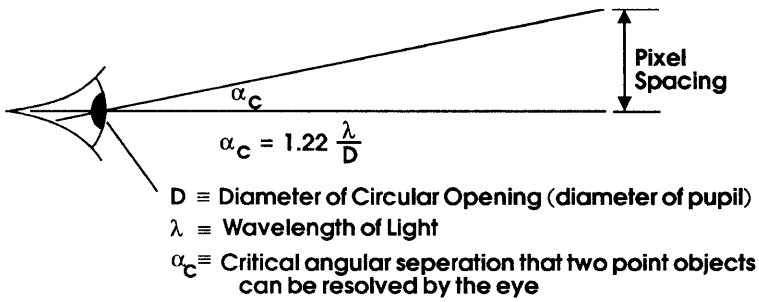


Fig. 5 - Rayleigh Criterion

48. While it should be noted that while it is not necessary for the eye to distinguish between every individual pixel the resolution must be such that it can resolve between the individual pixels on the opposite sides of a given letter.

Single vs. Multistroke Characters

49. The brightness vs. resolution often appears to be more pronounced as the width of the character is increased by the use of multistroke character formations. In this situation the legibility can be shown to be sensitive to the brightness variations caused by the extra width of the double stroke. At a distance, "a point is reached where both lines have the same apparent width." Rubin (1972) In a single stroke character it is not the actual size (stroke width) of the light emitting point that is the critical determinant, rather it is the brightness of the light emitting point.

50. The brightness of a character can affect the way in which the eye resolves the nature of the character. The resolvability of the lines making up the character is related to the visual acuity of the viewer. This changes with the intensity and the relative brightness of the line and goes through an optimum brightness level. Beyond the optimum point the irradiation caused in the interspace in the retinal cavity being "filled with light" Rubin (1972) causing a rapid decrease in the perceived contrast ratio. This reduction in contrast reduces the ability of the viewer to resolve the identity of the character. This is often observed when lane indicator signs are not reduced in brightness at night, the effect being to show the arrow as an indistinguishable blob, recognisable only by previous association with the colour or position rather than the content.

51. Tests have been conducted on the various technologies such as those by Jenkins (1991) and Upchurch et al (1991) to establish the comfortable viewing distance. The Upchurch et al (1991) report focused upon differing technologies that were in use at that time while the Jenkins (1991) report focused upon field trials and sought also to establish optimal pixel separations. Manufacturers that base their business around servicing the road traffic industry have usually performed similar tests either independently or in conjunction with Road Authorities. They will usually assist the potential client by providing details of such tests and assist with optimal layouts for their system.

52. While we do not intend to elaborate further, it is important to note that there is a minimum distance as well as a maximum distance from which a given type of sign can be read. This is influenced by the intensity of the light (at the source of emission), the angle at which the light is emitted (which dictates the intensity at a distance), the pixel spacing, and effects of atmospheric conditions (fog).

Atmospheric conditions

53. Fog is a major problem on some motorways and therefore requires close consideration. White light from the sun is scattered in fog to such a degree that that it can become difficult to ascertain from which direction it originates. Airline pilots often rely on instrumentation to determine which way is up. White light is scattered due to the different wavelengths refracting to a greater or lesser extent as they hit the denser medium (the water droplets). After emerging from the droplets they will be diffused extensively.

54. A monochromatic light (in particular yellow of around 578 nm wave length) has several advantages over other colours which allow it to penetrate such adverse conditions.

55. A monochromatic light will refract at a set rate as it enters and exits the denser medium (i.e. the water droplets). This means that while a displacement may occur the light will continue in the same direction. While this has advantages it does not mean that the light from different pixels (or even the same pixel) will all have a uniform displacement as the fog is not uniform and the various waves will encounter different amounts of fog.

56. "The Bezold-Brücke phenomenon refers to the fact that only three hues associated with spectral wavelengths appear the same when luminance is changed. ..... They are blue of about 478 nm, a green of about 503 nm, and a yellow of about 578 nm." (Pokorny and Smith 1972) This means that regardless of the intensity of the message on the sign it will still be seen as yellow.

57. Wavelength discrimination refers to the "difference at which an observer reports a hue difference .....Relative minima occur in the yellow (590 nm), blue green (490 nm)" (Pokorny and Smith 1972). This means that the yellow light (and blue green) is more likely to be identified from other surrounding light sources of similar colour.

58. Saturation refers to the change in hue that occurs when white light (present in the fog) mixes with a spectral wavelength. In the case of a "green associated with 530 nm will appear yellower when white is added to the 530-nm stimulus. There is one exception in the spectral region: a yellow of 570 nm appears invariant with change in saturation." (Pokorny and Smith 1972). This means that unlike a red which will turn to pink then white upon increasing saturation, the yellow will remain yellow through the saturation caused by the fog. This does not however mean that the yellow emitters will always be seen as the amount of white light and the distances involved need to be considered.

59. As described above a monochromatic yellow of around 578 nm has distinct advantages in that it will refract evenly, its colour is not affected by the intensity at which it is emitted, its colour is most easily discriminated from similar colours and, it retains its colour in a saturated environment.

ROAD GEOMETRY CONSIDERATIONS

60. The road geometry must be carefully considered in positioning a sign to allow the motorist satisfactory viewing time within his / her field of vision. Where possible the sign alignment should be such that the driver is aware of the presence of the sign in the direct line of sight and not in their peripheral vision. High vehicles in adjacent lanes need also to be considered in relation to the road geometry and the position of the driver.

Horizontal alignment

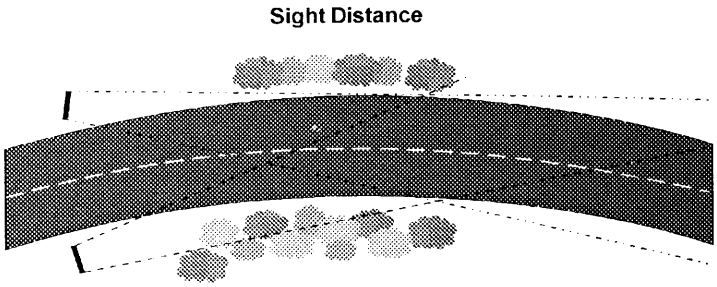


Fig 6 - Horizontal Alignment

61. VMS's may need to be placed on gantries over the center of the road or to the left or right of the road depending on the curvature existing at the selected point. As can be seen in the *figure 6* above a simple scale drawing may show if the drivers vision is affected by a horizontal curve.

Vertical Alignment

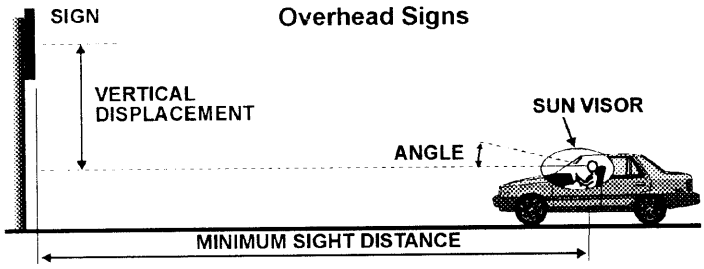


Fig 7 - Overhead Signs

62. As can be seen in *figure 7* above it is important that it is not only important that the optical axis is within motorists vision but this is not obstructed by the sun visor which will usually be down low when driving into the sun.

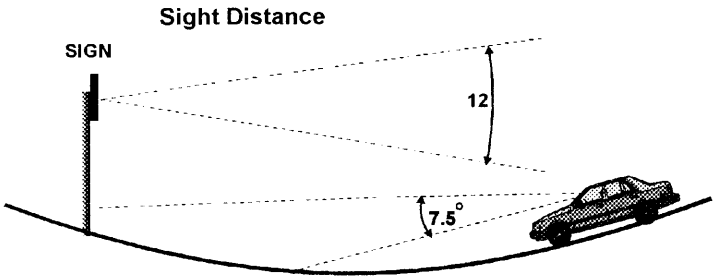


Fig 8 - Vertical Alignment

63. The vertical alignment of the road as shown in *figure 8* above will also have an impact on the motorists view of the road. The optical axis of the emitters (and therefore the angle that the sign face is tilted) must be carefully considered to ensure the minimum and maximum site distances are within acceptable limits.

Backlight

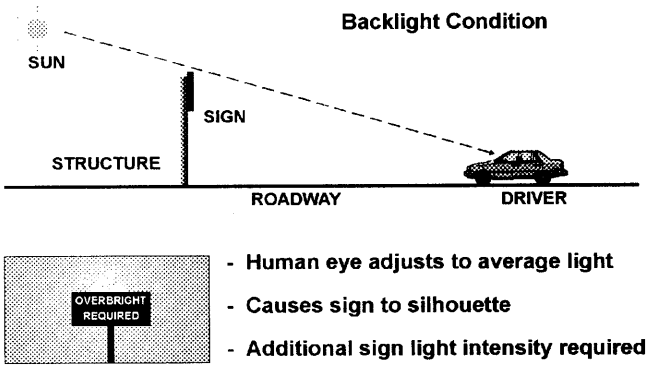


Fig 9 - Backlight Condition

64. Backlight as illustrated in *figure 9* above, refers to the condition where the sign becomes a silhouette due to the position of the sun behind the sign. This normally occurs in the morning or evening. The eye adjusts its aperture to accommodate the high ambient light intensity. This causes the eye to become "Light Adapted" and to only be able to "see" the characters if they are above the new threshold level. This means that the light output emitted needs to be more closely matched to the surrounding ambient light levels. This is often achieved by the "overbright" mode where more than one lamp is used to illuminate a fibre bundle.

65. The light being emitted from the sign entering the pupil becomes relatively less due to the pupils smaller diameter. A high performance sign (suitable for the high speed environment) therefore requires the ability to increase the amount of light it emits (the intensity) to maintain its contrast ratio to suit these non ideal conditions. A perimeter border also assists by isolating the sign message from the high intensity background surrounding the sign.

Washout

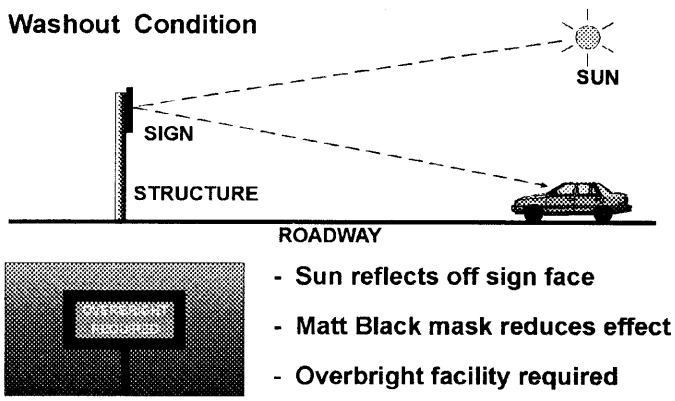


Fig 10 - Washout Condition

66. Washout (sometimes referred to as veiling glare) refers to the condition where light (usually from the sun) is reflected off the face of the sign toward the driver as illustrated in *figure 10* above. Should the face of the sign be constructed from glass or Polycarbonate then a large flat area can exist. In the case of a fibre optic system where the light emitters are small relative to the area of the face and hence the sign can be designed so that only the emitters are exposed or a mask applied over the face. Other types of technology such as a flip disc due to the size of the emitter may not have this option and require other alternatives to meet the performance objectives. When washout conditions occur the effects on the eye is similar to that when Backlight conditions occur. In these conditions increasing the light output from the emitters to ensure the contrast is maintained (between the light emitted and that coming from the face of the sign) needs assessment

Background Confusion

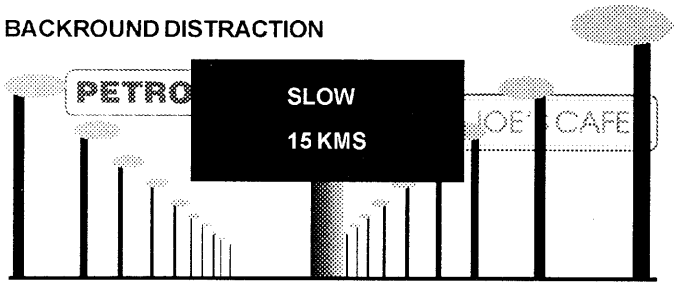


Fig 11 - Background Confusion

67. As distinct from backlight the problem of other lights blending into the VMS message must be considered as illustrated in *figure 11* above. Careful site selection to minimise these effects is advisable. A perimeter border assists by creating a physical barrier between the VMS message other messages or surrounding lights. This principle is commonly used in the treatment of traffic signals.

68. While we have discussed many of the functional requirements and geometric factors that will influence the positioning of a VMS. Some of the other considerations that influence the performance of a VMS system will be touched upon.

Sun Phantom

69. Sun phantom is caused by the sun being reflected off an optical emitter (or reflector) and giving the impression that the light source is on. While this effect should be considered, most VMS technology available have methods of either eliminating or minimising these effects.

Display Change Time

70. When multiple messages are displayed the time taken to change a screen display should be considered to ensure sufficient viewing time exists for both messages regardless of when the driver enters the zone of visibility. The eye however, is able to register the presence of a new message "within 100 mSec" (Newman 1972), so the time delay is more in the recognition of the content rather than the presence of the new message. Message duration has been investigated by Jenkins (1991).

Moving messages (fades wipes and veils)

71. Fades, wipes or veils have no place in a high speed motorway environment. The primary consideration is the time taken to change screens. Screen changes using these techniques potentially make the sign central to the motorists vision (and the traffic secondary). It is usually not the desired outcome to distract the driver who cannot comprehend either message for the time period that the screens are changing.

Communications with the sign

72. For mandatory and advisory signs it can have serious safety implications if a message inappropriate to the situation is displayed. The communications to a sign therefore needs to be carefully designed and implemented to ensure that the message relevance and integrity is maintained at all times. This may need the introduction of communications diversity or some form of backup circuits to maintain the desired level of availability. Fall back and message cancellation procedures need to also be considered in the event of loss of communications.

Power failure contingency planning

73. Once the purpose of the sign is established this will dictate its importance. If the sign is important (essential) then it will remain important particularly in adverse conditions, such as sunrise and sunset when effects such as backlight exist. In such cases alternate mains power supply or generation capacity to provide full backup power may be required. If the display is not essential then battery backup to maintain the communications and equipment settings may be all that is required.

Maintenance

74. Maintenance requirements should be considered from the beginning as should protection from vandalism. Access to the control equipment, lamps and modular design of the componentry for ease of replacement all need to be considered.

CONCLUSION

75. This paper covers many of the factors that must be considered in the implementation of VMS and CMS technology. The more salient issues include accuracy and relevance of information, clarity of messages and symbols, positioning of the sign, visibility and legibility of the sign, atmospheric conditions, road geometry, the effect of the suns position, communications and maintainability.

76. The paper has been prepared to show that an appreciation of the factors involved in the correct design and implementation of VMS technology will enhance the delivery of critical information to the motorist.

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