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VARIABLE MESSAGE SIGNS

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VARIABLE MESSAGE SIGNS

Summary

This technical report draws together research findings and practical experience of the visual performance of variable message signs which might affect their use in road traffic management. Variable message signs are divided into three categories of light emitting, light reflecting and hybrid signs. The qualities of the observer and the sign which might affect the sign's performance are discussed together with practical issues concerned with the installation of the sign. Light emitting signs and light reflecting signs are then discussed in detail and some views are presented as to how the visual performance of the signs can be maximised.

PANNEAUX DE SIGNALISATION A MESSAGES VARIABLES

Resumé

Ce rapport technique présente les résultats de recherche et d'expérience sur l'efficacité visuelle des panneaux à messages variables : il indique également ce que ces résultats peuvent impliquer quant à leur usage pour la gestion de la circulation routière. Le rapport distingue trois catégories de panneaux à message variable, soit par émission de lumière, soit par réflexion de lumière ou soit par un système mixte. Les caractéristiques de l'observateur, et des panneaux, qui pourraient influencer l'efficacité de la signalisation, sont envisagés en parallèle avec les problèmes pratiques liés à l'installation. Les panneaux fonctionnant par émission de lumière, ainsi que ceux qui fonctionnent par réflexion de lumière, sont ensuite envisagés dans le détail, et enfin, des perspectives sur la maximisation de l'efficacité visuelle des signaux sont présentés.

WECHSELVERKEHRSZEICHEN

Zusammenfassung

Dieser technische Bericht faßt die wissenschaftlichen Ergebnisse und praktischen Erfahrungen der visuellen Leistung von Wechselverkehrszeichen zusammen, welche ihren Gebrauch im Straßenverkehrsmanagement beeinflussen könnte. Wechselverkehrszeichen sind in drei verschiedene Kategorien unterteilt: licht-emittierende, licht-reflektierende und hybride Verkehrszeichen. Die Eigenschaften des Beobachters und des Zeichens, welche möglicherweise die Ergebnisse beeinflussen, werden im Zusammenhang mit praktischen Problemen der Installation diskutiert. Licht-emittierende und -reflektierende Verkehrszeichen werden im Detail erläutert und mögliche Wege der Verbesserung vorgestellt.

1. INTRODUCTION

The use of variable message signs has increased due to increased public demand for up-to-date information. The most flexible of the variable message signs use a matrix format upon which characters and symbols are formed by showing appropriate patterns of matrix elements. The use and siting of a variable message sign have requirements different to that of a conventional sign. Despite the increase in the use of variable message signs there are no clear guidelines for their design. The objective of this report is to gather the information base about the application of such signs to provide a sound background for their future application.

1.1 Scope of the report

The report is mainly concerned with matrix variable message signs where the elements are discernible to the viewer. Therefore no reference is made to signs where apparently complete characters are formed using elements that can only be seen at close range. This is because such signs can effectively mimic more conventional signs. Some reference has been made to non-matrix variable message signs that only show a few messages. Additionally no reference is made to seven or sixteen segment displays since these signs are perceptually quite different to matrix signs. Seven or sixteen segment displays use bars rather than the perceived continuity between matrix elements to form the components of a character. Only signs external to the vehicle in which the viewer is travelling are considered. It is the intention to describe the important characteristics of variable message signs for two basic forms of light emitting and diffuse light reflecting signs covering design, application and performance. Some mention will be made of retroreflecting signs but since this is a relatively recent development experience of this type of sign is limited. Much information that relates to conventional signs also relates to matrix variable message signs. Where necessary reference will be made to appropriate documents including the CIE Technical Report on *Roadsigns* (CIE 74-1988).

The proposition and ideas that are set forth in this report do not have the same weight of evidence to support each of them. Some may be based on practice, others may be founded on experimental evidence, and yet others are well justified by a combination of research and practice. Consequently, they will be divided into four categories. These four categories have also been used in the CIE Technical Report *A Guide for the Design of Road Traffic Lights* (CIE 79-1988) and are described below.

- A *Recommendation*, which is based on both research and current practice and may be expressed in a form such as "*It is recommended that...*".
- A *Proposal*, which is based on research, but its practicability has not yet been widely established. It may be expressed in a form such as "*It is proposed that...*".
- An *Advice*, which includes considerations based on practical experience, but has not yet been fully confirmed either by theory or experimental research. It may be expressed in a form such as "*It is advised that...*".
- A *Suggestion*, which is not based on established research or practical experience, but follows from other considerations, and it may be regarded as good practice. It may be expressed in a form such as "*It is suggested that...*".

The CIE Technical Report on *Roadsigns* (1988) defines a sign as a device that provides a visual message by virtue of its situation, shape, colour or pattern, and sometimes by the use of symbols or alphanumeric characters. It is variable message signs of the latter type that are dealt with within this report and the terminology of this report is consistent with that of the report on *Roadsigns* (1988) and with that of the *International Lighting Vocabulary* (CIE 17.4-1987). Further definitions are available in Chapter 7 GLOSSARY.

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1.2 Variable message sign systems

The CIE Technical Report on Roadsigns (1988) suggests that road signs serve three objectives aimed at improving the quality of service of the road network. These objectives are to:

- improve road safety,
- reduce journey times,
- increase road capacity.

Variable message signs in common with conventional signs have the same objectives.

Dudek and Huchingson (1986) identify three applications of variable message signs, these are:

- *Advisory signs:* The most commonly expected use of a variable message sign must be as an advisory sign. Displaying information about the status of a transport network and about the most appropriate course of action.
- *Advance signs:* In order to alert the user to the approach of an advisory sign it is sometimes beneficial to make use of an advance sign. This however need not be a variable message sign, a fixed message sign might be used to give advance warning of an advisory variable message sign.
- *Guide signs:* Where a user has been advised to take an alternative route, guide signs are used to direct the user along the advised route. Again this need not be a variable message sign, fixed message signs might provide a fixed alternate route or the user may simply be advised of a restriction and not guided along any specific route.

The increase in the use of micro-processors and the increased need for more information has provided many opportunities for the introduction of variable message signs. Variable message signs are one means of more effectively and flexibly providing information to manage a transport system. Variable message signs can be used to convey information about the state of a transport network based on the intelligence gathering system and the way the information is transferred to the public. The users will very often be able to directly test the quality of any information they are given. If this proves to be fallacious it will adversely affect the sign's credibility in the eyes of the user.

Variable message signs may be operated directly, giving the operator complete freedom for the form and content of a message or the message may be coded or structured in some way. It is likely that coding, structuring or pre-approval of variable message sign messages will improve the effectiveness of the sign, so fixed menu systems might be appropriate. This might add significantly to the consistency of message application and hence the credibility of the messages. This is especially important in multi-operator systems where free format systems will result in significant differences in message design and application from operator to operator. However such a system might be profitably arranged to allow for the possibility of an override with "type to screen" to cope with unusual circumstances.

1.3 Forms of matrix variable message sign

Matrix variable message signs may be divided conveniently into three categories, these are:

- Light reflecting signs
- Light emitting signs
- Hybrid signs

The first two categories cannot be considered to be mutually exclusive, some sign design have combined two technologies to produce hybrids which exhibit qualities of both the other two. The division between light reflecting and light emitting is however largely appropriate and therefore this report will consider the human factors aspects of matrix variable message signs under these two headings. Some of the main sign technologies for each of the three types are described in Table 1.1 below.

Table 1.1: Common variable message sign technologies for light reflecting, light emitting and hybrid signs

Type	Descriptions
Light reflecting	Flip-disk elements
Light emitting	Lamps Light emitting diodes Fibreoptic
Hybrid	Flip-disk with fibreoptics Flip-disk with light emitting diodes Retro reflective flip-disk, back lit

1.3.1 Light reflecting signs

Conventionally light reflecting signs have relied on reflecting/fluorescing elements mounted on bistable magnets either in a fluid or on an axis. In one position elements are "on" and in the other position the elements become part of the background allowing a message to be displayed on an array of elements. An example of this approach is the "flip-disk" used as a matrix element and shown in Figure 1.1.

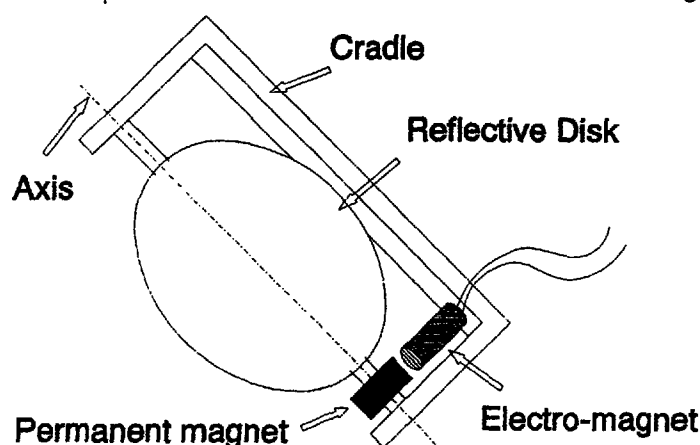


Fig. 1.1: An example of a "flip-disk" matrix element.

The characteristics of light reflecting signs will vary depending upon the particular technology that is employed. It is possible to make some reasonable generalisations about such signs and these are summarised in Table 1.2.

Table 1.2: Light reflecting variable message signs

Viewing angle	Can be read at a greater angle as the observer passes the sign, this may be a useful feature where the sign is placed on a curve in the road.
Luminance and contrast	Since the sign reflects light, either from the sun or luminaires, precise control over the luminance and contrast of a message is not often possible.
Daylight	The luminance and contrast of a reflecting sign with the sun shining directly at the sign can be very high. With the sun shining from behind the sign the luminance and contrast can be so low as to make the message unreadable.
Night time	Reflecting signs require some form of illumination at night to raise the luminance and contrast to acceptable levels. The luminaire used must provide the appropriate colour rendering for the colour of the elements of the sign.
Fog	In fog reflecting signs often perform poorly since the luminance and contrast of the message is neutralised by the prevailing fog conditions.
Power	Reflecting signs often do not require a large or continuous power supply.
Life	Some of the technologies used in reflecting signs are mature and have proved to be very durable. Some technologies have proved to exhibit intermittent mechanical problems. In some cases however the material of the face of the sign may age rapidly and require frequent replacement.
Maintenance	Reflecting signs often incorporate a large number of mechanical systems which while reliable may require more maintenance than solid state systems.

1.3.2 Light emitting signs

There are a number of approaches using light emitting devices which are constantly advancing in performance and provided significant opportunities for future development. There are a number of technologies which can be used to construct a matrix unit suitable for variable message sign application.

The most common technologies are lamps as individual sources, an example of this approach is given in Figure 1.2, or combined with fibreoptic techniques or solid state using light emitting diodes or liquid crystals.

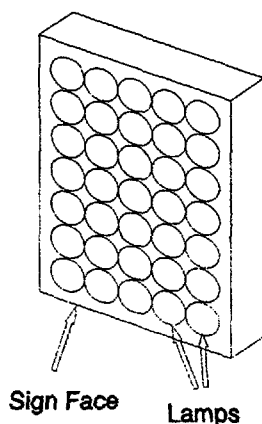


Fig. 1.2: A matrix array of lamps.

Another approach is using fibreoptic technology making use of rather fewer light sources, commonly high energy lamps. This approach can be divided into two categories.

In the first category, blank out signs, each fibre of a bundle is implanted in the front face as a dot of a predetermined message (text or image). The message appears by turning on the lamp attached to

the appropriate bundle. This type of multi-message sign is able to display typically from one to six different predetermined messages depending on their complexity. An example is given in Figure 1.3.

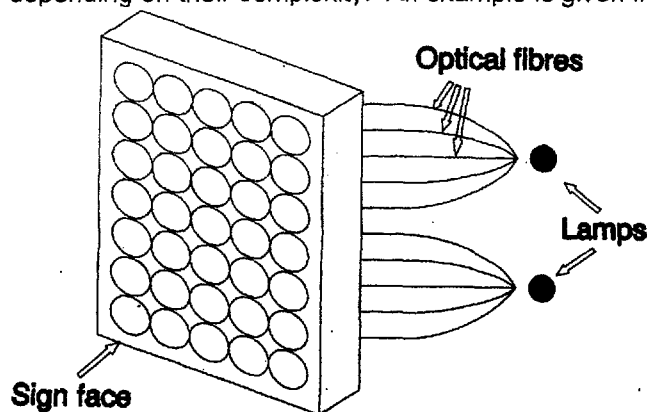


Fig. 1.3: A light emitting variable message sign employing fibre optics.

In the second category, variable message signs, each element of the matrix array has an individual fibre and each is equipped with a shutter device. A message is displayed by opening or closing the appropriate shutters and thus by exposing the chosen dots allowing the flexibility to form any type of message. An example of this type of fibreoptic variable message sign is shown in Figure 1.4.

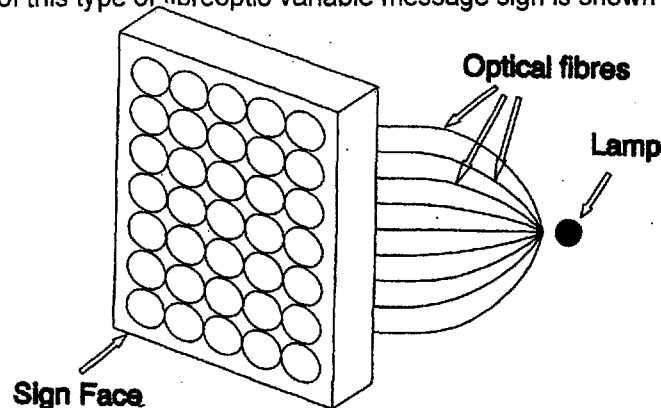


Fig. 1.4: A light emitting variable message sign employing shutters.

The characteristics of light emitting signs will vary depending upon the particular technology employed. It is possible to make some generalisations about such signs and these are summarised in the Table 1.3.

Table 1.3: Light emitting variable message signs

Viewing angle	Often quite restricted.
Luminance and contrast	Very easily controlled provided the technology is capable.
Daylight	Contrast is often too low for conditions of strong sun light.
Night time	Luminance and contrast can be easily controlled to suit the prevailing light conditions.
Fog	Luminance and contrast can often be controlled to provide the best available performance in fog.
Power	The power demands are often high and usually continuous.
Life	Many light emitting signs are solid state and therefore very long lasting.
Maintenance	Light emitting signs using a matrix of incandescent lamps may require a great deal of maintenance, others can provide very low levels of maintenance.

1.3.3 Comparison of light emitting and light reflecting signs

A comparison of light emitting and light reflecting signs is briefly made in the table below.

Table 1.4: Comparison of light reflecting and light emitting signs

	Light Reflecting	Light Emitting
Viewing angle	Wide	Narrow
Luminance and contrast	Difficult to control	Variable and easy to control
Daylight	Cannot be adjusted	Can be adjusted to suit light conditions
Night time	Requires external lighting	Can be adjusted
Fog	Poor performance	Good performance
Power consumption	Often low	Can be high
Life of elements	Can be short	Can be long
Light distribution	About 6° to 10°	Up to about 6°

1.3.4 Hybrid signs

A number of signs have combined both light emitting and light reflecting technologies, attempting to produce a sign which could have the advantages of both approaches. An example of such a sign is given in Figure 1.5.

The characteristics of hybrid signs will vary greatly depending upon which technologies are combined and how. Any generalisations that can be made about hybrid signs can be taken from Table 1.2, Light reflecting variable message signs and Table 1.3: Light emitting variable message signs.

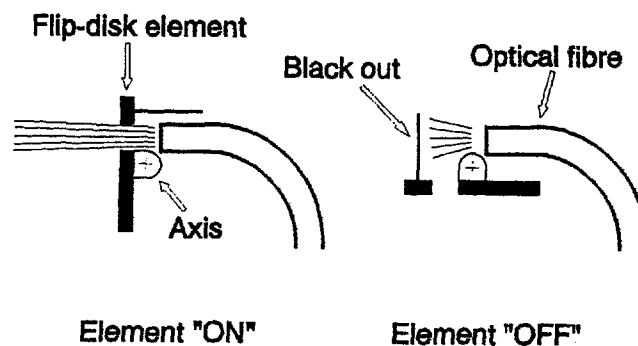


Fig. 1.5: A hybrid variable message sign element.

1.4 Non-matrix variable message signs

Variable message signs may employ systems other than a dot matrix. Goldby (1984) identified twelve technologically based classes of variable message traffic signs eight of which did not employ a dot matrix. The non-matrix classes may be summarised as:

- Roller Blinds
- Rotating drums, planks or prisms
- Hinged plates
- Sliding slats or plates

These four technologies provide signs which have the appearance of conventional signs and hence are most effectively discussed in the CIE Technical Report on Roadsigns (1988). While these signs provide good representations of conventional signs the number of messages which they may display is often limited. Also as Holmes (1989), in a paper discussing trends in passenger and driver information displays, points out the systems are prone to failure and are not likely to be used much in the future. Goldby (1984) omits to mention seven and fifteen segment displays which employ a rectangular pattern of bars rather than dots to create characters. Since these signs differ greatly from dot matrix signs they will not be considered in detail in this report.

1.5 Use in transport information systems

There is always limited communication between vehicle or vessel users and the central coordinating managers of a transportation network. Variable message signs provide a means of conveying information that can be more precise and more complete than that delivered by fixed message signs. Use of variable message signs also means that the message can be received or at least directed at all users rather than just those specially equipped to receive the information. Variable message signs offer a means of keeping all the users of a transportation system better informed as to the functioning of the system.

Introducing variable message signs is not without some problems. Until recently, most National Traffic Signs regulations were based on the use of fixed message signs, hence, variable message signs inevitably fell outside the scope of current legislation. The most common difference is that many variable message signs (though not necessarily all variable message signs) show light figures on a dark background rather than, as with most signs, a dark figure on a light background. To allow for the use of variable message signs some special dispensation is often required. Another problem particular to variable message signs is that the users may be unfamiliar with variable message signs and until such time that they are used extensively the user will be inexperienced in responding to information provided by variable message signs. These two factors combine to make the message on the sign more likely to go unnoticed or where it is noticed some small but important change of message might not be registered by the users.

Legal restrictions may be lifted and the human factors of the sign may be enhanced to reduce the effects of the second problem, but ultimately the performance of the sign as a system component relies on the users acceptance of the credibility of the message. Additionally every effort must be made by the sign operator to validate the accuracy of any message displayed, since the users will usually have an opportunity to test the credibility of the information.

Despite these potential problems variable message signs do offer benefits in affording the possibility of improving the efficiency of a transport system by reducing the risk of accidents and stress on the users.

1.5.1 On the road network

Drivers unfamiliar with a road network will require and make greater use of information provided to assist them in their task. The clarity and credibility of this information will influence the individuals' response. Appropriate road signs can provide a means of supplying information to the driver about parts of the road network which are outside the range of the drivers experience. Without the need for

personal reconnaissance, drivers who have no knowledge of the network in advance of arriving at a location, can make better and more timely decisions about route choice and road positioning. The better informed driver can choose shorter and more efficient routes. Also, advanced warning about network topology and geometry can allow drivers to make manoeuvres at the most opportune moment. The system of fixed road signing is effective at conveying a large amount of information to the driver who is unfamiliar with the road network. However, the fixed signing cannot respond to rapidly and widely changing conditions on the road network. It is for this reason that variable message signs are now being used to display a number of alternative messages appropriate to the status of the network and drivers' needs. Variable message signs placed at strategic points in the road network are able to supply drivers with up to date information about conditions elsewhere in the road network and allow drivers to make route choice and road positioning decisions that are tailored to the prevailing road and traffic conditions. The value of such information is likely to increase as greater demands are made for information on the road network. Also as the road network becomes more extensive, it will be possible for drivers making longer journeys to avoid incidents by choosing alternative routes whilst still at a great distance from an incident with appropriate saving for both the driver and the community.

Dot matrix variable message signs have been used in controlling traffic for a number of years, the Transportation Research Board (1979) considered the subject worthy of a summary report on matrix and non-matrix variable message signs.

Dudek and Huchingson (1986) however warn the transportation system managers against being enticed to display information which exceeds the surveillance capabilities of the system and which does not accurately reflect the circumstances at the time. Since repeated display of erroneous information is one way of losing driver confidence, which is vital to the effective functioning of a motorist information system.

The successful use of matrix variable message signs has been reported in a number of locations. Lines (1978), (1981) found only a minimal, although significant reduction in speed as a result of the use of motorway matrix signs. In Lines' first (1978) experiment a great deal of care was taken to ensure that the reason for the message on the matrix sign was not visible to the driver at the point, just after the sign where speed was measured. Lines' second (1981) experiment had similar findings. This was a more extensive experiment which, however, lacked the same degree of control as the first experiment. It should be remembered however that the matrix signs in Lines' experiments gave advisory speed limits not mandatory ones. Rutley, Hodge and Lines (1983) found that drivers were more responsive to instructions if the reason behind the instruction was given, though the problem itself might not be apparent to the driver at the time. In the Netherlands the Motorway and Tunnel Control and Signalling System (MTCSS) had been operational for five years when it was reported on by Jenezon, Klijnhout and Langelaar (1987). The MTCSS, it was considered, reduced accident rates by 15 to 25%, gave a saving in travel time and fuel consumption to users, and provided savings to the police in controlling traffic around road works. It was reported in Traffic Engineering and Control (1987) that the ADVISE (Advisory Display of Variable Information for Speed and Economy) system was activated in November of 1987 in Melbourne, Australia. It was expected that the system would reduce fuel consumption by 15% and would significantly reduce the number of rear end accidents. In both these cases variable message signs are being used to communicate to drivers the products of an intelligence gathering system. It must therefore be borne in mind when evaluating a matrix sign that poor performance may be the result of a poor intelligence gathering system displaying erroneous information as well as due to the sign's poor visual performance.

1.5.2 Requirements of an effective variable message sign

The CIE Technical Report on Roadsigns (1988) gives four requirements for an effective road sign, these requirements are however applicable to other transportation environments. These requirements are:

- *Conspicuity*: Signs need to attract attention so that they are noticed.
- *Legibility*: The message displayed on the sign by means of alphanumeric or symbolic characters must be legible at the distance from which the sign is to be read.
- *Comprehensibility*: The message must be easily understood and the response required by the message must be clearly conveyed.
- *Credibility*: The message should be such that the reader believes what is conveyed and acts upon it in the time available.

These four requirements are affected by both the qualities of the observer and the qualities of the sign itself.

2. THE OBSERVER

As has been mentioned in section: "1.5.2 Requirements of an effective variable message sign", a driver must notice, read, understand and believe the information displayed on a sign for the sign to be effective. The qualities of the observer or driver will affect all these processes and will therefore influence the design criteria used in specifying the performance of the sign.

2.1 Perception and attention

For a vehicle operator to respond to a sign it must be perceived and then attended to. The vehicle operators perceptual and attentional abilities will therefore have some bearing on the effectiveness of a sign.

Perception is the process whereby a person selects information from all the signals in the environment. It serves as a means of filtering out redundant information from the wealth of signals available in the surroundings. Rumar (1985) proposes a conceptual model of driver behaviour which includes a perceptual filter as one component of the information acquisition process. The perceptual filter is "mainly dependent on physiological limitations in our senses inherited from our ancestors". The visual sense is sensitive to bright, centrally located, moving and flashing targets. That is, these signals in the environment are more likely to be allowed through the perceptual filter. Flashing lights, in particular, have been used as a means of enhancing the probability of a sign being perceived. Crawford (1962) conducted a study of the effects of irrelevant lights on the response time of subjects to signal lights. It was found that the shortest response times were obtained when the signal light was flashing against a background of steady lights. In a further study Crawford (1963) found that the benefits of a shortened response time to a flashing light were lost if even one background light in the visual field was flashing.

Attention in humans is not 100% continuous, while a sign may be perceived it may not necessarily be attended to. Road signs are specifically designed to be easily perceived, however a proportion are not registered by drivers. Johansson and Rumar (1966) claim as many as 10% of highway signs are not registered by drivers. Rumar (1985) proposes a cognitive filter as another stage in the information acquisition process to come after perceptual filtering. While the perceptual filtering is largely physiological in nature the cognitive filter is more dependant on psychology. Motivation and experience influence the direction of the attention as a result filtering out further information. Whether a sign is attended to or not therefore depends on factors such as it's frequency of occurrence and the costs associated with missing it.

While the Rumar (1985) conceptual model of driver behaviour separates perceptual and cognitive filtering the processes are in practice considered as one and treated as such experimentally. Human performance in detection and identification tasks has often been measured using psychophysical methods. These procedures relate together the psychological and physical variables which are

associated with a task. A typical example is the method presented by Forbes (1939) for analyzing the effectiveness of highway signs. The legibility of a particular sign was measured by allowing observers to walk towards the sign until it became readable. This is termed the legibility distance of the sign. The physical dimensions of the sign can thus be related to the psychological point at which the sign can first be read.

The method does have a drawback in that the criterion upon which the observer is making judgements is not known to the experimenter. Indeed the experimenter has no way of telling if the observer is reporting honestly. Signal Detection Theory (Swets, 1966) attempts to overcome this problem by concentrating on response threshold rather than sensitivity limit. Further, it can be shown that this response threshold or criterion level will vary depending on the observers motivation, training, the signal frequency and the costs and benefits associated with it.

2.2 Visual ability and performance

Clearly, visual ability is of importance in a sign reading task. However in a review of relevant literature in Roadsigns (1988), no great correlation was found between accident rate and visual ability. Burg (1971) reports that dynamic visual acuity is the most reliable predictor of accident risk, but this only with a correlation coefficient of approximately 0.5. Hills (1975) suggests that the measures of visual ability are poor predictors of accident risk simply due to a lack of sensitivity of the measures. He goes further to suggest that "higher order visual tests, such as a Hazard Perception Test" might be "more exacting for the younger driver". Ysander and Herner (1976) in studying the traffic behaviour of elderly male automobile drivers suggest that the ageing driver, whose visual abilities are likely to be declining, is likely to operate a degree of self selection avoiding certain conditions or avoiding driving altogether. Driving behaviour is therefore adapted to maintain or reduce risk. It should be remembered that the driving population is already visually screened, however crudely, and that this will limit variability in the driving population. Persons with extremely poor visual ability and hence potentially higher accident rates are therefore eliminated from any correlation studies.

An observers visual performance or ability has a number of associated measures. To improve the practical relevance of such measures of acuity they may be related to speed in the concept of visual performance. Acuity is a measure of the ability to resolve fine detail at high levels of contrast, but not larger forms at lower levels of contrast. Measuring contrast sensitivity provides a measure of visual ability under both these conditions and perhaps provides a better measure of the complete performance of the eye. More simply, contrast sensitivity of the observer is important for detection of a signs, and acuity is important for seeing detail. Seeing is not simply a matter of considering the optical performance of the eye but includes an element of perceptual processing which begins initially in the structure of the retina. As a result perceived brightness is not so much a matter of the absolute level of contrast as a quality of visual perception. Very high levels of contrast can be glaring causing discomfort and/or reducing the observers visual ability. The discomfort and performance detriment varies between individuals and may be measured by a number of means. At very low light levels the eye adapts to using different light receptors which alter the performance of the eye both in terms of acuity and sensitivity to colour. The human eye is not equally sensitive to wave lengths or colours of light and there also exists variation in sensitivity between individuals. Finally the visual field available to the observer is limited by the construction of the eye and may be further limited by a number of pathologies.

In the case of sign reading performance, a measure of visual ability will often provide a good correlation. Sign reading tests are however often simply large scale measures of visual acuity so this is in no way surprising.

2.2.1 Static visual acuity

The CIE International Lighting Vocabulary (1987) defines visual acuity both qualitatively and quantitatively.

Qualitatively it is the capacity for seeing fine details that have very small angular separation.

Quantitatively it is any number of measures of spatial discrimination such as the reciprocal of the value of angular separation in minutes of arc of two neighbouring objects (points or lines or other specified stimuli) which the observer can just perceive to be separate.

In the United Kingdom a common test of visual acuity is the Snellen Chart. The chart shows black letters of the alphabet on a white background in rows each successive row having diminishing dimensions, the larger letters towards the top and the smaller ones towards the bottom of the chart. A person with "normal" vision is defined as being able to discern one minute of arc, this is however a nominal definition of normality, the average adult often having a higher acuity. In terms of a legibility distance a "normal" person can see characters at a distance 687 times the height of the characters. Each line of the chart has a distance in metres associated with it at which a person with "normal" vision should be able to read it. The Snellen chart is scored using a fraction of the distance to the chart over the smallest line of the chart read correctly. 6/6 is therefore "normal" vision whereas 6/20 is poorer and 6/5 is better.

The International Standards Organisation (ISO) Standard for visual acuity testing (International Standards Organisation, 1994) presents the Landolt ring, rather than letters, as the basic element to be discerned. The Landolt ring consists of a circle of thickness one fifth of its diameter, the circle is broken by a gap also of one fifth of the diameter. The observer is required to indicate which side of the circle is broken. Acuity is then expressed as an acuity grade varying from 0,05 to 2,0.

Static acuity measures are of particular relevance to sign reading and the driving task. In the United Kingdom the drivers vision is tested by a means similar to Snellen acuity but using a conventional vehicle number plate as the target. A driver must be able to read a number plate with 8,9 centimetres (3,5 inch) high characters at a distance of 22,86 metres (75 ft) (DEPARTMENT OF TRANSPORT, 1969). In terms of legibility distance this is 257 times the character height. The design of the text on road signs in the United Kingdom is based on a study by Christie and Rutley (1961) where a legibility distance of 462 times the character height was defined as the minimum. Clearly there is some apparent disparity between accepted "normal" vision, the drivers visual requirements and the standards for road signs. The test for drivers vision is considerably poorer than "normal" vision which is in turn poorer than the average adults vision. The actual legibility distance required for a sign while within the bounds on normal vision exceeds the demands of the test of drivers vision. A percentage of the driving population must therefore be unable to read conventional text road signs at the expected legibility distance. Davey (1958) gathered data on the binocular acuity of 1500 drivers who visited United Kingdom opticians during April of 1956. The sample might be criticised as being biased towards drivers who considered their vision to be poor, but Davey used the data to suggest that 0,05% of United Kingdom drivers were unable to meet the minimum required level of acuity. In practice, United Kingdom opticians, when evaluating the sight of drivers, take a more cautious approach and are required to notify anyone whose corrected vision is in the Snellen acuity range of 6/10 to 6/15 which in terms of legibility distance is 412 to 275 times the character height.

2.2.2 Dynamic and semi-dynamic visual acuity

Dynamic visual acuity is simply acuity measured under conditions where the target passes in front of the observer at a fixed distance and angular velocity. The test media does not approach or recede from the observer. In the case of the driver reading a sign this case of a fixed distance and angular velocity might be a somewhat rare occurrence since the driver is conventionally approaching the sign at a speed which may be varied by the driver. This situation represents a problem for the vision tester in that the angular separation of the acuity test medium is continually changing. This lack of an obvious fixed baseline has made experimentation of this type somewhat less attractive.

It is however considered (Burg, 1966) that dynamic visual acuity at a fixed distance "might be more closely correlated with task performance than is the score obtained on a test of static visual acuity". The apparatus to test dynamic visual acuity is less common than that used to test static visual acuity. Burg (1965) proposes a system where a checker board acuity target is passed in front of the subject

at angular velocities of up to 150 degrees per second. Burg (1966) found that dynamic visual acuity became progressively poorer as angular velocity increased and the effect was amplified as the subjects age increased. Burg used relatively high angular velocities of between 60 and 120 degrees per second. Other researchers such as Westheimer and McKee (1975) used lower angular velocities of 4 degrees per second and found no reduction in visual acuity. This might however reflect the sensitivity of the acuity testing apparatus used or simply that no loss of acuity is experienced at such low angular velocities. Brown (1972) effectively predicted dynamic visual acuity from eye movements and peripheral acuity. In Brown's experiment both dynamic visual acuity and eye movements were measured for 25 young subjects at a range of angular velocities from 0 to 90 degrees per second. It was shown that dynamic visual acuity is not a fundamental visual attribute but depends on sensory and motor components of the visual response. Dynamic visual acuity (in minutes of arc) and target angular velocity are approximately linearly related up to 90 degrees per second. The decrease in acuity with increasing angular velocity resulting from increasing position and velocity errors of the target image on the retina.

2.2.3 Visibility

The Oxford English Dictionary (1989) defines visibility simply as being visible but might more practically refer to how well something can be seen. A number of key factors must be considered in attempting to define a practical measure of visibility. These factors are described below.

- *Size of target.* Where the target is very small it may not be seen. This is limited by the acuity of the observer.
- *Time available to view the target.* A longer exposure time allows the observer to examine the target in great detail so the target must be considered to be more visible.
- *Threshold.* The threshold applied by the observer or the demands of the task will affect visibility. The observer may simply need to detect the presence of the target or may need to determine more detailed information about the target to identify it as one of a group or a particular individual from the group.
- *Contrast.* The contrast between the target and the background will affect visibility, higher contrast targets will be more easily seen.
- *Luminance.* The final factor which must be included. A target at low luminance may not be seen whereas at higher luminance the target may easily be seen.

Blackwell (1959) includes all these factors in a standard measure of visibility. Blackwell uses a standard target which is a uniformly illuminated disc which subtends a visual angle of four minutes of arc presented in pulses of 200 milliseconds on a uniformly luminous screen. Blackwell determined the threshold of visibility where the observer could detect the target for 50% of exposures by allowing observers to adjust the luminance of the target for various levels of screen luminance. By performing this experiment with approximately 100 young observers Blackwell determined the average relationship between the background luminance and the threshold contrast of the target disc. This was referred to as the Visibility Reference Function or Visibility Level 1 (VL1). Blackwell went on to conduct this experiment under varying conditions using a moving target, not telling the observers where in the visual field or when the target might appear and requiring 99% detection. The product of the additional factors which Blackwell found under each of the three experimental conditions was approximately 8. Blackwell termed this the curve Visibility Level 8. Blackwell (1981) introduced Visibility Level as a descriptive term described by the equation below.

$$L = \frac{\Delta L_a}{\Delta L_t} \quad (2.1)$$

where

VL is Visibility Level;
 ΔL_a is the actual luminance difference between target and background;
 ΔL_t is the threshold luminance difference between target and background.

(See also CIE Publication 19.21 and 19.22 (1981).)

Adrian (1989) provides a means of calculating threshold luminance based on physiological characteristics of the eye and experimental data. Adrian's model takes into account the same factors as Blackwell's investigation of size, time, threshold, contrast and luminance. However the model goes on to include additional factors such as disability glare and negative and positive contrast and subject variables such as age. The model provides a convenient method of determining threshold luminance values and can thus be employed to determine values of Visibility Level. Adrian's objective was to determine levels of street lighting and suggests that Visibility Levels should be between 10 and 20.

Concept of visibility relates to particular tasks and observers. Sometimes it is necessary to measure the subject's visual ability independent of the task being conducted. A method of measuring visual ability has been suggested which evaluates the eye using a measure of performance which has been applied in measuring the quality of lenses and other optical systems.

2.2.4 Modulation transfer function and contrast sensitivity

Conventional tests of visual acuity, such as the Snellen chart, do not accurately assess how well a person can see. As a measure of the performance of an optical system the ability to resolve fine high contrast detail does not predict ability to resolve large images of low contrast. Regan, Raymond, Ginsburg and Murray (1981) in discussing vision anomalies in multiple sclerosis sufferers suggest that visual acuity is insufficient as a measure of form vision.

Cornsweet (1970) describes a method which provides a more general means of measuring the quality of the visual system. The quality of an optical system might be described in general terms as its ability to resolve images. Such a very general definition is of little use, however it may be refined to provide a useable definition that allows measurements of the human optical system to be made. An image, for example of stripes, can be shown to be the sum of a number of sine waves by means of Fourier analysis. To produce a striped pattern an infinite number of sine waves must be added of higher and higher frequency. In fact any image might be considered to be the sum of a number of sine waves. The ability of a optical system to resolve sine wave gratings will therefore be a measure of its ability to resolve any image. If the output intensity (amplitude) of a sine wave grating were exactly the same as the input intensity then the transfer is perfect or unmodulated. There has been no modulation in the transfer of the sine wave grating. Typically modulation does occur and with a lens the degree of modulation decreases with increasing frequency of the input sine wave grating until at very high frequencies the modulation is zero. The output image at this point is a uniform distribution as the original input sine wave grating is "blurred out". The plot of modulation against frequency can describe the quality of any optical system and is termed the Modulation Transfer Function.

A practical means of measuring the modulation transfer function of the human visual system is by employing thresholds. The subject is presented with sine wave gratings the intensity of which is reduced until it is only just visible. The contrast at which this occurs is related to the modulation. However modulation occurs at low as well as high frequencies unlike a simple lens which modulates only at higher frequencies. Clearly the human visual system does not behave linearly and the resulting curve cannot strictly be termed a modulation transfer function.