Driving performance on an expressway
under fog conditions and its improvement
use of a fog warning system

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NOTE

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CHAPTER 2

BACKGROUND

2.1 Accidents

2.1.1 Accidents in Fog

Accidents are rare random events which occur due to driver error, vehicle failure, environmental factors or a combination of these. The occurrence of fog obviously changes the environment and can lead to increased driver errors. This is caused by drivers travelling with headways at less than the available stopping sight distances, usually due to either subjective speed misjudgements or overdriving (driving at a speed where inadequate stopping distance is available). Whilst the reasons for behavioural change are discussed more fully in Section 2.6, the results of increased driver errors can be increased accidents if drivers do not adjust their behaviour to the prevailing conditions.

Early research (Foldvary & Ashton, 1962) gave some indication that for conventional roads fog reduces the accident rate by 6 to 10% with the largest reduction in the more severe categories. US analysis (Schwab, 1972), whilst not as rigorous, indicated, "It does appear that fewer fatal accidents occur during fog than during clear weather conditions."
However analysis of freeway type roads (high speed restricted access divided carriageways) suggests the opposite to be true. A comparison of the conclusions is difficult in view of the differing definitions used regarding accidents, weather, data reporting and processing methods. Nevertheless common themes included the increasingly common (relatively) phenomenon of the multiple vehicle accidents and the increase in fatalities in such accidents. Schwab (1972) indicates: "the probability of a multiple-vehicle accident was greater in fog than in clear weather" and "For freeways......the fatality rate for fog accidents was almost twice that of nonfog accidents."

In terms of non-fatal injury accidents the conclusions are less clear. UK analysis (Moore & Cooper, 1972) states:

"On motorways the presence of fog increases the severity of injuries to a marked degree......A separate investigation on dual carriageways shows that although the number of fog accidents per km in fog is high the presence of fog causes no increase in severity index."

European research (OECD, 1976) concludes, "the severity of motorway accidents increases during fog". However it is not clear if this is a real increase (severity per vehicle) or just a reflection of the increased number of vehicles involved in individual accidents.

(Accidents information is commonly available in the form of both the type of accident and the severity of the accident (in human and property terms; the definition of degree of severity varies between countries). In order to rank the hazards of a Road Network, the more severe accidents are given a weighting. The resulting combination of the
‘severity index’ which is independent of the number of accidents. The weighting factors are not standardised throughout the world although the principle is common. The weightings adopted by Australian Road Authorities are set by AUSTROADS (NAASRA, 1988).

Comment is also made on the proportionately higher number of daytime accidents on divided carriageways. A study of UK Motorway accidents from 1969 to 1971 indicates, "the problem during the years reviewed was largely a daylight one" (Johnson, 1973).

Associated problems are also seen to exist at dusk. An OECD study found:

"At the time of transition from daylight visibility to night visibility, visibility conditions are particularly dangerous. This applies especially to visibility in fog because the reduction in surroundings luminance tends to obscure highway objects. .....

In general, the visual recognition range for small objects decreases at dusk, even if vehicle lights are used. At night it increases again.” (OECD, 1976).

It will be seen that this phenomena is reflected in accidents in the F6/Bulli Tops area during fog.

2.1.2 F6 Fog Accidents

Australia is not seen as a country with a significant accident problem due to fog conditions. However in NSW alone, 1313 accidents occurred from 1987 to 1990 in fog conditions.
Examination of the RTA's accident database shows that in the F6/Bulli Tops area there were 505 accidents during the 4 year period from 1987 - 1990 of which 37 occurred in fog conditions. (See Appendix B for full accident details and analysis.) Analysis of these accidents show similar accident patterns to those found in overseas research.

Fig 2.01 shows a comparison of the percentage of accidents in fog and clear conditions according to the number of vehicles involved. The figures have been broken down to compare the number of vehicles involved in a particular accident with the total number of accidents. As can be seen, these figures provide an indication of the increase in the average number of vehicles involved in accidents during fog. The actual average number of vehicles involved in an accident increases from 1.7 to 4.1 vehicles per accident in clear and fog conditions respectively.
FIG 2.02: COMPARISON OF VEHICLES IN ALL ACCIDENTS IN CLEAR & FOG CONDITIONS, 1987 - 1990

This supports overseas experience that "the average number of vehicles involved in fog accidents is considerably higher than in clear weather" (OECD, 1976).

This whole pattern becomes even more pronounced when an analysis is made of the actual number of vehicles involved in accidents broken down into the number of vehicles involved in each individual accident, as shown in Fig 2.02. This shows for example that around 70% of all vehicles involved in accidents in clear conditions are in accidents involving only 1 or 2 vehicles. In contrast in fog conditions such accidents only account 26% of vehicles involved in accidents.

Whilst the number of vehicles involved in accidents clearly increases during fog conditions, analysis does not support there being any increase in severity in accidents. Table 2.01 shows a breakdown of accidents in terms of severity and indicates a
remarkable similarity in fog and clear conditions. (No significant difference at the 1% level using an ANOVA analysis).

**TABLE 2.01: ACCIDENT SEVERITY: 1987 - 1990**

<table>
<thead>
<tr>
<th></th>
<th>FATAL</th>
<th>INJURY</th>
<th>PROPERTY</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOG</td>
<td>NUMBER</td>
<td>1</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td>%</td>
<td>3%</td>
<td>39%</td>
<td>58%</td>
<td></td>
</tr>
<tr>
<td>CLEAR</td>
<td>NUMBER</td>
<td>14</td>
<td>212</td>
<td>330</td>
</tr>
<tr>
<td>%</td>
<td>3%</td>
<td>38%</td>
<td>59%</td>
<td></td>
</tr>
</tbody>
</table>

Further analysis was carried out on accidents by time of day. Such analysis appears limited in earlier research. However as indicated by Behrendt (1978) the visibility of other vehicles varies by time of day with daytime conditions being the worst time (see Section 2.3.1). This supports Johnson's (1973) analysis of accidents on motorways in fog referred to earlier indicating in his study of UK Motorway fog accidents that the problem was mainly a daytime one.

Concern also exists with behaviour at the interchange period between day and night. McFarland and Domey (1958) observe for drivers at dusk:

"*After hours of driving in bright sunlight visual efficiency is reduced. If the persons involved were to drive during twilight and early evening, they would do so with less night vision proficiency than others who had not been exposed to bright sunlight for several hours.*"

Such behaviour in motorists at twilight could be expected to have an additional detrimental effect where a driver's vision might be less proficient but the benefits of the
additional visibility of tail lights in night conditions were not available. The OECD (1976) concluded in its summary of problems of fog, "the adverse effects of fog on visibility are most prevalent during dawn and dusk".

Table 2.02 gives a breakdown of accidents by time of day. These figures show a marked decline in the number of night accidents occurring in fog from 29% to 16%. Even more pronounced is the number of vehicles involved which reduces from 24% to 6% even though the average number of vehicles per accident only changes marginally from 1.5 to 1.7 vehicles per accident.

**TABLE 2.02: VEHICLES INVOLVED IN ACCIDENTS ON F6/BULLI TOPS BY TIME OF DAY: 1987 - 1990**

<table>
<thead>
<tr>
<th></th>
<th>DAWN</th>
<th>DAY</th>
<th>DUSK</th>
<th>NIGHT</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NON-FOG WEATHER ACCIDENTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO. OF ACCIDENTS</td>
<td>12</td>
<td>320</td>
<td>25</td>
<td>147</td>
<td>504</td>
</tr>
<tr>
<td>%AGE OF ACCIDENTS</td>
<td>2%</td>
<td>63%</td>
<td>5%</td>
<td>29%</td>
<td></td>
</tr>
<tr>
<td>NO. OF VEHICLES</td>
<td>17</td>
<td>583</td>
<td>58</td>
<td>213</td>
<td>948</td>
</tr>
<tr>
<td>%AGE OF VEHICLES</td>
<td>2%</td>
<td>67%</td>
<td>7%</td>
<td>24%</td>
<td></td>
</tr>
<tr>
<td><strong>VEHICLES PER ACCIDENT</strong></td>
<td>1.4</td>
<td>1.8</td>
<td>2.3</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>FOG ACCIDENTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO. OF ACCIDENTS</td>
<td>2</td>
<td>28</td>
<td>2</td>
<td>6</td>
<td>37</td>
</tr>
<tr>
<td>%AGE OF ACCIDENTS</td>
<td>5%</td>
<td>74%</td>
<td>5%</td>
<td>16%</td>
<td></td>
</tr>
<tr>
<td>NO. OF VEHICLES</td>
<td>6</td>
<td>124</td>
<td>16</td>
<td>10</td>
<td>156</td>
</tr>
<tr>
<td>%AGE OF VEHICLES</td>
<td>4%</td>
<td>79%</td>
<td>10%</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td><strong>VEHICLES PER ACCIDENT</strong></td>
<td>3.0</td>
<td>4.4</td>
<td>8.0</td>
<td>1.7</td>
<td>4.1</td>
</tr>
</tbody>
</table>
The same cannot be said for daylight and twilight accidents. As can be seen in Fig 2.03, the proportion of vehicles involved in accidents at these times increases substantially.

Purely in terms of accidents during daylight, the percentage of accidents increases from 64% to 74% during fog conditions. Even more pronounced is the vehicle involvement which increases by more than double from 1.8 to 4.4 vehicles per accident.

Dusk provides similar indications of motorists having difficulties with the conditions. Involvement remains unchanged at 5% of accidents but the number of vehicles per accident increases almost fourfold from 2.3 to 8 resulting in 10% of fog accident vehicles being involved at dusk.

FIG 2.03: PERCENTAGE OF VEHICLES IN ACCIDENTS BY TIME OF DAY 1987 - 1990

At dawn there is an increase in the proportional number of accidents occurring from 2% to 5% although the rate only increases from 1.4 to 3.0 vehicles per accident. This may reflect the lower volumes of traffic which occur at this time.
2.2 Fog Formation.

Fog is a composition of water droplets (and occasionally although rarely and not at the F6, ice) suspended in the atmosphere in a concentration sufficient to restrict vision to below 1000m. When visibility falls below 200m it is described as thick fog whilst a visibility of below 40m is classified as dense fog. Where visibility appears less restricted, the terms 'haze' and 'mist' are applicable.

In essence fog is the same as cloud and differs only in that the base of the fog is found at or near ground level.

There are considered to be three generic types of fog (OECD, 1976) consisting of:

a) Warm fog - Containing a cloud of water droplets at above 0°C.

b) Supercooled fog - As for warm fog except that droplets are in equilibrium with the atmosphere at 0°C or colder.

c) Ice fog formed entirely of ice crystals at a temperature considerably below 0°C.

Australia as a country with basically a temperate/tropical climate only has ice fog on extremely rare occasions and does not have frequent occurrences of supercooled fog either. However, the nature of the mountain ranges reasonably close to the coast line results in warm fog being seen in many locations and it is such a fog which is seen often on the Illawarra escarpment and in particular in the Bulli Tops area (See Appendix A).
Within the fog, droplets are nearly spherical and vary in diameter between two and 50 microns with a concentration of between 20 and 500 droplets per cubic centimetre. The transparency of a fog is dependant mainly upon the concentration of droplets. Although these water droplets have a density some 800 times greater than air, during fog conditions they are either buoyed up by rising air currents or continually replaced by new droplets condensing from the water vapour in the air (Myers, 1968).

The actual formation of fog occurs when water vapour condenses into liquid water as air reaches the saturation point (100% humidity), or when hygroscopic particles (condensation nuclei such as a sea salt or soil particle which have an affinity for water vapour) initiate condensation at subsaturation humidities.

In the latter case the nucleus usually dissolves in the droplet and because the saturation point is lower for solutions than for pure water, creates additional condensation into the droplet forms, increasing both their size and number and often turning a light fog into a dense one. Whilst still requiring the basic fog formation conditions, the presence of such particles due to industrial air pollution can lead to fogs in these areas becoming particularly dense causing them to form earlier, persist longer and be dirtier (and hence less transparent) than fogs developed at higher humidities. (Myers, 1968)

In order to distinguish between the various ways in which the saturation of water particles may occur, the following classification system was developed by Boyd in 1959 (Kocmond & Perchonok, 1970):

A) Air Mass Fogs - the cooling of moist air to a point where droplet growth occurs on the most favourable condensation nuclei:
1 Advection Fogs
   a. Land and sea-breeze fog
   b. Sea fog
   c. Tropical-air fog
   d. Steam fog

2 Radiation fogs
   a. Ground fog
   b. High invection fog

3 Advection-radiation fog

4 Upslope fogs

B) Frontal Fogs - increasing of the moisture content of the air until saturated conditions are achieved.

1 Pre-frontal (warm front)

2 Post-frontal (cold front)

3 Front-passage fog.

A full explanation of the cause and effect of these various fogs is not needed as part of this study. However it should be noted that the fogs occurring in the vicinity of Bulli Tops where the research was undertaken are predominantly Upslope Fogs (Fig 2.04).
FIG 2.04: UPSLOPE FOG CAUSED BY ESCARPMENT FORCING UP AIR FLOW

These are cooling fogs where an air mass is forced upward (by the escarpment) and becomes cooler as the pressure decreases. As the temperature diminishes, saturation is reached and fog develops. (In view of the proximity of the Port Kembla heavy industrial area with its relatively high air pollutants, this formation process may be accelerated by the outputs of the area; however no evidence is available to further study this possibility).

This is supported by examination of the data showing actual fog occurrences. Fig 2.05 shows that the hourly spread of recorded fog occurrences at the most prolific site (64N) of the F6 Driver Aid System is reasonably even with no significant concentration towards the colder night time hours as would be expected with radiation fog. (For a full analysis of fog on the F6 see Section 3.2.2 and Appendix A.)
2.3 Measurement of Visibility.

2.3.1 General.

The use of the word visibility has had a mixed usage over the years with the common and scientific world attributing a different meaning to the word (Middleton, 1952).

In general terms visibility is considered to be the clearness with which things stand out in relation to their surroundings. However, in scientific terminology visibility is the distance at which an object can be seen.

The difference in these two terms can lead to confusion and whilst this is a scientific thesis requiring that the scientific definition be used, it is important that the difference between the two definitions be adequately clarified.
Some indication of the difference between these two definitions is given in Table 2.03 (Behrendt, 1978).

TABLE 2.03 RELATIONSHIP BETWEEN STANDARD VISUAL RANGES AND ACTUAL VISIBILITY DISTANCES IN FOG (BEHRENDT, 1978)

2): lighted only by a succeeding vehicle

3): luminous intensity 2.5 cd;
   fog background luminance: 0.01 cd/m²
A modified breakdown of these figures is shown in Fig 2.06.

These findings are supported by US research (Kocmond & Perchonok, 1970) which included amongst its conclusions that:

'\textit{the difference in visual range between an unlighted target vehicle and one with tail lights alone is over 300 ft}'.

In terms of daytime use of tail lights it was indicated:

'\textit{as ambient light increased, the distinction between seeing the body of the target vehicle and seeing the lights on the vehicle becomes less meaningful.....show little benefit is to be expected from taillights in such a daytime fog conditions}'' (sic).
From this it can be seen that to interpret the absolute value of visibility as the value on which speed should be based will totally distort the safety margin provided by the calculation of safe distances between vehicles. An analysis of the effect of reduced visibility on safety margins is shown in more detail in Appendix C.

As an example, Fig 2.07 shows the difficulty of seeing in fog. The headlights of the approaching vehicle are approximately 80 m from the camera and can be see with some difficulty. However, a departing vehicle on the opposite side of the road is approximately 40 m from the camera. It can only be seen with the greatest of difficulty and would certainly not be apparent to an approaching driver. (The MOR is the Meteorological Optical Range and is defined later in this section.)
Similarly in Fig 2.08, the larger size of an approaching truck provides a bigger contrast target allowing it to be seen. A departing car going in the opposite direction lacks sufficient contrast to make the vehicle visible.

FIG 2.08 COMPARISON OF APPROACHING TRUCK AND DEPARTING CAR (MOR 130 M)

2.3.2 Daytime.

Visibility can be defined as the greatest distance at which an object of specified characteristics can be seen and identified. The World Meteorological Organisation indicates a number of factors (WMO, 1983) involved in estimating a visibility distance which are:
a) The photometric and dimensional characteristics of the object which is, or should be, perceived;

b) The conditions of visual perception, including the effects of extraneous lighting and observer location, and

c) The optical state of the atmosphere between the object and the observer.

The first of these is normally relatively uniform when referring to the outline of a vehicle or the tail lights of a vehicle, although some distortion occurs in fog conditions as outlined in 2.3.1 above.

The second factor deals with contrast values and the difference in contrast for which an object ceases to be visible. This is estimated to vary between the US adopted value of 2% (Kocmond & Perchonok, 1970) and the European preferred value of 5% (Moore & Cooper, 1972; White & Jeffery, 1980). The actual value of this figure has been the subject of considerable uncertainty for many years and it seems unlikely that an exact value can be determined, particular when the individual characteristics of the observer have to be taken into account. In an evaluation of 1000 observations carried out in Ottawa (Middleton, 1952) the range extended to 15% with a mean value of 3.1%.

A value of 5% is adopted by the WMO as the level to be used in determining the visibility of an object by comparing it with its surroundings and is the value to be adopted in determining the visibility in this analysis.
These two factors relate to the characteristics of the observer and have been defined and measured in specific instances to allow the contrast value parameters indicated above to be set (WMO, 1983).

The third factor is an objective evaluation of the optical state of the atmosphere which depends directly upon meteorological conditions (including atmospheric pollutants) which in turn depends upon the rate at which light travelling through the atmosphere is extinguished. It is defined by the WMO as:

_The Meteorological Optical Range is the length of path in the atmosphere required to reduce the luminous flux in a collimated beam from an incandescent lamp, at a colour temperature of 2,700 °K to 0.05 of its original value, the luminous flux being evaluated by means of the photopic luminosity function of the International Commission on Illumination._

During periods of fog, light reaching the observer is reduced by absorption and scattering. The reduction due to absorption by the moisture particles in the atmosphere is considered negligible (Moore & Cooper, 1972). The scattering by particles causes a proportion of the light not to reach the observer. In addition the dispersion of light from the object and other sources evens out the light and leads to a reduction in contrast between an object and the surrounding luminance with a consequent reduction in the visibility of an object.
FIG 2.09 VEILING LUMINANCE DUE TO HEADLIGHT BACKSCATTER
(ALLEN ET AL 1977)

In fog the headlights illuminate the suspended water particles (Fig 2.09) causing a veiling luminance in front of the target. The amount of scattering is a function of the scattering angle and the headlight illuminance characteristics.

FIG 2.10 SCATTERING FUNCTION (SPENCER, 1960)
This scattering function is fairly stable. As can be seen in Fig 2.10, the scattering is
greatest at low angles (e.g. immediately in front of headlights as observed by the driver)
and at a minimum when the light enters the visual range at an angle of between 90° and
110°. This light dispersion effect is the reason some types of street lighting,
particularly systems using the older non-cut-off lanterns, give little improvement to
object visibility during periods of fog. If lighting without sufficient cut off is provided,
the effect as the fog increases in density is a more even distribution of light illuminating
the background and reducing the luminance provided to an object.

Knowledge of the scattering effect of light in fog allowed the development in the 1960s
of street lighting specifically designed to deal with the problems of visibility in fog.
This lighting has a narrow beam spread with the beam perpendicular to the driver’s line
of sight and placed at low elevation alongside the roadside.

Visibility in fog is directly affected by the density of the fog which in turn is dependant
upon the number and size of water droplets in the atmosphere (the dispersion of light is
directly proportional to the square of the droplet diameter). This density is measured in
terms of the atmospheric extinction coefficient (σ), which is the attenuation
experienced by a light beam after it has passed through a unit length of atmosphere,
usually measured as a % loss per metre.
Adapting the usual inverse square relationship provides for the illumination of an object in fog conditions using

\[ E = I \cdot e^{-\sigma R^2} \quad \text{(Allard's Law)} \]

where:

- \( E \) is the illumination produced by a light source of intensity \( I \).
- \( R \) is the distance of the source to the point at which illumination is required.
- \( \sigma \) is the extinction or attenuation coefficient of the fog, defined as:

'\textit{the proportion of luminous flux lost by a collimated beam, emitted by an incandescent source at a colour temperature of 2,700 °K, while travelling the length of a unit distance in the atmosphere.}' \( \text{(WMO, 1983)} \)

\( \sigma \) is the sum of the scattering coefficient \( b \) (related to but not the same as \( F(\theta) \) in Fig 2.10) and the absorption coefficient \( \kappa \). In water fogs \( \kappa \) is usually considered to be so small compared with \( b \) that it may be neglected \( \text{(Moore & Cooper, 1972)} \).

This provides for

\[ \sigma = b = \frac{nKD^2}{4} \]

where:

- \( n \) is the number of droplets per unit volume (typically between 1 and 50/cm\(^3\)).
- \( d \) is the diameter of the droplet (ranging from 6 - 12 microns \( 10^{-6} \text{ m} \)).
- \( K \) is the scattering area ratio:
As a consequence of this, scattering of light can be used to measure visibility and most of the measuring devices make use of this as discussed later.

By comparing the luminance (and hence the contrast) of an object and its background (usually the fog itself), the Meteorological Optical Range (MOR), sometimes called the Meteorological Visual Range (MVR) can be expressed as:

\[ V = (\log_e 1/c)/\sigma \]

Koschmeider’s law (Middleton, 1952)

where \( c \) is the contrast ratio for which an object is just visible.

As indicated above, the value of \( c \) is considered to vary between 2% and 5% giving a value for \( V \) of between \( 4/\sigma \) and \( 3/\sigma \) respectively. The latter value conforms to the WMO definition (WMO 1983) and is the value adopted for measurement of visibilities in this research project.

The value of \( \sigma \) varies for different atmospheric conditions with fog giving the greatest values. As can be seen in Fig 2.11, the visibility resulting from suspended water particles (as occurs in fog) differs significantly from that which occurs due to moving raindrops. This was confirmed during the trials. Those occasions where rain fell at the same time as visibility dropped below 150 m represented only 6% of the total fog occurrences at that level. (See Table 4.08.)

Koschmeider's law shows that visibility is inversely proportional to \( \sigma \). It is this value of \( \sigma \) which various devices measure to provide a direct value of visual range.
2.3.3 Night time.

During night time cases visibility is related to the detection of the difference in the contrast between a point source of light (a vehicle’s tail light) and a luminous background produced by backscattered light from an observer’s headlights or street lighting.
Differences between the various intensities of rear running lights, variations due to either the level of background luminance caused by switching from dipped to main beam, or the effect of street lighting, or contaminated windscreens can significantly reduce the visual range to a preceding vehicle's lights at night.

Despite these differences, studies in the USA (Heiss, 1976) and the UK (White & Jeffery, 1980) indicate that Koschmeider's Law also provides a reasonable estimate for MOR at night over a limited range, particularly between visibilities of 50 and 200m (Fig 2.12).

FIG 2.12 VARIATION OF VISUAL RANGE WITH EXTINCTION COEFFICIENT (WHITE & JEFFERY, 1980)
As an example, Fig 2.13 shows that even a doubling of the intensity from 150 to 300 candela (the range allowed in Germany for supplementary rear lights) only changes visibility from 48 m to 52 m in conditions where $\sigma = 0.09$ m$^{-1}$ (dense fog conditions).

FIG 2.13 RELATION BETWEEN INTENSITY OF LIGHT SOURCE AND VISIBILITY DISTANCE IN VARIOUS DAYLIGHT FOGS (MOORE & COOPER, 1972)

However, the validity of night readings using this basis remains variable for the reasons given and is likely to be less reliable in attributing characteristics of a specific visual range. Analysis of day, night and twilight conditions will be made to assess any differing characteristics of during these periods.
It should be noted that during night conditions when visibility is based on the observance of a self-illuminated object, visual observance of objects relying on reflected illumination is considerably less. White and Jeffery (1980) suggest:

‘When the visual range to a representative rear light in a night time fog (about 2 candela in the UK) is about 150m, the visual range to an unlit vehicle or street furniture outline in the same fog is only about 50m.’

Given the psychological behaviour suggested earlier due to the absence of input to the senses from peripheral streaming together with the false sense of longitudinal distance perceived in fog, this night time phenomenon may enhance the problems of driving in fog at that time.

2.3.4 Daytime with Lights-on.

Two possibilities exist in this case. Either the outline of the preceding vehicle will be seen first or the tail lights will.

With the outline being the first observation the situation is similar to normal daylight considerations previously dealt with in Section 2.3.1. Although it may seem that additional consideration should be given to the illumination and backscatter if a vehicle's headlights are on, this light contribution is negligible, a finding substantiated by photometer measurements (Heiss, 1976).

When the first observation is the tail light of the preceding vehicle, the situation is similar to the night time case with additional consideration to be given to background luminance to allow for the fog-scattered ambient illumination. The effect of this
background luminance is to provide a light which is itself extinguished by the water droplets in the fog and therefore provided for by the consideration of \( \sigma \), the attenuation coefficient of the fog. As a result the tail light of a vehicle will not be seen before the outline of a vehicle in daylight conditions unless visibility falls below 30 m (Heiss, 1976).

However a further consideration is the visibility of the rear brake light. In fog situations the use of brake lights is a common occurrence. Since the brake light is some four times brighter than the ordinary taillight, use of the brake light will provide a greater luminance than would be the case for the taillight. While this may also be negligible in most situations when compared with the visibility of a vehicle outline, computer simulations by Heiss (1976) suggest that this may improve the visibility of another vehicle when visibility drops below 100 m. This may therefore provide some added margin of safety in the lower visibility ranges, although such a facility obviously cannot be relied upon.

### 2.4 Visibility in Fog.

It is commonly presumed that motor accidents in fog are due principally to driver error (National Transportation Safety Board, 1972) and would be eliminated if drivers paid more attention to driving to the conditions.

However, the problems associated with visibility during periods of fog are fourfold, only one of which can be attributed to the physical sight restrictions due to the fog phenomena.
This physical problem relates to when the basic ability to view another object is reduced due to the reduction in contrast between an object and its background.

Such contrast is related to the transparency of a fog which depends mainly on the concentration of the droplets; the more droplets, the denser the fog (Myers, 1968). Light arriving at an observer's eye from an object is scattered by the water droplets: in addition, light from other sources is scattered to form a luminous veil through which an object must be seen. The combined effect is to reduce the contrast between an object and its background, thereby reducing its visibility.

In daylight hours this contrast is set by the ambient light in the atmosphere. At night the level of background luminance is set by the illuminating object such as dipped or main beam or even street lighting. (White & Jeffery, 1980). Although there is this basic difference between day and night visibility, because the measurement is based on an absolute value (being the difference in contrast between an object and its background), a value for the appropriate maximum deceleration distance for a particular visual range can be calculated and measured in the manner set out in Appendix C.

However, whilst this first problem relates to the physical difficulties outlined above where a fixed signal can be measured and compared with a control value, the other three factors all relate to psychological effects on the brain which work towards forming certain behaviour patterns whilst driving in fog. The consequent effect is much harder to evaluate and although some research has been attempted in order to put some values on these psychological effects, much less is known on these effects. Brown (1970) suggests:
"Research into the phenomenon (of multiple collisions in fog) has been discouraged, on the grounds that the facts are known, and remedial measures seem limited to moral exhortations for 'more careful driving and proper allowance for conditions'." 

The first of these psychological problems is the distortion of an image in fog, known as aerial perspective (Ross, 1975), leading to a misconceived estimation of distance and consequent possibilities of driver error in these conditions.

When viewing an object there is a size invariant relationship between the apparent size, apparent distance and the size of the image on the retina which acts to produce size-constancy. In fog the loss of contrast of an image with its background leads to the brain overestimating the size of an object. In order to produce a consistent size image, the brain compensates by increasing the apparent distance to the object, possibly by as much as twice the correct distance (Brown, 1970).

For a motorist, this can lead to significant misjudgements in areas such as the assessment of headway distances and overtaking opportunities.

The problem of lost peripheral vision is also a psychological problem which removes the visual triggers required by a motorist. Whilst driving, speed of travel is partly judged by the rate at which objects stream past at the side of the road (Ross, 1976).

When fog occurs there is a loss of vision of these objects, due in part to the reduction in visibility of the objects. This effect is enhanced as driving speeds increase and tunnel vision occurs. For vehicles travelling at 100 km/h a driver’s field of vision is reduced to 25% of normal capacity (Safety Canada, 1980).
Etienne (1991) shows how this angle of vision changes with speed as shown in Table 2.04.

TABLE 2.04 DECREASE IN LATERAL VISION WITH SPEED (after ETIENNE 1991)

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>Angle of Vision From Direction Of Travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>180°</td>
</tr>
<tr>
<td>25</td>
<td>70°</td>
</tr>
<tr>
<td>50</td>
<td>67°</td>
</tr>
<tr>
<td>75</td>
<td>57°</td>
</tr>
<tr>
<td>100</td>
<td>45°</td>
</tr>
<tr>
<td>OVER 100</td>
<td>40°</td>
</tr>
</tbody>
</table>

In order to provide peripheral streaming information at a usable rate drivers may increase their perceived speed, especially if this does not conflict with the incorrect safe headway distance already discussed above. Alternatively, vestibular and kinaesthetic (bodily) cues may be relied upon, senses which adapt very quickly and thus again lull drivers into a feeling of slowness.

The last of the psychological effects known to be responsible for changes in driver behaviour is "empty field myopia" (OECD, 1976). This occurs when false conclusions are drawn from not seeing any vehicles or obstacles ahead and assuming the road is clear. In such circumstances the eye can become fixated and accommodate a distance of up to 3m, resulting in a reduced assumed distance to an object. This means that
when visibilities fall below 100m, the available stopping distance can be reduced by up to a further 5%.

In addition to the above, the differing environment of day and night (and even more so at dawn and dusk where there is some overlap of conditions) have separate implications in terms of visibility.

The combination of these effects can lead to a driver relying upon kinetic motion to assess speed with the inevitable consequences which are known to occur. In commenting on MoT Road Research Laboratory Report LR97 by G.G. Denton, Brown (1970) indicates, ‘if the man relies upon subjective assessment to reduce speed, he could be driving twice as fast as he intends’.

2.5 F6 Southern Expressway.

The existing Driver Aid System on the F6 Southern Expressway was installed in 1974 at a cost of $500,000 (1974 Dollars) (Morris, 1975).

The original design provided for a system which would advise motorists of hazardous driving conditions and an appropriate speed for travelling in those conditions. This information would be provided through 36 fibre optic variable message signs displayed at 1.6 km spacing throughout the freeway and the surrounding road system at the major fog area at the southern end of the Expressway. (Fig 2.14).
FIG 2.14 CONTROL SITES ON EXISTING DRIVER AID SYSTEM
Whilst the system provided for manual control of a set number of programmed display messages, a wide range of information was to be provided to the Supervisor (based at the local toll collection office at the Northern end of the site) from various devices in the area of likely fog including:

- loop detectors in the roadway (to detect volume, lane distribution and speed percentiles),
- telephones at each sign site,
- a weather station to detect the conditions conducive to fog formation.

FIG 2.15 ADVISORY MESSAGE SIGN ON F6 (DMR, 1975)
Provision was also included for future installation of automatic transmissometers type fog detectors (reliable forward and back scatter measuring devices were not developed until the 1980s). These were to be installed at most sign locations and would be switched on by weather station relay to provide quantitative data on visibility distance to assist the Supervisor in selecting the appropriate advisory speed to be displayed on the variable message signs (Fig 2.15).

The system was commissioned and was working for 18 years; however it has never been fully operational in the manner intended by the original design. An investigation into the effectiveness of the system was carried out by the Department of Main Roads in 1987 following several multiple vehicle accidents (Brisbane, 1987).

Whilst many of the findings in that report were of a technical nature not relevant to this study, it did find:

1) The weather station was never successful in providing advance warning on fog conducive conditions and was removed within 5 years of the system's installation.

2) Vehicle detectors were not able to be used to measure vehicles speeds and could only be used as presence detectors to measure volumes. This was due to the loss of tuning (tuning is the fixing of the time lag for the detection pulse to travel from the input point to the measuring point; any variation in time lag between the two incoming signals necessary to allow speed calculations to be made causes significant change in the assessed speed of the vehicle). This problem was not able to be addressed by the technology of the time and presented a major difficulty in
designing the equipment to be used in this project. An evaluation of 1970s research by Hawkins (1988) says:

'Extensive trials showed that the results could not be regarded as being reliable due to loop tuning difficulties'.

3) Transmissometers or some equivalent method of measuring visibility were never installed.

4) Sites 68N and 05N no longer operate and were disconnected from the system some time in the late 1970s.

As a consequence of these factors, the present system has only ever been used to provide advice to drivers on a totally subjective basis. Displays, both when to show a warning and what warning to show, have been based on verbal advice received from various sources, usually that of the various patrol officers attached to the Toll Office.

Whilst there is therefore some information on frequency of restricted visibility at certain locations on a macro scale, there remains no information on the degree of the restriction, the frequency and length of specific restrictions and the characteristics of drivers during these times. (DMR 1974 - see attached brochure.)

In order to determine driver characteristics in restricted visibility conditions it has consequently been necessary to design a new arrangement to assess the variables of speed and visibility, details of which are provided in Chapter 3.
An introduction to the...

DRIVER AID SYSTEM

installed on the

Waterfall — Bulli Pass Tollwork
An electronic driver aid system has been installed on the 22.9 km length of the Waterfall — Bulli Pass Tollwork.

During fog or when traffic lanes on the Tollwork are blocked or closed for any reason, advisory speeds and other directions to drivers are displayed on roadside signs. These signs are activated by a traffic supervisor who directs the operations of the system from a computerised control centre at Waterfall.

Along the southern half of the Tollwork, fogs are likely to be encountered on about 31 days of every year. Consequently, if it is acted upon correctly, this driver aid system will add considerably to the safety and convenience of motorists travelling between Sydney and Wollongong.

A small weather station has recently been established by the Department at the top of Bulli Pass to continually measure humidity, wind direction and wind speed. When a combination of these three factors indicates a likelihood of fog developing, equipment at the weather station automatically relays a warning to the control centre. At present, radio-equipped patrol vehicles on the Tollwork are then called on to give regular reports of existing conditions. Later, fog detectors along the Tollwork will automatically switch on an alarm in the control centre as soon as fog occurs.

When fog or other weather conditions reduce visibility, the traffic supervisor transmits appropriate messages to the roadside signs, by means of a central computer and a number of field stations. Automatic electronic switching apparatus at the back of the signs allows certain words, numbers and symbols to be displayed. The signs advise drivers to reduce speed, change lanes or stop, where necessary, and typical messages are shown on the inside pages of this leaflet.

There are 36 signs spaced approximately 1.6 km apart along the whole length of the Tollwork. All the signs (which measure 2 metres wide by 1 metre high) are cantilevered out above the left-hand shoulder of each carriageway (as shown on the front cover illustration). Each sign gives directions to motorists in both lanes. To attract drivers' attention, amber lights at each corner of the signs flash whenever a message is displayed. Red flashing lights and a red STOP sign are shown if conditions become too hazardous for travel. The brightness of the messages displayed can be varied in intensity depending on the time and conditions. They are clearly legible from a distance of 200 metres in clear weather, day or night, while the flashing lights give advance warning at 500 metres.

When operating the system the traffic supervisor chooses the advisory speed or other directions most appropriate to the circumstances. The computer then transmits a pre-determined series of directions to the roadside signs. Special sequences have been developed so that the speeds displayed on consecutive signs approaching the fog-affected area or accident zone give motorists adequate time to slow down gradually. This helps to avoid accidents which could occur if the desired direction (such as "STOP") was displayed immediately, without prior warning, and drivers braked suddenly.
WHEN YOU ARE INVOLVED IN AN ACCIDENT OR BREAKDOWN ON THE TOLLWORK

As well as giving guidance during fog, the driver aid system is, of course, of vital importance in warning drivers when any lane of the Tollwork ahead is blocked. This could be due to a collision or breakdown or split load, or because road maintenance is being carried out. In such cases, the traffic supervisor can display advisory speeds, lane closed signs, change lane signs, slow signs or stop signs, depending on the circumstances.

If your vehicle has broken down or been involved in an accident, you should endeavour, as soon as possible to move it off the "through" lanes onto the road shoulders (appropriately called "breakdown" lanes) provided on both sides of the carriageway. It is also important, for your own safety as well as for the safety of other travellers, that you ring the control centre as soon as possible, especially if your vehicle cannot be moved and is blocking the roadway.

Emergency roadside telephones can be found along the left-hand side of each carriageway, in blue painted boxes, usually attached to the poles supporting the driver aid system signs. Simply lift the receiver and you will be connected automatically to the traffic supervisor on duty at the control centre. It should be noted that there is no dial tone on these telephones – so don’t think the line is “dead”. You will hear a recorded message if other emergency calls prevent the traffic supervisor answering you straight away. Please remember to hang up the receiver when you have completed your call.

On receiving your message, the traffic supervisor will be able to pinpoint your position immediately on a large electronic mimic diagram of the Tollwork. He can then warn approaching motorists to slow down and to change lanes when necessary. He can also call in police or ambulance services, if required, and direct a radio-controlled service vehicle to give you assistance. This service is provided 24 hours a day on every day of the year.

WHEN YOU ARE DRIVING ALONG THE TOLLWORK

At all times and particularly in fog, watch out on your left, not on your right, for messages displayed on the signs erected along the Tollwork. Having seen one and followed its directions, keep an alert eye open for any vehicles stopped ahead of you. Also watch out for the next sign at approximately 1.6 km further on. The messages displayed will change and become even more important as you approach the area of fog or the location of the breakdown or accident, etc. It should be noted that the signs apply to drivers travelling in both traffic lanes; there are not separate signs for each lane.

The illustrations opposite show typical words, symbols and numbers which can be displayed on the signs. Adjacent to each one is an explanation of the message which the sign is intended to convey and what you are expected to do. In all cases, the numbers relate to advisory speeds in kilometres (not miles) an hour.
• **FOG AHEAD**
• **SLOW DOWN TO THE SPEED INDICATED** (in this case, it's 25 km/h)
• **DO NOT STOP, UNLESS VEHICLES AHEAD OF YOU HAVE STOPPED**
• **WATCH FOR NEXT SIGN**

If you have not already done so, switch on your vehicle's head lights (low beam) and tail lights so that it can be seen clearly by other drivers, especially those following.

• **HAZARD AHEAD**
• **SLOW DOWN**
• **WATCH FOR NEXT SIGN**

When electronic devices along the Tollwork warn that too many vehicles are exceeding the advisory speeds already displayed, this SLOW sign is usually brought into use to try to reduce the speed of approaching traffic. It should therefore be regarded as a serious warning and not treated lightly.

• **ROADWAY AHEAD IS BLOCKED**
• **BOTH LANES ARE CLOSED**
• **YOU MUST STOP**

If possible, pull over onto the road shoulder (i.e., "breakdown" lane) nearest to you. Keep your lights on and face the sign. Await further directions. Do not overtake vehicles already parked on the road shoulders. This sign will always be preceded some distance back by signs warning you to reduce speed.

• **ROADWAY IS NOW CLEAR AHEAD**
• **YOU MAY RESUME YOUR NORMAL SPEED UP TO THE LIMIT APPLICABLE ON THE TOLLWORK (I.E., 110 KM/H)**

Please do not increase your travelling speed or move off from a stopped position until this sign indicates that it is safe to do so.
• THE LEFT-HAND LANE AHEAD IS CLOSED
• THE RIGHT-HAND LANE AHEAD IS OPEN
• SLOW DOWN TO THE SPEED INDICATED
• YOU MAY PROCEED IN EITHER LANE AT THIS STAGE UNLESS VEHICLES AHEAD OF YOU HAVE STOPPED

Watch for traffic merging from left lane into right lane. Watch for next sign which will probably display the “change lane” legend shown below. A similar legend is displayed when the right-hand lane ahead is closed and the left-hand lane is open.

• THE LEFT-HAND LANE AHEAD IS CLOSED
• THE RIGHT-HAND LANE AHEAD IS OPEN
• SLOW DOWN TO THE SPEED INDICATED
• MOVE CAREFULLY INTO THE RIGHT-HAND LANE
• IF YOU ARE ALREADY IN IT, WATCH FOR MERGING TRAFFIC

A similar legend is displayed when the right-hand lane ahead is closed and you are required to move into the left-hand lane.

• ROADWAY AHEAD IS BLOCKED
• BOTH LANES ARE CLOSED
• SLOW DOWN TO THE SPEED INDICATED
• DO NOT STOP, UNLESS VEHICLES AHEAD OF YOU HAVE STOPPED

Watch for the next sign (which will probably display the STOP sign, shown opposite, or the message shown below).

• ROADWAY AHEAD IS BLOCKED
• BOTH LANES ARE CLOSED
• PREPARE TO CROSS THE MEDIAN TO THE OPPOSITE CARRIAGeway, WHEN DIRECTED BY POLICE OR OTHER TRAFFIC OFFICIALS

Do not cross the median, and do not enter any traffic lane usually used by vehicles moving in the opposite direction, unless traffic in it has been stopped and you have been clearly directed to do so by police.
2.6 Driving Performance in Restricted Visibility.

2.6.1 Speed.

There is no doubt that the restriction of visibility affects the driving performance of a motorist. The degree to which this occurs has been determined through much research over the years, although none of this has been in Australia and with most of the work having been carried out in the 1970s.

The earliest detailed study was carried out by the California Division of Highways (Tamburri and Theobald, 1967) who found that on freeways:

* Generally, fog by itself causes a reduction in speeds ranging from 5-8 mph (8-13km/h) for both the mean and 85th percentile speeds. The exceptions are during high volume daytime and low volume nighttime operations when no or very small speed reductions are noted.

* Generally fog does not reduce the variability in speeds.

* With low volumes, posted speeds affect a further reduction in both the mean and 85th percentile speeds generally from 5-10 mph (8-16 km/h).

* Posted speeds rarely reduce variability.

* When using variable message displays, only the posting of speed limits had any measurable effect on traffic. These effects had little or no additional effect when displayed below 40 mph (65 km/h), regardless of the safe travel speed for the conditions.
Other early research suggested that changes were minimal or even non-existent. In the US (Kocmond and Perchonok, 1970) confirmed a speed reduction in the order of 5 to 8 km/h. With regard to patterns by time of day it was stated: ‘...the night and dawn data were similarly analysed, in spite of their small sample size, with the result that virtually no contradictions with the daylight findings occurred’.

In UK trials on the M4 comment was made that, “During the period when complete data were collected in fog there were no significant differences between the mean speed on the road with the fog and without the fog, but the data have not yet been fully analysed.”. (Moore and Cooper, 1972)

However research carried out in the latter part of the 1970s and later was more able to detect changes in performance, both in quantity and by time of day. It seems quite probable that this could be attributed to improvements in technology in terms of the ability to measure both visibility and speed.

In German research of 1973 (OECD, 1976) reductions of 15 - 27 km/h were obtained in the 85th percentile speeds.

In UK research in 1976 (Sumner et al, 1977) reductions of 25 - 40 km/h are shown to have occurred by the time visibilities have reduced to 50 m. (Fig 2.16). However the time of day was still assessed as not being a factor in determining driver speed performance when it was stated: ‘Daylight or darkness had no significant affect on vehicle speeds during periods of fog’. This supported earlier US research (Kocmond and Perconok, 1970) who in detecting a reduction of speed in daylight fog of approximately 4.5 mph added,
“It should be noted that although the results presented in this section are based only on daytime data, the night and dawn data were similarly analyzed, in spite of their small sample sizes, with the result that virtually no contradictions with the daylight findings occurred.”

FIG 2.16 MEAN SPEED AND VISIBILITY IN FOG M4 WINTER 75/76

(SUMNER ET AL, 1976)
More recent research (Hawkins, 1988) continued to show a mean speed reduction in the order of 30 km/h.

The point at which drivers begin to modify their performance also varies in the research. Kocmond and Perchonok (1970) indicate: 'Reductions in speed were observed even when visual distance exceeded 500 ft'. In a similar vein White and Jeffery (1980) suggest: 'The traffic remains substantially unaffected until the MVR drops to around 200 m'.

More recent research by Hawkins (1988) suggests: 'speeds....began to fall at a visibility of around 300 m and continued to fall with increasing rapidity with decreasing visibility'.

Early results from the research being undertaken as part of this project suggests that Australian drivers begin to reduce speed well before visibility drops to 300 m (Brisbane 1992). This early study indicated that by the time visibility had dropped to 250 m, speeds had reduced by an average 11 km/h.

Of course the actual point at which restricted visibility results in a speed reduction is not as critical as the speed differential between drivers (i.e. the variability of speed). Where these speed differentials exceed the safe stopping distance for a particular visibility, there is an increased probability of collision.

Whilst it would be reasonable to expect an increase in speed variability as drivers make individual interpretations of the appropriate speed for the conditions, the limited comments in the research literature provide differing opinions on the issue. A major
California study on speeds on freeways and expressways in the Sacramento area states, ‘there was no general effect of fog on speed variation.’ (Kocmond & Perconok, 1970). This is supported in an Analytical Evaluation of Vehicle Fog Lighting carried out by the National (US) Highway Traffic Safety Administration which comments, ‘nor does fog affect traffic speed variability’ (Koth et al, 1978). However in Hawkins (1988) experiments on the M1 (UK) he found ‘Standard deviations of speed reduced with reducing visibility but there were marginal increases in the coefficient of variation.’

The ability to modify the speed performance of motorists during periods of restricted visibility is less clear. The most favoured method was through the use of Driver Aid Systems similar to that on the F6 as described in Section 2.5 and Appendix G. Many of these were installed, particularly in the US, although others were installed in Europe including in the UK, Germany and Italy. These systems were intended to warn drivers of approaching fog and then modify the performance when driving through the fog.

As detailed in Section 2.8 which describes some of the systems installed, analysis of the effectiveness of these systems was limited. This can be attributed to many reasons including the difficulties in experimenting with different variables where public safety was involved, the willingness and funding availability to undertake research, and the difficulties in obtaining absolute visibility measurements to compare with driving variables such as speed and headway at a specific point.

Nevertheless, some research was undertaken particularly in the Murder Creek project in Oregon where the final report indicates the advance warning nature of these systems can
be effective: ‘The analysis of variance of the data collected indicated that, prior to the
fog, the effects of the signing were significant’ (Wagner, 1978)

Measuring the effect of warning drivers actually in fog to modify their performance was
more difficult to assess and considered either generally unmeasurable or ineffectual.
The early study of this type carried out in California in the 1960s indicated; ‘When
confronted with a bright illuminated sign, drivers reduced speeds an additional 5 mph.
when they considered the displayed speed to be reasonable’ (National Transportation

However, in reviewing the status of these systems the OECD concluded, ‘a simple fog
warning at a given spot is of questionable value’ (OECD, 1976) and in a detailed
analytical study into vehicle fog lighting it was concluded, ‘Restrictive speed signing
has been shown to produce little or no significant effect on traffic behaviour, nor does
fog effect traffic speed variability, or time/distance headways.’ (Koth et al, 1978)

In the Oregon project final analysis it was stated, ‘...it was not possible to determine
what percentage of the speed reduction was due to fog and what percentage was due to
the signing’. (George et al, 1979).

In none of these studies was an attempt made to evaluate the effect of signage when
compared to specific visibilities.

Furthermore where the systems were used incorrectly they could actually in some
instances be detrimental to reducing speed. ‘The speed data also indicated that as the
posted speeds was lowered the vehicle speeds did not necessarily decrease. In fact, in some cases the inverse actually occurred.' (George et al, 1979).

While the research was generally unable to detect any speed reductions specifically attributable to sign systems, accident analyses in the Oregon project did show reductions in accidents during fog. The final report stated, '...the fog-warning sign system alone has significantly reduced the accident rate on this section of highway.' (George et al, 1979). However, it is noted that there was no correlation of accident with fog frequency.

No evidence could be found of analyses of accidents in other fog signage projects.

2.6.2 Headway.

The phenomenon of reducing the headway between two vehicles has long been popularly perceived as a problem which worsens during fog conditions (usually referred to as 'tailgating'). It is also worth noting that with a constant headway, a reduced speed will increase the safety margin by reducing the stopping or deceleration distance required. A small reduction in headway may not therefore affect a driver's stopping ability if all other factors remain constant (e.g. reaction time).

The research evidence in regard to headways is not nearly as available as for speeds. Whilst most research projects included headways in the data obtained, very few papers have detailed the results of any analysis of headway data.
Studies by Perchonok (Kocmond & Perchonok, 1970) looked at the probability of headways occurring in less than 2 second intervals, this being the time of the recommended headway. The result stated "no trend was found". As a fixed headway time does not make allowances for the dangers which can still occur with large speed variations, further analysis was carried out on the 'collision course time', this being the headway spacing divided by the relative speed. Again it is indicated that there is 'virtually no monotonic relationship existing between visual distance and the collision course time'.

However the study concluded that:

'at least at the high volume levels, these data show fewer long headways in fog: this is in agreement with a hypothesis that in fog there is a tendency for drivers to shorten headways to maintain visual contact with the vehicle in front'.

In view of the earlier comments, this statement would appear to be hedging and is not fully consistent with earlier statements.

In contrast early UK research does propose that changes occur in headways during fog conditions. Research in 1978 (White & Jeffery, 1980) states:

'At driver visibility distances of about 150 m by day and night, up to about 30% of vehicles, i.e. around 2.5 times the proportion in normal flow with clear weather conditions, close up to follow within a time gap of less than 2 seconds. This appears to demonstrate that fog promotes platooning and provokes less safe following behaviour.'

Particular reference is made to: '...the proportion of drivers who drive within 2 seconds of the vehicle in front increases markedly as the visibility decreases'. For visibilities of
153 m the results suggest an increase ranging from 190% in the slow lane to 84% in the fast lane (of a three lane road).

This increase may in part be explained by the more recent research (Hawkins, 1984: Hawkins, 1988) which found a decrease in very short gaps (< 0.5 sec) with a 25% increase in 1 and 2 second gaps, although the nature of this increase is qualified by lane distribution. It notes: 'There does seem to be evidence of a different reaction by motorists to close following in thick fog at higher flows compared with lower flows'.

This would suggest that the increase in headways in the 1 - 2 second range was partly due to the decrease in too close following and partly to an increase in tailgating. However the proportions of these changes if due to such causes cannot be determined from the published research results.

Further research in 1983 (Hawkins, 1988) supported findings that headway characteristics changes as visibility decreases. The conclusions in this research states:

'The bunching of vehicles across all three lanes was more prevalent in thick fog compared with clear visibility conditions, using a 2 second headway criteria; for example a 6% increase in across lane headways of less than 2 seconds for a flow of 1200 veh/h'

and

'It is estimated that from an in-depth study......between 70 m and 100 m visibility......the increase in the proportion of vehicles in platoons (all lanes totalled together) was 50%, 37% and 10.5% using a 1 second, 3 second and 6 second platoon criterion respectively'
It should be noted that analysis of headways is much more complicated than that for just speeds. Averaging of headways is obviously pointless as this only represents the volume over a particular time period. (Any increase in volumes will lead to a corresponding decrease in average headways.)

In addition in order to make a valid comparison between fog and clear conditions it is necessary for the fog to be uniform over the period when the headway comparison is being made. This may have been possible where fog conditions are uniform for a sufficient period to obtain enough data to make a meaningful analysis, as appears to have been assumed in overseas research but is not the case at Bulli Tops. The lowest time blocks appear to be the UK trials which looked at 15 minute visibility bands (White and Jeffery 1980, Hawkins 1988). Other studies give little or no information on how visibility variations were catered for. Such an assessment would certainly not be appropriate in the conditions which occur in the Bulli Tops area where visibilities vary dramatically in very short time periods (see Section 3.1.2 i)).

It will therefore be necessary to develop a system more appropriate to the specific site in this instance if changes in headways are to be analysed.

2.7 Visibility Measurement Devices.

2.7.1 General Background.

There are two basic types of instrument used to measure visibility.
The first of these are instruments which directly measure the loss of light as it passes through the atmosphere, (i.e. the measurement of the attenuation or extinction coefficient of a long column of air). The most common of these is a transmissometer.

However there are other similar devices which can be used for this purpose such as Telephotometric instruments (used to compare the apparent luminance of a distant object with that of the sky background during daylight conditions) and Visual Extinction Meters (used at nights when a light of known intensity at a fixed distance is adjusted until it is only just visible giving a measurement of the transparency of the air from which the extinction coefficient can be calculated).

The second type of instruments are the various scatter types which are diffuse light meters measuring the intensity of the scattered light from a transmitted beam in a given angular range. These allow measurements to be made over very short lengths and are available at a fifth of the price of transmissometers.

2.7.2 Transmissometers.

Transmissometers measure the fraction of luminous flux which remains after a single beam of light is projected through a given length in the atmosphere.

The length over which the decrease in illuminance is measured varies from five to several hundred metres and the instruments are sometimes divided accordingly into long and short baseline classes.
Calibration in terms of MOR uses Koschmeider's theory with periodic checks made when visibility exceeds 15 km to enable the stability of the instrument to be measured.

In its analysis of transmissometers and their effectiveness (Griggs et al, 1989), the WMO showed that the accuracy of the instruments was dependant upon the length of the baseline used. Whilst this can lead to significant errors if the instruments are used over too wide a range, a specific baseline will give an acceptable accuracy (10%) over a certain span of visual range.

2.7.3 Scatter Devices.

The attenuation of light is due both to the scattering of light and to the absorption of it by particles in the atmosphere. As indicated in Section 2.4 the absorption is so small in comparison to the scattering of light when it passes through air containing water droplets that the extinction coefficient may be considered as directly proportional to the coefficient of scattering.

In scatter devices instrumentation is used to measure the intensity of light for a particular angle (see Fig 2.09). The light so measured has been scattered by moisture droplets in the atmosphere when a transmitted beam of light (usually in pulses) is propelled through the air.

As was seen in Fig 2.10, the maximum scatter of this light occurs immediately behind the angle of projection (backward scatter) or at an angle of 150° to the axis of the incident beam (forward scatter) (Kocmond & Perchonok, 1970: Spencer, 1960).
Backscatter devices transmit pulses of light to a volume of fog located 10-25 m from the instrument. The amount of this light which is scattered through 180° is monitored by a detector mounted close to the projector.

Forward scatter again measures the light scattered from a projected pulse, although in this case in the forward direction. In order not to include direct light, the receiving monitor is offset so that the light scattered to one side of the projector axis is detected.

In both cases it is essential that the reception cone is small enough to exclude diffracted light from other sources.

As a consequence of these restrictions, the sample of air upon which the evaluation of MOR is made is about 0.2 litres compared with 1 litre for the samples used by transmissometers. To compensate for this and the wide variations which may occur by only measuring over a small area, a large number of readings are taken in a short time period and these are averaged to present a value for MOR. Despite this, the small volume of sampling only reduces the accuracy of scatter instruments to around 80%, only half that of transmissometers. This accuracy can be improved by calibration to local conditions (Heiss, 1976).

In a review of weather measurement devices by Purdon (1995) the vice president of systems integrator, Farradyne Systems (US) was quoted as saying “Forward scatter visibility detection is the best for many types of application, but the problem is a spot check and doesn’t cover a long distance.”.
It is important therefore to note that the localised nature of the readings of scatter devices mean that such techniques cannot be truly representative in non homogeneous conditions such as the patchy conditions which occur at Bulli Tops, and the visibility measured can only be considered as relevant to the immediate vicinity.

In terms of the work to be done in this research project, localised readings may actually be beneficial and provide better information on the visibility on which a driver bases the decision making process.

This is because an instrument which makes its evaluation of visibility over a large distance in patchy fog will provide a value which is effectively an average of the conditions through which the light passes.

On the basis that a driver makes an evaluation of a safe driving speed after assessing the conditions in the immediate environment, then the visibility ahead of a driver at a specific location will produce a speed at a point where the vehicle will have travelled a distance covered by the reaction time, around 1.4 sec (Heiss, 1976), plus or minus a negligible distance for the acceleration or deceleration applied during that time.

For a speed of 100 km/h, this would be in the order of 50 m. In such a case fog only needs to be uniform over this short distance for the speed at the measurement point to represent the chosen speed of the driver for that visibility. This provides a speed more appropriate than an average visibility over the range required when using a transmissometer.
2.8 **Driver Aid Systems**

As indicated in Section 2.6, a number of Driver Aid Systems were installed since the mid 1960s although the study of their effectiveness has been limited. These systems vary from those which advise of fog through the use of single signs to others which attempt to advise of an appropriate travel speed based on an automatic evaluation of the conditions.

A system installed on the freeways and expressways around Sacramento in California was the first system to be the subject of a major study. This study was published by the California State Transportation Agency in 1967 and concluded that "speed limit signs were effectively used to reduce speeds of vehicles by 5 to 10 mph over the reduction attributable to fog alone" (Kocmond & Perconok, 1970).

However the most comprehensive long term study was carried out on a system installed at Murder Creek on Interstate 5 in Oregon, a system inspected by the author on a visit to the site in 1993. The installation was completed in 1968 and was the subject of a long term 11 year study which saw many papers published on its usage and a final report put out in June 1979 (George et al, 1979). The system is described in the final report as:

"The system consists of 3 signs in each direction over a 10 km section of a divided highway. Each sign contained two 300 mm yellow flashing beacons with the word "SLOW" in 900 mm high letters. They also included the words "WRECK", "FOG" and "SPEED" in letters 450 mm high with speeds of 10 to 50 MPH in 10 MPH increments. All letters and numerals were formed with 10 mm high-intensity red neon tubing. The "SLOW" message came on whenever the sign was activated. The legend "FOG" or
"WRECK" and "SPEED" and the numerical speed indication were chosen for each particular situation."

The system was operated by the State Police who had control from a remote site in Albany and could be activated locally if required.

The research project involved setting up inductance loops throughout the site and setting up an ongoing monitoring system to correlate performance with specific sign conditions.

Fig 2.17 shows one of the signs operating in clear conditions.

FIG 2.17: CLOSE-UP OF OREGON ADVISORY SIGN INSTALLATION

(GEORGE ET AL, 1979)
The final conclusions were supportive of the system as a method of reducing accidents in fog and the system remains in use today in its original designed format. Amongst the conclusions of particular relevance to this study was:

“However, it was not possible to separate the effects of the signs from the effects of the fog. The speed data also indicated that as the posted speed was lowered the vehicle speeds did not necessarily decrease. In fact, in some cases the inverse actually occurred.”

This conclusion is supported in research carried out by Hawkins (1984) at Trowell on the M1 when he states “It follows that it is inappropriate to advise on an unrealistically low speed because larger reductions can be achieved with a higher value.” UK systems in the 1970s and 1980s on the M1, M4 and M25 consisted of bulb matrix displays which provided an advisory speed to motorists.

The use of the M25 system was banned in 1987 by the police (Rutherford, 1987) who believed their use resulted in a lack of credibility which contaminated their effectiveness when used for other purposes such as accidents and oil spills. This system on the M25 has now been replaced with a combined variable message and bulb matrix system which allows a relationship to be established between the advisory speed and the need for the change. (Fig 2.18)
Many other systems have been developed as indicated in Appendix G, although there is little information into research on their effectiveness. In Germany remote controlled message signs with flashing lights attached (similar to Fig 2.19) were positioned in pairs at distances of about 400 m before fog-prone zones. Detection devices within the fog zone trigger the signs. An initial accident study showed an encouraging reduction in accidents (Behrendt, 1978) but no final report is available.
FIG 2.19 EUROPEAN STYLE FOG WARNING SIGN

A system, installed in North Caroline in 1974, consisting of ten variable speed limit signs was removed in 1984-85 due to manpower requirements associated with maintenance and the discontinued availability of replacement parts (Strong, 1985), a problem common with the original F6 system.

In summary it can be seen that many systems have been tried over the years with mixed results. It is intended that the outcome of this project will give an indication as to the effectiveness of such systems using technology which has improved options significantly since the nineteen sixties and seventies.